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Updated Buildings Sector Appliance and Equipment Costs and Efficiencies

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Updated Buildings Sector Appliance and Equipment Costs and Efficiency

Energy used in the residential and commercial sectors provides a wide range of services, including heating, cooling, lighting, refrigeration, cooking, and numerous other end uses.

The U.S. Energy Information Administration (EIA) conducts multiple building-sector surveys—the Residential Energy Consumption Survey (RECS) and the Commercial Buildings Energy Consumption Survey (CBECS)—that provide information on the equipment stock and energy consumption within existing buildings. However, these surveys do not directly gather other information that is important to projecting future energy consumption, such as equipment cost information or nameplate efficiency ratings.

The Residential Demand Module (RDM) and the Commercial Demand Module (CDM) of the National Energy Modeling System (NEMS) contain equipment cost and performance technology *menus* that represent competing options for most of the major end uses. Multiple equipment classes and types are represented in these menus so that the projected equipment stock can change over time in response to fuel prices and other factors that affect equipment choice, such as appliance standards. The equipment menus interact with other NEMS parameters to determine market shares, equipment efficiency levels, cost estimates, and equipment interactions,[1] and they are used to translate service demand into energy demand.

The contract reports in Appendices A–D provide the information basis on which these menus can be built with a consistent perspective on cost and efficiency characterizations across equipment and fuel types. Previous editions of the *Annual Energy Outlook* (AEO) used similar contract reports.

Appendices A and B constitute one set of reports that characterizes most major residential equipment and commercial heating, cooling, and water heating equipment. Appendix A is used in developing Reference case projections, while Appendix B is used in developing advanced technology cases.[2] These assumptions were developed and implemented during the AEO2018 and AEO2019 cycles.

Appendices C and D constitute another set of reports that characterizes residential and commercial lighting, as well as commercial ventilation and refrigeration equipment. Appendix C is used in developing the Reference case, while Appendix D is used in developing advanced technology cases. These assumptions were developed and implemented during the AEO2017 cycle.

When referencing the contract reports in Appendices A–B, they should be cited as reports by Navigant Consulting, Inc. prepared for the U.S. Energy Information Administration. When referencing the contract reports in Appendices C–D, they should be cited as reports by Navigant Consulting, Inc. and Leidos (formerly SAIC) prepared for the U.S. Energy Information Administration.

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[1] Examples of equipment interactions are solar water heaters that supplement traditional water heaters, clothes washers that reduce the need for clothes drying, and water heaters that provide dishwashers and clothes washers with heated water.

[2] In addition to the Reference case, the demand sectors also project scenarios to explore different assumptions for the cost and performance of future technologies. For the more optimistic cases, some equipment achieves lower life-cycle costs through improved efficiency or lower upfront costs, or both. The contracted reports provide a base case and an advanced case for modeling the AEO Reference case along with the more optimistic cases. Advanced case assumptions are used to develop side cases for full AEO report years that include such analyses.

APPENDIX A

FINAL

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case

Presented to:

U.S. Energy Information Administration

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DISCLAIMER

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The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

- Installed base in 2012 (for commercial products) or 2009 and 2015 (for residential products) and current market (2017)
  - Review of literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
- Forecast of technology improvements that are projected to be available through 2050
  - Review of trends in standards, product enhancements, and Research and Development (R&D).
  - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- Only currently published efficiency standards and regulations are considered when predicting technology developments, unpublished future regulatory action is not predicted.
- All costs are shown in 2017 dollars (2017$).
- Ranges, when given, represent the span of typical values for a given parameter (e.g.. installed cost for equipment meeting the federal standard) not the highest and lowest available on the market.

Definitions

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2012 for commercial products (or 2009 and 2015 for residential products) to the highest efficiency equipment that is expected to be commercially available by 2050, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- 2009/2012/2015 Installed Base: Efficiency values are for those units installed and "in use" in that year. Cost values are for the typical new unit sold in that year.
- 2017 Current Standard: the minimum efficiency required by current standards.
- Typical: the average, or "typical" product being sold in the particular timeframe. This may represent either the shipments-weighted average product performance or the most common product on the market.
- ENERGY STAR: the minimum efficiency required to meet the ENERGY STAR criteria, where applicable.
- Mid-Level: middle tier high-efficiency product available in the particular timeframe.
- High: the product with the highest efficiency available in the particular timeframe.

The market for the reviewed products has changed since the analysis performed in 2013 and is reflected in the efficiency and cost characteristics.

- In some categories the typical new product purchased today is significantly more efficient than the average product in the installed base in 2012 (comm.) or 2015 (res.):
  - Residential sector: central air conditioners and heat pumps, water heaters
  - Commercial sector: gas-fired and oil-fired boilers, oil-fired storage water heaters
- More stringent Federal standards have taken effect for the following products:
  - Residential furnaces in 2013 and 2015
  - Residential room air conditioners in 2014
  - Residential water heaters in 2015
  - Residential central air conditioners, air-source heat pumps in 2015
  - Residential and commercial water-source heat pumps in 2015
  - Commercial oil-fired storage water heaters in 2015
- ENERGY STAR continues to raise the bar with revised criteria for:
  - Residential furnaces in 2013
  - Residential room air conditioners, central air conditioners, and central heat pumps in 2015
  - Residential dishwashers in 2016
  - Residential and commercial boilers in 2014 and 2016, respectively
  - Residential and commercial water heaters in 2017 and 2013, respectively

Residential Gas-Fired Furnaces (North)

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DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (North)	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	80	80	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	92	95	99	92	99	92	99	92	99	93	99
Electric Consumption (kWh/yr)*	548	522	470	470	384	418	322	334	322	334	322	334	317	334
Average Life (yrs)**	16	16	16	16	16	16	16	16	16	16	16	16	16	16
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	840	860	890	1,190	1,320	1,620	1,340	1,620	1,340	1,620	1,340	1,620	1,340	1,620
Total Installed Cost (2017$)	2,000	2,020	2,050	2,610	2,740	3,040	2,760	3,040	2,760	3,040	2,760	3,040	2,760	3,040
Annual Maintenance Cost (2017$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40

* Electric Consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.

** Average life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, a sensitivity analysis offers 16 to 27 years as the low and high range of the product lifetime for gas-fired furnaces.

Residential Gas-Fired Furnaces (Rest of Country)

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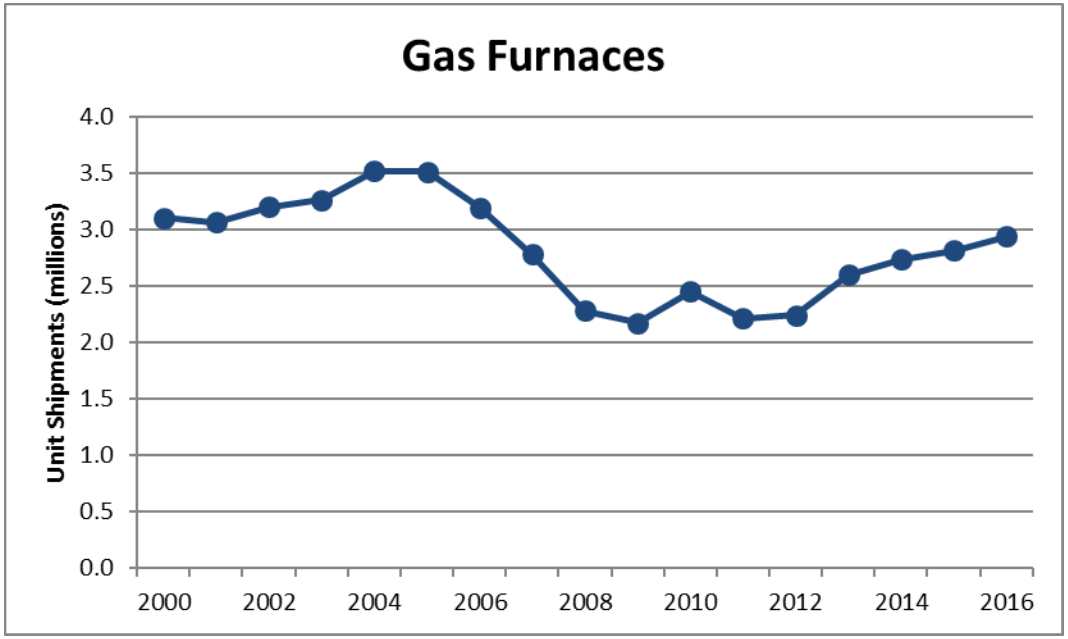
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (South)	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	80	80	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	80	90	99	80	99	80	99	80	99	80	99
Electric Consumption (kWh/yr)*	548	522	470	470	408	418	329	334	329	334	329	334	329	334
Average Life (yrs)**	16	16	16	16	16	16	16	16	16	16	16	16	16	16
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	840	860	890	890	1,150	1,620	1,080	1,620	1,080	1,620	1,080	1,620	1,080	1,620
Total Installed Cost (2017$)	2,000	2,020	2,050	2,050	2,560	3,040	2,240	3,040	2,240	3,040	2,240	3,040	2,240	3,040
Annual Maintenance Cost (2017$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40

* Electric Consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.

** Average life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, a sensitivity analysis offers 16 to 27 years as the low and high range of the product lifetime for gas-fired furnaces.

- Current Federal standards for non-weatherized gas furnaces:
  - AFUE ≥ 80%
- ENERGY STAR criteria for gas furnaces:
  - South: AFUE ≥ 90%
  - North: AFUE ≥ 95%
  - Furnaces must be equipped with electronically commutated fan motor and have less than or equal to 2.0% air leakage
- Most efficient unit currently available: 98.7% AFUE. The current market is nearly evenly split between non-condensing units (AFUE≤82%) and condensing units (AFUE≥90%).
- The highest efficiency furnaces (~99% AFUE) employ electronically commutated motors (ECMs) and can fully modulate rather than cycling on and off. Because they modulate, there is an increase in total fan-on time. Because the fan operates for more total hours and consumes more energy, the annual electricity consumption is higher for these products
- Non-condensing AFUE levels for natural gas top out at around 82%; above this level, the potential for exhaust gas condensation increases. This condensate is corrosive and requires cost restrictive corrosion resistant venting.
- High-efficiency condensing furnaces typically have high-grade stainless steel (AL 29-4C) heat exchangers.
- Many are available as direct vent and sealed combustion systems, which do not use room air for combustion, but instead draws combustion air directly from outdoors.
- Depending on the location of the home, piping materials in use, and other considerations, condensing furnaces may need an acid neutralizer and/or lift pump for the condensate.
- Furnaces may contain permanent split capacitor (PSC) or brushless permanent magnet (BPM) fan motors. The 2015 Energy Conservation Standards for Residential Furnace Fans Final Rule requires that all furnaces use BPM fans. The type of motor effects the electrical consumption of the furnace as well as the SEER/EER of the associated air conditioner.

Annual shipments peaked at 3.5 million units in 2005 then declined each year until 2009 and leveled off at about 2.25 million units. Since 2012, shipments have increased steadily.



Source: *AHRI* (http://www.ahrinet.org/Resources/Statistics/Historical-Data/Furnaces-Historical-Data.aspx)

Residential Oil-Fired Furnaces

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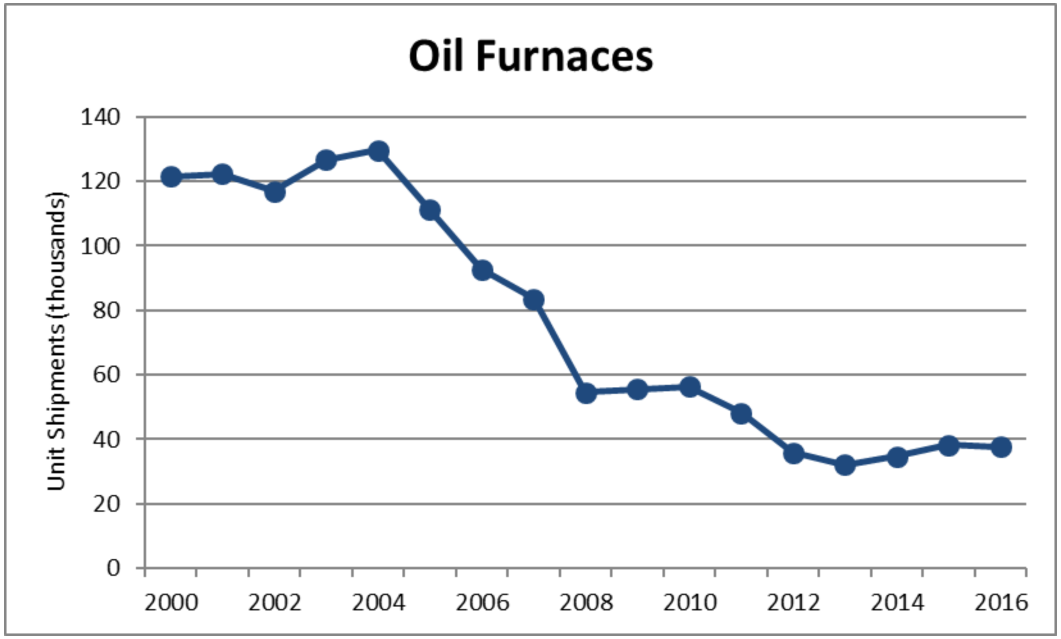
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	83	83	83	85	97	83	97	84	97	84	97	84	97
Electric Consumption (kWh/yr)*	490	477	477	477	466	410	477	410	472	410	472	410	472	410
Average Life (yrs)**	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Retail Equipment Cost (2017$)	2,150	2,200	2,200	2,200	2,250	2,700	2,200	2,700	2,250	2,700	2,250	2,700	2,250	2,700
	2,350	2,900	2,900	2,900	2,950	3,450	2,900	3,450	2,950	3,450	2,950	3,450	2,950	3,450
Total Installed Cost (2017$)	2,700	2,750	2,750	2,750	2,950	4,350	2,750	4,350	2,750	4,350	2,750	4,350	2,750	4,350
	3,400	5,500	5,500	5,500	5,750	8,550	5,500	8,550	5,700	8,550	5,700	8,550	5,700	8,550
Annual Maintenance Cost (2017$)	70	70	70	70	70	200	70	200	70	200	70	200	70	200

* Electric Consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.

**Average Life was previously reported as a range sourced from Appliance Magazine (2012). The EERE 2015 TSD offers a Weibull distribution with an average value of 26.5 years and a 25%-75% confidence interval range of 19.7 to 33.1 years.

- Current Federal standards:
  - AFUE ≥ 83%
  - ≤ 11 watts of electrical power when in standby and off modes (non-weatherized models only)
- ENERGY STAR criteria: AFUE ≥ 85%
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Most efficient currently available: 96.7% AFUE – condensing units with tiny market share (<1%), due to market acceptance issues.
- Condensate from condensing oil furnaces is typically even more corrosive than that of gas-fired systems due to the higher sulfur content in fuel oil. Hence, condensing oil furnaces also likely require the use of an acid neutralizer. By 2019, ultra-low sulfur heating oil will be required in most northeastern states; this will reduce corrosion effects.
- Oil-fired furnaces, like gas-fired furnaces, achieve condensing conditions through the use of a secondary heat exchanger. Typically, these secondary heat exchangers use a high-grade stainless steel (AL 29-4C).
- Sooting is an issue for all oil-fired appliances, but secondary heat exchangers, with their narrow passages, are even more prone to be plugged by soot. Because of this, condensing oil furnaces typically require frequent cleaning and maintenance.

Annual shipments declined rapidly after 2004, likely due at least in part to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2012 shipments have largely levelled off.



Source: *AHRI* (http://www.ahrinet.org/Resources/Statistics/Historical-Data/Furnaces-Historical-Data.aspx)

Residential Gas-Fired Boilers

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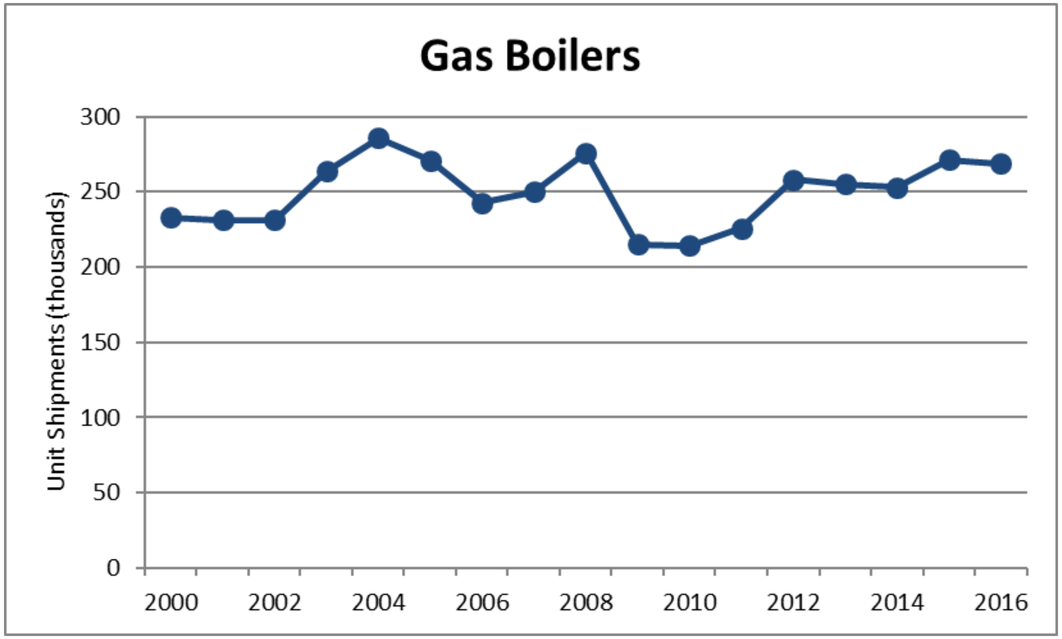
DATA	2009	2015	2017				2020		2030**		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	100	100	100	100	100	100	100	100	100	100	100	100	100
AFUE (%)	80	82	82	82	90	97	90	97	90	97	90	97	90	97
Average Life (yrs)*	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost (2017$)	2,050	1,950	1,950	1,950	2,750	3,750	2,750	3,750	2,750	3,750	2,750	3,750	2,750	3,750
	2,650	2,550	2,550	2,550	3,250	4,300	3,250	4,300	3,250	4,300	3,250	4,300	3,250	4,300
Total Installed Cost (2017$)	4,100	4,600	4,600	4,600	5,750	6,800	5,750	6,800	5,750	6,800	5,750	6,800	5,750	6,800
	4,700	9,750	9,750	9,750	10,000	11,050	10,000	11,050	10,000	11,050	10,000	11,050	10,000	11,050
Annual Maintenance Cost (2017$)	50	90	90	90	90	90	90	90	90	90	90	90	90	90

*Average Life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, an average of 26.5 years is calculated for gas-fired hot water boilers, with a low and high range from 20 to 30 years respectively.
** In 2021, new energy conservation standards for Residential Boilers will take effect. These projections reflect the 2021 minimum AFUE requirement for residential oil-fired boilers, 84%. However, by 2020, the majority of the gas-fired boiler market is expected to be condensing, with a minimum efficiency of 90% AFUE.
Note: Water boilers considered. Steam boilers also exist, but make up only about 15% of the market.

- Federal standard for gas-fired hot-water boilers (more common than steam):
  - AFUE ≥ 82%
  - Design requirements that took effect on September 1, 2012 prohibit a constant burning pilot and require an automatic means for adjusting water temperature
  - AFUE ≥ 84% required on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 90%
- Most efficient available: 96.8% AFUE
- Have lost market share to furnaces and heat pumps over the past 30 years
- U.S. gas hot water boiler sales are split roughly 50/50 between condensing and non-condensing. Condensing boilers typically have heat exchangers made of stainless steel and non-condensing boiler typically have heat exchangers made of case iron.
- Typically, condensing boilers are low-mass in construction with modulating burners, variable-speed inducer fan systems, sealed powered direct-vent combustion, multiple sensor technologies, and electronic ignition and control.
- Due to incentives and market pressure, the U.S. boiler industry has been shifting towards also providing condensing boilers. Most of these boilers are private-labeled products sourced from Europe, where the hydronic market is much bigger and condensing appliances are much more common and/or required by law.
- Most value-added components for condensing boilers are sourced abroad, even when the condensing boiler is assembled in North America (e.g., heat exchanger, gas valve, burner, sensors, and/or controls).

Annual shipments had a significant decrease following the 2009 financial crisis and a steady recovery in the years since.



Source: *National Impact Analysis Spreadsheet from the 2015 Energy Conservation Standards for Residential Boilers Final Rule. (https://www.regulations.gov/document?D=EERE-2012-BT-STD-0047-0072)*

Residential Oil-Fired Boilers

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DATA	2009	2015	2017				2020		2030****		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR*	High**	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	140	140	140	140	140	140	140	140	140	140	140	140	140	140
AFUE (%)	80	84	84	84	87	90	84	90	86	90	86	90	86	90
Average Life (yrs)***	18	18	18	18	18	18	18	18	18	18	18	18	18	18
	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Retail Equipment Cost (2017$)	2,400	4,000	4,000	4,000	4,450	6,150	4,000	6,150	4,300	6,150	4,300	6,150	4,300	6,150
	3,050	4,300	4,300	4,300	4,800	6,700	4,300	6,700	4,650	6,700	4,650	6,700	4,650	6,700
Total Installed Cost (2017$)	4,350	6,600	6,600	6,600	6,900	9,400	6,600	9,400	6,900	9,400	6,900	9,400	6,900	9,400
	5,000	11,650	11,650	11,650	11,950	13,500	11,650	13,500	11,950	13,500	11,950	13,500	11,950	13,500
Annual Maintenance Cost (2017$)	140	140	140	140	140	150	140	150	140	150	140	150	140	150

*ENERGY STAR levels were not examined in the EERE 2015 rulemaking, therefore ENERGY STAR retail costs were extrapolated from the non-condensing levels. All other costs are the same for non-condensing models.

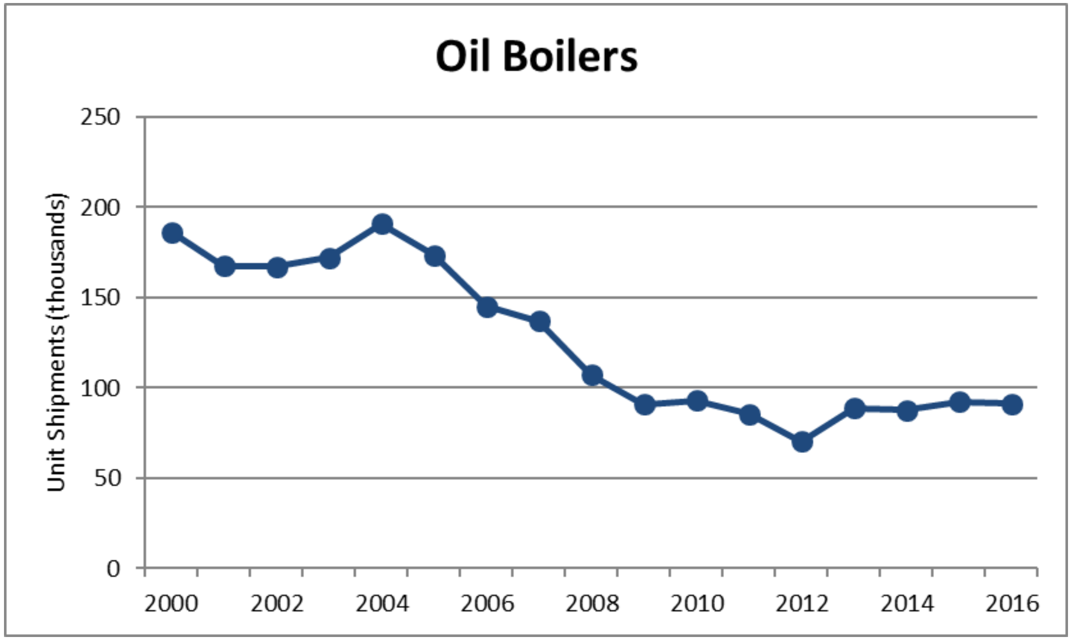
**2017 High - EERE 2015 has analysis for 91% AFUE, maximum AFUE identified in the AHRI and CCMS databases at time of publication is 90%. There is only one condensing level within the EERE analysis so extrapolation to 90% cannot be done, therefore, cost values are those presented in EERE 2015 for 91% AFUE.

*** Average Life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, an average of 24.8 years is calculated for oil-fired hot water boilers, with a low and high range from 18 to 28 years respectively.

**** In 2021, new energy conservation standards for Residential Boilers will take effect. These projections reflect the 2021 minimum AFUE requirement for residential oil-fired boilers, 86%.

- Federal standard for oil-fired hot-water boilers (more common than steam):
  - AFUE ≥ 84%
  - Design requirements that took effect on September 1, 2012 require an automatic means for adjusting water temperature
  - AFUE ≥ 86% required on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 87%
- Most efficient available: 90% AFUE
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Oil boilers have heat exchangers made of cast iron or stainless steel.

Annual shipments declined rapidly after 2004, likely due at least in part to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2009 shipments have largely levelled off.



Source: *National Impact Analysis Spreadsheet from the 2015 Energy Conservation Standards for Residential Boilers Final Rule.* *(https://www.regulations.gov/document?D=EERE-2012-BT-STD-0047-0072)*

Residential Electric Resistance Furnaces

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DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	68	68	68	68	68	68	68
AFUE (%)	98	98	98	98	98	98	98
Average Life (yrs)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost (2017$)	600	600	600	600	600	600	600
	700	700	700	700	700	700	700
Total Installed Cost (2017$)	1,000	1,000	1,000	1,000	1,000	1,000	1000
	1,200	1,200	1,200	1,200	1,200	1,200	1200
Annual Maintenance Cost (2017$)	40	40	40	40	40	40	40

- Federal standards for electric furnaces:
  - AFUE ≥ 78%
  - Standby and off mode power consumption ≤ 10 watts
- According to RECS 2015 data, electric central warm-air furnaces are the main source of space heating in approximately 17.9 million US homes or about 15%. The majority of these installations are part of a heat pumps system, where the electric resistance is used as back-up heating.
- Electric furnaces range in capacity from 10 to 25 kW (34 to 85 kBtu/hr), with 20 kW (68 kBtu/hr) being the typical for units on the market.
- Electric resistance furnaces are considered near 100% efficient because there is no flue heat loss and any jacket losses are contained within the home.
  - ASHRAE Standard 103, the test method for furnaces incorporated by reference into the federal test procedure, specifies that for electric furnaces AFUE = 100 – 1.7 x jacket losses. Jacket losses can be determined either through testing or assumed to be 1%. Thus, the minimum AFUE of electric furnaces is 98.3%.

Residential Electric Resistance Unit Heaters

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DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Efficiency (%)	100	100	100	100	100	100	100
Average Life (yrs)*	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost (2017$)	75	75	75	75	75	75	75
	200	200	200	200	200	200	200
Total Installed Cost (2017$)	125	125	125	125	125	125	125
	275	275	275	275	275	275	275
Annual Maintenance Cost (2017$) **	-	-	-	-	-	-	-

* Assumes similar lifetime to Electric Furnaces on the basis that both products have heating elements that burn out and lead to product failure.
** Annual Maintenance Cost is negligible

- Electric resistance unit heaters include electric wall and baseboard heaters. Plug-in space heaters are not included.
- There are currently no federal efficiency requirements for electric resistance unit heaters.
- According to RECS 2015 data, electric resistance unit heaters are the main source of space heating in approximately 8.9 million US homes or about 8%.
- Electric heaters range in capacity from 500 to 2,500 watts (1.7 to 8.5 kBtu/hr), with 1,000 watts (3.5 kBtu/hr) being the most typical for units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion. An efficiency of 98% is selected here to account for IR losses and fan inefficiency.

North (Not Hot-Dry or Hot-Humid)

DATA	2009	2015	2017				2020		2030**		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	12.5	13.0	13.9	15.0	16.5	13.9	16.5	14.4	16.5	14.4	16.5	14.4	16.5
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$)	1,750	2,050	2,200	2,250	2,650	3,200	2,250	3,200	2,350	3,200	2,350	3,200	2,350	3,200
Total Installed Cost (2017$)	2,150	3,400	3,550	3,650	4,000	4,650	3,650	4,650	3,700	4,650	3,700	4,650	3,700	4,650
Annual Maintenance Cost (2017$)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	125	125	125	125	125	125	125	125	125	125	125	125	125	125

* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for ducted "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for Residential Air Source HP, which is why the "High" SEER levels are higher for HPs than for ACs.

** In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps will take effect. The new standards specify a different metric for Central ACs (SEER2). These projections reflect the equivalent levels for the 2023 standard under the current metric, 14 SEER.

South (Hot-Dry and Hot-Humid)

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	13.0	14.0	14.4	15.0	16.5	14.4	16.5	15.1	16.5	15.1	16.5	15.1	16.5
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$)	1,750	2,200	2,250	2,350	2,650	3,200	2,350	3,200	2,700	3,200	2,700	3,200	2,700	3,200
Total Installed Cost (2017$)	2,150	3,600	3,650	3,700	4,000	4,650	3,700	4,650	4,100	4,650	4,100	4,650	4,100	4,650
Annual Maintenance Cost (2017$)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	125	125	125	125	125	125	125	125	125	125	125	125	125	125

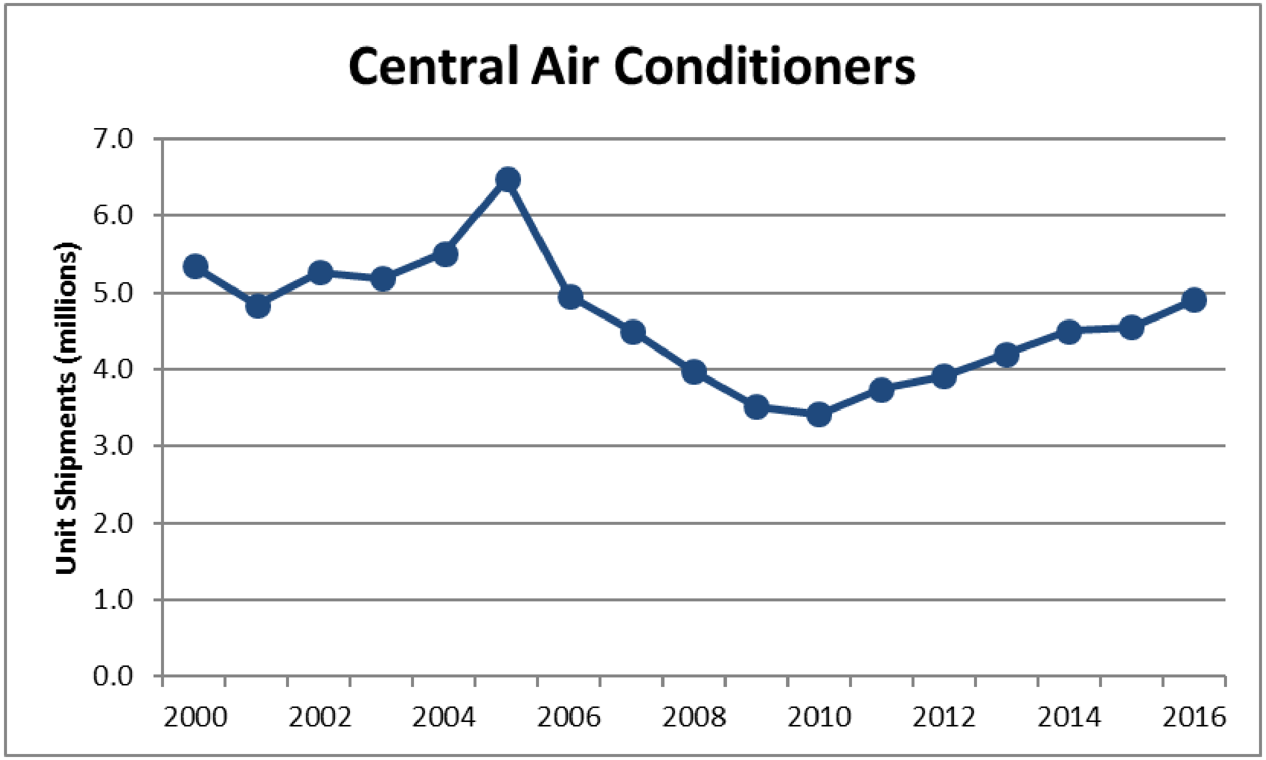
* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for ducted, "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for Residential Air Source HP, which is why the "High" SEER levels are higher for HPs than for ACs.

** In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps will take effect. The new standards specify a different metric for Central ACs (SEER2). These projections reflect the equivalent levels for the 2023 standard under the current metric, 15 SEER.

Residential Central Air Conditioner Product Class	Current Standards			Current ENERGY STAR Criteria	
	Min. SEER in North	Min. SEER in South	Max. Off Mode Power (W)	Min. SEER	Min. EER
Split-System AC	13	14	30	15	12.5
Single-Package AC	14	14	30	15	12
Small-Duct, High-Velocity	12	12	30	–	–
Space-Constrained	12	12	30	–	–

- Current standards, which took effect in 2015, represent an improvement in efficiency in all regions from 13 SEER for single-package units.
- Current standards in the South and Southwest represent an improvement in efficiency from 13 SEER for split systems.
- Systems installed in the Southwest (CA, AZ, NM, and NV) also have to meet an energy efficiency ratio (EER) standard that varies by cooling capacity and system configuration.
- Current standards took effect in 2015, amended standards for all product classes will take effect in 2023.
- Small-Duct, High-Velocity and Space-Constrained units both have very small market shares

Annual shipments spiked at 6.5 million units in 2005 at the peak of the housing boom and just before more stringent Federal standards took effect in 2006. Annual shipments have been steadily increasing since 2010 but have not yet reached the previous high.



Source: *AHRI* (available at http://www.ahrinet.org/Resources/Statistics/Historical-Data/Central-Air-Conditioners-and-Air-Source-Heat-Pumps.aspx)

Residential Air Source Heat Pumps

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DATA	2009	2015	2017				2020		2030**		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER (Cooling)*	12.0	13.1	14.0	15.3	15.0	19.0	15.3	19.0	15.8	19.0	15.8	19.0	15.8	19.0
HSPF (Heating)*	7 .0	7.9	8.2	8.6	8.5	9.0	8.6	9.0	8.8	9.0	8.8	9.0	8.8	9.0
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost (2017$)*	2,550	2,800	3,350	3,600	3,500	4,550	3,600	4,550	3,700	4,550	3,700	4,550	3,700	4,550
Total Installed Cost (2017$)*	3,000	3,250	4,850	5,100	4,950	6,100	5,100	6,100	5,150	6,100	5,150	6,100	5,150	6,100
Annual Maintenance Cost (2017$)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	125	125	125	125	125	125	125	125	125	125	125	125	125	125

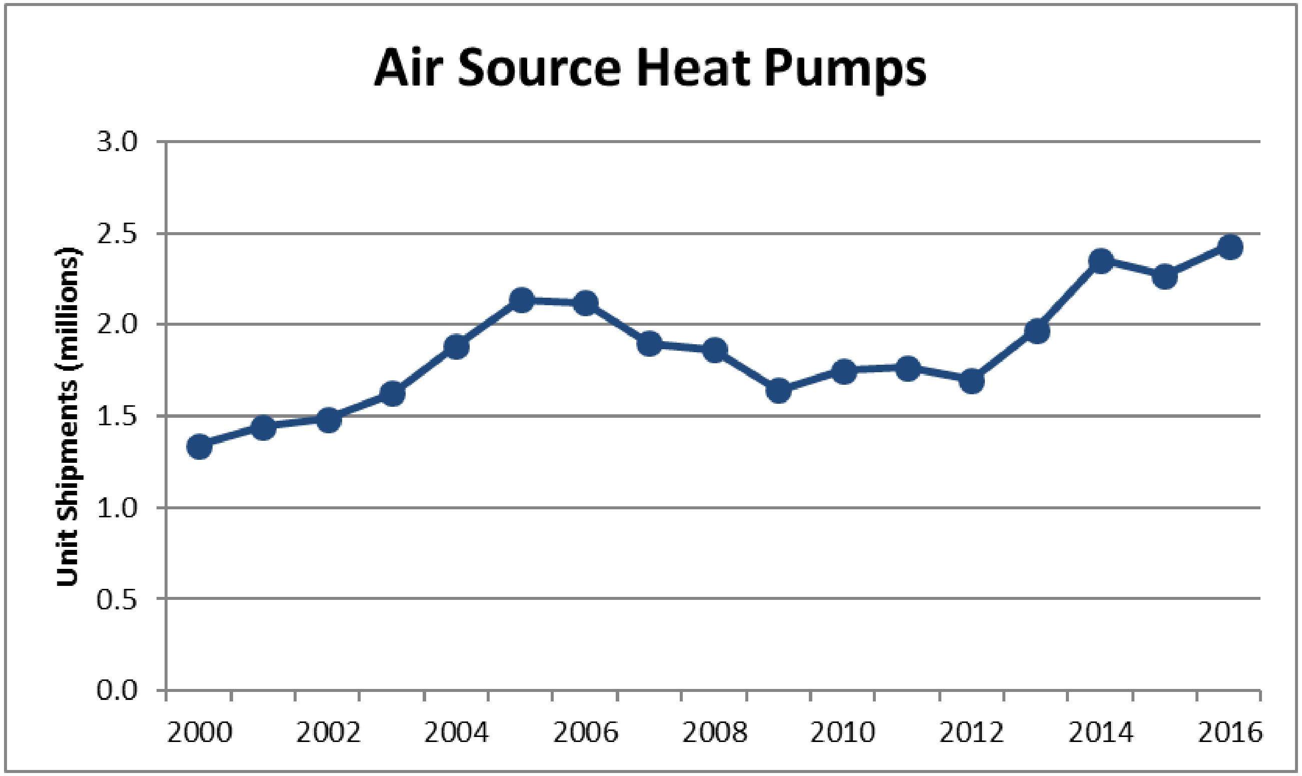
* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class which represent the largest market share based on 2016 Energy Conservation Standards for Central Air Conditioners and Heat Pumps, Government Regulatory Impact Model. Costs and efficiency levels are for ducted systems with integral indoor blowers. Note coil-only systems were analyzed for Residential Central AC North and South, which is why the "High" SEER levels are higher for HPs than for ACs.

**In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps will take effect. The new standards specify different metrics (SEER2 and HSPF2). These projections reflect the equivalent levels for the 2023 standard under the current metrics, 15 SEER and 8.8 HSPF.

Residential Heat Pump Product Class	Current Standards			Current ENERGY STAR Criteria		
	Min. SEER	Min. HSPF	Max. Off Mode Power (W)	Min. SEER	Min. EER	Min. HSPF
Split-System	14	8.2	33	15	12.5	8.5
Single-Package	14	8	33	15	12	8.2
Small-Duct, High-Velocity	12	7.2	30	–	–	–
Space-Constrained	12	7.4	33	–	–	–

- High efficiency cooling does not necessarily correlate with high efficiency heating. The range of SEER–HSPF combinations is very broad.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, electric resistance heat is used to supplement.
- Variable-speed compressors improve efficiency of heat pumps by reducing cyclic losses and by operating above their nominal speed, boosting heating capacity and reducing the need for supplementary electric resistance heat.
- Current standards took effect in 2015, amended standards for all product classes will take effect in 2023.

From 2000 to 2005 annual shipments increased nearly 60% to 2.1 million units, then dropped and leveled off around 1.7 million units. In 2014 annual shipments surpassed the 2005 peak.



Source: *AHRI* (available at http://www.ahrinet.org/Resources/Statistics/Historical-Data/Central-Air-Conditioners-and-Air-Source-Heat-Pumps.aspx)

- Principal energy efficiency drivers for central air conditioners and heat pumps :
  - Heat exchanger (surface area, number of tube rows)
  - Compressor (type and single-stage vs. two-stage vs. variable-speed operation)
  - Fan motor choices (PSC vs. ECM fan motors on inside and outside)
  - Control choices (i.e., piston, thermal, and electronic expansion valves)
- When the heat pump or air conditioner's capacity exceeds the heating or cooling load, the unit starts and stops more frequently, causing wear and tear on the components and an overall loss of efficiency. Multi-stage and/or variable-speed compressors can help, as does sophisticated refrigerant management.
- Typical high-efficiency unit (≥16 SEER) has very large heat exchanger, ECM evaporator fan motor, and two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, making possible high-SEER condensing units with smaller heat exchangers, and thus, smaller enclosures.
- Efficiency levels >21 SEER made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and electronic expansion valves.

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
COP (Heating)*	3.0	3.1	3.2	3.7	3.6	4.5	3.7	4.5	3.7	4.5	3.7	4.5	3.7	4.5
EER (Cooling)**	12.3	13.3	14.1	17.3	17.1	22.4	17.3	22.4	17.3	22.4	17.3	22.4	17.3	22.4
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2017$)	6,200	3,950	4,100	4,650	4,600	5,550	4,650	5,550	4,650	5,550	4,650	5,550	4,650	5,550
Total Installed Cost (2017$)	18,100	11,950	12,100	12,650	12,650	13,550	12,650	13,550	12,650	13,550	12,650	13,550	12,650	13,550
	20,650	18,950	19,100	19,650	19,650	20,550	19,650	20,550	19,650	20,550	19,650	20,550	19,650	20,550
Annual Maintenance Cost (2017$)	75	75	75	75	75	75	75	75	75	75	75	75	75	75

* COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.

** EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. Previous analysis relied on Energy Star ratings which are an average of the full-load and part-load "ground loop" conditions. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note: Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs 4-ton) and slightly higher installation costs for commercial. DOE does not distinguish between residential and commercial units in its regulations.

- There are currently over 20 ground source heat pump manufacturers/OEMs in the US.
- Heating COP does not correlate with cooling EER (coefficient of determination, $R^2 = 0.59$ for ENERGY STAR certified products). The highest efficiency GSHP is the 7 Series by WaterFurnace International, Inc. (41 EER & 5.3 COP). Note that these are equipment-level thermal ratings tested according to standardized lab conditions and do not necessarily represent system-level or "real-world" performance.
- The ENERGY STAR® criteria for water-to-air ground source heat pumps are:

Type	Heating COP	Cooling EER
Closed Loop	3.6	17.1
Open Loop	4.1	21.1
Direct Expansion	3.6	16

- The most common ground source heat pump is a closed-loop system in which water or an anti-freeze solution is circulated through plastic pipes buried underground. Open loop systems that employ ground water or surface water (e.g., open well, pond, lake) are used in some parts of the country, but water supply and water quality issues impose limitations on such applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger represents a majority of the installation cost. Installed costs for these systems vary widely.
- Variable speed electronically commutated motors (ECMs) improve performance on high end models.

Residential Room Air Conditioners

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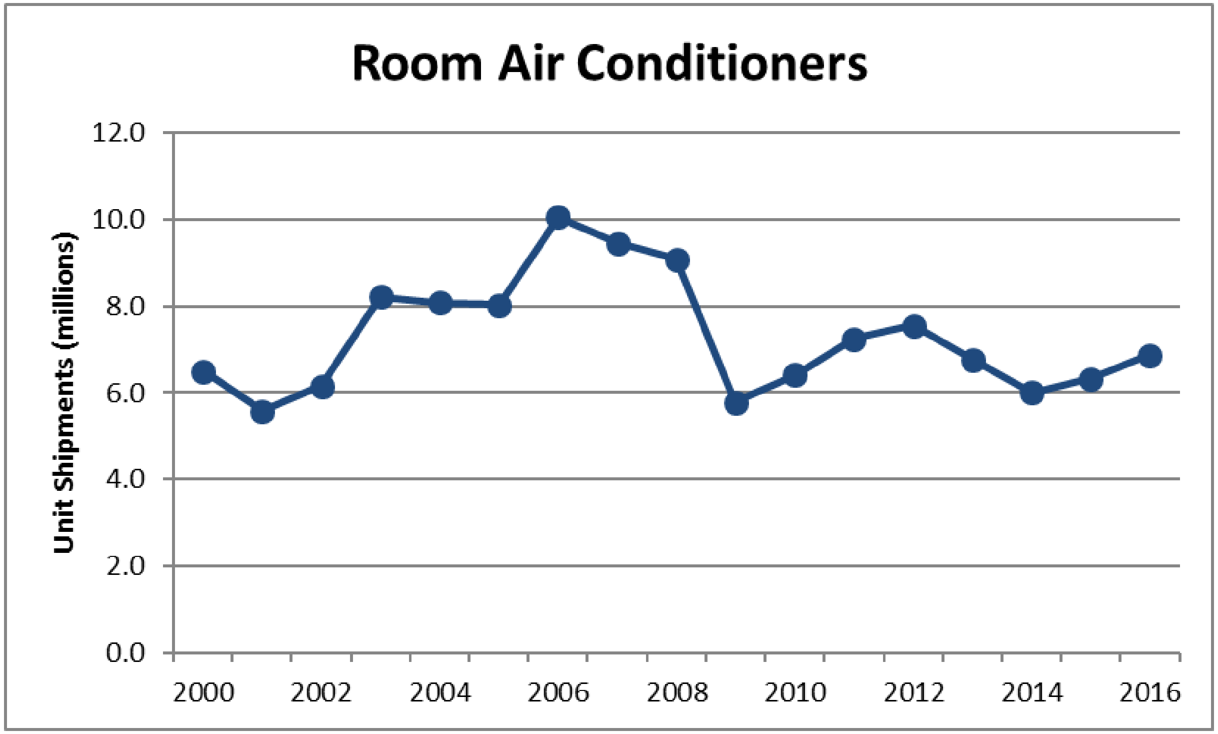
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)*	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
CEER (Btu/Wh)	9.3	10.9	10.9	12.0	12.0	12.3	12.0	12.5	12.3	13.0	12.5	13.5	12.5	13.5
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2017$)	480	470	470	510	510	510	510	510	510	510	510	510	510	510
	580	600	600	600	600	730	600	730	600	730	600	730	600	730
Total Installed Cost (2017$)	550	540	540	580	580	580	580	580	580	580	580	580	580	580
	680	700	700	700	700	830	700	830	700	830	700	830	700	830
Annual Maintenance Cost (2017$)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).
** Maintenance costs are negligible.

- Focus on most common type: louvered sides (window air conditioners) without reverse cycle and having cooling capacity of 8,000–13,999 Btu/h (DOE Product Class 3).
- Federal standards for Product Class 3:
  - CEER ≥ 10.9 (beginning June 1, 2014)
- Combined Energy Efficiency Ratio (CEER) incorporates energy use in cooling mode and standby and off modes.
- Of the 474 individual models in Product Class 3 listed in DOE's compliance certification database[1]:
  - 42% are at the standard level (≥ 10.9 CEER, < 12.0 CEER)
  - 58% are at the ENERGY STAR level (≥ 12.0 CEER)
  - Most efficient model is at 12.3 CEER
- ENERGY STAR criteria for Product Class 3
  - CEER ≥ 12.0 (effective October 26, 2015)
- Most efficient product in 2030: 13.1 CEER, based on Building Technologies Program R&D[2].
- Efficiency improvements are attained by:
  - Higher efficiency compressor and fan motors, and
  - An increased heat transfer area in the evaporator and condenser through the use of larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.

1. Accessed December 2017. https://www.regulations.doe.gov/certification-data
2. ORNL. High Efficiency Room Air Conditioner. http://info.ornl.gov/sites/publications/files/Pub53922.pdf

Annual shipments dropped sharply in 2009, likely due to the recession and an unusually cool summer in the Northeast. Sales have largely leveled off in the years since, fluctuating between 6 and 7.5 million.



Source: *Appliance Magazine.*

DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)*	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
CEER	5.6	5.6	5.6	6.7	5.6	6.7	5.6	6.7	5.6	6.7	5.6	6.7
Average Life (yrs)	7	7	7	7	7	7	7	7	7	7	7	7
	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)	720	690	670	800	670	800	670	800	670	800	670	800
Total Installed Cost (2017$)	720	690	670	800	670	800	670	800	670	800	670	800
Annual Maintenance Cost (2017$)**	-	-	-	-	-	-	-	-	-	-	-	-

* All values are for the average capacity for single-duct and dual-duct portable ACs available on the market.
** Maintenance costs are negligible.

Note: In December of 2016 EREE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Portable Air Conditioners. As of October 2017, this rule has not yet been published and therefore these standards are not reflected in the values shown above.

- A new test procedure for portable ACs was published June 1, 2016
- The test procedure addresses single-duct and dual-duct portable ACs, configurations typically used in residential applications. No procedures were established for other portable AC configurations (e.g., spot coolers).
- Spot coolers, a portable AC configuration with no condenser-side ducts and with adjustable evaporator exhaust ducts, are commonly used in commercial applications.
- A final rule, Energy Conservation Standards for Portable Air Conditioners, was issued in December 28, 2016 to address standards for single-duct and dual-duct portable ACs. It never published, so there are no existing energy conservation standards for portable ACs.
- The final rule outlined an equation-based conservation standard (in CEER) for both single-duct and dual-duct portable ACs, based on the seasonally adjusted cooling capacity (SACC).
- For a typical portable AC in 2017 with a capacity of 6,600 Btu/h, the corresponding CEER is typically 4.3 Btu/Wh.
- Efficiency improvements are attained by:
  - Higher efficiency compressor and fan motors, and
  - An increased heat transfer area in the evaporator and condenser through the use of larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.

Residential Natural Gas Heat Pumps

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DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	60	60	60	60	60	60	60
Heating (COP)	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Cooling (COP)	0.6	0.6	0.6	0.7	0.7	0.7	0.7
Annual Electric Use (kWh/yr)*	2,000	1,500	1,500	1,500	1,500	1,500	1,500
Average Life (yrs)	12	12	12	12	12	12	12
	18	18	18	18	18	18	18
Retail Equipment Cost (2017$)	11,000	11,000	11,000	11,000	11,000	11,000	11,000
	12,200	12,200	12,200	12,200	12,200	12,200	12,200
Total Installed Cost (2017$)	12,500	12,500	12,500	12,500	12,500	12,500	12,500
	14,700	14,700	14,700	14,700	14,700	14,700	14,700
Annual Maintenance Cost (2017$)	170	170	170	170	170	170	170

* Annual Electric Use accounts for the electricity consumption of components such as the heat pump fan.

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- Residential Gas Heat Pumps are not currently covered by NAECA. CEC Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for gas heat pumps.
- Gas heat pumps are much more popular in other parts of the world, such as Europe. Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market in the U.S.
- Currently, Robur is the predominant manufacturer of residential-sized gas heat pumps with sales operations in the US. Robur units are 5-ton nominal cooling capacity, a size typically associated with larger homes. Since only one product is available, no mid-level or high efficiency categories are included.
- The data represents air-source absorption heat pumps. Gas engine-driven vapor compression heat pumps are available in other parts of the world; York formerly offered the Triathlon gas engine-driven heat pump in the US. It is possible to couple either technology to the ground (ground source) rather than the atmosphere (air source).
- The absorption heat pump is a gas-fired, ammonia-water absorption cycle, combined with a high-efficiency low-pressure boiler integrated into one outdoor unit.
- The cooling efficiency of a gas-fired air source absorption heat pump is considerably lower than for an electric air source heat pump. Heating efficiency of an air source heat pump (electric or gas-fired absorption) decreases as outdoor temperature decreases; however the gas-fired absorption heat pump recovers waste heat from the combustion process to improve heating efficiency.

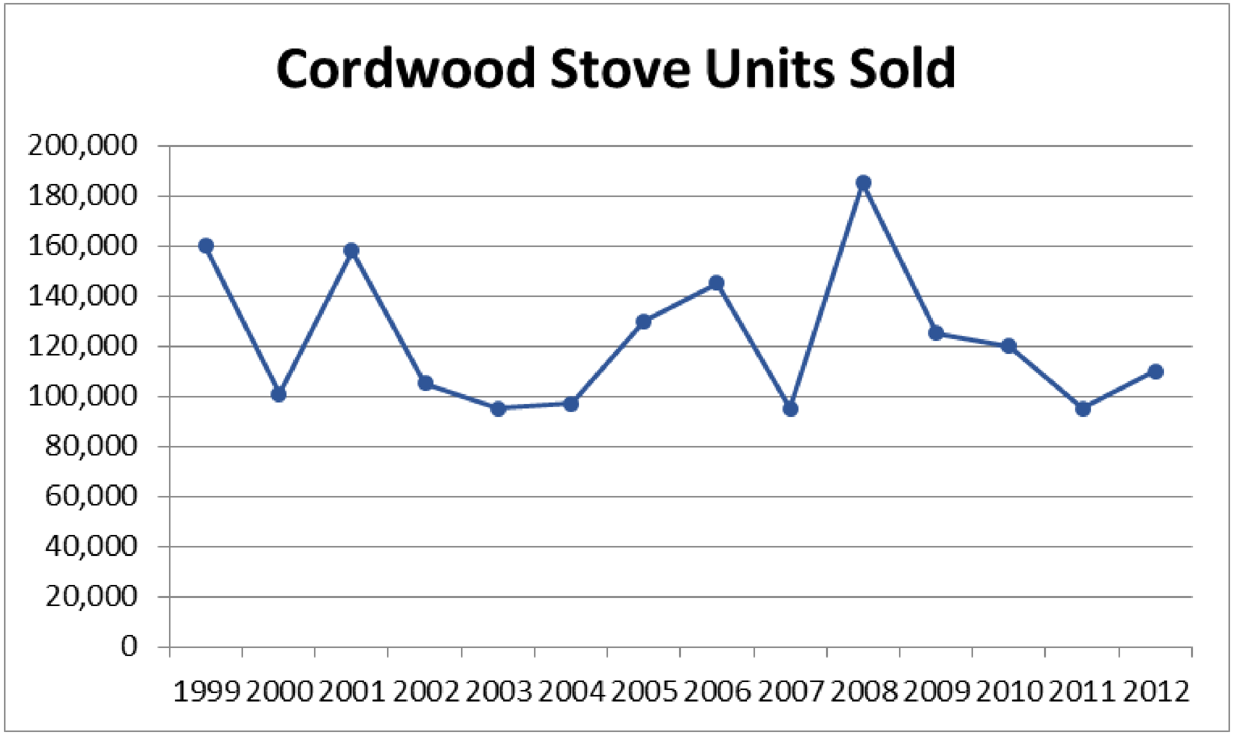
DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical*	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50	50	50
Efficiency (Non-Catalytic) (HHV)**	58	63	70	76	70	77	73	78	74	79	75	80
Efficiency (Catalytic) (HHV)**	68	72	78	84	78	84	81	85	82	86	83	87
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$) (Non-Catalytic)	2,400	2,450	2,450	2,650	2,450	2,650	2,550	2,750	2,650	2,850	2,750	2,950
Retail Equipment Cost (2017$) (Catalytic)	3,300	3,000	3,000	3,200	3,000	3,200	3,100	3,300	3,200	3,400	3,300	3,500
Total Installed Cost (2017$) (Non-Catalytic)	7,000	7,050	7,050	7,250	7,050	7,250	7,150	7,350	7,250	7,450	7,350	7,550
Total Installed Cost (2017$) (Catalytic)	7,900	7,600	7,600	7,800	7,600	7,800	7,700	7,900	7,800	8,000	7,900	8,100
Annual Maintenance Cost (2017$) (Non Catalytic)	160	160	160	160	160	160	160	160	160	160	160	160
Annual Maintenance Cost (2017$) (Catalytic)	235	235	235	235	235	235	235	235	235	235	235	235

* EPA Certified Default Level no longer listed here because 2015 EPA rule requires that manufacturers test and report the efficiency of their stoves and, therefore, manufacturers no longer have the option to report the default value.
** Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
*** Installed cost includes cost of hearth and stainless steel chimney liner - materials and labor.
**** Annual maintenance cost of catalytic stove includes periodic cost of replacing the catalytic combustor.

- Residential cordwood stoves that must meet EPA particulate limits fall into two broad classes based on whether or not they use a catalyst for air treatment. Catalytic wood stoves use a catalytic combustor to reduce emissions from the combustion air. Non-catalytic wood stoves use baffles and introduce secondary air above the flames to enable more complete combustion and reduce emissions.
- In 2015, EPA published an update to its New Source Performance Standards (NSPS), decreasing the emissions limit (previously set by 1988 EPA rule) to 4.5 g/hr for both catalytic and non-catalytic stoves. The new rule did not institute efficiency standards, but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- The 2015 EPA rule stipulates that, in 2020, emissions requirements for wood stoves will be lowered to 2.5 or 2.0 g/hr (depending on the test method used).
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or certify with the default efficiency value designated by EPA. EPA's default efficiency values were 63% for non-catalytic wood stoves and 72% for catalytic wood stoves. Under this system, few manufacturers submitted efficiency test data to EPA.
- Some states still have emissions requirements that are more stringent than the EPA's standard (e.g., Washington).
- EPA notes in its 2015 rule that efficiency requirements may be included in a future rulemaking.

- A federal tax credit for efficient wood stoves was offered from 2009 to 2016 and retroactively for 2017. Some states offered tax credits through 2017 (e.g., Oregon).
- Multiple test standards are commonly used to assess stove efficiency and data from product literature does not generally identify the efficiency test method. It's not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Cordwood stoves require chimneys for venting combustion gases. Whether conventional masonry chimneys are used or metal chimney liners, these add considerable cost to the overall system. Accordingly, installed costs can be twice that of the wood stove itself.

Cordwood stove shipments have averaged 123,000 per year since 1999 and have fluctuated roughly in accordance with fuel oil costs.



Source: HPBA, no post-2012 sales data was publicly available at time of publication.

Residential Wood Pellet Stoves

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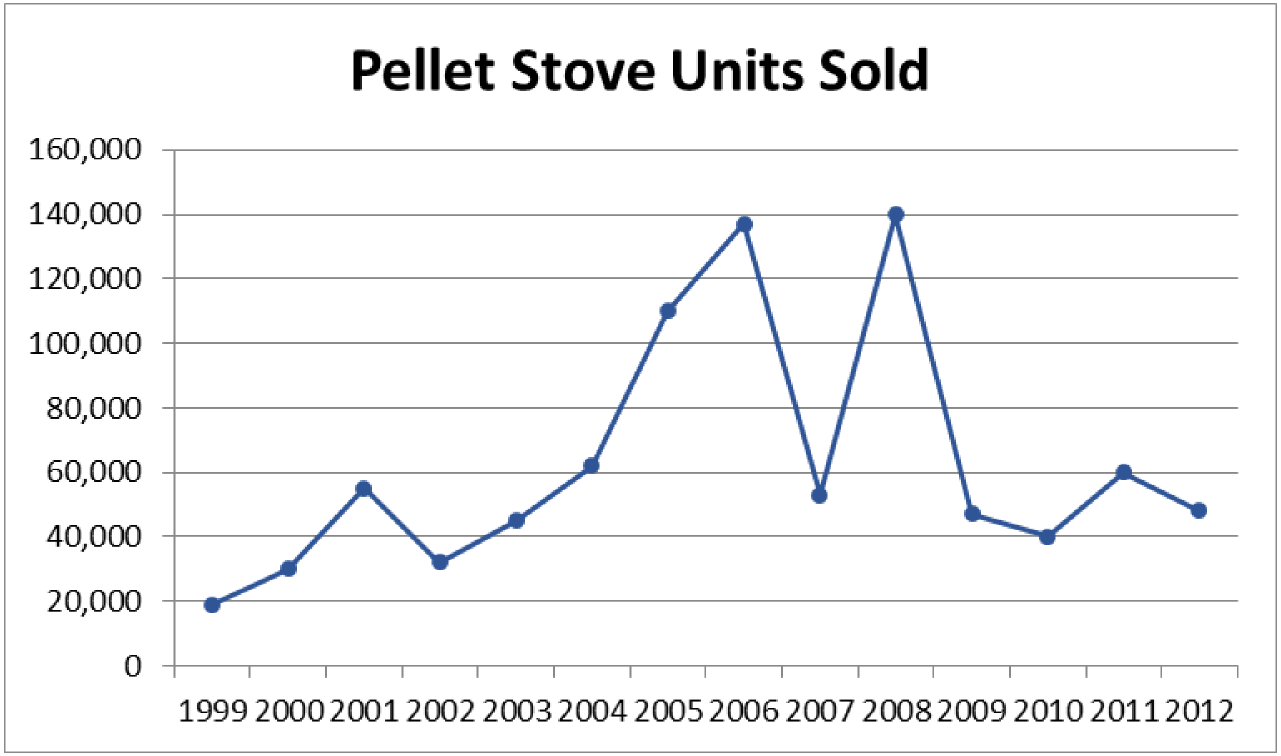
DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)	65	70	76	87	76	87	77	87	78	88	79	89
Annual Electricity Consumption (kWh)	600	600	600	600	600	600	600	600	600	600	600	600
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$)	3,300	3,300	3,300	4,000	3,300	4,000	3,400	4,000	3,500	4,100	3,600	4,200
Total Installed Cost (2017$)	4,700	4,700	4,700	5,400	4,700	5,400	4,800	5,400	4,900	5,500	5,000	5,600
Annual Maintenance Cost (2017$)	260	260	260	260	260	260	260	260	260	260	260	260

* EPA Certified Default Level removed because 2015 EPA rule requires that manufacturers test and report the efficiency of their stoves. Therefore, manufacturers no longer have the option to report the default value.
** Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
*** Installed cost includes cost of hearth and vent pipe - materials and labor.

- In 2015, EPA published an update to its New Source Performance Standards (NSPS), limiting emissions for wood pellet stoves to 4.5 g/hr. Prior to the 2015 EPA rule, most pellet stoves were exempt from EPA's NSPS requirements. The new rule did not institute efficiency standards, but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- The 2015 EPA rule stipulates that, in 2020, emissions requirements for wood stoves will be lowered to 2.5 or 2.0 g/hr (depending on the test method used).
- EPA notes in its 2015 rule that efficiency requirements may be included in a future rulemaking.
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or use a default efficiency value designated by EPA (78% for pellet stoves). Under this system, few manufacturers submitted efficiency test data to EPA.
- Some states still have emissions requirements that are more stringent than the EPA's standard (e.g., Washington).
- A federal tax credit for efficient wood stoves was offered from 2009 to 2016 and retroactively for 2017. Some states offered tax credits through 2017 (e.g., Oregon).

- Multiple test standards are commonly used to assess stove efficiency and data from product literature does not generally identify the efficiency test method.
- It's not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Wood pellet stoves may be able to be direct vented to the outdoors, eliminating the need for a chimney. This reduces the overall system cost as compared to a cord wood stove. However, they do use electricity to power the pellet feeder, the combustion air fan, and the blower. In the event of a power outage, a pellet stove can not operate without some back-up source of electricity (e.g., battery) .

Wood pellet stove shipments grew substantially in the 2005 – 2008 time period, but have averaged only 40,000 – 60,000 units since that time.



Source: HPBA, no post-2012 sales data was publicly available at time of publication.

- On December 29, 2016, the metric for the current Federal standard was translated from Energy Factor (EF) to Uniform Energy Factor (UEF)[1].

- The UEF test procedure is conceptually similar to the EF test procedure in that it is a 24-hour simulated-use test of how the water heater would be expected to perform in the field.
  - The EF test procedure consists of one draw pattern for all models.
  - The UEF test procedure consists of 4 possible draw patterns.
    - The particular draw pattern a water heater is tested to is determined through a delivery capacity test (first-hour rating or maximum GPM).
    - A draw pattern is a set of instructions specifying when, how fast (flow rate), and how much (volume) hot water is removed from the water heater.
    - Therefore, a water heater designed to deliver a small amount of hot water is not tested the same as a water heater designed to deliver a large amount of hot water.

[1]Test Procedures for Consumer and Commercial Water Heaters; Final rule. 81 FR 96204.

Residential Gas-Fired Storage Water Heaters

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DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Uniform Energy Factor (UEF)*	0.58	0.58	0.61	0.63	0.66	0.81	0.63	0.81	0.63	0.81	0.63	0.81	0.63	0.81
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	500	500	700	750	800	1,850	750	1,850	750	1,850	750	1,850	750	1,850
	550	550	1,000	1,200	1,350	2,100	1,200	2,100	1,200	2,100	1,200	2,100	1,200	2,100
Total Installed Cost (2017$)**	1,050	1,050	1,350	1,400	1,500	2,450	1,400	2,450	1,400	2,450	1,400	2,450	1,400	2,450
	1,050	1,050	2,300	2,450	2,550	3,700	2,450	3,700	2,450	3,700	2,450	3,700	2,450	3,700
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-	-	-

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.60 EF. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market.

** Installed cost reflects differences in installation cost between typical and high efficiency products. Typical efficiency products are non-condensing, whereas the high efficiency products are condensing and require different installation. Furthermore, higher UEF can be achieved by additional insulation, which also increases the size of the unit and the associated installation cost.

*** Maintenance costs are negligible.

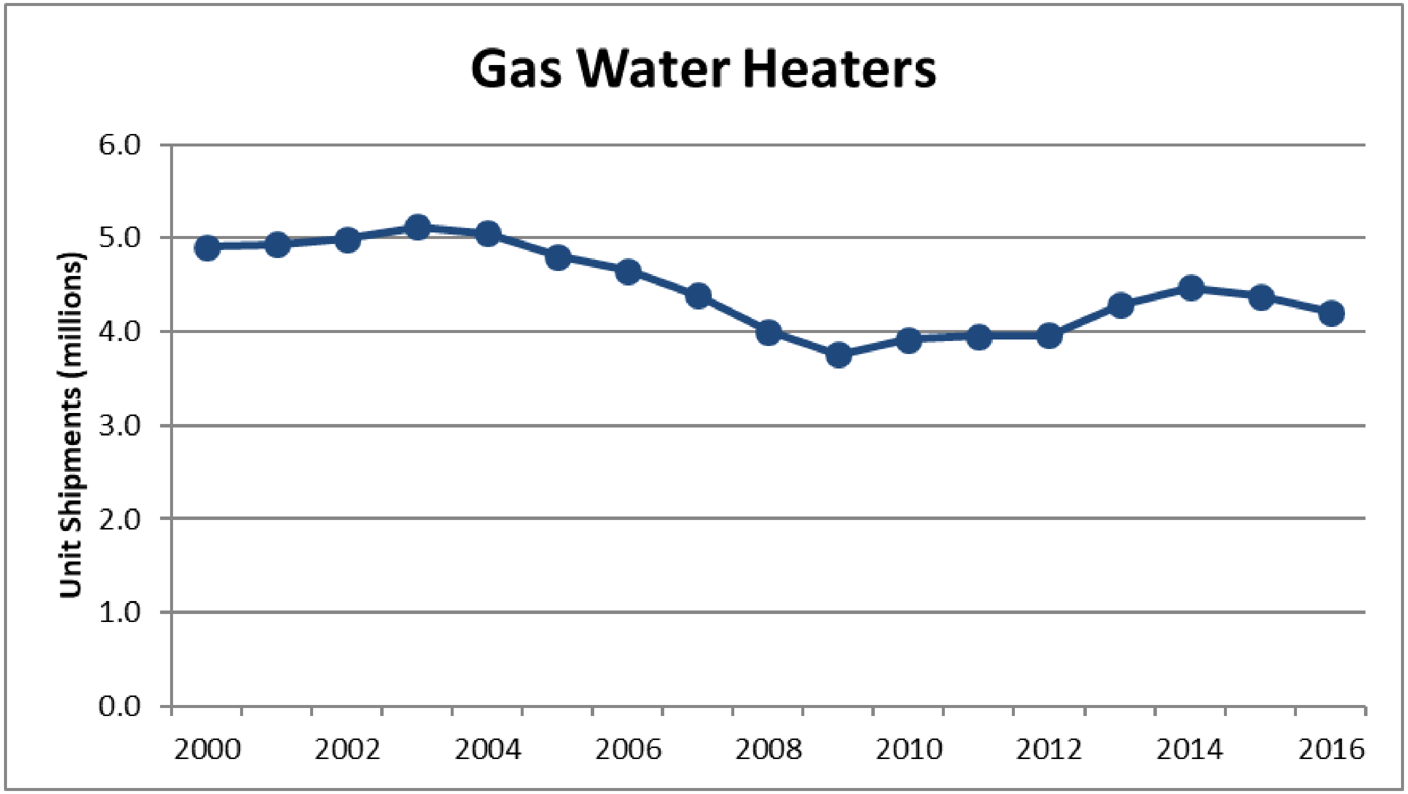
- The equations for the revised Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.3456-(0.002*Gal)	No models on the market	N/A
	Low	UEF=0.5982-(0.0019*Gal)	0.54 for a 29-gallon water heater	N/A
	Medium	UEF=0.6483-(0.0017*Gal)	0.58 for a 38-gallon water heater	0.64
	High	UEF=0.692-(0.0013*Gal)	0.64 for a 48-gallon water heater	0.68
> 55 gal and ≤ 100 gal	Very Small	UEF=0.647-(0.0006*Gal)	No models on the market	N/A
	Low	UEF=0.7689-(0.0005*Gal)	No models on the market	N/A
	Medium	UEF=0.7897-(0.0004*Gal)	No models on the market	0.78
	High	UEF=0.8072-(0.0003*Gal)	No models on the market	0.80

- There are currently no models on the market above 55 gallons due to the high UEF which would require using condensing or gas-fired heat pump (e.g., absorption) technology to achieve.
- The ENERGY STAR UEF levels for models with storage volume ≤ 55 gallons are typically achievable through the use of a power vent or flue damper.
- The cost of installation is typically $600 to $1200, which exceeds that of electric water heaters. This difference can be attributed to multiple differences, gas-fired heaters require an extra 1.5 hours of labor for 2 plumbers.
- Condensing units are high efficiency and use PVC venting instead of stainless-steel. Condensing units also use an electrical supply for electronic ignition and power venting. Some building codes require condensate neutralizer filters.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Shipments were flat at 5 million units per year through 2004, then declined gradually over 5 years to a new plateau at 4 million units until rising again to a max of 4.5 million units in 2014.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Residential-Storage-Water-Heaters-Historical-Data.aspx*

Residential Oil-Fired Storage Water Heaters

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DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	30	32	32	32	32	32	32	32	32	32	32	32	32
Uniform Energy Factor (UEF)*	0.51	0.51	0.64	0.67	0.69	0.67	0.69	0.67	0.69	0.67	0.69	0.67	0.69
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	1,350	1,350	1,500	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
	1,450	1,450	1,900	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
Total Installed Cost (2017$)	2,000	2,000	2,100	2,250	2,200	2,250	2,200	2,250	2,200	2,250	2,200	2,250	2,200
	2,100	2,100	2,700	2,850	2,850	2,850	2,850	2,850	2,850	2,850	2,850	2,850	2,850
Annual Maintenance Cost (2017$)	180	180	180	180	180	180	180	180	180	180	180	180	180

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.50 EF. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market

- The equations for the Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≤ 50 gal	Very Small	UEF=0.2509-(0.0012*Gal)	No models on the market	N/A
	Low	UEF=0.533-(0.0016*Gal)	No models on the market	N/A
	Medium	UEF=0.6078-(0.0016*Gal)	No models on the market	N/A
	High	UEF=0.6815-(0.0014*Gal)	0.64 for a 29-gallon water heater	N/A

- There are no ENERGY STAR levels for oil-fired storage water heaters.
- Annual shipments of residential oil-fired storage water heaters are approximately 40,000, which is ~1% of shipments of residential gas-fired storage water heaters.
- Oil-fired storage water heaters often have smaller tanks with larger input ratings relative to natural gas-fired and electric storage water heaters.
- No condensing residential oil-fired storage water heaters currently exist in the U.S. market. The highest efficiencies currently on the market are at near-condensing levels.
- Residential oil-fired water heaters utilize power burners and have at least some level of electrical power consumption.
- The max-tech model on the market uses a proprietary "turbo-flue" design to increase heat transfer to water.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Electric Resistance Storage Water Heaters

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DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50	50	50	50
Uniform Energy Factor (UEF)*	0.88	0.88	0.92	0.93	0.95	0.93	0.95	0.93	0.95	0.93	0.95	0.93	0.95
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	300	250	250	300	700	300	700	300	700	300	700	300	700
	350	450	500	550	900	550	900	550	900	550	900	550	900
Total Installed Cost (2017$)**	600	500	550	600	1,000	600	1,000	600	1,000	600	1,000	600	1,000
	650	800	1,000	1,100	1,450	1,100	1,450	1,100	1,450	1,100	1,450	1,100	1,450
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-	-

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.90 EF. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market

** Installed cost reflects differences in installation cost between typical and high efficiency products. The high UEF products have a larger size (due to insulation differences) and therefore require more installation work.

*** Maintenance costs are negligible.

- The equations for the Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.8808-(0.0008*Gal)	No models on the market	2.00
	Low	UEF=0.9254-(0.0003*Gal)	0.91 for a 27-gallon water heater	2.00
	Medium	UEF=0.9307-(0.0002*Gal)	0.92 for a 36-gallon water heater	2.00
	High	UEF=0.9349-(0.0001*Gal)	0.93 for a 45-gallon water heater	2.00
> 55 gal and ≤ 120 gal	Very Small	UEF=1.9236-(0.0011*Gal)	No models on the market	2.20
	Low	UEF=2.0440-(0.0011*Gal)	No models on the market	2.20
	Medium	UEF=2.1171-(0.0011*Gal)	2.03 for a 77-gallon water heater	2.20
	High	UEF=2.2418-(0.0011*Gal)	2.15 for a 82-gallon water heater	2.20

- The federal standards for residential electric storage water heaters apply to both electric resistance storage water heaters and integrated heat pump water heaters (HPWHs; heat pump module and storage tank combined in one unit).
  - The Federal standard levels for the ≤55 gallon range are achievable through electric resistance and heat pump technology.
  - The Federal standards for the >55 gallon range and all ENERGY STAR levels are only achievable through heat pump technology. Most HPWH on the market exceed both Federal standards and ENERGY STAR levels by a significant margin.
- Typical storage volumes range from 25-55 gallons for electric resistance storage water heaters and 45-80 gallons for HPWHs.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Heat Pump Water Heaters

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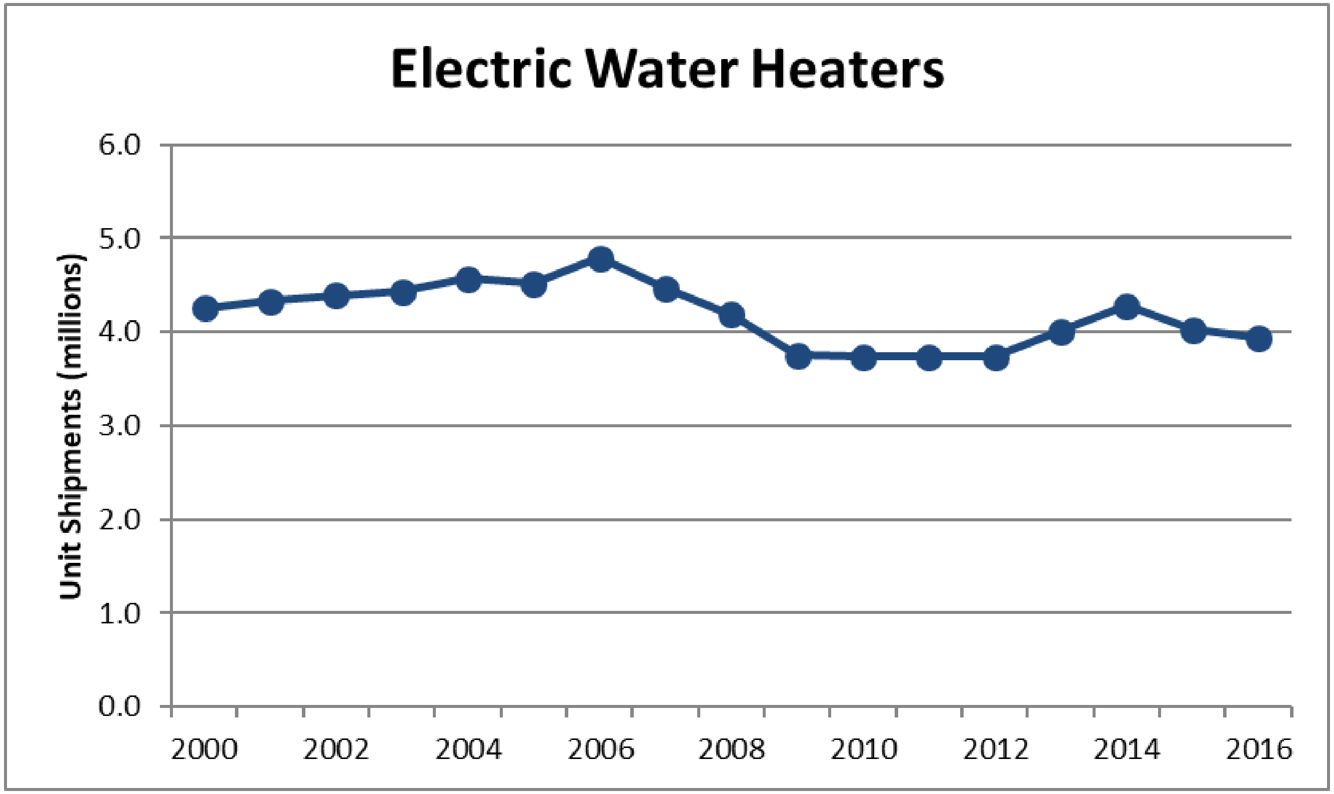
DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50	50	50	50
Uniform Energy Factor (UEF)*	2.05	2.05	3.28	2.00	3.55	3.28	3.55	3.28	3.55	3.28	3.55	3.28	3.55
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	1,550	1,100	1,200	1,050	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
	1,900	1,400	1,500	1,350	2,300	1,500	2,300	1,500	2,300	1,500	2,300	1,500	2,300
Total Installed Cost (2017$)	1,700	1,450	1,600	1,400	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
	2,450	2,500	2,550	2,400	3,350	2,550	3,350	2,550	3,350	2,550	3,350	2,550	3,350
Annual Maintenance Cost (2017$)	20	20	20	20	20	20	20	20	20	20	20	20	20

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 2.00 EF. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market

- Technology improvements have advanced efficiency and reliability, but the high first-cost and lack of awareness among consumers and contractors still precludes high-volume market penetration. Although there is an installed base listed for 2009, the market penetration of heat pump water heaters (HPWHs) was quite low at that time.
- New Federal standards that came into effect in April 2015 effectively mandate heat pump technology for electric storage water heaters with storage volume > 55 gallons.
- Integrated models are the most common configuration for residential HPWHs. Several major water heater manufacturers produce such models, and other competitors offer integrated or add-on units (for existing electric or indirect storage water heaters).
- Sales are estimated to be driven partly by rebates and tax credits at the utility, local, state, and Federal level.
- Resistive heating elements are virtually 100% efficient, but there is a jump in efficiency when heat pump technology is adopted because heat pumps' Coefficient of Performance (COP) are usually between 2.5 and 4.
- Heat pumps raise the water temperature more slowly than resistive heating elements, so most models use backup resistive elements along with the heat pump when hot water demand is high. Most HPWHs allow the consumer to control whether resistive elements are used in periods of high demand (e.g., "hybrid mode" or "heat pump only mode").

Shipments peaked in 2006 then dropped a total of 22 percent over three years and leveled off between 3.7 and 4.3 million units per year.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Residential-Storage-Water-Heaters-Historical-Data.aspx*

Residential Solar Water Heaters

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DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical / ENERGY STAR**	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	42	42	42	42	42	42	42
	63	65	65	65	65	65	65
Solar Fraction (SF)	0.5	0.5	0.56	0.56	0.56	0.56	0.56
Solar Energy Factor (SEF)	2.5	2.5	2.7	2.7	2.7	2.7	2.7
Average Life (yrs)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost* (2017$)	3,500	4,800	4,800	4,800	4,800	4,800	4,800
	5,400	8,300	8,300	8,300	8,300	8,300	8,300
Total Installed Cost* (2017$)	7,800	7,100	7,100	7,100	7,100	7,100	7,100
	10,200	11,000	11,000	11,000	11,000	11,000	11,000
Annual Maintenance Cost (2017$)	25	25	25	25	25	25	25

* Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.
** ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

- Solar water heaters (SWHs) are not subject to federal energy conservation standards, the ENERGY STAR requirements are:

Applicable Products	Backup Fuel	ENERGY STAR Requirement	Test Method
Whole-home solar units	Gas	SEF ≥ 1.2	SRCC – OG-300: Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems
	Electric	SEF ≥ 1.8	

- Solar water heaters can be either active or passive. An active system uses an electric pump to circulate the heat transfer fluid; a passive system has no pump. Most solar water heaters in the United States are the active type.
- Solar water heaters are also characterized as open loop (also called "direct") or closed loop (also called "indirect"). An open-loop system circulates household (potable) water through the collector. A closed-loop system uses a heat transfer fluid (water or diluted antifreeze, for example) to collect heat and a heat exchanger to transfer the heat to household water.
- Solar fraction represents the fraction of total annual water heating energy met by the solar water heater. A backup water heating system is required with SWHs, and it is typically most economical to size the system to provide about 50% of water heating energy (solar fraction = 0.5).
- Solar Energy Factor (SEF) is defined by the Solar Rating and Certification Corporation (SRCC) as the useful energy delivered by the system divided by the total electrical and/or fossil fuel required for backup heating, pumping, and controls (the free solar energy input is neglected).
- Over 2/3 of the current SWH market is in the southern or western US (including Hawaii). A collector area of 42 ft^2 would be typical for these areas. Colder areas of the US would require a larger collector (e.g. 65 ft^2).
- Installed costs are higher for colder areas where larger collectors are required. Costs also vary widely depending on collector quality, type of system, and site-specific characteristics.

Residential Gas-fired Instantaneous Water Heaters

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DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	185	199	199	199	199	199	199	199	199	199	199	199	199	199
Uniform Energy Factor (UEF)*	0.81	0.81	0.81	0.89	0.87	0.97	0.89	0.97	0.89	0.97	0.89	0.97	0.89	0.97
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost (2017$)	1,150	1,200	700	1,000	850	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050
	1,300	1,500	1,200	1,200	1,200	1,650	1,200	1,650	1,200	1,650	1,200	1,650	1,200	1,650
Total Installed Cost (2017$)	1,750	2,200	1,500	1,500	1,550	1,600	1,500	1,600	1,500	1,600	1,500	1,600	1,500	1,600
	1,850	3,250	3,200	2,850	3,050	3,300	2,850	3,300	2,850	3,300	2,850	3,300	2,850	3,300
Annual Maintenance Cost (2017$)	90	130	130	130	130	130	130	130	130	130	130	130	130	130

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.82 EF. Analysis is based on an average of low, medium, and high draw pattern units, as this is most reflective of the market

- The Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
<2 gal and >50,000 Btu/h	Very Small	UEF=0.80	No models on the market	0.87
	Low	UEF=0.81	No models on the market	0.87
	Medium	UEF=0.81	0.81	0.87
	High	UEF=0.81	0.81	0.87

- The ENERGY STAR levels require the use of condensing technology.
- Navien and Bosch manufacture the highest efficiency high draw pattern models currently available on the market, which have a UEF of 0.97. Navien manufactures the highest efficiency medium draw pattern models currently available on the market, which have a UEF of 0.96. These levels are achieved through the use of electronic ignition, power-direct venting, and condensing the flue gases.
- All of the major water heater manufacturers now offer an instantaneous model.
- The maintenance costs include cleaning the water inlet filter and the heat exchanger of mineral deposits and replacing the water valve approximately once every five years for all instantaneous water heaters.
- When replacing a storage water heater with an instantaneous water heater, there are significant additional costs to upsize the gas supply line to ¾ inch from the typical ½ inch and change the venting.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Refrigerator-Freezers (Top)

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DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/yr)***	657	512	405	389	364	358	389	358	389	358	389	358	389	358
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost (2017$)	580	570	700	750	850	880	750	880	750	880	750	880	750	880
Total Installed Cost (2017$)	580	570	700	750	850	880	750	880	750	880	750	880	750	880
Annual Maintenance Cost (2017$)****	10	10	10	10	10	10	10	10	10	10	10	10	10	10

* Product Class 3 is used for this analysis (Refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost)

** The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.

*** Based on an adjusted volume of 21 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.

**** Maintenance costs include cost of repairing integral components (e.g. compressor, evaporator fan, electronics)

Residential Refrigerator-Freezers (Side)

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DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Energy Consumption (kWh/yr)***	1,146	893	705	671	635	509	671	509	671	509	671	509	671	509
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost (2017$)	1,200	1,190	1,310	1,420	1,550	1,980	1,420	1,980	1,420	1,980	1,420	1,980	1,420	1,980
Total Installed Cost (2017$)	1,200	1,190	1,310	1,420	1,550	1,980	1,420	1,980	1,420	1,980	1,420	1,980	1,420	1,980
Annual Maintenance Cost (2017$)****	25	25	25	25	25	25	25	25	25	25	25	25	25	25

* Product Class 7 is used for this analysis (Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service)
** The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 32 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g. compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g. water filters)

Residential Refrigerator-Freezers (Bottom)

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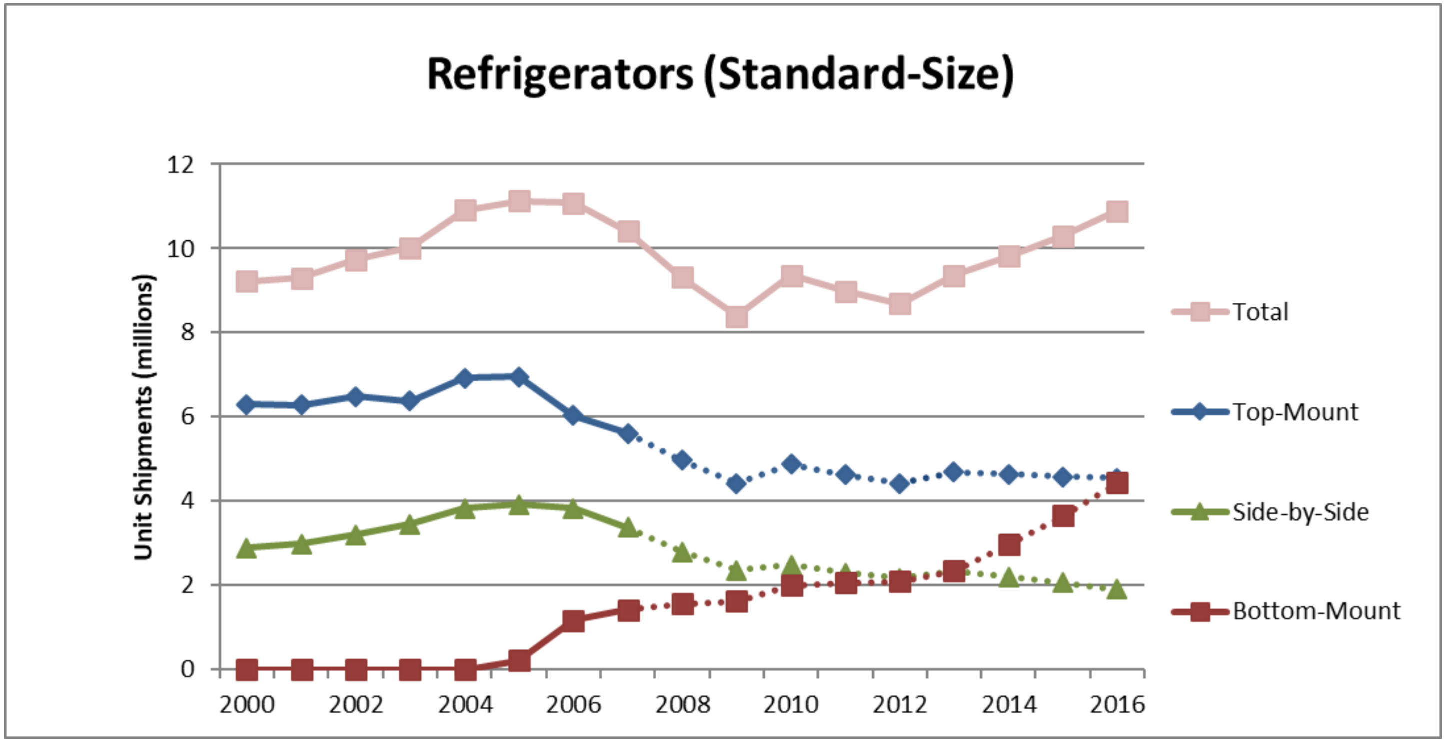
DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	21	19	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/yr)***	651	547	521	480	469	469	480	469	480	469	480	469	480	469
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost (2017$)	980	1,010	1,030	1,120	1,160	1,160	1,120	1,160	1,120	1,160	1,120	1,160	1,120	1,160
Total Installed Cost (2017$)	980	1,010	1,030	1,120	1,160	1,160	1,120	1,160	1,120	1,160	1,120	1,160	1,120	1,160
Annual Maintenance Cost (2017$)****	25	25	25	25	25	25	25	25	25	25	25	25	25	25

* Product Class 5 is used for this analysis (Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service)
** The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 25 ft^3 for 2009 and 23 ft3 for all other years. All values represent use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g. compressor, evaporator fan, electronics)

- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014.
  - Models divided into 32 product classes based on size (standard or compact), location of freezer (top, bottom, or side), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence and configuration (through-the-door or inside cabinet) of automatic icemaker
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
  - New product classes for built-in units
  - Amount by which standards are tightened varies by product class
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard.
- Current analysis focuses on the three representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating

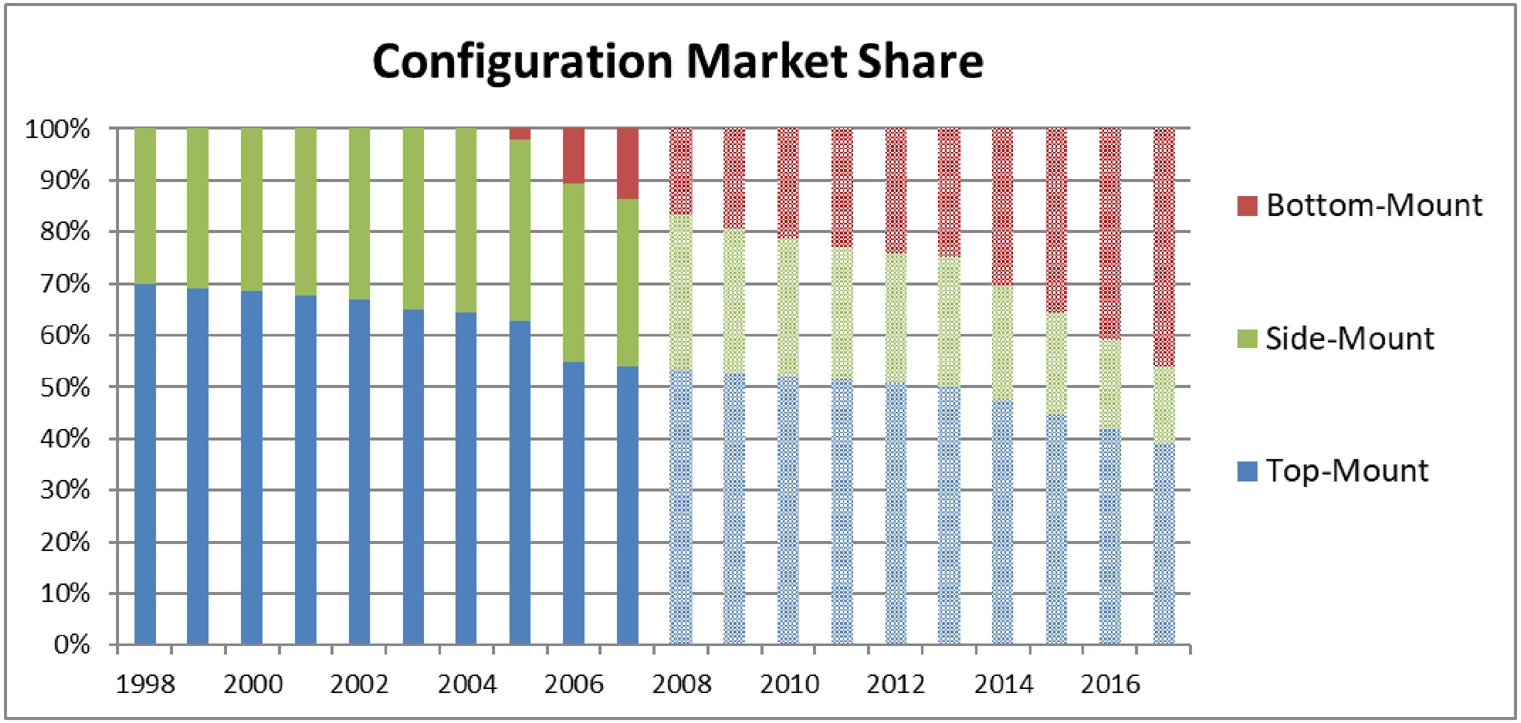
[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume).

Annual shipment volumes have rebounded from a sharp decline between 2006 and 2009, reaching approximately 10.9 million units in 2016.



Source: *Appliance Magazine*; DOE's Compliance and Certification Database (as of December 2017); Navigant analysis. Dashed lines indicate interpolated data.

Bottom-mount units have gained market share, likely surpassing top-mount units in 2016.



Sources: August 2011 Refrigerator Final Rule TSD; DOE's Compliance Certification Database (as of December 2017); Navigant analysis. Dashed bars indicate interpolated data.

Residential Freezers (Chest)

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DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	17	16	16	16	16	16	16	16	16	16	16	16	16	16
Energy Consumption (kWh/yr)***	428	360	300	297	277	275	297	275	297	275	297	275	297	275
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	420	430	500	500	550	540	500	540	500	540	500	540	500	540
Total Installed Cost (2017$)	420	430	500	500	550	540	500	540	500	540	500	540	500	540
Annual Maintenance Cost (2017$)****	5	5	5	5	5	5	5	5	5	5	5	5	5	5

* Product Class 10 is used for this analysis (Chest freezers and all other freezers except compact freezers)
** The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 26 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g. compressor, evaporator fan, electronics)

Residential Freezers (Upright)

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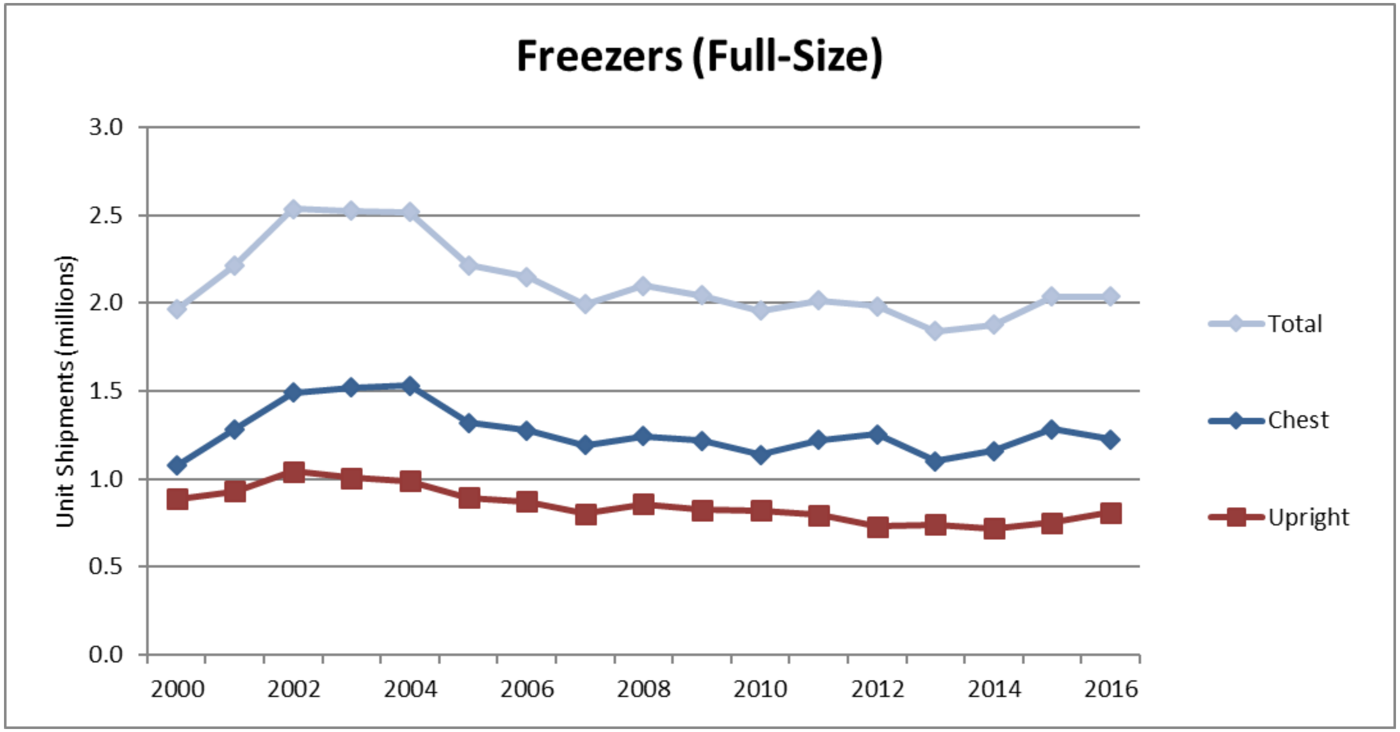
DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Energy Consumption (kWh/yr)***	763	615	477	446	430	419	446	419	446	419	446	419	446	419
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	580	590	690	750	790	810	750	810	750	810	750	810	750	810
Total Installed Cost (2017$)	580	590	690	750	790	810	750	810	750	810	750	810	750	810
Annual Maintenance Cost (2017$)****	5	5	5	5	5	5	5	5	5	5	5	5	5	5

* Product Class 9 is used for this analysis (Upright freezers with automatic defrost)
** The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 29 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g. compressor, evaporator fan, electronics)

- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014
  - Models divided into 10 product classes based on size (standard or compact), orientation (chest or upright), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence of automatic icemaker
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard.
- Current analysis focuses on the two representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating
  - Use of forced convection condenser (for upright freezers)

[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume).

Shipment volumes have held steady since 2007 at about 2 million units per year. Chest freezers represent about 60% of the market.



Source: *Appliance Magazine.*

Residential Natural Gas Cooktops

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DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9	9	9	9
	23	23	23	23	23	23	23	23	23	23	23	23
Integrated Annual Energy Consumption (kbtu/yr)*	1,105	1,061	914	730	914	730	914	730	914	730	914	730
Cooking Efficiency (%)	39	40	45	52	45	52	45	52	45	52	45	52
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9	9
	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2017$)**	250	250	260	260	260	260	260	260	260	260	260	260
Total Installed Cost (2017$)**	360	360	370	370	370	370	370	370	370	370	370	370
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-

* Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to Integrated Annual Energy Consumption (kBtu/yr) based on the 2016 Energy Conservation Standards for Residential Conventional Cooking Products

** Equipment and installed costs are for cooktops only (not combined range units).

*** Maintenance costs are negligible.

DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	16	16	16	16	16	16	16	16	16	16	16	16
	18	18	18	18	18	18	18	18	18	18	18	18
Typical Cavity Volume (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kbtu/yr)*	2,077	2,038	1,915	1,660	1,915	1,660	1,915	1,660	1,915	1,660	1,915	1,660
Cooking Efficiency (%)	6.5	6.6	7.0	7.8	7.0	7.8	7.0	7.8	7.0	7.8	7.0	7.8
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9	9
	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2017$)**	510	510	560	610	560	610	560	610	560	610	560	610
Total Installed Cost (2017$)**	620	620	680	720	680	720	680	720	680	720	680	720
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-

* Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to Integrated Annual Energy Consumption (kBtu/yr) based on the 2016 Energy Conservation Standards for Residential Conventional Cooking Products

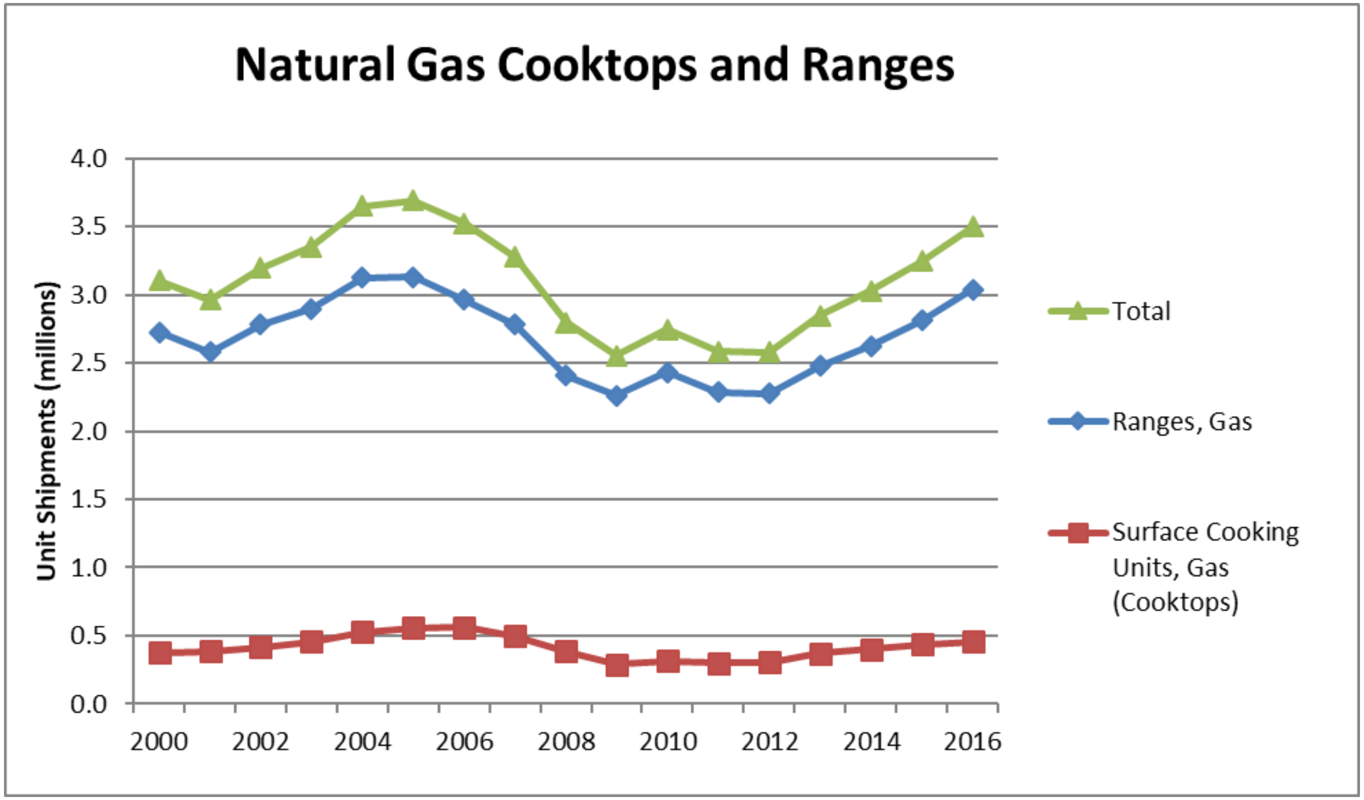
** Equipment and installed costs are for ovens only (not combined ranges). Furthermore, they are reflective of freestanding oven units, which represent 90% of the market.

*** Maintenance costs are negligible.

- DOE analyzes cooktops and ovens separately, although they are often sold together in a single unit that combines both a cooktop and an oven into a product referred to as a range.
- Since January 1, 1990, gas cooking products *with* an electrical supply cord have been required to not be equipped with a constant burning pilot light. This requirement extended to gas cooking products *without* an electrical supply cord, as of April 9, 2012.
- DOE final rule published in 2009[1]: no standard for cooking efficiency is cost-justified.
- DOE initiated a standards rulemaking in 2014 to consider amended standards for cooking products, including gas cooktops and ovens[2].
  - Most recently, on September 2, 2016, DOE proposed performance-based standards for gas cooktops and ovens that would take effect in 2020 if adopted.
- DOE established a new metric called integrated annual energy consumption (kBtu/year) to replace cooking efficiency (%).

[1]Energy Conservation Standards for Certain Consumer Products (Dishwashers, Dehumidifiers, Microwave Ovens, and Electric and Gas Kitchen Ranges and Ovens) and for Certain Commercial and Industrial Equipment (Commercial Clothes Washers); Final Rule. 74 FR 16040.
[2]Energy Conservation Standards for Residential Conventional Cooking Products; Supplemental notice of proposed rulemaking (SNOPR). 81 FR 60784.

Shipments have been rising since 2012 and are approaching the peak reached in 2005.



Note: Excludes separate ovens, which were categorized as "built-in" units prior to 2007 and represent a relatively negligible portion of the market. For example, between 2012-2014 an average of 32,000 standalone gas ovens, 360,000 gas cooktops, and 4.46 million ranges were sold per year.
Source: *Appliance Magazine.*

Residential Clothes Dryers (Electric)

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DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7	7	7
Combined Energy Factor (lb/kWh)*	3.55	3.59	3.73	3.74	4.50	3.74	4.50	3.74	4.50	3.74	4.50	3.74	4.50
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2017$)	410	410	420	430	650	430	650	430	650	430	650	430	650
Total Installed Cost (2017$)	520	520	530	540	770	540	770	540	770	540	770	540	770
Annual Maintenance Cost (2017$)**	-	-	-	-	-	-	-	-	-	-	-	-	-

*The efficiency metric changed from energy factor (EF) to combined energy factor (CEF) in 2015. The CEF value for installed base 2009 is a converted value equivalent to 3.01 EF

** Maintenance costs are negligible.

Residential Clothes Dryers (Gas)

DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7	7	7
Combined Energy Factor (lb/kWh)*	3.14	3.18	3.30	3.32	3.49	3.32	3.49	3.32	3.61	3.32	3.61	3.32	3.61
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2017$)	460	460	480	500	610	500	610	500	640	500	640	500	640
Total Installed Cost (2017$)	630	630	650	660	770	660	770	660	810	660	810	660	810
Annual Maintenance Cost (2017$)**	-	-	-	-	-	-	-	-	-	-	-	-	-

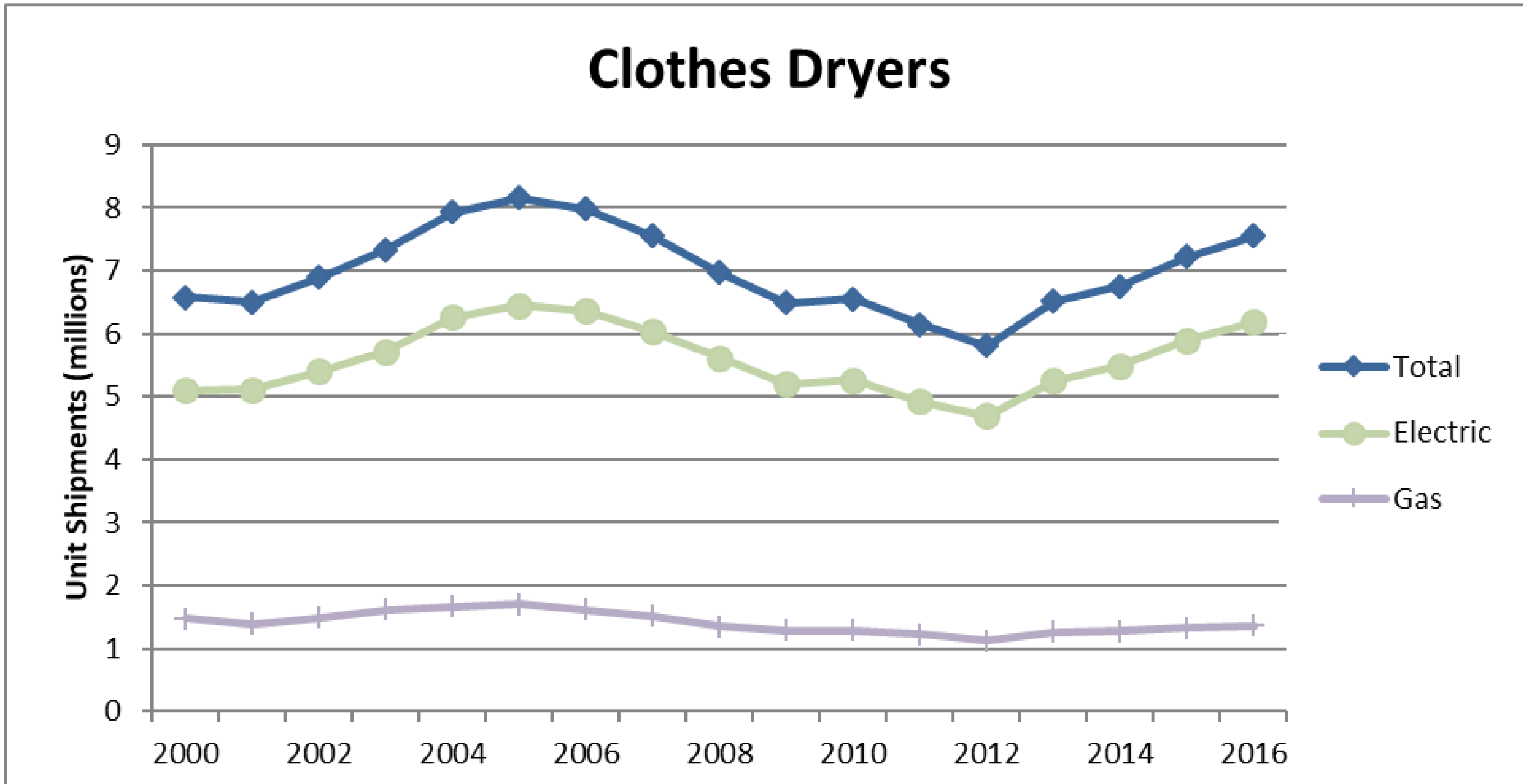
*The efficiency metric changed from energy factor (EF) to combined energy factor (CEF) in 2015. The CEF value for installed base 2009 is a converted value equivalent to 2.67 EF

** Maintenance costs are negligible.

- Current standards[1] in effect since 2015:
  - For standard-size electric units : CEF ≥ 3.73 lb/kWh
  - For gas units: CEF ≥ 2.30 lb/kWh
- Remaining efficiency improvement opportunities include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Better control systems for cycle termination
  - Heat pump (for electric clothes dryers)
  - Ultrasonic drying (prototype in development at Oak Ridge National Lab)
- EPA developed an ENERGY STAR program for residential clothes dryers, which became effective in 2015. In addition, EPA developed an Emerging Technology Award in 2014 to recognize advanced high-efficiency clothes dryers introduced to the U.S. market.
- Standard-size heat pump clothes dryers with CEF of 4.5 currently available in the U.S. market. High initial cost and longer drying times have limited market penetration, but some utilities are offering rebates to support market penetration.

[1]Energy Conservation Standards for Consumer Clothes Dryers. 10 CFR 430.32(h).

Shipment volumes have been on the rise since 2012. Gas dryers continue to account for about one-fifth of the market.



Source: *Appliance Magazine*.

Residential Clothes Washers (Front)

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DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.09	3.66	3.41	4.5	4.2	4.5	4.5	5.6	4.5	5.6	4.5	5.6	4.5	5.6
Integrated Modified Energy Factor (ft^3/kWh/cycle)*	1.67	2.16	1.84	2.76	2.38	2.92	2.76	3.10	2.92	3.10	2.92	3.10	2.92	3.10
Integrated Water Factor (gal/cycle/ft^3)**	6.5	4.7	4.7	3.2	3.7	2.9	3.2	2.7	2.9	2.7	2.9	2.7	2.9	2.7
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	20	17	16	14	16	13	14	15	13	15	13	15	13	15
Hot Water Energy (kWh/cycle)	0.68	0.21	0.36	0.17	0.24	0.14	0.17	0.15	0.14	0.15	0.14	0.15	0.14	0.15
Machine Energy (kWh/cycle)	0.15	0.17	0.15	0.21	0.29	0.17	0.21	0.28	0.17	0.28	0.17	0.28	0.17	0.28
Dryer Energy (kWh/cycle)	1.02	1.31	1.34	1.22	1.19	1.22	1.22	1.37	1.22	1.37	1.22	1.37	1.22	1.37
Retail Equipment Cost (2017$)	550	550	600	600	600	600	600	600	700	700	700	700	700	700
	700	700	1,000	1,100	1,000	1,200	1,100	1,200	1,200	1,300	1,200	1,300	1,200	1,300
Total Installed Cost (2017$)	700	700	750	750	750	750	750	1350	750	1350	750	1350	750	1350
	850	850	1150	1250	1150	1350	1250	1350	1350	1350	1350	1350	1350	1350
Annual Maintenance Cost (2017$)	10	10	10	10	10	10	10	10	10	10	10	10	10	10

*2009 installed base value is equivalent to 2.07 Modified Energy Factor (MEF). The efficiency metric changed from Modified Energy Factor to Integrated Modified Energy Factor (IMEF) in 2015.

**2009 installed base value is equivalent to 6.2 Water Factor (WF). The efficiency metric changed from Water Factor to Integrated Water Factor (IWF) in 2015.

Residential Clothes Washers (Top)

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DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3	3.28	3.3	3.3	4.5	4.9	3.9	4.9	4.5	4.9	4.5	4.9	4.5	4.9
Integrated Modified Energy Factor (ft^3/kWh/cycle)*	0.78	1.14	1.29	1.29	2.06	2.76	1.57	2.76	2.06	2.76	2.06	2.76	2.06	2.76
Integrated Water Factor (gal/cycle/ft^3)**	12.4	9.2	8.4	8.4	4.3	3.5	6.5	3.5	4.3	3.5	4.3	3.5	4.3	3.5
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	37	30	28	28	19	17	25	17	19	17	19	17	19	17
Hot Water Energy (kWh/cycle)	2.25	0.90	0.77	0.77	0.36	0.18	0.71	0.18	0.36	0.18	0.36	0.18	0.36	0.18
Machine Energy (kWh/cycle)	0.28	0.25	0.26	0.26	0.15	0.12	0.24	0.12	0.15	0.12	0.15	0.12	0.15	0.12
Dryer Energy (kWh/cycle)	1.31	1.73	1.50	1.50	1.65	1.46	1.51	1.46	1.65	1.46	1.65	1.46	1.65	1.46
Retail Equipment Cost (2017$)	550	450	400	400	600	750	400	750	500	750	500	750	500	750
	700	550	600	600	1,000	1,200	600	1,200	700	1,200	700	1,200	700	1,200
Total Installed Cost (2017$)	700	600	550	550	750	900	550	900	650	900	650	900	650	900
	850	700	750	750	1150	1350	750	1350	850	1350	850	1350	850	1350
Annual Maintenance Cost (2017$)	10	10	10	10	10	10	10	10	10	10	10	10	10	10

*2009 installed base value is equivalent to 1.2 Modified Energy Factor (MEF). The efficiency metric changed from Modified Energy Factor to Integrated Modified Energy Factor (IMEF) in 2015.

**2009 installed base value is equivalent to 12 Water Factor (WF). The efficiency metric changed from Water Factor to Integrated Water Factor (IWF) in 2015.

- The analysis treats front- and top-loading models separately due to their different energy use characteristics.
- Federal standards[1] for standard-capacity clothes washers (≥ 1.6 cubic feet):

	Integrated Modified Energy Factor		Integrated Water Factor	
	Top-Loading	Front-Loading	Top-Loading	Front-Loading
Current DOE Standard (effective 3/7/2015)	≥ 1.29	≥ 1.84	≤ 8.4	≤ 4.7
Current ENERGY STAR (effective 3/7/2015)	≥ 2.06	≥ 2.38	≤ 4.3	≤ 3.7
Future DOE Standard (effective 1/1/2018)	≥ 1.57	≥ 1.84 (no change)	≤ 6.5	≤ 4.7 (no change)
Future ENERGY STAR (effective 1/1/2018)	≥ 2.06 (no change)	≥ 2.76	≤ 4.3 (no change)	≤ 3.2

- In 2017, around 30% of top-loading models and almost all front-loading models achieve the ENERGY STAR level.
- Energy efficiency improvement opportunities include:
  - Higher efficiency motors and higher spin speeds
  - Better load sensing for adaptive water fill control
  - Reduced water temperature and quantity, while providing equivalent cleaning and rinsing performance
- Maintenance costs include replacement or repair of the drain pump, control board, motor, rubber gaskets, or control panel knobs.
- The products on the market with the highest Integrated Modified Energy Factor have significantly larger capacity and therefore use more energy per cycle than typical, smaller capacity products but still perform more efficiently on a per volume basis.

[1] Energy Conservation Standards for Consumer Clothes Washers. 10 CFR 430.32(g).

Shipment volumes have returned to pre-housing boom levels. Front-loaders' market share peaked in 2010 at just under 50% and has since declined to around 40%.

Sources: *Appliance Magazine;* Residential Clothes Washer Direct Final Rule TSD, EERE, April 2012; ENERGY STAR shipments data 2015-2016. Dashed lines indicate extrapolated/interpolated data.

Residential Dishwashers

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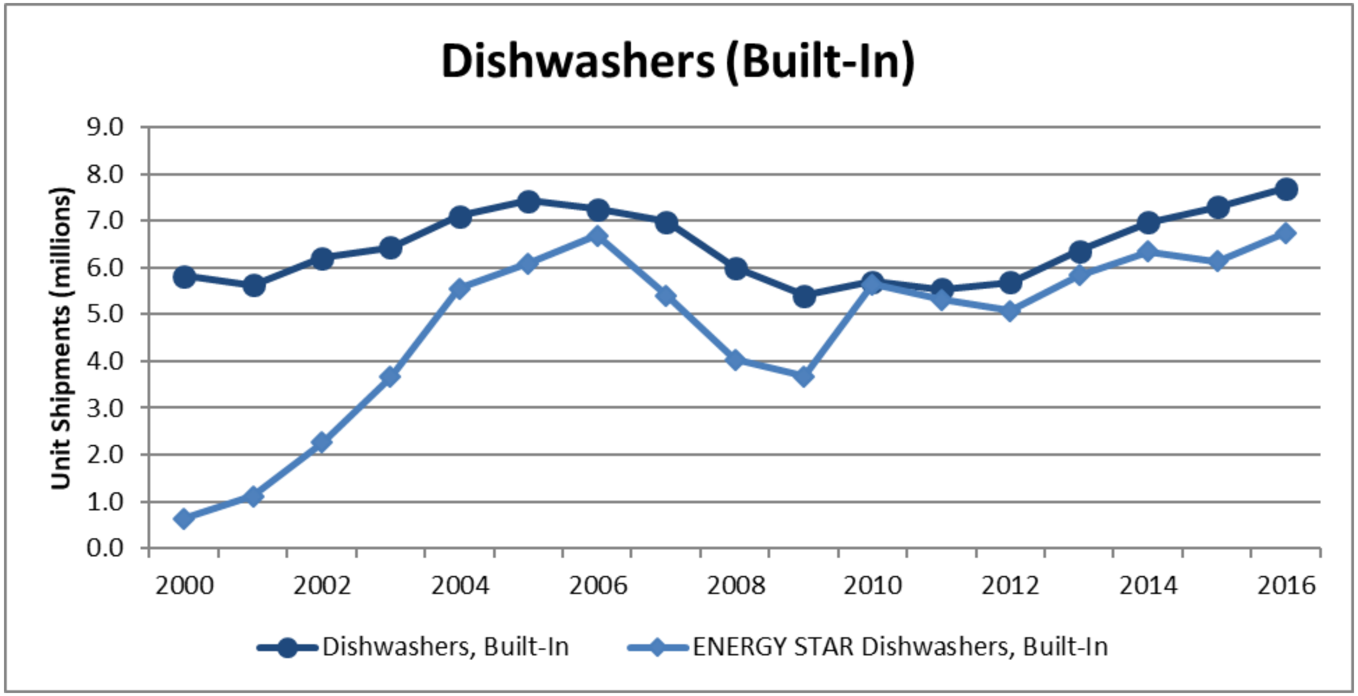
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/yr)	383	347	307	270	270	225	270	225	270	225	270	225	270	225
Water Consumption (gal/cycle)	6.88	6.23	5.00	3.50	3.50	2.40	3.50	2.40	3.50	2.40	3.50	2.40	3.50	2.40
Water Heating Energy Use (kWh/yr)*	249	226	176	125	125	86	125	86	125	86	125	86	125	86
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Retail Equipment Cost (2017$)**	365	370	260	320	320	390	320	390	320	390	320	390	320	390
Total Installed Cost (2017$)**	705	710	425	485	485	555	485	555	485	555	485	555	485	555
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Refers to that portion of "Typical Annual Energy Use" that is the energy used to heat water in a separate water heater before it enters the dishwasher. The energy used to heat water inside the dishwasher cannot be disaggregated from the total.
** Equipment and installation cost estimates changed significantly between the 2012 DOE analysis, the source for installed base costs, and the 2016 DOE analysis, the source for costs in 2017 and later.
*** Maintenance costs are negligible.
<u>Note</u>: All values in table reflect 215 cycles/year, as dictated by the test procedure.

- Performance criteria for standard-capacity dishwashers (assumes 215 cycles/year[1]):
  - Federal Standards:
    - Jan. 1, 2010: ≤ **355** kWh/yr, ≤ **6.5** gal/cycle (EISA 2007)
    - May 30, 2013: ≤ **307** kWh/yr, ≤ **5.0** gal/cycle (DOE Direct Final Rule, published May 2012)
  - ENERGY STAR Criteria:
    - Aug. 11, 2009 : ≤ **324** kWh/yr, ≤ **5.8** gal/cycle (version 4.0, announced Nov. 2008)
    - Jan. 20, 2012: ≤ **295** kWh/yr, ≤ **4.25** gal/cycle (version 5.0, announced April 2011)
    - Jan. 29, 2016: ≤ **270** kWh/yr (5% allowance for connected), ≤ **3.5** gal/cycle (version 6.0, announced April 2015)
- ENERGY STAR has maintained a very high market share for several years, so sales-weighted-average efficiency has tracked ENERGY STAR levels.
- Test procedures:
  - Accounts for motor, dryer, booster heater (if present), and hot water from separate water heater
  - Amended test procedure, which took effect May 30, 2013, includes standby and off-mode energy
  - ENERGY STAR established a cleaning performance test method; however, cleaning performance reporting is currently optional.
- Efficiency improvement opportunities include:
  - Better soil sensing
  - Water distribution (small pipes, fine filter, small sump, alternating water use) and controls (flow meter, temperature sensor)
  - Inline water heater (to minimize sump volume)
  - Separate drain pump, high-efficiency, variable-speed circulation pump motor
  - Condensation drying (rather than power dry)

[1] 215 cycles/year is assumed in the current test procedure and current standard. In the 2016 DOE "Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers" the energy use and economic analyses were updated to include RECS 2009 data which resulted in a value of 207 cycles/year.

Shipments peaked in 2005 during the housing boom, dropped during the 2008-2009 recession, and reached a new high in 2016.



Sources: *DOE Residential Dishwashers Final Rule Technical Support Document (Table 3.9.2); ENERGY STAR Unit Shipment and Market Penetration Report, Calendar Year 2016 Summary; Appliance Magazine*

Commercial Gas-Fired Furnaces

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DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400	400	400	400	400	400
Thermal Efficiency (%)*	80	80	80	95	80	95	81	95	81	95	81	95
Average Life (yrs)	23	23	23	23	23	23	23	23	23	23	23	23
Retail Equipment Cost (2017$)	1,050	1,050	1,050	2,450	1,050	2,450	1,050	2,450	1,050	2,450	1,050	2,450
Total Installed Cost (2017$)	2,150	2,150	2,150	3,950	2,150	3,950	2,200	3,950	2,200	3,950	2,200	3,950
Annual Maintenance Cost (2017$)**	170	170	170	180	170	180	170	180	170	180	170	180

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.
**In 2023, the new Energy Conservation Standards for Commercial Warm Air Furnaces will take effect. These projections reflect the 2023 minimum thermal efficiency requirement for gas-fired furnaces, 81%.

- Current Federal standard requires minimum 80% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applies to all units manufactured on or after January 1, 1994 with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increases to 81% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial furnaces are typically non-condensing with thermal efficiencies ranging from 80% to 82%. Recently condensing commercial furnaces have been introduced, which achieve up to 95% thermal efficiency. However, condensing models currently make up a very small portion of the market.
- Besides capacity, commercial units can differ from residential furnaces in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.

Commercial Oil-Fired Furnaces

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DATA	2012	2017			2020	2030**	2040	2050
	Installed Base	Current Standard	Typical	High	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400	400
Thermal Efficiency (%)*	81	81	82	85	82	82	82	82
Average Life (yrs)	23	23	23	23	23	23	23	23
Retail Equipment Cost (2017$)	4,650	4,650	4,700	5,050	4,700	4,700	4,700	4,700
Total Installed Cost (2017$)	6,550	6,550	6,600	6,750	6,600	6,600	6,600	6,600
Annual Maintenance Cost (2017$)**	300	300	300	300	300	300	300	300

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.
**In 2023, the new Energy Conservation Standards for Commercial Warm Air Furnaces will take effect. These projections reflect the 2023 minimum thermal efficiency requirement for oil-fired furnaces, 82%.

- Current Federal standard requires minimum 81% thermal efficiency. This metric, more commonly called “combustion efficiency” in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applies to all units manufactured on or after January 1, 1994 with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increases to 82% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial oil-fired furnaces have thermal efficiencies ranging from 81% to 85% and are non-condensing (i.e., not designed for condensation of flue gases).
- Besides capacity, commercial units can differ in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Commercial Electric Resistance Heaters

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DATA	2012		2017		2020		2030		2040		2050	
	Installed Base: Small	Installed Base: Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBtu/h)*	17	170	17	170	17	170	17	170	17	170	17	170
Efficiency (%)	100	100	100	100	100	100	100	100	100	100	100	100
Average Life (yrs)	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2017$)	850	5,375	850	5,375	850	5,375	850	5,375	850	5,375	850	5,375
Total Installed Cost (2017$)	1,050	6,350	1,050	6,350	1,050	6,350	1,050	6,350	1,050	6,350	1,050	6,350
Annual Maintenance Cost (2017$)**	-	-	-	-	-	-	-	-	-	-	-	-

* Capacity is *output*
** Annual Maintenance Cost is negligible

- This analysis examined electric unit heaters.
- Electric unit heaters range in capacity from 2 to 100 kW (7 to 340 kBtu/hr), with 5 to 50 kW (17 to 170 kBtu/hr) being the most typical units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion.
- Installation time and costs are estimated to be minimal.

Commercial Electric Boilers

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DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kW)*	165	165	165	165	165	165
Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost (2017$)	9,875	9,850	9,850	9,850	9,850	9,850
Total Installed Cost (2017$)	14,875	11,750	11,750	$11,750	11,750	11,750
Annual Maintenance Cost (2017$)	145	110	110	110	110	110

* Capacity is *output*

- There are currently no federal standards associated with electric boilers.
- The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/hr.
- Service life is determined mainly by water quality. Water conditioning (e.g., filters, softeners, de-alkizers, chemical feeders) may be necessary for a given application.
- Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.
- Minor end-use inefficiencies for electric boilers result from heat loss through the boiler (jacket losses).

Commercial Gas-Fired Boilers

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DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard *	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	800	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)**	77	80	85	93	99	85	99	85	99	85	99	85	99
Average Life (yrs)	30	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$)	13,150	16,600	22,700	33,250	37,500	22,700	37,500	22,700	37,500	22,700	37,500	22,700	37,500
Total Installed Cost (2017$)	20,825	25,800	32,450	42,650	46,750	32,450	46,750	32,450	46,750	32,450	46,750	32,450	46,750
Annual Maintenance Cost (2017$)***	1445	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800

* The standard level shown here is for small (300 kBtu/h to 2500 kBtu/h) gas-fired hot water commercial packaged boilers, the most common type of boiler available on the market.
** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.
*** The updated maintenance costs for 2017 and post-2017 are based on the recently issued commercial packaged boilers final rule. The annualized maintenance costs estimated in the final rule are based on 2016 RS Means data and differ for condensing vs non-condensing boilers. Appendix 8E of the 2016 final rule TSD for commercial packaged boilers provides additional information on how the values are calculated. The cost values in the table are for gas-fired hot water CPBs.

Note: In December of 2016, EREE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. As of October 2017, this rule has not yet been published and therefore these standards are not reflected in the values shown above.

- Commercial packaged gas-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
  - Draft type (natural draft or not) – for steam boilers
- Most common type is small gas-fired hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- Federal standards require thermal efficiency ≥ 77%, 79%, or 80%, depending on type.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Large gas-fired hot water boilers i.e., boilers with rated heat input greater than 2,500,000 Btu/h are required to have *combustion* efficiency ≥ 82%.
- Similar technologies to the those used in the residential market can be leveraged in the commercial arena. The higher efficiency units typically include electronic ignition, power burners, and improved heat exchangers. Some also condense water vapor from the flue gases to improve heating efficiency.
- DOE issued a Final Rule for Energy Conservation Standards for Commercial Packaged Boilers on December 28, 2016 that would update the efficiency ratings of gas-fired commercial packaged boilers.

Commercial Oil-Fired Boilers

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DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Current Standard*	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	1,200	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)**	81	82	85	97	85	97	87	97	89	97	92	97
Average Life (yrs)	30	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$)	14,250	19,800	22,850	44,550	22,850	44,550	22,850	44,550	22,850	44,550	22,850	44,550
Total Installed Cost (2017$)	18,625	28,000	31,500	53,250	31,500	53,250	31,500	53,250	31,500	53,250	31,500	53,250
Annual Maintenance Cost (2017$)***	1445	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300

* The standard level shown here is for small (300 kBtu/h -2500 kBtu/h) oil-fired hot water commercial packaged boilers, the most common type of oil-fired boiler available on the market.
** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.
*** The updated maintenance costs for 2017 and post-2017 are based on the recently issued commercial packaged boilers final rule. The annualized maintenance costs estimated in the final rule are based on 2016 RS Means data and differ for condensing vs non-condensing boilers. Appendix 8E of the 2016 final rule TSD for commercial packaged boilers provides additional information on how the values are calculated. The cost values in the table are for oil-fired hot water CPBs.

Note: In December of 2016 EREE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. As of October 2017, this rule has not yet been published and therefore these standards are not reflected in the values shown above.

Commercial Oil-Fired Boilers

- Commercial packaged oil-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
- Most common type is small hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Federal standards require thermal efficiency ≥ 81% for steam boilers and ≥ 82% for hot water boilers.
- Exception is large hot water boilers, which must have *combustion* efficiency ≥ 84%.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.
- Based on current shipment trends, projected shipments of oil-fired CPBs post-2017 are expected to decrease with time.
- DOE issued a Final Rule for Energy Conservation Standards for Commercial Packaged Boilers on December 28, 2016 that would update the efficiency ratings of oil-fired commercial packaged boilers.

Commercial Centrifugal Chillers (Water Cooled)

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DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	ASHRAE 90.1**	Typical***	High***	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	400	400	400	400	400	400	400	400	400	400	400	400
	600	600	600	600	600	600	600	600	600	600	600	600
Efficiency [full-load] (kW/ton)	0.66	0.56	0.53	0.45	0.49	0.44	0.46	0.42	0.43	0.41	0.42	0.40
Efficiency [IPLV] (kW/ton)	0.61	0.50	0.37	0.30	0.36	0.29	0.35	0.27	0.34	0.25	0.33	0.24
COP [full-load]	5.4	6.3	6.6	7.8	7.2	8.0	7.6	8.4	8.2	8.6	8.4	8.8
COP [IPLV]	5.9	7.0	9.5	11.7	9.8	12.1	10.0	13.0	10.3	14.1	10.7	14.7
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($/ton)	325	400	425	575	425	575	425	575	425	575	425	575
Total Installed Cost ($/ton)	375	450	475	625	475	625	475	625	475	625	475	625
	425	475	500	650	500	650	500	650	500	650	500	650
Annual Maintenance Cost ($/ton)	25	25	25	25	25	25	25	25	25	25	25	25
	35	35	35	35	35	35	35	35	35	35	35	35

* Capacity is *output*

**ASHRAE 90.1 data here are for units larger than 400 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

***2017 typical and high efficiency levels determined base on the range of products currently available on the market.

Note: For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

- ASHRAE 90.1-2016 stipulates minimum efficiencies for centrifugal chillers separately from positive displacement water-cooled chillers. They are separated into 5 size categories, with categories divided at: 150, 300, 400, and 600 tons; ASHRAE 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly high full-load consumption in exchange for much lower part-load consumption. For example, for a 600 Ton unit:
  - Path A: ≥ 0.56 kW/ton full load and ≥0.50 kW/ton IPLV
  - Path B: ≥ 0.585 kW/ton full load and ≥.38 kW/ton IPLV
- Federal Energy Management Program (FEMP) recommendations, last updated in Aug 2016, match ASHRAE 90.1-2016.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed drive (VSD) compressors
  - Dedicated heat recovery (heat pump chiller)
  - Magnetic bearing technology (oil-free operation)
  - Greater heat exchanger surface areas; enhanced tube configurations (counterflow)
  - Optimized fluid flow velocities
  - High efficiency electric motors
  - Improved turbomachinery design, resulting in higher compressor efficiency
  - Better piping and valving, including electronic expansion valves
  - Evaporative condenser for the heat rejection equipment
- Installed costs vary widely depending on equipment needed for installation (e .g. crane) and size of system. This is a mature market with centrifugal chillers representing 75% of commercial chiller sales larger than 200 tons.
- Water cooled chiller ratings do not include energy consumption of the cooling tower and therefore are not directly comparable to rating for air-cooled chillers.

Commercial Reciprocating Chillers (Air Cooled Only)

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DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	ASHRAE 90.1[2]	Typical[3]	High[3]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[4]	100	100	100	100	100	100	100	100	100	100	100	100
	200	200	200	200	200	200	200	200	200	200	200	200
Efficiency [full-load] (kW/ton)[1]	1.26	1.19	1.19	1.00	1.15	1.00	1.15	1.00	1.15	1.00	1.15	1.00
Efficiency [IPLV] (kW/ton)[1]	1.13	0.86	0.86	0.79	0.80	0.79	0.80	0.79	0.80	0.79	0.80	0.79
COP [full-load][1]	2.8	3.0	3.0	3.5	3.1	3.5	3.1	3.5	3.1	3.5	3.1	3.5
COP [IPLV][1]	3.1	4.1	4.1	4.5	4.4	4.5	4.4	4.5	4.4	4.5	4.4	4.5
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	725	750	750	875	750	875	750	875	750	875	750	875
	600	650	650	750	650	750	650	750	650	750	650	750
Total Installed Cost ($/ton)	800	850	850	1000	850	1000	850	1000	850	1000	850	1000
	700	700	700	925	700	925	700	925	700	925	700	925
Annual Maintenance Cost ($/ton)	45	45	45	45	45	45	45	45	45	45	45	45
	25	25	25	25	25	25	25	25	25	25	25	25

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

[2] ASHRAE 90.1 data here are for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

[3] 2017 typical and high efficiency levels determined base on the range of products currently available on the market.

[4] Capacity is *output*

- Reciprocating chillers are most cost effective for small loads (30-150 ton range). However, reciprocating chiller market share continues to be supplanted by screw and scroll chillers. This trend has accelerated with the phase out of R-22, which was the refrigerant of choice for reciprocating products, which has in turn driven major manufacturers to replace their reciprocating product lines with scroll products (rather than redesign reciprocating products for new refrigerants). As a result, product options are very limited.
- Reciprocating chillers can be used in either air-cooled or water cooled applications. Reciprocating chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2016 stipulates minimum efficiencies for all air-cooled chillers together, including reciprocating chillers, while water-cooled chillers are separated by positive displacement (e.g., reciprocating) versus centrifugal models. Air cooled chiller efficiencies are further split by size for more and less than 150 tons. ASHRAE 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100 Ton unit:
  - Path A: ≥10.1 EER full load and ≥13.7 IPLV EER
  - Path B: ≥9.7 EER full load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated August 2016) are:
  - Path A (<150 tons): ≥10.4 EER full load and ≥13.7 IPLV EER
  - Path B (<150 tons): ≥9.7 EER full load and ≥15.8 IPLV EER (same as 90.1-2016)
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	ASHRAE 90.1[2]	Typical[3]	High[3]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[4]	100	100	100	100	100	100	100	100	100	100	100	100
	300	300	300	300	300	300	300	300	300	300	300	300
Efficiency [full-load] (kW/ton)[1]	1.26	1.19	1.18	0.94	1.13	0.91	1.04	0.86	0.98	0.81	0.94	0.77
Efficiency [IPLV] (kW/ton)[1]	1.13	0.86	0.84	0.57	0.79	0.53	0.72	0.49	0.68	0.45	0.65	0.41
COP [full-load][1]	2.8	3.0	3.0	3.7	3.1	3.9	3.4	4.1	3.6	4.3	3.7	4.6
COP [IPLV] [1]	3.1	4.1	4.2	6.2	4.5	6.6	4.9	7.2	5.2	7.8	5.4	8.6
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	650	825	825	900	825	900	825	900	825	900	825	900
	525	725	725	800	725	800	725	800	725	800	725	800
Total Installed Cost ($/ton)	775	975	975	1,050	975	1,050	975	1,050	975	1,050	975	1,050
	725	800	800	900	800	900	800	900	800	900	800	900
Annual Maintenance Cost ($/ton)	45	45	45	45	45	45	45	45	45	45	45	45
	20	20	20	20	20	20	20	20	20	20	20	20

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

[2] ASHRAE 90.1 data here are for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

[3] 2017 typical and high efficiency levels determined base on the range of products currently available on the market.

[4] Capacity is *output*

Commercial Screw Chillers

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- Screw chillers are common in 150 - 500 ton capacities, but are most cost effective for small (<300 tons) loads; screw chillers dominate the current market for small to mid-size chillers.
- Screw chillers can be used in either air-cooled or water cooled applications. Screw chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2016 stipulates minimum efficiencies for all air-cooled chillers together, including screw chillers, while water cooled chillers are separated by positive displacement (e.g., screw) versus centrifugal models. Air cooled chiller efficiencies are further split by size for more and less than 150 tons. 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100 Ton unit:
  - Path A: ≥10.1 EER full load and ≥13.7 IPLV EER
  - Path B: ≥9.7 EER full load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated August 2016) are:
  - Path A (<150 tons): ≥10.4 EER full load and ≥13.7 IPLV EER
  - Path B (<150 tons): ≥9.7 EER full load and ≥15.8 IPLV EER (same as 90.1-2016)
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Economizers
  - Improved heat-exchangers

Commercial Scroll Chillers (Air-Cooled Only)

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DATA	2012	2017		2020		2030		2040		2050		
	Installed Base	ASHRAE 90.1[2]	Typical[3]	High[3]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[4]	50	50	50	50	50	50	50	50	50	50	50	50
	140	140	140	140	140	140	140	140	140	140	140	140
Efficiency [full-load] (kW/ton)[1]	1.23	1.19	1.16	1.10	1.15	1.09	1.11	1.06	1.07	1.02	1.02	0.97
Efficiency [IPLV] (kW/ton)[1]	0.99	0.88	0.77	0.72	0.75	0.71	0.73	0.68	0.71	0.65	0.69	0.62
COP [full-load][1]	2.9	3.0	3.0	3.2	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.6
COP [IPLV] [1]	3.7	4.0	4.6	4.9	4.7	5.0	4.8	5.2	5.0	5.4	5.1	5.7
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	575	800	850	950	850	950	850	950	850	950	850	950
	475	650	700	800	700	800	700	800	700	800	700	800
Total Installed Cost ($/ton)	825	975	1,025	1,125	1,025	1,125	1,025	1,125	1,025	1,125	1,025	1,125
	725	775	825	925	825	925	825	925	825	925	825	925
Annual Maintenance Cost ($/ton)	50	50	50	50	50	50	50	50	50	50	50	50
	35	35	35	35	35	35	35	35	35	35	35	35

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

[2] ASHRAE 90.1 data here are for units smaller than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

[3] 2017 typical, mid, and high efficiency levels determined base on the range of products currently available on the market.

[4] Capacity is *output*

- Scroll chillers range in size from ~20 tons to ~200 tons and can be used in either air-cooled or water cooled applications. They are the most common type of chiller for small chiller plants. The scroll chillers shown in the data are air-cooled, which is most common. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2016 stipulates minimum efficiencies for all air-cooled chillers together, including scroll chillers, while water cooled chillers are separated by positive displacement (e.g., scroll) versus centrifugal models. Air cooled chiller efficiencies are distinct for more and less than 150 tons. 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100 Ton unit:
  - Path A: ≥10.1 EER full load and ≥13.7 IPLV EER
  - Path B: ≥9.7 EER full load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated Aug. 2016) are:
  - Path A (<150 tons): ≥10.4 EER full load and ≥13.7 IPLV EER
  - Path B (<150 tons): ≥9.7 EER full load and ≥15.8 IPLV EER (same as 90.1-2016)
- The highest efficiency scroll chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers
  - Variable speed compressor (or other modulation controls)
- With the phase out of R-22, manufacturers have replaced many of their small reciprocating chiller products with equivalent scroll products, making them a primary choice for small tonnage applications.

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DATA	2012		2017				2020		2030		2040		2050	
	Installed Base: Absorption	Installed Base: Engine-Driven	ASHRAE 90.1 Absorption	CA Title 24 - Engine	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven
Typical Capacity (tons)[2]	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400
COP [full-load]	1.1	1.7	1.0	1.2	1.2	1.7	1.3	1.8	1.4	1.8	1.4	1.8	1.4	1.8
COP [IPLV]	NA	NA	1.0	2.0	1.6	2.6	1.6	2.6	1.6	2.6	1.6	2.6	1.6	2.6
Average Life (yrs)	23	25	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost ($/ton)	750	750	750	750	750	750	750	750	750	750	750	750	750	750
	900	850	850	850	900	850	900	850	900	850	900	850	900	850
Total Installed Cost ($/ton)	850	850	850	850	850	850	850	850	850	850	850	850	850	850
	1,100	1,050	975	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050
Annual Maintenance Cost ($/ton)	20	35	20	35	20	35	20	35	20	35	20	35	20	35
	35	50	35	50	35	50	35	50	35	50	35	50	35	50

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value. For the 2012 analysis, IPLV was not evaluated and is therefore not available (NA).

[2] Capacity is *output*

- Gas-fired chillers are available as either air-cooled (~25-50 tons) or water-cooled (150+ tons). This analysis covers only water-cooled chillers of two varieties: absorption and engine-driven vapor compression (direct-fired only; indirect steam or hot water driven units are excluded).
- Direct gas firing provides high enough temperatures to operate double effect absorption chillers, which operate at a 50-60% higher COP than single effect systems. Triple effect chillers, though not commercially available, can boost cooling COP 30-50% beyond double effect chillers. York, Trane, and others have worked on prototype direct-fired triple effect absorption chillers, but prohibitively high cost of advanced high heat/corrosion-resistant materials required for triple effect absorption chillers suggest that this technology will not likely have an impact on the market in the near-term.
- Gas-fired engine-driven chillers pair conventional vapor compression systems(typically screw or centrifugal compressors) with natural gas powered-reciprocating engines. They exhibit higher peak cooling COP than absorbers, and engine modulation results in better part load performance. Future efficiency improvements for engine-driven chillers are not anticipated. Engine driven chillers allow the opportunity to recover waste heat for useful purposes.
- Maintenance costs for engine driven chillers are higher than for other chillers are they include all the typical components of a vapor compression chiller in addition to an engine; The engine maintenance costs vary depending on the annual run hours of the unit.
- Limited sales data suggest that the U.S. market for gas-fired chillers is very limited and is mostly for replacement units, not for new installations. Recent increases in electric chiller efficiency has narrowed the operating cost differential with gas chillers. Asia has the majority of the global gas-fired chiller market.
- Gas-fired chiller installations are particularly valuable in locations where electric rates are high and gas prices are low (i.e., low spark spread), where digester or landfill gas sources are available, or where waste heat sources are available (e.g., an industrial process or microturbine CHP system) that could be used with a hybrid direct/indirect-fired absorption chiller to offset the use of natural gas.

Commercial Rooftop Air Conditioners

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DATA	2012	2017				2020***		2030****		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR**	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Output Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	10.6	11.2	11.3	11.7	12.8	11.8	12.8	12.2	12.8	12.2	12.8	12.2	12.8
Part Load Efficiency (IEER)*	12.4	-	11.6	11.8	21.5	13.1	21.5	15.1	21.5	15.1	21.5	15.1	21.5
Average Life (yrs)	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2017$)	6,600	6,600	6,600	6,650	10,350	7,150	10,350	7,150	10,350	7,150	10,350	7,150	10,350
Total Installed Cost (2017$)	8,800	8,800	8,800	9,400	14,900	10,250	14,900	10,250	14,900	10,250	14,900	10,250	14,900
Annual Maintenance Cost (2017$)	310	310	310	310	310	310	310	310	310	310	310	310	310

* Values shown are for air-cooled units with either electric resistance heating or no heating within the same enclosure.
** In 2018 the ENERGY STAR levels will change to 12.2 EER and 14.0 IEER.
*** In 2018, new energy conservation standards for Small (<135 kBtu/h) Commercial Packaged Air Conditioning and Heating Equipment will take effect. At this time the DOE-regulated metric will change from EER to IEER, and the minimum IEER will be 12.9.
**** In 2023, new energy conservation standards for Small (<135 kBtu/h) Commercial Packaged Air Conditioning and Heating Equipment will take effect. These projections reflect the 2023 minimum efficiency requirement, 14.8 IEER.

Air-Cooled Commercial Packaged Air Conditioners

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010 Min. EER	ENERGY STAR version 2.2 Effective 1/1/2011	
			Min. EER	Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	11.2	11.7	11.8
	Any other type	11.0	11.5	11.6
Large (≥ 135 and < 240)	Electric resistance or none	11.0	11.7	11.8
	Any other type	10.8	11.5	11.6

- This analysis focused on small air-cooled commercial packaged rooftop air conditioners (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial air conditioners.
- Amended standards in terms of IEER for all equipment classes will take effect in 2018. More stringent standards in terms of IEER for all equipment classes will take effect in 2023.

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners

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DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (tons)	18	11	11	11	11	11
Heating COP	1.4	1.4	1.4	1.4	1.4	1.4
Cooling COP	0.9	1.2	1.2	1.2	1.2	1.2
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($/ton)	2,850	2,400	2,400	2,400	2,400	2,400
	3,450	3,000	3,000	3,000	3,000	3,000
Total Installed Cost ($/ton)	3,250	2,800	2,800	2,800	2,800	2,800
	4,250	3,800	3,800	3,800	3,800	3,800
Annual Maintenance Cost (2017$)	62	62	62	62	62	62

* Only one product available in 2012, market has grown slightly in years since. Typical capacity and COP for 2017 and later are averages of units currently available.

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- There are only a few gas-fired engine-driven rooftop units currently available in the US market. The first unit was introduced in 2010. It is an 11 ton packaged heat pump with dual scroll compressors, variable refrigerant flow, and a variable speed supply fan. Engine coolant heat recovery improves the heating mode COP.
- There are currently no Federal requirements on gas-fired engine-driven rooftop air conditioners or heat pumps.
- Annual sales of the engine-driven rooftop heat pump are estimated at less than 5,000 units per year.

DATA	2012	2017				2020***		2030****		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR**	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	10.2	11.0	11.2	11.3	13.1	11.2	13.1	11.7	13.1	11.7	13.1	11.7	13.1
Part Load Efficiency (IEER)	12.0	-	11.3	11.4	20.3	12.4	20.3	14.4	20.3	14.4	20.3	14.4	20.3
COP (Heating)	3.3	3.3	3.3	3.4	3.7	3.3	3.7	3.4	3.7	3.4	3.7	3.4	3.7
Average Life (yrs)	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2017$)	6,050	6,050	6,050	6,250	11,000	7,750	11,000	8,750	11,000	8,750	11,000	8,750	11,000
Total Installed Cost (2017$)	7,550	7,550	7,550	7,750	16,050	11,150	16,050	12,750	16,050	12,750	16,050	12,750	16,050
Annual Maintenance Cost (2017$)	310	310	310	310	310	310	310	310	310	310	310	310	310

* Values shown are for air-cooled units with either electric resistance heating or no heating within the same enclosure.
** In 2018 the ENERGY STAR levels will change to 11.8 EER, 12.8 IEER, and 3.4 COP.
*** These efficiency levels reflect DOE's energy conservation standards for Small Commercial Packaged Air Conditioning and Heating Equipment with a 2018 compliance deadline. In 2018 the DOE-regulated metric will switch from EER to IEER, and the minimum IEER will be set at 12.2.
**** In 2023, new energy conservation standards for Small Commercial Packaged Air Conditioning and Heating Equipment will take effect. These projections reflect the 2023 minimum efficiency requirements IEER of 14.1 and COP of 3.4.

Air-Cooled Commercial Packaged Heat Pumps

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010		ENERGY STAR version 2.2 Effective 1/1/2011		
		Min. EER	Min. COP at 47°F	Min. EER	Min. IEER	Min. COP at 47°F
Small (≥ 65 and < 135)	Electric resistance or none	11.0	3.3	11.3	11.4	3.35
	Any other type	10.8	3.3	–	–	–
Large (≥ 135 and < 240)	Electric resistance or none	10.6	3.2	10.9	11.0	3.25
	Any other type	10.4	3.2	–	–	–

- This analysis focused on small air-cooled commercial packaged rooftop heat pumps (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial heat pumps.
- Amended standards in terms of IEER for all equipment classes will take effect in 2018. More stringent standards in terms of IEER for all equipment classes will take effect in 2023.

Commercial Ground Source Heat Pumps

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DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	Mid	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	48	48	48	48	48	48	48	48	48	48	48	48	48
COP (Heating)*	3.1	3.2	3.7	3.8	4.0	3.7	4.0	3.7	4.0	3.7	4.0	3.7	4.0
EER (Cooling)**	12.7	14.1	17.4	19.7	22.1	17.4	22.1	17.4	22.1	17.4	22.1	17.4	22.1
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost (2017$)	8,500	4,750	5,550	6,100	6,700	5,550	6,700	5,550	6,700	5,550	6,700	5,550	6,700
Total Installed Cost (2017$)	16,500	14,750	15,550	16,100	16,700	15,550	16,700	15,550	16,700	15,550	16,700	15,550	16,700
	37,500	21,750	22,550	23,100	23,700	22,550	23,700	22,550	23,700	22,550	23,700	22,550	23,700
Annual Maintenance Cost (2017$)	150	150	150	150	150	150	150	150	150	150	150	150	150

* COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.

** EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note: Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs 4-ton) and slightly higher installation costs for commercial. DOE does not distinguish between residential and commercial units in its regulations.

- The most common commercial ground source heat pump systems are closed-loop in which water or anti-freeze solution is circulated through plastic pipes buried underground. Commercial water-to-air heat pumps (WAHPs) range in size from 1 ton or less to over 500 tons depending on whether a distributed or centralized architecture is used. Distributed systems are more prevalent.
- Most geothermal WAHPs are rated for capacity and efficiency based on the ISO 13256-1 standard. Heating and cooling efficiency measurements under this standard include input energy for fans and pumps on a proportional basis that only includes that power required to transport air and liquid through the heat pump. The reason for this method is to simplify comparisons between heat pumps and to allow equipment to be optimized for real world conditions without suffering rating penalties. Real world energy use will exceed ratings predictions as a result of higher fluid static pressure requirements.
- ISO 13256-1 cooling rating conditions call for 77F entering water temperature and 80.6F entering air temperature. More typical peak design criteria would be 80-90F entering water temperature and 75F entering air temperature. As a result, ISO 13256-1 rated cooling efficiency would be higher than typical design peak operation.
- Some WAHPs include efficiency data for a part load operating condition as allowed by ISO 13256-1 for multiple stage or variable speed compressors. No seasonal energy efficiency metric (analogous to SEER or IEER) currently applies to WAHPs. The annual performance of a geothermal WAHP system can vary more widely than for other system types due to the large influence of ground loop design and characteristics.
- The ENERGY STAR® criteria for ground source heat pumps apply only to residential applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger and distribution pumping systems represent a majority of the installation cost.
- Low end WAHPs utilize single stage compressors. Higher efficiency units incorporate multiple stage or variable speed compressor controls to improve efficiency as well as humidity and temperature control. Variable speed electronically commutated (EC) fan motors also improve overall energy efficiency.

Commercial Gas-Fired Storage Water Heaters

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DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	100	100	100	100	100	100	100	100	100	100	100	100	100
Typical Input Capacity (kBtu/h)	199	199	199	199	199	199	199	199	199	199	199	199	199
Thermal Efficiency (%)	81	80	82	94	99	82	99	82	99	82	99	82	99
Average Life (yrs)	13	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2017$)**	3,400	3,300	3,450	3,950	4,050	3,450	4,050	3,450	4,050	3,450	4,050	3,450	4,050
	4,200	4,100	4,300	4,850	4,950	4,300	4,950	4,300	4,950	4,300	4,950	4,300	4,950
Total Installed Cost (2017$)**	4,200	4,150	4,300	5,450	5,550	4,300	5,550	4,300	5,550	4,300	5,550	4,300	5,550
	6,050	5,950	6,150	6,500	6,600	6,150	6,600	6,150	6,600	6,150	6,600	6,150	6,600
Annual Maintenance Cost (2017$)	270	270	270	270	270	270	270	270	270	270	270	270	270

*Different levels of standby loss were not included in this analysis.
**The range of retail and installed costs represent the range from replacement market to new construction market.

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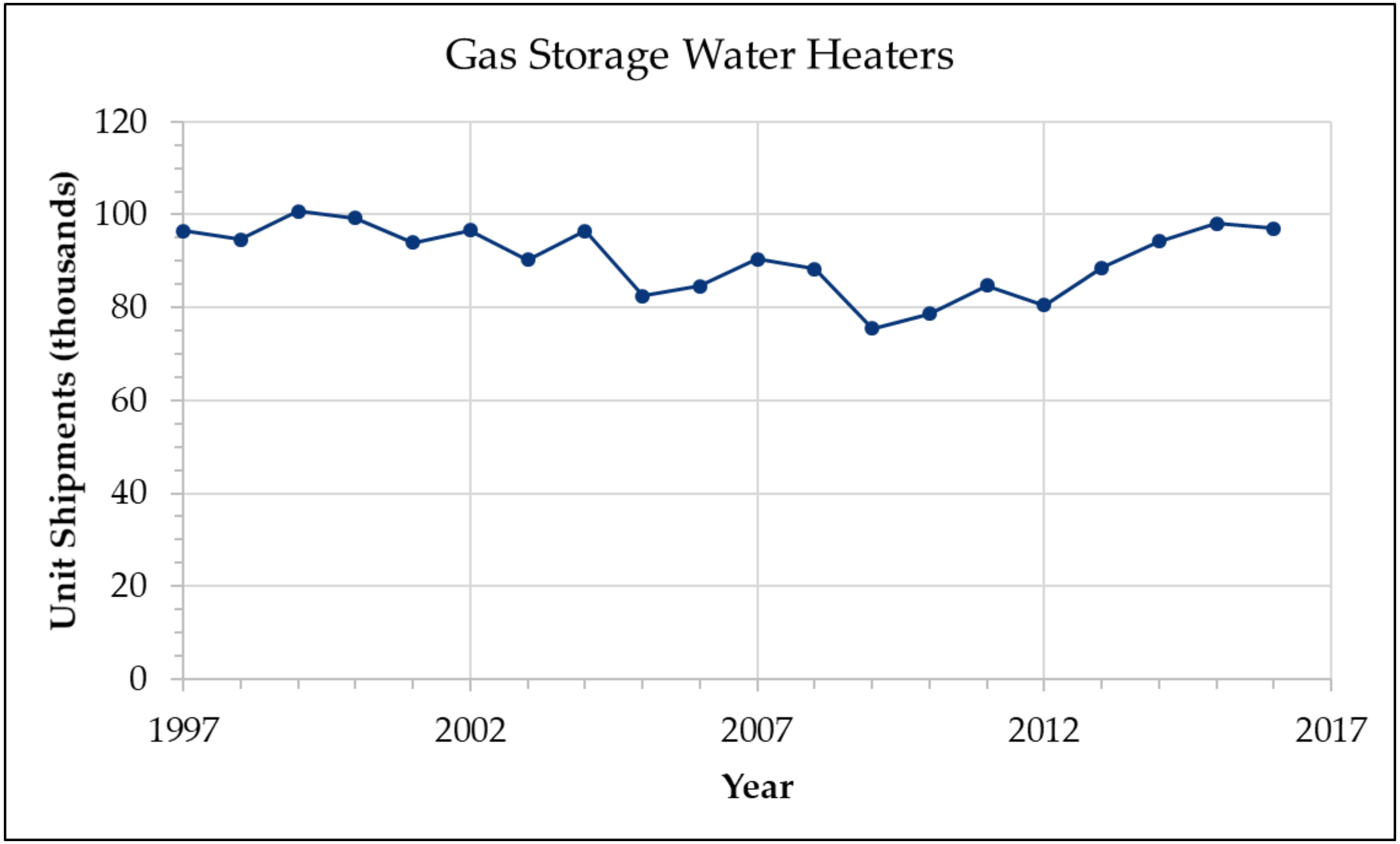
- Input capacity ≥ 75,000 Btu/h, and < 4,000 Btu/h per gallon of stored water
- Federal standard[1]:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h) : Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss (Btu/h): 0.84 × [(Input Rate/800) + 110 × (Rated Volume)$^{1/2}$]
- Baseline units are typically constructed similarly to residential units, though with higher input capacities (and often higher storage volumes).
- High-efficiency units include condensing heat exchangers (typically stainless or enameled steel) to extract additional heat by condensing water vapor in flue gases. Condensing units also include an inducer fan system or power burner. The heat exchanger is typically contained within the tank, but some designs consist of an external heating module attached to a storage tank.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $270 for annual maintenance.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Annual shipments have fluctuated from 99,000 units in 2000 to 80,000 units in 2012, back to 99,000 units in 2016.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Commercial-Storage-Water-Heaters-Historical-Data.aspx*

Commercial Electric Resistance Storage Water Heaters

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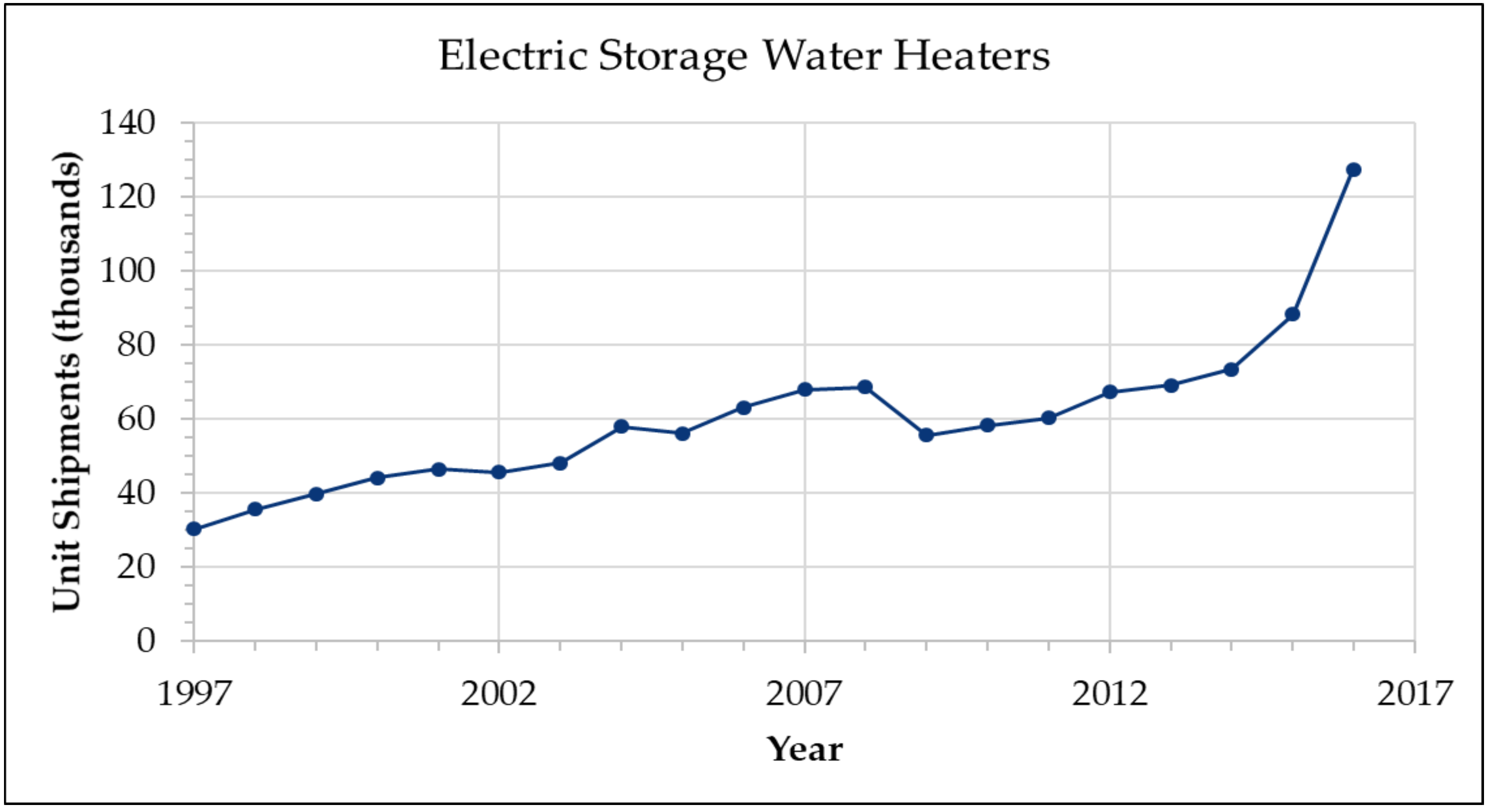
DATA	2012	2017		2020	2030	2040	2050
	Installed Base	Current Standard	Typical	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	119	119	119	119	119	119	119
Typical Input Capacity (kW)	18	18	18	18	18	18	18
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (yrs)	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)**	2,700	2,700	2,700	2,700	2,700	2,700	2,700
	3,200	3,200	3,200	3,200	3,200	3,200	3,200
Total Installed Cost (2017$)**	3,800	3,800	3,800	3,800	3,800	3,800	3,800
	3,950	3,950	3,950	3,950	3,950	3,950	3,950
Annual Maintenance Cost (2017$)	50	50	50	50	50	50	50

*Different levels of standby loss were not included in this analysis.
**The range of retail equipment and installed costs represents the range from replacement market to new construction market.

- Federal standard[1]:
  - Maximum standby loss (%/h) : 0.30 + 27/Measured Storage Volume
  - Minimum thermal efficiency: no standard, but all units ≥ 98% anyway
- Storage capacity: typically 50 to 120 gallons, though smaller and larger units exist for specialized applications
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- There is very little variation in thermal efficiency on the market; variation in standby loss is typically due to tank design and insulation thickness.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $50 for annual maintenance.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Annual shipments increased more than 50 percent over 12 years from 44 thousand units in 2000 to 67 thousand units in 2012. Since 2012, shipments have increased by 89%, with the largest increase of 44% occurring in 2016.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Commercial-Storage-Water-Heaters-Historical-Data.aspx*

Commercial Heat Pump Water Heaters

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DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Water Flow Rate (gal/min)	34	34	34	34	34	34
Typical Output Capacity (kW)	50	50	50	50	50	50
Coefficient of Performance (COP_h)	3.9	3.9	3.9	3.9	3.9	3.9
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost (2017$)	47,100	47,100	47,100	47,100	47,100	47,100
Total Installed Cost (2017$)	50,950	50,950	50,950	50,950	50,950	50,950
Annual Maintenance Cost (2017$)	100	100	100	100	100	100

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- There are no integrated commercial HPWHs (CHPWHs) on the market (i.e., heat pump module and storage tank combined in one unit); all units are add-on units which are typically designed to be used with a storage tank(s).
- CHPWHs serve only a small portion of the commercial water heating (CWH) market. Three manufacturers (including only one major CWH manufacturer) sell CHPWHs.
- CHPWHs can extract heat from either air or water for heating potable water ("air-source" or "water-source"). The capacity of air-source CHPWHs falls at lower ambient air temperatures.
- Air-source CHPWHs cool the surrounding air, which can be desirable when installed indoors in applications with a year-round cooling load (e.g., a commercial kitchen).
- Output capacities for CHPWHs range from 17 kW to over 70 kW for air-source units and over 600 kW for water-source units.
- Some commercial applications require water as hot as 180 °F, such as dishwashing; however, most CHPWHs cannot deliver hot water at temperatures higher than 150 °F.
- There are no current Federal standards for CHPWHs, but DOE prescribes a test procedure for determining COP_h for CHPWHs.
- ENERGY STAR levels for CWH equipment are under revision. The public final draft of the updated specification includes a COP_h level of 3.0 for CHPWHs.

Commercial Oil-Fired Storage Water Heaters

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DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	70	85	85	85	85	85	85	85	85	85	85	85
Typical Input Capacity (kBtu/h)	300	300	300	300	300	300	300	300	300	300	300	300
Thermal Efficiency (%)	79	80	81	82	81	82	81	82	81	82	81	82
Average Life (yrs)	13	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2017$)	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650
Total Installed Cost (2017$)	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200
Annual Maintenance Cost (2017$)	168	168	168	168	168	168	168	168	168	168	168	168

*Different levels of standby loss were not included in this analysis.

- Input capacity ≥ 105,000 Btu/h, and < 4,000 Btu/h per gallon of stored water
- Federal standard[1]:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h): Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- Condensing units do not exist, thus the highest thermal efficiency on the market is 86%.
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $100–$200 per year for one or two cleanings performed by a plumber.
- The market for commercial oil-fired storage water heaters is very small; shipments are approximately 3% of shipments for commercial gas-fired storage water heaters.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Commercial Electric Booster Water Heaters

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DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (gal)	6	6	6	6	6	6
	16	16	16	16	16	16
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	3	3	3	3	3	3
	10	10	10	10	10	10
Retail Equipment Cost (2017$)	1,300	1,300	1,300	1,300	1,300	1,300
	2,800	3,000	3,000	3,000	3,000	3,000
Total Installed Cost (2017$)	1,500	1,500	1,500	1,500	1,500	1,500
	3,000	3,200	3,200	3,200	3,200	3,200
Annual Maintenance Cost (2017$)*	-	-	-	-	-	-

* Maintenance costs negligible.

Commercial Gas-fired Booster Water Heaters

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DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	3	3	3	3	3	3	3	3	3	3	3	3
	5	5	5	5	5	5	5	5	5	5	5	5
Thermal Efficiency (%)	80	80	80	91	80	91	80	91	80	91	80	91
Average Life (yrs)	5	5	5	5	5	5	5	5	5	5	5	5
	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2017$)	4,700	4,900	4,900	8,000	4,900	8,000	4,900	8,000	4,900	8,000	4,900	8,000
	6,800	7,700	7,700	9,500	7,700	9,500	7,700	9,500	7,700	9,500	7,700	9,500
Total Installed Cost (2017$)	5,000	5,200	5,200	8,300	5,200	8,300	5,200	8,300	5,200	8,300	5,200	8,300
	7,100	8,000	8,000	9,800	8,000	9,800	8,000	9,800	8,000	9,800	8,000	9,800
Annual Maintenance Cost (2017$)	160	160	160	160	160	160	160	160	160	160	160	160

- Booster water heaters are installed, often at the point of use, in series with the main service water heating system to boost service water temperatures. The main service water heating system may provide 110-140 °F water, and the booster water heater may increase that temperature to 180-195 °F. Typical commercial applications for booster water heaters include commercial dishwashers, laundromats, hospitals, and car washes.
- Commercial booster water heaters are regulated by DOE as either storage or instantaneous water heaters, depending on the ratio of input capacity to storage volume. Units with input capacity < 4,000 Btu/h per gallon of stored water are storage water heaters; all other units are instantaneous water heaters.
- DOE's regulations do not currently include standards for electric instantaneous water heaters, but standards are included for electric storage water heaters, gas-fired instantaneous water heaters, and gas-fired storage water heaters.
- Booster water heaters typically have short lifetimes because of high usage and extreme temperatures.
- Shipments are small due to the limited number of applications.

Commercial Gas-Fired Instantaneous Water Heaters

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DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	250	250	250	250	250	250	250	250	250	250	250	250	250
	399	399	399	399	399	399	399	399	399	399	399	399	399
Thermal Efficiency (%)	80	80	92	94	98	92	98	92	98	92	98	92	98
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17	17	17
	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$)*	1,900	1,900	2,200	2,250	2,300	2,200	2,300	2,200	2,300	2,200	2,300	2,200	2,300
	4,800	4,800	8,450	8,800	9,150	8,450	9,150	8,450	9,150	8,450	9,150	8,450	9,150
Total Installed Cost (2017$)*	2,550	2,550	3,700	3,750	3,800	3,700	3,800	3,700	3,800	3,700	3,800	3,700	3,800
	11,000	11,000	11,300	11,650	12,050	11,300	12,050	11,300	12,050	11,300	12,050	11,300	12,050
Annual Maintenance Cost (2017$)*	40	40	100	100	110	100	110	100	110	100	110	100	110

*Commercial gas-fired instantaneous water heaters are categorized into two groups: tankless water heater and hot water supply boiler. Tankless units are similar in design to residential tankless units. The hot water supply boiler has a much higher input and is similar in design to boilers. The large variation of total input capacity and design causes a large range of costs. The low and high range of retail and installed costs represent the differences in design, as well as the cost ranges arising from replacement versus new construction markets.

- Input capacity ≥ 200,000 Btu/h, and ≥ 4,000 Btu/h per gallon of stored water
- Federal standard[1]:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h): Input Rate/800 + 110 x $(\text{Rated Volume})^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
- Wall-mounted ("tankless") units typically top out at ~400,000 Btu/h and are similar in design to residential tankless units. Floor-mounted units ("circulating" or "volume" water heaters) are similar in design to boilers and can have input capacities in the millions of Btu/h. Floor-mounted units are typically installed with a storage tank.
- Despite high available input capacities, some installations use multiple units staged together, which may have reliability and/or efficiency benefits.
- Similar to storage water heaters, higher efficiencies are achieved with condensing operation, which requires a condensing heat exchanger and inducer fan or power burner. Some units include both non-condensing and condensing heat exchangers, while others include a single condensing heat exchanger.
- When replacing a storage water heater with an instantaneous water heater, there may be significant additional costs to upsize the gas supply line and change the venting.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Commercial Solar Water Heaters

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DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical / ENERGY STAR**	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	83	83	83	83	83	83
Solar Fraction (SF)	0.5	0.56	0.56	0.56	0.56	0.56
Solar Energy Factor (SEF)	2.5	2.7	2.7	2.7	2.7	2.7
Average Life (yrs)	20	20	20	20	20	20
Retail Equipment Cost (2017$)*	8,300	8,300	8,300	8,300	8,300	8,300
	9,500	9,500	9,500	9,500	9,500	9,500
Total Installed Cost (2017$)*	11,000	11,000	11,000	11,000	11,000	11,000
	13,100	13,100	13,100	13,100	13,100	13,100
Annual Maintenance Cost (2017$)	25	25	25	25	25	25

* Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.
** ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

- Solar water heaters are not subject to federal energy conservation standards, the ENERGY STAR requirements are:

Applicable Products	Backup Fuel	ENERGY STAR Requirement	Test Method
Whole-home solar units	Gas	SEF ≥ 1.2	SRCC – OG-300: Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems
	Electric	SEF ≥ 1.8	

- Commercial solar water heaters are typically custom designed for a specific installation.
- One major CWH manufacturer sells a commercial integrated solar water heater similar to residential designs that includes an indirect solar water heat exchanger and a gas-fired backup heat exchanger, and this model is certified to the Solar Rating and Certification Corporation (SRCC)'s OG-300, "Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems."
- Commercial solar water heaters may include backup heating, from sources such as electric resistance or hydronic heat (supplied from a gas-fired boiler or geothermal heat pump).
- Storage volumes of tanks for commercial solar water heaters can span from 140 gallons to over 2,000 gallons.
- SRCC's OG-300 can be used to certify commercial systems, but most commercial systems are larger and unique, so this certification program is mostly used for residential solar water heaters.
  - Many incentive programs require that solar collectors for commercial systems be certified to SRCC's certification program for collectors, OG-100.

Commercial Natural Gas Range with Griddle and Oven

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DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Typical	ENERGY STAR*	High	Typical	High	Typical	High	Typical	High	Typical	High
Total Input Capacity (kBtu)	275	275	275	275	275	275	275	275	275	275	275	275
Griddle - Cooking Energy Efficiency (%)	30	30	38	52	30	52	30	52	30	52	30	52
Oven - Cooking Energy Efficiency (%)	35	35	46	50	35	50	35	50	35	50	35	50
Range - Cooking Energy Efficiency (%)	30	30	N/A	40	30	40	30	40	30	40	30	40
Griddle - Normalized Idle Energy Rate ($Btu/h/ft^2$)	3,000	3,000	2,650	1,080	3,000	1,180	3,000	1,180	3,000	1,180	3,000	1,180
Oven - Idle Energy Rate (Btu/h)	18,000	18,000	12,000	7,180	18,000	7,180	18,000	7,180	18,000	7,180	18,000	7,180
Range - Idle Energy Rate (Btu/h)	3,600	3,600	N/A	1,900	3,600	1,900	3,600	1,900	3,600	1,900	3,600	1,900
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)**	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450
Total Installed Cost (2017$)	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600
Annual Maintenance Cost (2017$)*	–	–	–	–	–	–	–	–	–	–	–	–

*ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
** Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
*** Maintenance costs are negligible.

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Typical	ENERGY STAR*	High	Typical	High	Typical	High	Typical	High	Typical	High
Total Input Capacity (kW)	20	20	20	20	20	20	20	20	20	20	20	20
Griddle - Cooking Energy Efficiency (%)	65	70	70	86	70	86	70	86	70	86	70	86
Oven - Cooking Energy Efficiency (%)	65	65	N/A	80	65	80	65	80	65	80	65	80
Range - Cooking Energy Efficiency (%)	75	75	N/A	85	75	85	75	85	75	85	75	85
Griddle - Normalized Idle Energy Rate (kW/ft^2)	0.44	0.34	0.32	0.20	0.34	0.20	0.34	0.20	0.34	0.20	0.34	0.20
Oven - Idle Energy Rate (kW)	1.50	1.50	1.00	0.90	1.50	0.90	1.50	0.90	1.50	0.90	1.50	0.90
Range - Idle Energy Rate (kW)**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)***	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550
Total Installed Cost (2017$)	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700
Annual Maintenance Cost (2017$)****	–	–	–	–	–	–	–	–	–	–	–	–

*ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
**No data on electric range top idle energy rates.
*** Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
**** Maintenance costs are negligible.

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- Combined product that typically includes 2-6 range tops, a 24 in. x 24 in. griddle surface, and one or two half- or full-size ovens.
- Combined product is not covered by ENERGY STAR. However, the individual product ENERGY STAR specifications are provided below.

Product	ENERGY STAR Requirements	Gas	Electric
Griddle	Cooking Energy Efficiency	≥ 38%	≥ 70%
	Normalized Idle Energy Rate	≤ 2,650 Btu/h per ft^2	≤ 0.320 kW per ft^2
Oven	Cooking Energy Efficiency	≥ 46%	≥ 71%
	Idle Energy Rate	≤ 12,000 Btu/h	Half size: ≤1.00 kW Full size: ≤1.60 kW

- ENERGY STAR does not provide certification for range tops.
- There are no Federal standards for commercial cooking products.
- Product pricing in this market does not scale with efficiency, but rather depend on a number of other factors such as brand name, aesthetics, and additional features.

Commercial Hot Food Holding Cabinets

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DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	State Standards	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4
Maximum Idle Energy Rate (W)	900	856	856	297	154	856	154	856	154	856	154	856	154
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)	2,500	3,850	3,850	4,200	5,500	3,850	5,500	3,850	5,500	3,850	5,500	3,850	5,500
Total Installed Cost (2017$)	2,500	3,850	3,850	4,200	5,500	3,850	5,500	3,850	5,500	3,850	5,500	3,850	5,500
Annual Maintenance Cost (2017$)*	–	–	–	–	–	–	–	–	–	–	–	–	–

* Maintenance costs are negligible.

- Used in commercial kitchens to keep food warm until it is served.
- Many shapes and sizes, but interior volumes around 21.4 ft^3 typical in many settings.
- Annual unit energy consumption can range from < 1,000 to > 30,000 kWh/y, depending on size, efficiency, and usage.
- Energy performance metric is "Idle Energy Consumption Rate" in Watts, measured using ASTM Standard F2140-11.
- No Federal standards, but eight identical State standards, first took effect in California in 2006, now considered the typical or "baseline" product. ENERGY STAR version 2.0 took effect October 1, 2011.
- Maximum Idle Energy Consumption Rate for products $12 \le V < 28$:
  - State standards: $\le \mathbf{40 \times \mathit{V}}$ (baseline)
  - ENERGY STAR: $\le \mathbf{2.0 \times \mathit{V} + 254}$ (about 65% below baseline)

  where V is interior volume in ft^3.
- The most efficient products are about 80% below baseline.
- Energy savings achieved with insulation, automatic door closers, magnetic door gaskets, and Dutch doors (half-doors).

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Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19 St. NW, Suite 700
Washington, D.C. 20036
(202) 973-2400

www.navigantconsulting.com

North & Rest of Country

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (North)	High	Typical / High			
Typical Input Capacity (kBtu/h)	Navigant	Navigant	EERE				Navigant			
AFUE (%)	Navigant	Navigant	EERE	EERE	ENERGY STAR v4.1	AHRI				
Electric Consumption (kWh/yr)	EERE/ Navigant	EERE 2015								
Average Life (yrs)										
Retail Equipment Cost (2017$)										
Total Installed Cost (2017$)										
Annual Maintenance Cost (2017$)										

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td colspan="2">Navigant</td><td colspan="4">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>AFUE (%)</td><td colspan="2">Navigant</td><td>EERE</td><td>Navigant</td><td>ENERGY STAR v4.1</td><td>AHRI</td></tr>
<tr><td>Electric Consumption (kWh)</td><td>EERE</td><td colspan="5">EERE 2011</td></tr>
<tr><td>Average Life (yrs)</td><td>EERE</td><td colspan="5">EERE 2015</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE</td><td colspan="5">EERE 2011</td></tr>
<tr><td>Total Installed Cost ($)</td><td>EERE</td><td colspan="5">EERE 2011</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE</td><td colspan="5">EERE 2011</td></tr>
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<tr><td>Typical Input Capacity (kBtu/h)</td><td>EERE 2007</td><td colspan="5">EERE 2015 (Section 5.4.1 of the TSD)</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>AFUE (%)</td><td>EERE 2007/ Navigant</td><td>EERE 2007</td><td>EERE 2007</td><td>AHRI Database</td><td>ENERGY STAR v3.0</td><td>AHRI Database</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE 2007</td><td colspan="5" rowspan="2">EERE 2015 (LCC Analysis Spreadsheet "Statistics" tab)</td></tr>
<tr><td>Total Installed Cost ($)</td><td>EERE 2007</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE 2007</td><td colspan="5">EERE 2015 (Section 8.2.2.4 of the TSD)</td></tr>
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Data Sources » Residential Oil-Fired Boilers

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Input Capacity (kBtu/h)	EERE	EERE 2015 (Section 5.4.1 of the TSD)					Navigant			
AFUE (%)	EERE / Navigant	EERE 2007	EERE 2007	AHRI Database	ENERGY STAR v3.0	EERE 2007				
Average Life (yrs)	EERE	EERE								
Retail Equipment Cost ($)	EERE	EERE 2015 (LCC Analysis Spreadsheet "Statistics" tab)								
Total Installed Cost ($)	EERE	EERE 2015 (LCC Analysis Spreadsheet "Statistics" tab)								
Annual Maintenance Cost ($)	EERE	EERE 2015 (Section 8.2.2.4 of the TSD)								

Data Sources » Residential Electric Resistance Furnaces

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical			
Typical Capacity (kBtu/h)	Distributors			Navigant			
Efficiency (%)	DOE/ASHRAE						
Average Life (yrs)	Distributors						
Retail Equipment Cost ($)	RS Means 2017						
Total Installed Cost ($)	RS Means 2017						
Annual Maintenance Cost ($)	Navigant						

Data Sources » Residential Electric Resistance Heaters

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical			
Typical Capacity (kBtu/h)	Distributors			Navigant			
Efficiency (%)	Navigant						
Average Life (yrs)	Navigant						
Retail Equipment Cost ($)	2017 RS Means						
Total Installed Cost ($)	2017 RS Means						
Annual Maintenance Cost ($)	Navigant						

South (Hot-Dry and Hot-Humid)

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
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<tr><td>SEER</td><td rowspan="5">EERE / Navigant</td><td>EERE / Navigant</td><td>eCFR</td><td>EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5" rowspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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North (Rest of Country)

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<tr><th rowspan="2">SOURCES</th><th>2009</th><th>2015</th><th colspan="4">2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
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<tr><td>Typical Capacity (kBtu/h)</td><td>EERE</td><td colspan="5">EERE</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>SEER</td><td rowspan="5">EERE / Navigant</td><td>EERE / Navigant</td><td>eCFR</td><td>EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5" rowspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td></tr>
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<tr><td>Typical Capacity (kBtu/h)</td><td>EERE / AHRI</td><td colspan="5">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>SEER (Cooling)</td><td rowspan="6">EERE / Navigant</td><td>EERE / Navigant</td><td>eCFR</td><td>EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>HSPF (Heating)</td><td colspan="5" rowspan="5">EERE</td></tr>
<tr><td>Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost ($)</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
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</table>

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (kBtu/h)	AHRI/Navigant	EERE					Navigant			
COP (Heating)	Navigant	AHRI Database	ASHRAE 90.1-2016	AHRI Database	ENERGY STAR	AHRI Database				
EER (Cooling)	Navigant	AHRI Database		AHRI Database	ENERGY STAR	AHRI Database				
Average Life (yrs)	Navigant / EERE	Navigant / EERE								
Retail Equipment Cost ($)	Distributors/IGSHPA /EERE 2009/Navigant									
Total Installed Cost ($)	Distributors/IGSHPA /EERE 2009/Navigant									
Annual Maintenance Cost ($)	Navigant									

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (kBtu/hr)	Distributors		AHAM				Navigant			
EER and CEER	Navigant		EERE	CCMS	ENERGY STAR	CCMS				
Average Life (yrs)	Appliance Magazine, 2012									
Retail Equipment Cost (2017$)	EERE									
Total Installed Cost (2017$)										
Annual Maintenance Cost (2017$)	Navigant		Navigant							

Data Sources » Residential Portable Air Conditioners

SOURCES	2009	2015	2017		2020	2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High			
Typical Capacity (kBtu/hr)	EERE				Navigant			
CEER								
Average Life (yrs)								
Retail Equipment Cost ($)								
Total Installed Cost ($)								
Annual Maintenance Cost ($)								

SOURCES	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical			
Typical Capacity (kBtu/h)	Manufacturer			Navigant			
Heating (COP)	Product Literature						
Cooling (COP)	Product Literature						
Annual Electric Use (kWh/yr)	Product Literature						
Average Life (yrs)	Navigant						
Retail Equipment Cost ($)	PERC						
Total Installed Cost ($)	Navigant						
Annual Maintenance Cost ($)	Navigant						

Data Sources » Residential Cord Wood Stoves

SOURCES	2009	2015	2017		2020	2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High			
Typical Capacity (kBtu/h)	Distributors / Product Literature				Navigant			
Efficiency (Non-Catalytic) (HHV)	Navigant / Literature	EPA Default / Literature / Navigant	EPA Certified Wood Heater List August 2016					
Efficiency (Catalytic) (HHV)								
Average Life (yrs)	Navigant							
Retail Equipment Cost ($)	Product Lit. / Dealers	Product Literature/Dealers						
Total Installed Cost ($)	Dealers	Dealers/Navigant						
Annual Maintenance Cost ($)	Dealers / Navigant							

SOURCES	2009	2015	2017		2020	2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High			
Typical Capacity (kBtu/h)	Distributors / Product Literature				Navigant			
Efficiency (HHV)	Navigant/ Literature	EPA Default/Literature/Navigant	EPA Default/EPA Certified Wood Heater List August 2016/Navigant					
Average Life (yrs)	Navigant							
Retail Equipment Cost ($)	Product Literature/ Dealers							
Total Installed Cost ($)	Dealers	Dealers/Navigant						
Annual Maintenance Cost ($)								

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (gal)	AHRI / Distributors	Navigant	EERE 2010/AHRI				Navigant			
Uniform Energy Factor (UEF)	Navigant		EERE 2016	CCMS	ENERGY STAR	AHRI/CCMS				
Average Life (yrs)	EERE 2010									
Retail Equipment Cost (2017$)	Distributors		EERE 2010			Distributors				
Total Installed Cost (2017$)	Distributors / RS Means 2010		EERE 2010							
Annual Maintenance Cost (2017$)	EERE 2010									

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<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td rowspan="2">Navigant</td><td colspan="3">EERE 2010/AHRI</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Uniform Energy Factor (UEF)</td><td>Navigant</td><td>EERE 2016</td><td colspan="2">AHRI/CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE 2010</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td>Distributors</td><td colspan="4" rowspan="2">EERE 2010</td></tr>
<tr><td>Total Installed Cost (2017$)</td><td>Distributors / RS Means 2007</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="5">EERE 2010</td></tr>
</table>

Data Sources » Residential Electric Resistance Storage Water Heaters

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SOURCES	2009	2015	2017			2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Capacity (gal)	AHRI / Distributors	AHRI	EERE 2010/AHRI			Navigant			
Uniform Energy Factor (UEF)	Navigant		EERE 2016	AHRI/CCMS	AHRI				
Average Life (yrs)	EERE 2010								
Retail Equipment Cost (2017$)	Distributors	EERE 2010	EERE 2010		Distributors				
Total Installed Cost (2017$)	Distributors / RS Means 2010	EERE 2010							
Annual Maintenance Cost (2017$)	EERE 2010								

SOURCES	2009	2015	2017			2020	2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (gal)	AHRI	Navigant	AHRI			Navigant			
Uniform Energy Factor (UEF)	Navigant	Navigant	CCMS	ENERGY STAR	AHRI/CCMS				
Average Life (yrs)	EERE 2010								
Retail Equipment Cost (2017$)	RS Means 2010 / ACEEE 2007	EERE 2010	Distributors	EERE 2010	Distributors				
Total Installed Cost (2017$)		EERE 2010							
Annual Maintenance Cost (2017$)	EERE 2010								

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SOURCES	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical / ENERGY STAR**	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	SRCC / Navigant			Navigant			
Overall Efficiency (Solar Fraction)	DOE / SRCC / Navigant						
Solar Energy Factor	SRCC / Navigant						
Average Life (yrs)	DOE / Navigant						
Retail Equipment Cost1 (2017$)	RS Means Online 2017						
Total Installed Cost1 (2017$)	RS Means Online 2017						

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SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	**Installed Base**	**Current Standard**	**Typical**	**ENERGY STAR**	**High**	**Typical / High**			
Typical Capacity (kBtu/hr)	EERE	AHRI	EERE 2010/AHRI				Navigant			
Uniform Energy Factor (UEF)	Navigant	Navigant	EERE 2016	CCMS	ENERGY STAR	CCMS				
Average Life (yrs)	EERE 2010									
Retail Equipment Cost (2017$)	Distributors / RS Means 2010	EERE 2010								
Total Installed Cost (2017$)	DEER 2008									
Annual Maintenance Cost (2017$)	Navigant									

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (ft^3)	EERE 2011 / Navigant						Navigant			
Energy Consumption (kWh/yr)	Navigant		EERE 2011	Navigant	ENERGY STAR	Navigant				
Average Life (yrs)	EERE 2011 / Navigant									
Retail Equipment Cost (2017$)										
Total Installed Cost (2017$)										
Annual Maintenance Cost (2017$)										

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<tr><td>Typical Capacity (kBtu/h)</td><td colspan="4">Distributors / Product Literature</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Integrated Annual Energy Consumption (kBtu/yr)</td><td>EERE</td><td>Navigant</td><td colspan="2">EERE</td></tr>
<tr><td>Cooking Efficiency (%)</td><td colspan="4">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4" rowspan="3">EERE</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="4">Navigant / EERE</td></tr>
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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (ft3)</td><td colspan="5">Navigant / CCMS</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>CEF (lb/kWh)</td><td colspan="2">EERE / Navigant</td><td colspan="2">EERE</td><td>CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">EERE</td><td colspan="3" rowspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td colspan="2" rowspan="2">EERE / Navigant</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="2">EERE</td></tr>
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SOURCES	2009	2015	2017			2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Capacity (ft^3)	EERE / Navigant		CCMS			Navigant			
CEF (lb/kWh)			EERE		CCMS				
Average Life (yrs)	EERE		EERE						
Retail Equipment Cost (2017$)	EERE / Navigant								
Total Installed Cost (2017$)									
Annual Maintenance Cost (2017$)	EERE								

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<tr><td>Typical Capacity (ft^3)</td><td rowspan="3">Navigant</td><td>Navigant</td><td>CCMS</td><td rowspan="3">CCMS</td><td>CCMS</td><td rowspan="3">CCMS</td><td colspan="4" rowspan="11">Navigant</td></tr>
<tr><td>Integrated Modified Energy Factor (ft^3/kWh/cycle)</td><td rowspan="2">AHAM / Navigant</td><td rowspan="2">EERE</td><td>ENERGY STAR</td></tr>
<tr><td>Integrated Water Factor (gal/cycle/ft^3)</td><td>ENERGY STAR</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Water Consumption (gal/cycle)</td><td colspan="6">Navigant / EERE</td></tr>
<tr><td>Hot Water Energy (kWh/cycle)</td><td colspan="6" rowspan="3">Navigant</td></tr>
<tr><td>Machine Energy (kWh/cycle)</td></tr>
<tr><td>Dryer Energy (kWh/cycle)</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td colspan="6">EERE / Distributors</td></tr>
<tr><td>Total Installed Cost (2017$)</td><td colspan="6">Navigant / RS Means 2016</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="6">EERE</td></tr>
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<tr><td>Typical Capacity (ft^3)</td><td rowspan="3">Navigant</td><td>Navigant</td><td>CCMS</td><td rowspan="3">CCMS</td><td>CCMS</td><td rowspan="3">CCMS</td><td colspan="4" rowspan="12">Navigant</td></tr>
<tr><td>Integrated Modified Energy Factor (ft^3/kWh/cycle)</td><td rowspan="2">AHAM / Navigant</td><td rowspan="2">EERE</td><td rowspan="2">ENERGY STAR</td></tr>
<tr><td>Integrated Water Factor (gal/cycle/ft^3)</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Water Consumption (gal/cycle)</td><td colspan="6">Navigant / EERE</td></tr>
<tr><td>Hot Water Energy (kWh/cycle)</td><td colspan="6" rowspan="3">Navigant</td></tr>
<tr><td>Machine Energy (kWh/cycle)</td></tr>
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<tr><td>Retail Equipment Cost (2017$)</td><td colspan="6">EERE / Distributors</td></tr>
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<tr><td>Typical Annual Energy Use (kWh/yr)</td><td colspan="2" rowspan="3">AHAM 2014 / EERE 2012</td><td rowspan="2">CFR</td><td rowspan="2">Navigant / CCMS / ENERGY STAR</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">EERE 2016</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Water Consumption (gal/cycle)</td></tr>
<tr><td>Water Heating Energy Use (kWh/yr)</td><td colspan="4">EERE 2016</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE 2016 / Navigant</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td colspan="2" rowspan="2">EERE 2012</td><td colspan="4" rowspan="2">EERE 2016</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="6">Navigant</td></tr>
</table>

Data Sources » Commercial Gas-Fired Furnaces

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Input Capacity (kBtu/h)	AHRI	EERE			Navigant			
Thermal Efficiency (%)	AHRI	10 CFR 431.77	DOE CCMS					
Average Life (yrs)	EERE							
Retail Equipment Cost ($)								
Total Installed Cost ($)								
Annual Maintenance Cost ($)								

Data Sources » Commercial Oil-Fired Furnaces

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<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="4">Typical</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td rowspan="2">AHRI</td><td colspan="3">DOE CCMS</td><td rowspan="6" colspan="4">Navigant</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>10 CFR 431.77</td><td colspan="2">DOE CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td rowspan="3">EERE</td><td rowspan="3" colspan="3">EERE / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

DATA	2012		2017		2020	2030	2040	2050
	Small	Large	Small	Large	Small / Large			
Typical Capacity (kBTU/h)	Distributors/Navigant				Navigant			
Efficiency (%)	Navigant							
Average Life (yrs)	Technology Cost and Performance File for Commercial Model for AEO2010							
Retail Equipment Cost ($)	RS Means 2017							
Total Installed Cost ($)								
Annual Maintenance Cost ($)	Navigant							

SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical			
Typical Capacity (kW)	BSRIA		Navigant			
Efficiency (%)	EERE / Navigant					
Average Life (yrs)	ASHRAE 2007 HVAC Applications	ASHRAE 2015 HVAC Applications				
Retail Equipment Cost ($)	RS Means 2013/Navigant	RS Means 2017				
Total Installed Cost ($)						
Annual Maintenance Cost ($)						

Data Sources » Commercial Gas-Fired Boilers

SOURCES	2012	2017				2020		2030	2040	2050
	Installed Base	Current Standard*	Typical	Mid-Range	High	Typical	High	Typical/High		
Typical Input Capacity (kBtu/h)	Navigant	EERE Issued Final Rule				Navigant		Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Navigant	EERE Issued Final Rule				Navigant				
Average Life (yrs)	EERE	EERE Issued Final Rule				Navigant				
Retail Equipment Cost ($)	RS Means 2011	EERE Issued Final Rule				Navigant				
Total Installed Cost ($)	RS Means 2011	EERE Issued Final Rule				Issued Final Rule				
Annual Maintenance Cost ($)	Navigant	EERE Issued Final Rule				Navigant				

Data Sources » Commercial Oil-Fired Boilers

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Input Capacity (kBtu/h)	Navigant	Issued Final Rule (Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers)			Navigant			
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004							
Average Life (yrs)	EERE							
Retail Equipment Cost ($)	RS Means 2011 / Navigant							
Total Installed Cost ($)								
Annual Maintenance Cost ($)	EERE							

Data Sources » Commercial Centrifugal Chillers

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	ASHRAE 90.1	Typical	High	Typical / High			
Typical Capacity (tons)	IPCC/ARB/TEAP/Navigant				Navigant			
Efficiency (kW/ton)	ASHRAE 90.1-2010/FEMP/eSource/Product Literature	ASHRAE 90.1-2016 (>400 TR)	Product Lit	Progress Energy Data Sheet				
COP								
Average Life (yrs)	2007 ASHRAE Applications Handbook	2015 ASHRAE Applications Handbook A37 Table 4						
Retail Equipment Cost ($/ton)	RS Means/Distributors/Navigant	RS Means 2017/Navigant						
Total Installed Cost ($/ton)								
Annual Maintenance Cost ($/ton)	Navigant/Alabama Power							

Data Sources » Commercial Reciprocating Chillers

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	ASHRAE 90.1	Typical	High	Typical / High			
Typical Capacity (tons)	BSRIA/DEER				Navigant			
Efficiency (kW/ton)	ASHRAE 90.1-2010/DEER/ FEMP/Product Literature	ASHRAE 90.1-2016 (>150 TR)	ASHRAE 90.1-2016 (>150 TR)	Product Lit				
COP								
Average Life (yrs)	Manufacturers	2015 ASHRAE Applications Handbook A37 Table 4						
Retail Equipment Cost ($/ton)	RS Means/ Distributors/ Navigant	RS Means 2017/Navigant						
Total Installed Cost ($/ton)								
Annual Maintenance Cost ($/ton)	Navigant/Alabama Power							

Data Sources » Commercial Screw Chillers

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	ASHRAE 90.1	Typical	High	Typical / High			
Typical Capacity (tons)	Navigant							
Efficiency (kW/ton)	Navigant	ASHRAE 90.1-2016 (>150 TR)	ASHRAE 90.1-2016 (>150 TR)	Product Lit				
COP								
Average Life (yrs)	Manufacturers	FacilitiesNet			Navigant			
Retail Equipment Cost ($/ton)	RS Means 2013/Distributors/Navigant	RS Means 2017/Navigant						
Total Installed Cost ($/ton)								
Annual Maintenance Cost ($/ton)	Navigant/Alabama Power							

Data Sources » Commercial Scroll Chillers

SOURCE	2012	2017			2020	2030	2040	2050
	Installed Base	ASHRAE 90.1	Typical	High	Typical / High			
Typical Capacity (tons)	Navigant/Manufacturers				Navigant			
Efficiency [full-load/IPLV] (kW/ton)	Navigant	ASHRAE 90.1-2016 (>150TR)	Product Lit/Navigant	Product Lit				
COP [full-load/IPLV]								
Average Life (yrs)	Manufacturers							
Retail Equipment Cost ($/ton)	Manufacturers/RS Means 2013/Navigant	RS Means 2017/Navigant						
Total Installed Cost ($/ton)								
Annual Maintenance Cost ($/ton)	Navigant /Alabama Power							

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<tr><th>Installed Base: Absorption</th><th>Installed Base: Engine-Driven</th><th>ASHRAE 90.1 absorption</th><th>CA Title 24 - engine</th><th>Absorption</th><th>Engine-Driven</th><th colspan="4">Absorption / Engine-Driven</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="6">BSRIA/Distributors</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>COP [full-load]</td><td colspan="2" rowspan="2">Product Literature/Navigant</td><td rowspan="2">ASHRAE 90.1-2016 direct-fired double effect</td><td rowspan="2">CA Title 24 gas Engine standard</td><td colspan="2" rowspan="2">Product Lit</td></tr>
<tr><td>COP [IPLV]</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">2007 ASHRAE Applications Handbook/Distributors</td><td colspan="4">2015 ASHRAE Applications Handbook A37 Table 4</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="2" rowspan="2">Manufacturer/Distributors/RS Means 2013/GIT/Navigant</td><td colspan="4" rowspan="2">RS Means 2017/Navigant</td></tr>
<tr><td>Total Installed Cost ($/ton)</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="6">Navigant/Alabama Power</td></tr>
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<tr><th rowspan="2">SOURCES</th><th>2012</th><th colspan="4">2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Output Capacity (kBtu/h)</td><td>AHRI / Navigant</td><td colspan="4">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Efficiency (EER)</td><td>Distributors / Navigant</td><td>eCFR</td><td rowspan="2">EERE</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">EERE</td></tr>
<tr><td>Part Load Efficiency (IEER)</td><td>EERE</td><td>N/A</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td rowspan="2">Distributors / Navigant / DEER, 2008</td><td colspan="4" rowspan="2">EERE</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="5">EERE</td></tr>
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Data Sources » Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners/Heat Pumps

<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th>2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Typical</th><th colspan="4">Typical</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="2" rowspan="3">Product Literature/Navigant</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Heating COP</td></tr>
<tr><td>Cooling COP</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">Manufacturer/RS Means 2017/Navigant</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td colspan="2">Abuheiba 2017/Manufacturer/RS Means 2017/Navigant</td></tr>
<tr><td>Total Installed Cost ($/ton)</td><td colspan="2" rowspan="2">Manufacturer/RS Means 2017/Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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<tr><th rowspan="2">SOURCES</th><th>2012</th><th colspan="4">2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="5">EERE</td><td colspan="4" rowspan="8">Navigant</td></tr>
<tr><td>Efficiency (EER)</td><td>ASHRAE Standard 90.1-2004 / Navigant</td><td>eCFR</td><td>EERE / Navigant</td><td rowspan="3">ENERGY STAR</td><td>EERE / Navigant</td></tr>
<tr><td>Part Load Efficiency</td><td>EERE</td><td>N/A</td><td rowspan="2">EERE</td><td rowspan="2">EERE</td></tr>
<tr><td>COP (Heating)</td><td>EERE / Navigant</td><td>eCFR</td></tr>
<tr><td>Average Life (yrs)</td><td rowspan="4">Distributors / RS Means 2010 / DEER / Navigant</td><td colspan="4" rowspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>Mid</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td>US DOE/EIA</td><td colspan="4">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>COP (Heating)</td><td rowspan="2">Navigant</td><td rowspan="2">ASHRAE 90.1-2016</td><td colspan="3" rowspan="2">AHRI Database</td></tr>
<tr><td>EER (Cooling)</td></tr>
<tr><td>Average Life (yrs)</td><td>Navigant / EERE</td><td colspan="4" rowspan="4">Navigant / EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors/Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td>US DOD/IGSHPA/MA DOER/CEFIA/ASHRAE</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>Geothermal Heat Pump Consortium, Inc. (US DOE Contract DE-FG07-95ID13347)</td></tr>
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<table>
<tr><th rowspan="2">SOURCES</th><th>2012</th><th colspan="4">2017</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th><th colspan="2">2050</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td>Arthur D. Little / Distributors / AHRI</td><td colspan="4" rowspan="2">CCMS</td><td colspan="8" rowspan="7">Navigant</td></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>EERE / ASHRAE Standard 90.1-2004 / Navigant</td><td>CFR</td><td>CCMS</td><td>ENERGY STAR</td><td>CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td>EERE 2001</td><td colspan="4" rowspan="3">EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td rowspan="2">Distributors / CEC / Navigant</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="5">EERE/Distributors</td></tr>
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<tr><th rowspan="2">SOURCES</th><th>2012</th><th colspan="2">2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th colspan="4">Typical</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td>Navigant / Product Literature</td><td colspan="2" rowspan="2">EERE 2016</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Typical Input Capacity (kW)</td><td>Product Literature</td></tr>
<tr><td>Thermal Efficiency (%)</td><td colspan="3">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="3">EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td rowspan="3">EERE 2016 /Navigant</td><td colspan="2" rowspan="3">EERE 2016</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td></tr>
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SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	Distributors/Navigant		Navigant			
Typical Input Capacity (kBtu/h)						
Coefficient of Performance (COP)	Distributors					
Average Life (yrs)	EERE/Navigant					
Retail Equipment Cost (2017$)	RS Means Online2017					
Total Installed Cost (2017$)						
Annual Maintenance Cost (2017$)	Navigant					

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Storage Capacity (gal)	AHRI / Navigant	CCMS/Navigant			Navigant			
Typical Input Capacity (kBtu/h)								
Thermal Efficiency (%)	Navigant	CFR	CCMS					
Average Life (yrs)	EERE 2001							
Retail Equipment Cost (2017$)	Distributors / Navigant							
Total Installed Cost (2017$)								
Annual Maintenance Cost (2017$)								

SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical			
Typical Capacity (gal)	Product Literature / Navigant	Product Literature	Navigant			
Thermal Efficiency (%)	Product Literature					
Average Life (yrs)						
Retail Equipment Cost (2017$)	Distributors/Navigant					
Total Installed Cost (2017$)						
Annual Maintenance Cost (2017$)						

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SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Capacity (gal)	Distributors/Navigant				Navigant			
Thermal Efficiency (%)	Product Literature/ Navigant	CFR	Product Literature/ Navigant					
Average Life (yrs)	Product Literature/Navigant							
Retail Equipment Cost (2017$)	Distributors/Navigant							
Total Installed Cost (2017$)								
Annual Maintenance Cost (2017$)								

Data Sources » Commercial Gas-Fired Instantaneous Water Heaters

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SOURCES	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	ENEGRY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	CCMS					Navigant							
Thermal Efficiency (%)	Navigant	CCMS		ENERGY STAR	CCMS								
Average Life (yrs)	EERE 2016												
Retail Equipment Cost (2017$)	EERE 2016 /Navigant	EERE 2016											
Total Installed Cost (2017$)													
Annual Maintenance Cost (2017$)													

SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical / ENERGY STAR	Typical			
Typical Capacity (sq. ft.)	SRCC / Navigant		Navigant			
Overall Efficiency (Solar Fraction)	DOE / SRCC / Navigant					
Solar Energy Factor	SRCC / Navigant					
Average Life (yrs)	DOE / Navigant					
Retail Equipment Cost (2017$)	RS Means Online 2017					
Total Installed Cost (2017$)	RS Means Online 2017					

Data Sources » Commercial Natural Gas Ranges, Griddles, and Ovens

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SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Typical	ENERGY STAR	High	Typical / High			
Total Input Capacity (kBtu)	Distributors				Navigant			
Griddle - Cooking Energy Efficiency (%)	Navigant	FSTC	ENERGY STAR	FSTC				
Oven - Cooking Energy Efficiency (%)			N/A					
Range Burner - Cooking Energy Efficiency (%)								
Griddle - Normalized Idle Energy Rate (Btu/h/ft^2)			ENERGY STAR					
Oven - Idle Energy Rate (Btu/h)	FEMP							
Range - Idle Energy Rate (Btu/h)	FSTC		-	FSTC				
Average Life (yrs)	FSTC							
Retail Equipment Cost (2017$)**	Distributors							
Total Installed Cost (2017$)	FSTC / Navigant							
Annual Maintenance Cost (2017$)*	FSTC							

Data Sources » Commercial Electric Ranges, Griddles, and Ovens

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Typical	ENERGY STAR	High	Typical / High			
Total Input Capacity (kW)	Distributors				Navigant			
Griddle - Cooking Energy Efficiency (%)	Navigant	FSTC	ENERGY STAR	FSTC				
Oven - Cooking Energy Efficiency (%)	Navigant	FSTC	-	FSTC				
Range Top - Cooking Energy Efficiency (%)	Navigant	FSTC	-	FSTC				
Griddle - Normalized Idle Energy Rate (W/ft^2)	Navigant	FSTC	ENERGY STAR	FSTC				
Oven - Idle Energy Rate (kW)	Navigant	FSTC	ENERGY STAR	FSTC				
Range Top - Idle Energy Rate (kW)	N/A							
Average Life (yrs)	FSTC							
Retail Equipment Cost (2017$)	Distributors							
Total Installed Cost (2017$)	FSTC / Navigant							
Annual Maintenance Cost (2017$)*	FSTC							

SOURCES	2012	2017				2020	2030	2040	2050
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Interior Volume (ft^3)	FEMP					Navigant			
Maximum Idle Energy Rate (W)	CEE / Navigant	FEMP							
Average Life (yrs)	FEMP								
Retail Equipment Cost (2017$)	Distributors / ENERGY STAR Savings Calculator / Navigant								
Total Installed Cost (2017$)	Navigant								
Annual Maintenance Cost (2017$)	FSTC								

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Appendix B
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APPENDIX B

FINAL

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case

Presented to:

U.S. Energy Information Administration

Prepared by:

Navigant Consulting, Inc.

1200 19 St. NW, Suite 700

Washington, D.C. 20036

April 2018

DISCLAIMER

April 2018

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The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

- Installed base in 2012 (for commercial products) or 2009 and 2015 (for residential products) and current market (2017)
  - Review of literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
- Forecast of technology improvements that are projected to be available through 2050
  - Review of trends in standards, product enhancements, and Research and Development (R&D).
  - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.
- Only currently published efficiency standards and regulations are considered when predicting technology developments, unpublished future regulatory action is not predicted.
- All costs are shown in 2017 dollars (2017$).
- Ranges, when given, represent the span of typical values for a given parameter (e.g.. installed cost for equipment meeting the federal standard) not the highest and lowest available on the market.

The Advanced Case and Reference Case both assume current level of effort for standards. However, the Advanced Case assumes an increase in market incentive and federal R&D. The general approach for the Advanced Case is outlined below.

The Advanced Case takes into account future changes to product groups such as:

- Product or component changes that are fully developed, but have not yet been commercialized.
- Expected incremental improvements in existing technologies due to increased R&D
- Increased adoption of existing higher efficiency technology options due to increased market incentives

The Advanced Case did *not* include future changes to product groups that are due to:

- Prototype technology changes or products that are in preliminary research that may have performance improvements, but have only been demonstrated in theoretical calculations.

Definitions

The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2012 for commercial products (or 2009 and 2015 for residential products) to the highest efficiency equipment that is expected to be commercially available by 2050, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.

- 2009/2012/2015 Installed Base: Efficiency values are for those units installed and "in use" in that year. Cost values are for the typical new unit sold in that year.
- 2017 Current Standard: the minimum efficiency required by current standards.
- Typical: the average, or "typical" product being sold in the particular timeframe. This may represent either the shipments-weighted average product performance or the most common product on the market.
- ENERGY STAR: the minimum efficiency required to meet the ENERGY STAR criteria, where applicable.
- Mid-Level: middle tier high-efficiency product available in the particular timeframe.
- High: the product with the highest efficiency available in the particular timeframe.

The market for the reviewed products has changed since the analysis performed in 2013 and is reflected in the efficiency and cost characteristics.

- In some categories the typical new product purchased today is significantly more efficient than the average product in the installed base in 2012 (comm.) or 2015 (res.):
  - Residential sector: central air conditioners and heat pumps, water heaters
  - Commercial sector: gas-fired and oil-fired boilers, oil-fired storage water heaters
- More stringent Federal standards have taken effect for the following products:
  - Residential furnaces in 2013 and 2015
  - Residential room air conditioners in 2014
  - Residential water heaters in 2015
  - Residential central air conditioners, air-source heat pumps in 2015
  - Residential and commercial water-source heat pumps in 2015
  - Commercial oil-fired storage water heaters in 2015
- ENERGY STAR continues to raise the bar with revised criteria for:
  - Residential furnaces in 2013
  - Residential room air conditioners, central air conditioners, and central heat pumps in 2015
  - Residential dishwashers in 2016
  - Residential and commercial boilers in 2014 and 2016, respectively
  - Residential and commercial water heaters in 2017 and 2013, respectively

Typical efficiency level and product costs increase to ENERGY STAR levels.

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (North)	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	80	80	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	92	95	99	92	99	95	99	95	99	95	99
Electric Consumption (kWh/yr)*	548	522	470	470	384	418	322	334	307	334	307	334	307	334
Average Life (yrs)**	16	16	16	16	16	16	16	16	16	16	16	16	16	16
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	840	860	890	1,190	1,320	1,620	1,340	1,620	1,480	1,620	1,480	1,620	1,480	1,620
Total Installed Cost (2017$)	2,000	2,020	2,050	2,610	2,740	3,040	2,760	3,040	2,890	3,040	2,890	3,040	2,890	3,040
Annual Maintenance Cost (2017$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40

* Electric Consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.
** Average life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, a sensitivity analysis offers 16 to 27 years as the low and high range of the product lifetime for gas-fired furnaces.

Residential Gas-Fired Furnaces (Rest of Country)

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Same as Reference Case

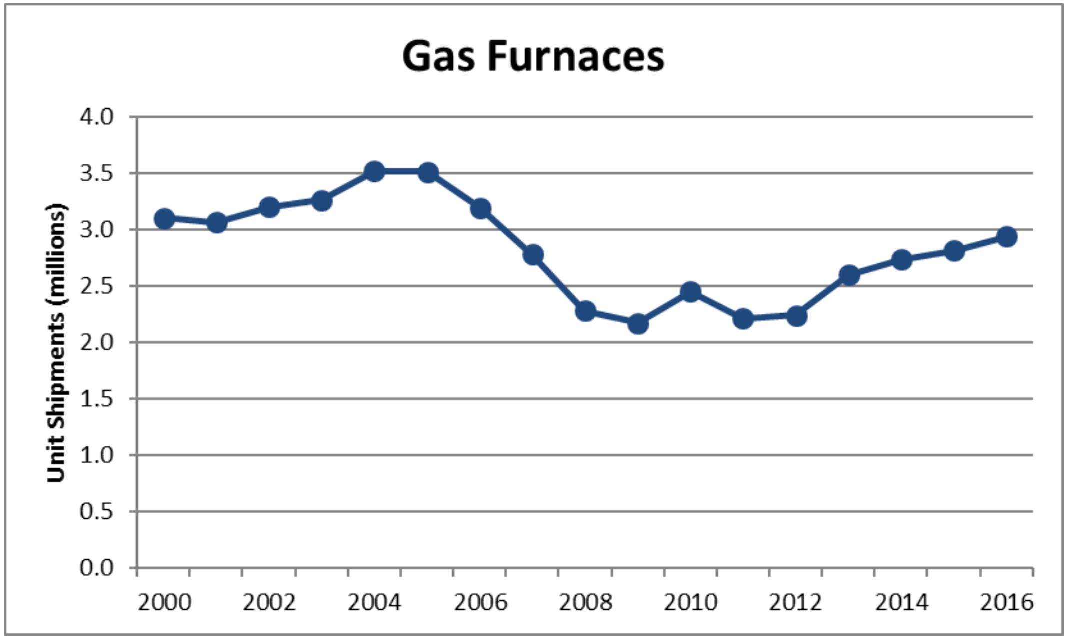
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR (South)	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	80	80	80	80	80	80	80	80	80	80	80	80	80	80
AFUE (%)	80	80	80	80	90	99	80	99	80	99	80	99	80	99
Electric Consumption (kWh/yr)*	548	522	470	470	408	418	329	334	329	334	329	334	329	334
Average Life (yrs)**	16	16	16	16	16	16	16	16	16	16	16	16	16	16
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	840	860	890	890	1,150	1,620	1,080	1,620	1,080	1,620	1,080	1,620	1,080	1,620
Total Installed Cost (2017$)	2,000	2,020	2,050	2,050	2,560	3,040	2,240	3,040	2,240	3,040	2,240	3,040	2,240	3,040
Annual Maintenance Cost (2017$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40

* Electric Consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.

** Average life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, a sensitivity analysis offers 16 to 27 years as the low and high range of the product lifetime for gas-fired furnaces.

- Current Federal standards for non-weatherized gas furnaces:
  - AFUE ≥ 80%
- ENERGY STAR criteria for gas furnaces:
  - South: AFUE ≥ 90%
  - North: AFUE ≥ 95%
  - Furnaces must be equipped with electronically commutated fan motor and have less than or equal to 2.0% air leakage
- Most efficient unit currently available: 98.7% AFUE. The current market is nearly evenly split between non-condensing units (AFUE≤82%) and condensing units (AFUE≥90%).
- The highest efficiency furnaces (~99% AFUE) employ electronically commutated motors (ECMs) and can fully modulate rather than cycling on and off. Because they modulate, there is an increase in total fan-on time. Because the fan operates for more total hours and consumes more energy, the annual electricity consumption is higher for these products
- Non-condensing AFUE levels for natural gas top out at around 82%; above this level, the potential for exhaust gas condensation increases. This condensate is corrosive and requires cost restrictive corrosion resistant venting.
- High-efficiency condensing furnaces typically have high-grade stainless steel (AL 29-4C) heat exchangers.
- Many are available as direct vent and sealed combustion systems, which do not use room air for combustion, but instead draws combustion air directly from outdoors.
- Depending on the location of the home, piping materials in use, and other considerations, condensing furnaces may need an acid neutralizer and/or lift pump for the condensate.
- Furnaces may contain permanent split capacitor (PSC) or brushless permanent magnet (BPM) fan motors. The 2015 Energy Conservation Standards for Residential Furnace Fans Final Rule requires that all furnaces use BPM fans. The type of motor effects the electrical consumption of the furnace as well as the SEER/EER of the associated air conditioner.
- Advanced Case: Increased incentives move typical efficiency products to ENERGY STAR levels by 2030. The current price difference between 92% AFUE and 95% AFUE products is not large. It is expected that with more market incentives, manufacturers will produce more products that can be ENERGY STAR certified at the 95% level.

Annual shipments peaked at 3.5 million units in 2005 then declined each year until 2009 and leveled off at about 2.25 million units. Since 2012, shipments have increased steadily.



Source: *AHRI* (http://www.ahrinet.org/Resources/Statistics/Historical-Data/Furnaces-Historical-Data.aspx)

Residential Oil-Fired Furnaces

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Typical efficiency level and product costs increase to ENERGY STAR levels.

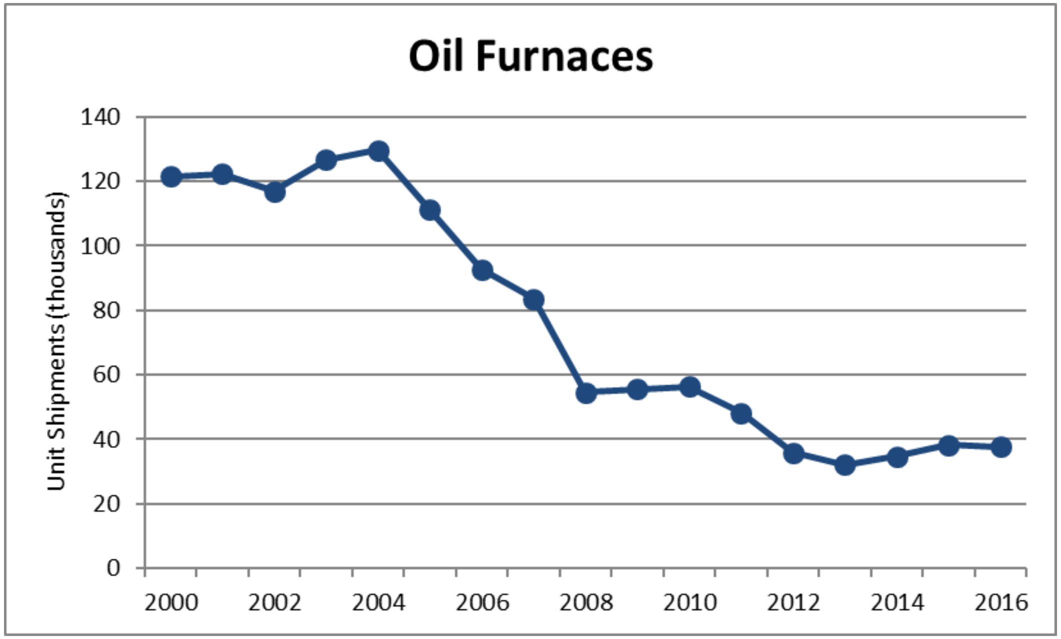
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	105	105	105	105	105	105	105	105	105	105	105	105	105
AFUE (%)	80	83	83	83	85	97	83	97	85	97	85	97	85	97
Electric Consumption (kWh/yr)*	490	477	477	477	466	410	477	410	466	410	466	410	466	410
Average Life (yrs)**	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Retail Equipment Cost ($)	2,150	2,200	2,200	2,200	2,250	2,700	2,200	2,700	2,250	2,700	2,250	2,700	2,250	2,700
	2,350	2,900	2,900	2,900	2,950	3,450	2,900	3,450	2,950	3,450	2,950	3,450	2,950	3,450
Total Installed Cost ($)	2,700	2,750	2,750	2,750	2,950	4,350	2,750	4,350	2,950	4,350	2,950	4,350	2,950	4,350
	3,400	5,500	5,500	5,500	5,750	8,550	5,500	8,550	5,750	8,550	5,750	8,550	5,750	8,550
Annual Maintenance Cost ($)	70	70	70	70	70	200	70	200	70	200	70	200	70	200

* Electric Consumption accounts for the electricity consumption of components such as the furnace fan, draft inducer, and the ignitor. In some high efficiency products, this component also includes auxiliary equipment, such as condensate pumps and heat tape.

**Average Life was previously reported as a range sourced from Appliance Magazine (2012). The EERE 2015 TSD offers a Weibull distribution with an average value of 26.5 years and a 25%-75% confidence interval range of 19.7 to 33.1 years.

- Current Federal standards:
  - AFUE ≥ 83%
  - ≤ 11 watts of electrical power when in standby and off modes (non-weatherized models only)
- ENERGY STAR criteria: AFUE ≥ 85%
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Most efficient available: 96.7% AFUE – condensing units with tiny market share (<1%), due to market acceptance issues.
- Condensate from condensing oil furnaces is typically even more corrosive than that of gas-fired systems due to the higher sulfur content in fuel oil. Hence, condensing oil furnaces also likely require the use of an acid neutralizer. By 2019, ultra-low sulfur heating oil will be required in most northeastern states; this will reduce corrosion effects.
- Oil-fired furnaces, like gas-fired furnaces, achieve condensing conditions through the use of a secondary heat exchanger. Typically, these secondary heat exchangers use a high-grade stainless steel (AL 29-4C).
- Sooting is an issue for all oil-fired appliances, but secondary heat exchangers, with their narrow passages, are even more prone to be plugged by soot. Because of this, condensing oil furnaces typically require frequent cleaning and maintenance.
- Advanced Case: Increased incentives move typical efficiency products to ENERGY STAR levels by 2030. The current typical efficiency product is at 83% AFUE, while ENERGY STAR is at 85%, with only a small difference in costs. It is expected that with more market incentives, manufacturers will produce more products that can be ENERGY STAR certified at the 85% level.

Annual shipments declined rapidly after 2004, likely due at least in part to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2012 shipments have largely levelled off.



Source: *AHRI* (http://www.ahrinet.org/Resources/Statistics/Historical-Data/Furnaces-Historical-Data.aspx)

Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017				2020		2030**		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	105	100	100	100	100	100	100	100	100	100	100	100	100	100
AFUE (%)	80	82	82	82	90	97	90	97	94	97	94	97	94	97
Average Life (yrs)*	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost ($)	2,050	1,950	1,950	1,950	2,750	3,750	2,750	3,750	2,750	3,750	2,750	3,750	2,750	3,750
	2,650	2,550	2,550	2,550	3,250	4,300	3,250	4,300	3,250	4,300	3,250	4,300	3,250	4,300
Total Installed Cost ($)	4,100	4,600	4,600	4,600	5,750	6,800	5,750	6,800	5,750	6,800	5,750	6,800	5,750	6,800
	4,700	9,750	9,750	9,750	10,000	11,050	10,000	11,050	10,000	11,050	10,000	11,050	10,000	11,050
Annual Maintenance Cost ($)	50	90	90	90	90	90	90	90	90	90	90	90	90	90

*Average Life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, an average of 26.5 years is calculated for gas-fired hot water boilers, with a low and high range from 20 to 30 years respectively.

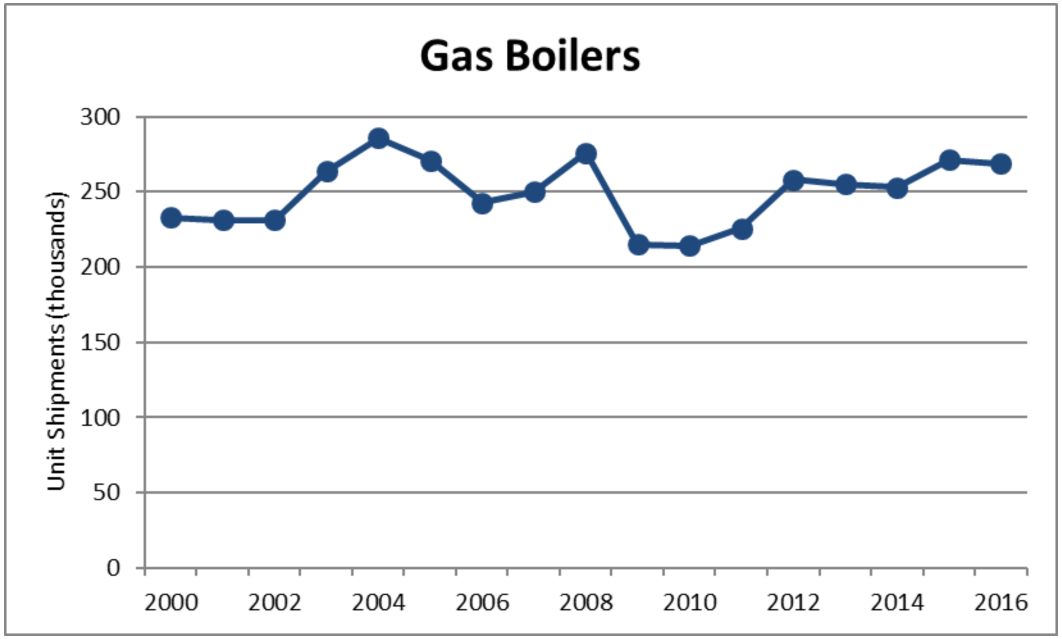
** In 2021, new energy conservation standards for Residential Boilers will take effect. These projections reflect the 2021 minimum AFUE requirement for residential oil-fired boilers, 84%. However, by 2020, the majority of the gas-fired boiler market is expected to be condensing, with a minimum efficiency of 90% AFUE.

Note: Water boilers considered. Steam boilers also exist, but make up only about 15% of the market.

Residential Gas-Fired Boilers

- Federal standard for gas-fired hot-water boilers (more common than steam):
  - AFUE ≥ 82%
  - Design requirements that took effect on September 1, 2012 prohibit a constant burning pilot and require an automatic means for adjusting water temperature
  - AFUE ≥ 84% required on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 90%
- Most efficient available: 96.8% AFUE
- Have lost market share to furnaces and heat pumps over the past 30 years
- U.S. gas hot water boiler sales are split roughly 50/50 between condensing and non-condensing. Condensing boilers typically have heat exchangers made of stainless steel and non-condensing boiler typically have heat exchangers made of case iron.
- Typically, condensing boilers are low-mass in construction with modulating burners, variable-speed inducer fan systems, sealed powered direct-vent combustion, multiple sensor technologies, and electronic ignition and control.
- Due to incentives and market pressure, the U.S. boiler industry has been shifting towards also providing condensing boilers. Most of these boilers are private-labeled products sourced from Europe, where the hydronic market is much bigger and condensing appliances are much more common and/or required by law.
- Most value-added components for condensing boilers are sourced abroad, even when the condensing boiler is assembled in North America (e.g., heat exchanger, gas valve, burner, sensors, and/or controls).
- Advanced Case: Costs on the market for current 94% AFUE units are slightly higher than 90% AFUE (ENERGY STAR) units. With increased market incentives and R&D, the costs of 94% units are expected to decline to current costs for 90% units. The decreased costs for these units will help drive overall adoption of condensing units, thereby raising the typical efficiency, without increasing cost.

Annual shipments had a significant decrease following the 2009 financial crisis and a steady recovery in the years since.



Source: *National Impact Analysis Spreadsheet from the 2015 Energy Conservation Standards for Residential Boilers Final Rule. (https://www.regulations.gov/document?D=EERE-2012-BT-STD-0047-0072)*

Residential Oil-Fired Boilers

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Typical efficiency level and product costs increase to ENERGY STAR levels.

DATA	2009	2015	2017				2020		2030****		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR*	High**	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	140	140	140	140	140	140	140	140	140	140	140	140	140	140
AFUE (%)	80	84	84	84	87	90	84	90	87	90	87	90	87	90
Average Life (yrs)***	18	18	18	18	18	18	18	18	18	18	18	18	18	18
	28	28	28	28	28	28	28	28	28	28	28	28	28	28
Retail Equipment Cost ($)	2,400	4,000	4,000	4,000	4,450	6,150	4,000	6,150	4,450	6,150	4,450	6,150	4,450	6,150
	3,050	4,300	4,300	4,300	4,800	6,700	4,300	6,700	4,800	6,700	4,800	6,700	4,800	6,700
Total Installed Cost ($)	4,350	6,600	6,600	6,600	6,900	9,400	6,600	9,400	6,900	9,400	6,900	9,400	6,900	9,400
	5,000	11,650	11,650	11,650	11,950	13,500	11,650	13,500	11,950	13,500	11,950	13,500	11,950	13,500
Annual Maintenance Cost ($)	140	140	140	140	140	150	140	150	140	150	140	150	140	150

*ENERGY STAR levels were not examined in the EERE 2015 rulemaking, therefore ENERGY STAR retail costs were extrapolated from the non-condensing levels. All other costs are the same for non-condensing models.

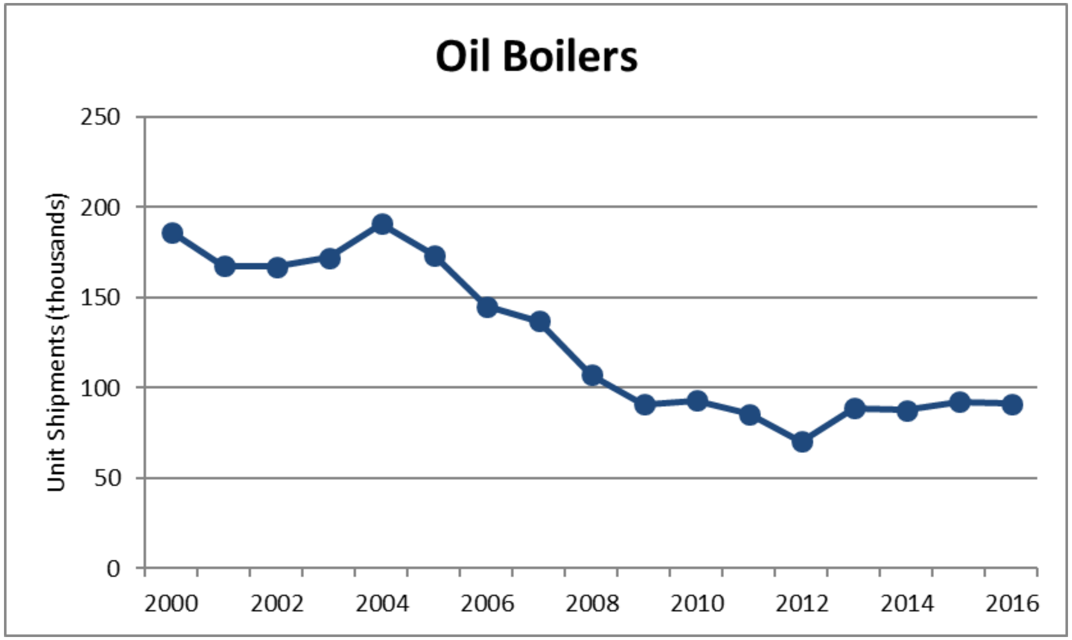
**2017 High - EERE 2015 has analysis for 91% AFUE, maximum AFUE identified in the AHRI and CCMS databases at time of publication is 90%. There is only one condensing level within the EERE analysis so extrapolation to 90% cannot be done, therefore, cost values are those presented in EERE 2015 for 91% AFUE.

*** Average Life was previously reported as a range sourced from Appliance Magazine (2012). In the EERE 2015 TSD, an average of 24.8 years is calculated for oil-fired hot water boilers, with a low and high range from 18 to 28 years respectively.

**** In 2021, new energy conservation standards for Residential Boilers will take effect. These projections reflect the 2021 minimum AFUE requirement for residential oil-fired boilers, 86%.

- Federal standard for oil-fired hot-water boilers (more common than steam):
  - AFUE ≥ 84%
  - Design requirements that took effect on September 1, 2012 require an automatic means for adjusting water temperature
  - AFUE ≥ 86% required on January 21, 2021
- ENERGY STAR criteria: AFUE ≥ 87%
- Most efficient available: 90% AFUE
- Since the latent heat content of oil is lower than that for either propane or natural gas, oil-fired appliances can typically operate at a higher AFUE rating than comparable gas-fired appliances before condensation issues arise.
- Oil boilers have heat exchangers made of cast iron or stainless steel.
- Advanced Case: Increased incentives move typical efficiency products to ENERGY STAR levels by 2030. The current typical efficiency product is at 84% AFUE, while ENERGY STAR is at 87%, with only a small difference in costs. It is expected that with more market incentives, manufacturers will produce more products that can be ENERGY STAR certified at the 87% level.

Annual shipments declined rapidly after 2004, likely due at least in part to an increase in fuel oil prices, which more than tripled from 2002 to 2008. Since 2009 shipments have largely levelled off.



Source: *National Impact Analysis Spreadsheet from the 2015 Energy Conservation Standards for Residential Boilers Final Rule. (https://www.regulations.gov/document?D=EERE-2012-BT-STD-0047-0072)*

Residential Electric Resistance Furnaces

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Same as reference case

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	68	68	68	68	68	68	68
AFUE (%)	98	98	98	98	98	98	98
Average Life (yrs)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost ($)	600	600	600	600	600	600	600
	700	700	700	700	700	700	700
Total Installed Cost ($)	1,000	1,000	1,000	1,000	1,000	1,000	1000
	1,200	1,200	1,200	1,200	1,200	1,200	1200
Annual Maintenance Cost ($)	40	40	40	40	40	40	40

- Federal standards for electric furnaces:
  - AFUE ≥ 78%
  - Standby and off mode power consumption ≤ 10 watts
- According to RECS 2015 data, electric central warm-air furnaces are the main source of space heating in approximately 17.9 million US homes or about 15%. The majority of these installations are part of a heat pumps system, where the electric resistance is used as back-up heating.
- Electric furnaces range in capacity from 10 to 25 kW (34 to 85 kBtu/hr), with 20 kW (68 kBtu/hr) being the typical for units on the market.
- Electric resistance furnaces are considered near 100% efficient because there is no flue heat loss and any jacket losses are contained within the home.
  - ASHRAE Standard 103, the test method for furnaces incorporated by reference into the federal test procedure, specifies that for electric furnaces AFUE = 100 – 1.7 x jacket losses. Jacket losses can be determined either through testing or assumed to be 1%. Thus, the minimum AFUE of electric furnaces is 98.3%.

Residential Electric Resistance Unit Heaters

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Same as reference case

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Efficiency (%)	100	100	100	100	100	100	100
Average Life (yrs)*	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost ($)	75	75	75	75	75	75	75
	200	200	200	200	200	200	200
Total Installed Cost ($)	125	125	125	125	125	125	125
	275	275	275	275	275	275	275
Annual Maintenance Cost ($) **	-	-	-	-	-	-	-

* Assumes similar lifetime to Electric Furnaces on the basis that both products have heating elements that burn out and lead to product failure.
** Annual Maintenance Cost is negligible

- Electric resistance unit heaters include electric wall and baseboard heaters. Plug-in space heaters are not included.
- There are currently no federal efficiency requirements for electric resistance unit heaters.
- According to RECS 2015 data, electric resistance unit heaters are the main source of space heating in approximately 8.9 million US homes or about 8%.
- Electric heaters range in capacity from 500 to 2,500 watts (1.7 to 8.5 kBtu/hr), with 1,000 watts (3.5 kBtu/hr) being the most typical for units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion. An efficiency of 98% is selected here to account for IR losses and fan inefficiency.

North (Not Hot-Dry or Hot-Humid)

Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017				2020		2030**		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	12.5	13.0	13.9	15.0	16.5	13.9	16.5	15.0	16.5	15.5	16.5	15.5	16.5
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	1,750	2,050	2,200	2,250	2,650	3,200	2,250	3,200	2,350	3,200	2,350	3,200	2,350	3,200
Total Installed Cost ($)	2,150	3,400	3,550	3,650	4,000	4,650	3,650	4,650	3,700	4,650	3,700	4,650	3,700	4,650
Annual Maintenance Cost ($)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	125	125	125	125	125	125	125	125	125	125	125	125	125	125

* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for ducted "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for Residential Air Source HP, which is why the "High" SEER levels are higher for HPs than for ACs.

** In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps will take effect. The new standards specify a different metric for Central ACs (SEER2). These projections reflect the equivalent levels for the 2023 standard under the current metric, 14 SEER.

South (Hot-Dry and Hot-Humid)

Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017				2020		2030**		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER*	11.4	13.0	14.0	14.4	15.0	16.5	14.4	16.5	15.5	16.5	16.0	16.5	16.0	16.5
Average Life (yrs)	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	1,750	2,200	2,250	2,350	2,650	3,200	2,350	3,200	2,700	3,200	2,700	3,200	2,700	3,200
Total Installed Cost ($)	2,150	3,600	3,650	3,700	4,000	4,650	3,700	4,650	4,100	4,650	4,100	4,650	4,100	4,650
Annual Maintenance Cost ($)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	125	125	125	125	125	125	125	125	125	125	125	125	125	125

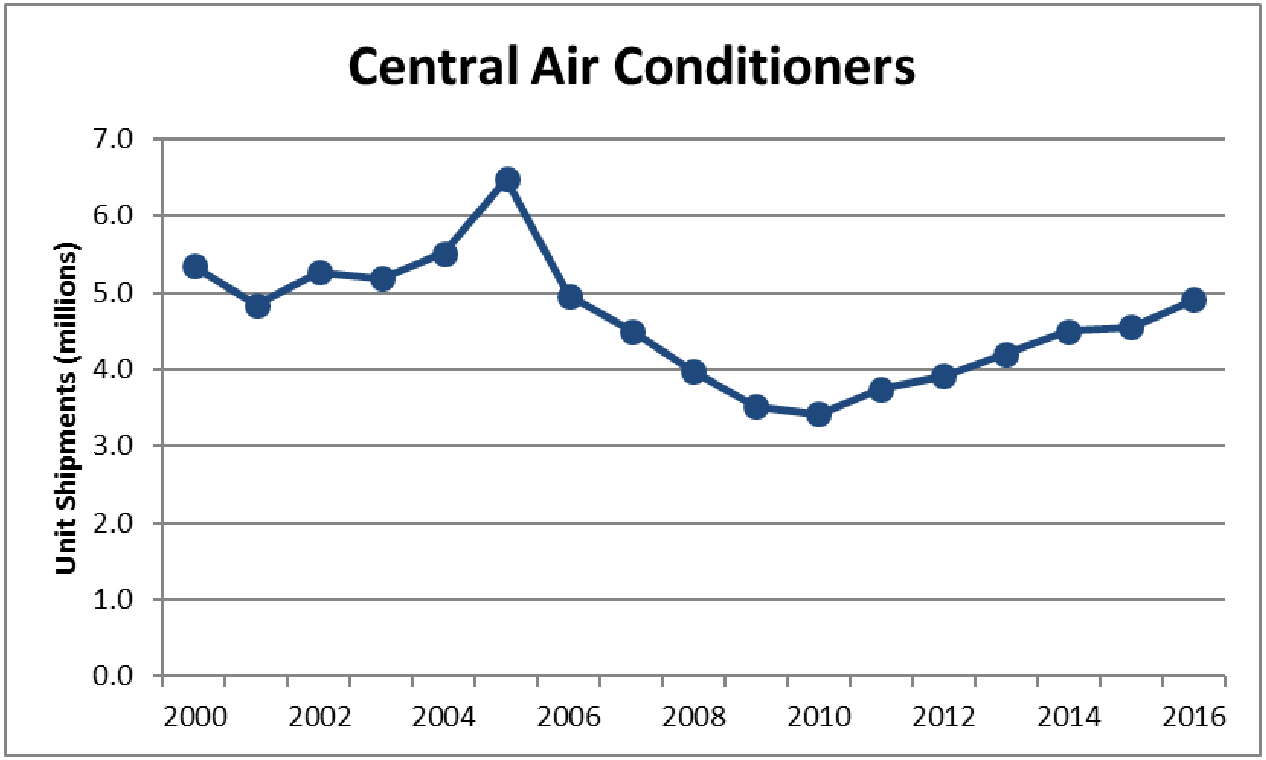
* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class. Costs and efficiency levels are for ducted "coil-only" systems, meaning they do not include a blower. Note blower-coil systems were analyzed for Residential Air Source HP, which is why the "High" SEER levels are higher for HPs than for ACs.

** In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps will take effect. The new standards specify a different metric for Central ACs (SEER2). These projections reflect the equivalent levels for the 2023 standard under the current metric, 14 SEER.

Residential Central Air Conditioner Product Class	Current Standards			Current ENERGY STAR Criteria	
	Min. SEER in North	Min. SEER in South	Max. Off Mode Power (W)	Min. SEER	Min. EER
Split-System AC	13	14	30	15	12.5
Single-Package AC	14	14	30	15	12
Small-Duct, High-Velocity	12	12	30	–	–
Space-Constrained	12	12	30	–	–

- Current standards, which took effect in 2015, represent an improvement in efficiency in all regions from 13 SEER for single-package units.
- Current standards in the South and Southwest represent an improvement in efficiency from 13 SEER for split systems.
- Systems installed in the Southwest (CA, AZ, NM, and NV) also have to meet an energy efficiency ratio (EER) standard that varies by cooling capacity and system configuration.
- Current standards took effect in 2015, amended standards for all product classes will take effect in 2023.
- Small-Duct, High-Velocity and Space-Constrained units both have very small market shares
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Annual shipments spiked at 6.5 million units in 2005 at the peak of the housing boom and just before more stringent Federal standards took effect in 2006. Annual shipments have been steadily increasing since 2010 but have not yet reached the previous high.



Source: *AHRI* (available at http://www.ahrinet.org/Resources/Statistics/Historical-Data/Central-Air-Conditioners-and-Air-Source-Heat-Pumps.aspx)

Residential Air Source Heat Pumps

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017				2020		2030**		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
SEER (Cooling)*	12.0	13.1	14.0	15.3	15.0	19.0	15.3	19.0	16.0	19.0	16.5	19.0	16.5	19.0
HSPF (Heating)*	7.4	7.9	8.2	8.6	8.5	9.0	8.6	9.0	8.8	9.0	9.0	9.0	9.0	9.0
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost ($)*	2,550	2,800	3,350	3,600	3,500	4,550	3,600	4,550	3,700	4,550	3,700	4,550	3,700	4,550
Total Installed Cost ($)*	3,000	3,250	4,850	5,100	4,950	6,100	5,100	6,100	5,150	6,100	5,150	6,100	5,150	6,100
Annual Maintenance Cost ($)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	125	125	125	125	125	125	125	125	125	125	125	125	125	125

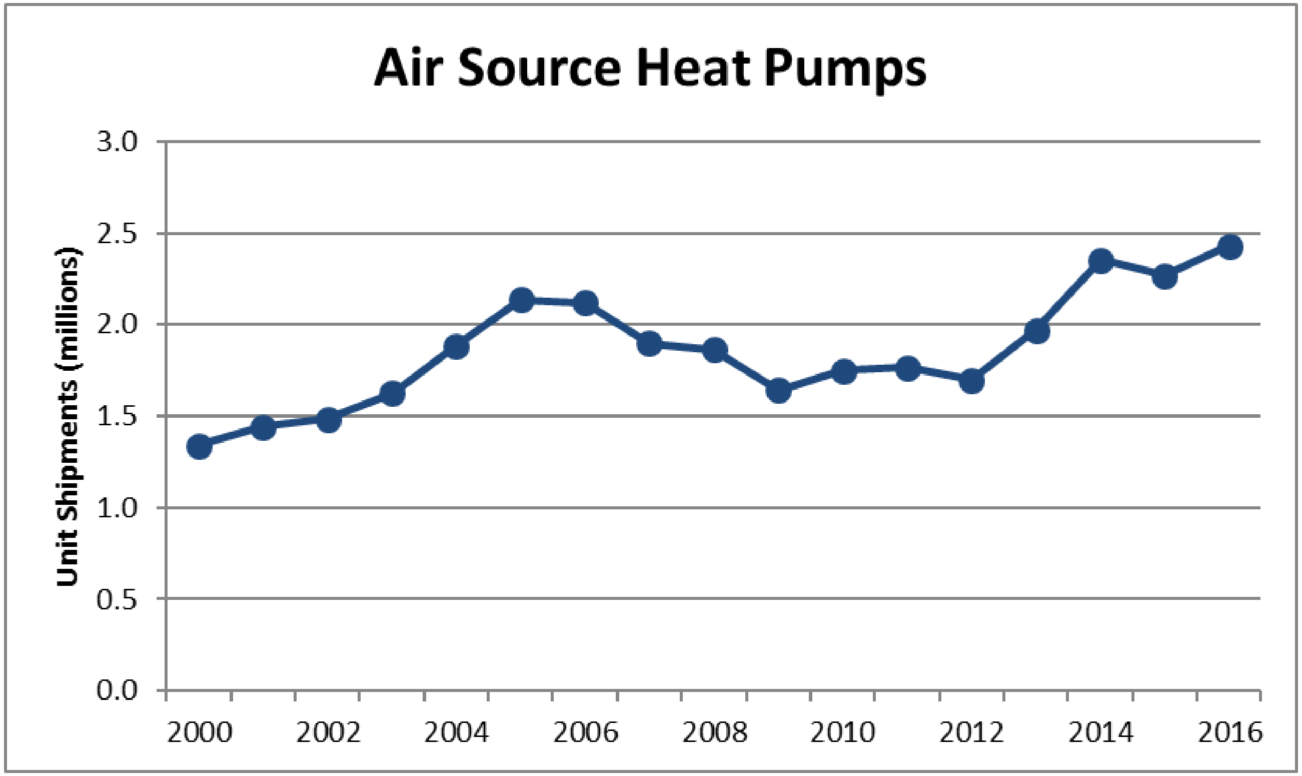
* Values shown are for split-system units in the 36 kBtu/h (3-ton) size class which represent the largest market share based on 2016 Energy Conservation Standards for Central Air Conditioners and Heat Pumps, Government Regulatory Impact Model. Costs and efficiency levels are for ducted systems with integral indoor blowers. Note coil-only systems were analyzed for Residential Central AC North and South, which is why the "High" SEER levels are higher for HPs than for ACs.

**In 2023, new energy conservation standards for Residential Central Air Conditioners and Heat Pumps will take effect. The new standards specify different metrics (SEER2 and HSPF2). These projections reflect the equivalent levels for the 2023 standard under the current metrics, 15 SEER and 8.8 HSPF.

Residential Heat Pump Product Class	Current Standards			Current ENERGY STAR Criteria		
	Min. SEER	Min. HSPF	Max. Off Mode Power (W)	Min. SEER	Min. EER	Min. HSPF
Split-System	14	8.2	33	15	12.5	8.5
Single-Package	14	8	33	15	12	8.2
Small-Duct, High-Velocity	12	7.2	30	–	–	–
Space-Constrained	12	7.4	33	–	–	–

- High efficiency cooling does not necessarily correlate with high efficiency heating. The range of SEER–HSPF combinations is very broad.
- Heat pumps are generally sized to meet the cooling load of the house. When the heating load exceeds heat pump heating capacity, electric resistance heat is used to supplement.
- Variable-speed compressors improve efficiency of heat pumps by reducing cyclic losses and by operating above their nominal speed, boosting heating capacity and reducing the need for supplementary electric resistance heat.
- Current standards took effect in 2015, amended standards for all product classes will take effect in 2023.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

From 2000 to 2005 annual shipments increased nearly 60% to 2.1 million units, then dropped and leveled off around 1.7 million units. In 2014 annual shipments surpassed the 2005 peak.



Source: *AHRI* (available at http://www.ahrinet.org/Resources/Statistics/Historical-Data/Central-Air-Conditioners-and-Air-Source-Heat-Pumps.aspx)

- Principal energy efficiency drivers for central air conditioners and heat pumps :
  - Heat exchanger (surface area, number of tube rows)
  - Compressor (type and single-stage vs. two-stage vs. variable-speed operation)
  - Fan motor choices (PSC vs. ECM fan motors on inside and outside)
  - Control choices (i.e., piston, thermal, and electronic expansion valves)
- When the heat pump or air conditioner's capacity exceeds the heating or cooling load, the unit starts and stops more frequently, causing wear and tear on the components and an overall loss of efficiency. Multi-stage and/or variable-speed compressors can help, as does sophisticated refrigerant management.
- Typical high-efficiency unit (≥16 SEER) has very large heat exchanger, ECM evaporator fan motor, and two-stage scroll compressor.
- Variable-speed compressor technology typically leads to a significant SEER boost, making possible high-SEER condensing units with smaller heat exchangers, and thus, smaller enclosures.
- Efficiency levels >21 SEER made possible through combining existing large heat exchangers with variable-speed compressors, ECM fan motors, and electronic expansion valves.

Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	36	36	36	36	36	36	36	36	36	36	36	36	36	36
COP (Heating)*	3.0	3.1	3.2	3.7	3.6	4.5	3.7	4.5	4	4.5	4.2	4.5	4.2	4.5
EER (Cooling)**	12.3	13.3	14.1	17.3	17.1	22.4	17.5	22.4	18	22.4	18.5	22.4	18.5	22.4
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost ($)	6,200	3,950	4,100	4,650	4,600	5,550	4,650	5,550	4,650	5,550	4,650	5,550	4,650	5,550
Total Installed Cost ($)	18,100	11,950	12,100	12,650	12,650	13,550	12,650	13,550	12,650	13,550	12,650	13,550	12,650	13,550
	20,650	18,950	19,100	19,650	19,650	20,550	19,650	20,550	19,650	20,550	19,650	20,550	19,650	20,550
Annual Maintenance Cost ($)	75	75	75	75	75	75	75	75	75	75	75	75	75	75

* COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.

** EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. Previous analysis relied on Energy Star ratings which are an average of the full-load and part-load "ground loop" conditions. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note: Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs 4-ton) and slightly higher installation costs for commercial. DOE does not distinguish between residential and commercial units in its regulations.

- There are currently over 20 ground source heat pump manufacturers/OEMs in the US.
- Heating COP does not correlate with cooling EER (coefficient of determination, $R^2 = 0.59$ for ENERGY STAR certified products). The highest efficiency GSHP is the 7 Series by WaterFurnace International, Inc. (41 EER & 5.3 COP). Note that these are equipment-level thermal ratings tested according to standardized lab conditions and do not necessarily represent system-level or "real-world" performance.
- The ENERGY STAR® criteria for water-to-air ground source heat pumps are:

Type	Heating COP	Cooling EER
Closed Loop	3.6	17.1
Open Loop	4.1	21.1
Direct Expansion	3.6	16

- The most common ground source heat pump is a closed-loop system in which water or an anti-freeze solution is circulated through plastic pipes buried underground. Open loop systems that employ ground water or surface water (e.g., open well, pond, lake) are used in some parts of the country, but water supply and water quality issues impose limitations on such applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger represents a majority of the installation cost. Installed costs for these systems vary widely.
- Variable speed electronically commutated motors (ECMs) improve performance on high end models.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more advanced compressors, fan motors) are expected to increase efficiency without substantially increasing costs.

Residential Room Air Conditioners

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Increased efficiency with corresponding cost increases.

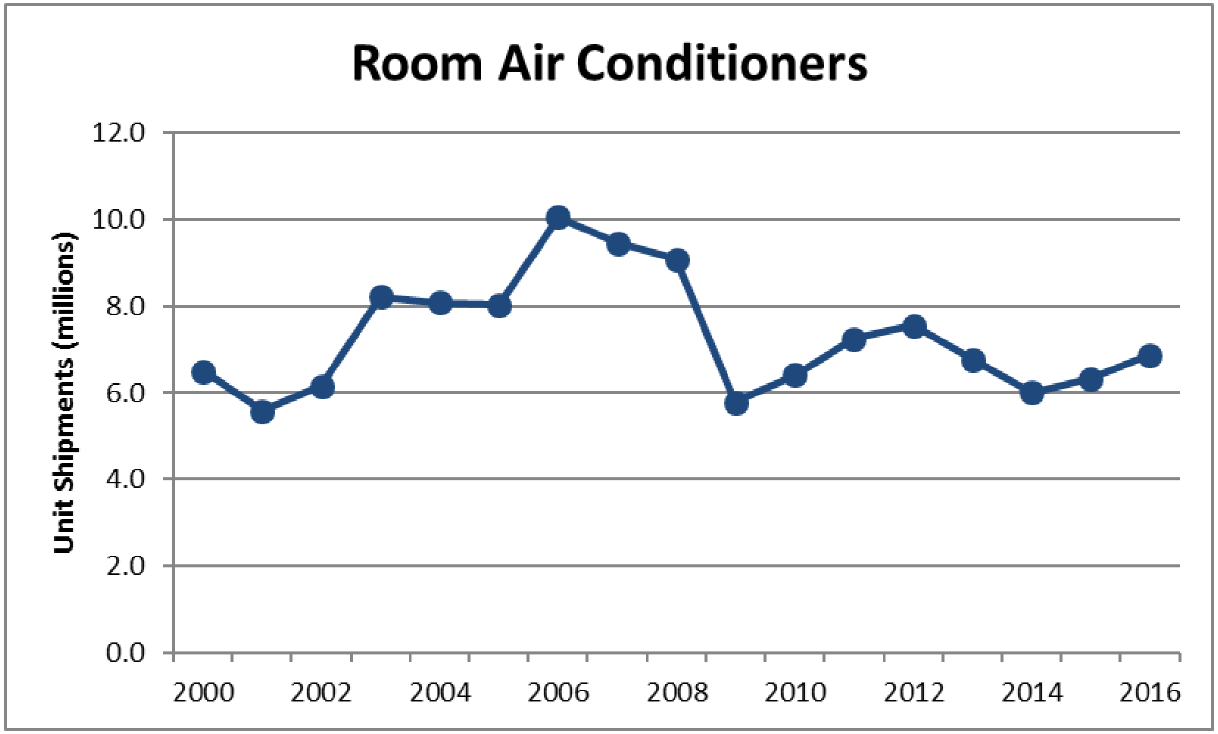
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)*	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
CEER (Btu/Wh)	9.3	10.9	10.9	12.0	12.0	12.3	12.3	12.8	12.8	13.5	13.0	13.8	13.5	14.5
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost ($)	480	470	470	510	510	510	510	550	550	590	570	610	590	630
	580	600	600	600	600	730	730	780	780	830	810	860	830	880
Total Installed Cost ($)	550	540	540	580	580	580	580	620	620	660	640	680	660	750
	680	700	700	700	700	830	830	880	880	930	910	960	930	860
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* All values are for the most common product class, Product Class 3 (without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h).
** Maintenance costs are negligible.

- Focus on most common type: louvered sides (window air conditioners) without reverse cycle and having cooling capacity of 8,000–13,999 Btu/h (DOE Product Class 3).
- Federal standards for Product Class 3:
  - CEER ≥ 10.9 (beginning June 1, 2014)
- Combined Energy Efficiency Ratio (CEER) incorporates energy use in cooling mode and standby and off modes.
- Of the 474 individual models in Product Class 3 listed in DOE's compliance certification database[1]:
  - 42% are at the standard level (≥ 10.9 CEER, < 12.0 CEER)
  - 58% are at the ENERGY STAR level (≥ 12.0 CEER)
  - Most efficient model is at 12.3 CEER
- ENERGY STAR criteria for Product Class 3
  - CEER ≥ 12.0 (effective October 26, 2015)
- Efficiency improvements are attained by:
  - Higher efficiency compressor and fan motors, and
  - An increased heat transfer area in the evaporator and condenser through the use of larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more efficient motors and compressors, larger cross-section heat exchangers, adoption of variable speed technologies) are expected to increase efficiency with corresponding increases in cost.

[1] Accessed December 2017. https://www.regulations.doe.gov/certification-data

Annual shipments dropped sharply in 2009, likely due to the recession and an unusually cool summer in the Northeast. Sales have largely leveled off in the years since, fluctuating between 6 and 7.5 million.



Source: *Appliance Magazine.*

Residential Portable Air Conditioners

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Increased efficiency with corresponding cost increases.

DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)*	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
CEER (Btu/Wh)	5.6	5.6	5.6	6.7	6.7	8.0	8.0	9.0	9.0	9.5	9.5	10.0
Average Life (yrs)	7	7	7	7	7	7	7	7	7	7	7	7
	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost ($)	720	690	670	800	800	825	825	850	850	875	875	900
Total Installed Cost ($)	720	690	670	800	800	825	825	850	850	875	875	900
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-	-

* All values are for the average capacity for single-duct and dual-duct portable ACs available on the market.
** Maintenance costs are negligible.

Note: In December of 2016 EREE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Portable Air Conditioners. As of October 2017, this rule has not yet been published and therefore these standards are not reflected in the values shown above.

- A new test procedure for portable ACs was published June 1, 2016
- The test procedure addresses single-duct and dual-duct portable ACs, configurations typically used in residential applications. No procedures were established for other portable AC configurations (e.g., spot coolers).
- Spot coolers, a portable AC configuration with no condenser-side ducts and with adjustable evaporator exhaust ducts, are commonly used in commercial applications.
- A final rule, Energy Conservation Standards for Portable Air Conditioners, was issued in December 28, 2016 to address standards for single-duct and dual-duct portable ACs. It was never published, so there are no existing energy conservation standards for portable ACs.
- The final rule outlined an equation-based conservation standard (in CEER) for both single-duct and dual-duct portable ACs, based on the seasonally adjusted cooling capacity (SACC).
- For a typical portable AC in 2017 with a capacity of 6,600 Btu/h, the corresponding CEER is typically 4.3 Btu/Wh.
- Efficiency improvements are attained by:
  - Higher efficiency compressor and fan motors, and
  - An increased heat transfer area in the evaporator and condenser through the use of larger heat exchangers, finer fin spacing, micro-channel heat exchangers, and similar design options.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more efficient motors and compressors, larger cross-section heat exchangers, adoption of variable speed technologies) are expected to increase efficiency with corresponding increases in cost.

Residential Natural Gas Heat Pumps

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Same as reference case

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kBtu/h)	60	60	60	60	60	60	60
Heating (COP)	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Cooling (COP)	0.6	0.6	0.6	0.7	0.7	0.7	0.7
Annual Electric Use (kWh/yr)*	2,000	1,500	1,500	1,500	1,500	1,500	1,500
Average Life (yrs)	12	12	12	12	12	12	12
	18	18	18	18	18	18	18
Retail Equipment Cost ($)	11,000	11,000	11,000	11,000	11,000	11,000	11,000
	12,200	12,200	12,200	12,200	12,200	12,200	12,200
Total Installed Cost ($)	12,500	12,500	12,500	12,500	12,500	12,500	12,500
	14,700	14,700	14,700	14,700	14,700	14,700	14,700
Annual Maintenance Cost ($)	170	170	170	170	170	170	170

* Annual Electric Use accounts for the electricity consumption of components such as the heat pump fan.

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- Residential Gas Heat Pumps are not currently covered by NAECA. CEC Title 24, Part 6 Section 112 does indicate cooling efficiency requirements for gas heat pumps.
- Gas heat pumps are much more popular in other parts of the world, such as Europe. Gas-fired cooling equipment currently comprises less than 1% of the residential air conditioning/heat pump market in the U.S.
- Currently, Robur is the predominant manufacturer of residential-sized gas heat pumps with sales operations in the US. Robur units are 5-ton nominal cooling capacity, a size typically associated with larger homes. Since only one product is available, no mid-level or high efficiency categories are included.
- The data represents air-source absorption heat pumps. Gas engine-driven vapor compression heat pumps are available in other parts of the world; York formerly offered the Triathlon gas engine-driven heat pump in the US. It is possible to couple either technology to the ground (ground source) rather than the atmosphere (air source).
- The absorption heat pump is a gas-fired, ammonia-water absorption cycle, combined with a high-efficiency low-pressure boiler integrated into one outdoor unit.
- The cooling efficiency of a gas-fired air source absorption heat pump is considerably lower than for an electric air source heat pump. Heating efficiency of an air source heat pump (electric or gas-fired absorption) decreases as outdoor temperature decreases; however the gas-fired absorption heat pump recovers waste heat from the combustion process to improve heating efficiency.

Residential Cordwood Stoves

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Same as reference case

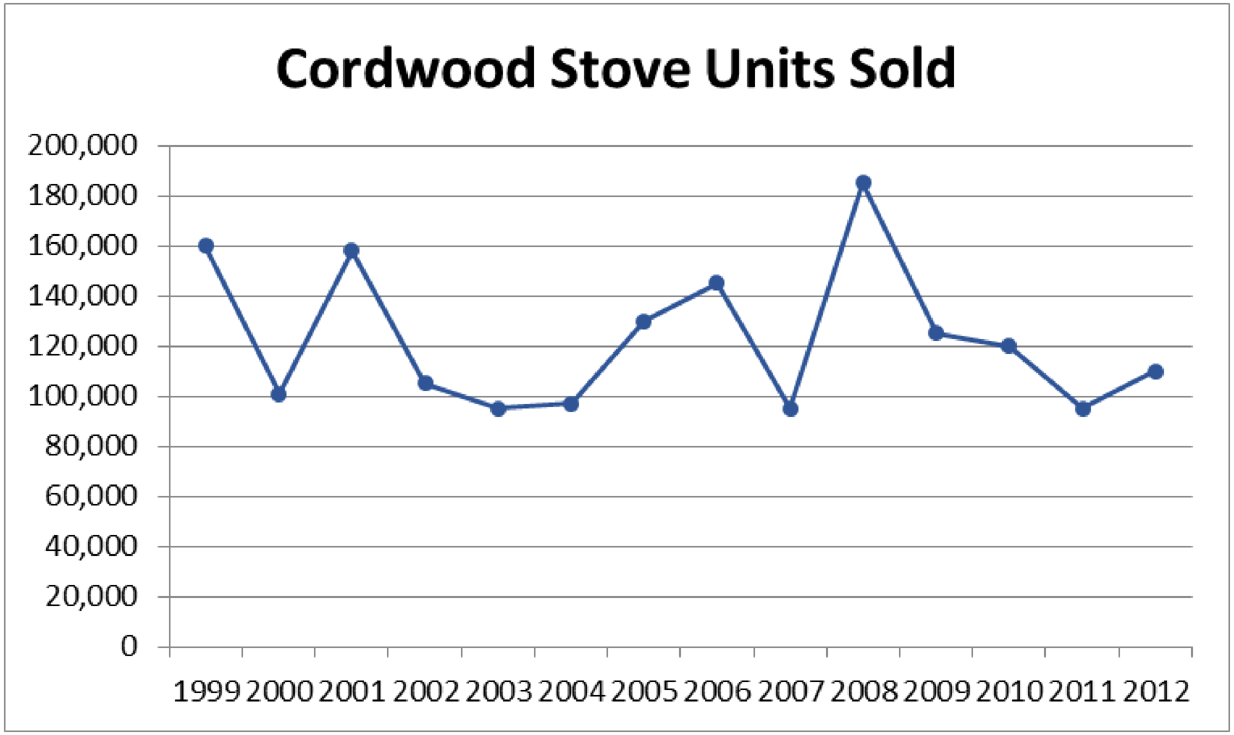
DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical*	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50	50	50
Efficiency (Non-Catalytic) (HHV)**	58	63	70	76	70	77	73	78	74	79	75	80
Efficiency (Catalytic) (HHV)**	68	72	78	84	78	84	81	85	82	86	83	87
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($) (Non-Catalytic)	2,400	2,450	2,450	2,650	2,450	2,650	2,550	2,750	2,650	2,850	2,750	2,950
Retail Equipment Cost ($) (Catalytic)	3,300	3,000	3,000	3,200	3,000	3,200	3,100	3,300	3,200	3,400	3,300	3,500
Total Installed Cost ($) (Non-Catalytic)	7,000	7,050	7,050	7,250	7,050	7,250	7,150	7,350	7,250	7,450	7,350	7,550
Total Installed Cost ($) (Catalytic)	7,900	7,600	7,600	7,800	7,600	7,800	7,700	7,900	7,800	8,000	7,900	8,100
Annual Maintenance Cost ($) (Non Catalytic)	160	160	160	160	160	160	160	160	160	160	160	160
Annual Maintenance Cost ($) (Catalytic)	235	235	235	235	235	235	235	235	235	235	235	235

* EPA Certified Default Level no longer listed here because 2015 EPA rule requires that manufacturers test and report the efficiency of their stoves and, therefore, manufacturers no longer have the option to report the default value.
** Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
*** Installed cost includes cost of hearth and stainless steel chimney liner - materials and labor.
**** Annual maintenance cost of catalytic stove includes periodic cost of replacing the catalytic combustor.

- Residential cordwood stoves that must meet EPA particulate limits fall into two broad classes based on whether or not they use a catalyst for air treatment. Catalytic wood stoves use a catalytic combustor to reduce emissions from the combustion air. Non-catalytic wood stoves use baffles and introduce secondary air above the flames to enable more complete combustion and reduce emissions.
- In 2015, EPA published an update to its New Source Performance Standards (NSPS), decreasing the emissions limit (previously set by 1988 EPA rule) to 4.5 g/hr for both catalytic and non-catalytic stoves. The new rule did not institute efficiency standards, but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- The 2015 EPA rule stipulates that, in 2020, emissions requirements for wood stoves will be lowered to 2.5 or 2.0 g/hr (depending on the test method used).
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or certify with the default efficiency value designated by EPA. EPA's default efficiency values were 63% for non-catalytic wood stoves and 72% for catalytic wood stoves. Under this system, few manufacturers submitted efficiency test data to EPA.
- Some states still have emissions requirements that are more stringent than the EPA's standard (e.g., Washington).
- EPA notes in its 2015 rule that efficiency requirements may be included in a future rulemaking.

- A federal tax credit for efficient wood stoves was offered from 2009 to 2016 and retroactively for 2017. Some states offered tax credits through 2017 (e.g., Oregon).
- Multiple test standards are commonly used to assess stove efficiency and data from product literature does not generally identify the efficiency test method. It’s not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Cordwood stoves require chimneys for venting combustion gases. Whether conventional masonry chimneys are used or metal chimney liners, these add considerable cost to the overall system. Accordingly, installed costs can be twice that of the wood stove itself.

Cordwood stove shipments have averaged 123,000 per year since 1999 and have fluctuated roughly in accordance with fuel oil costs.



Source: HPBA, no post-2012 sales data was publicly available at time of publication.

Residential Wood Pellet Stoves

Same as reference case

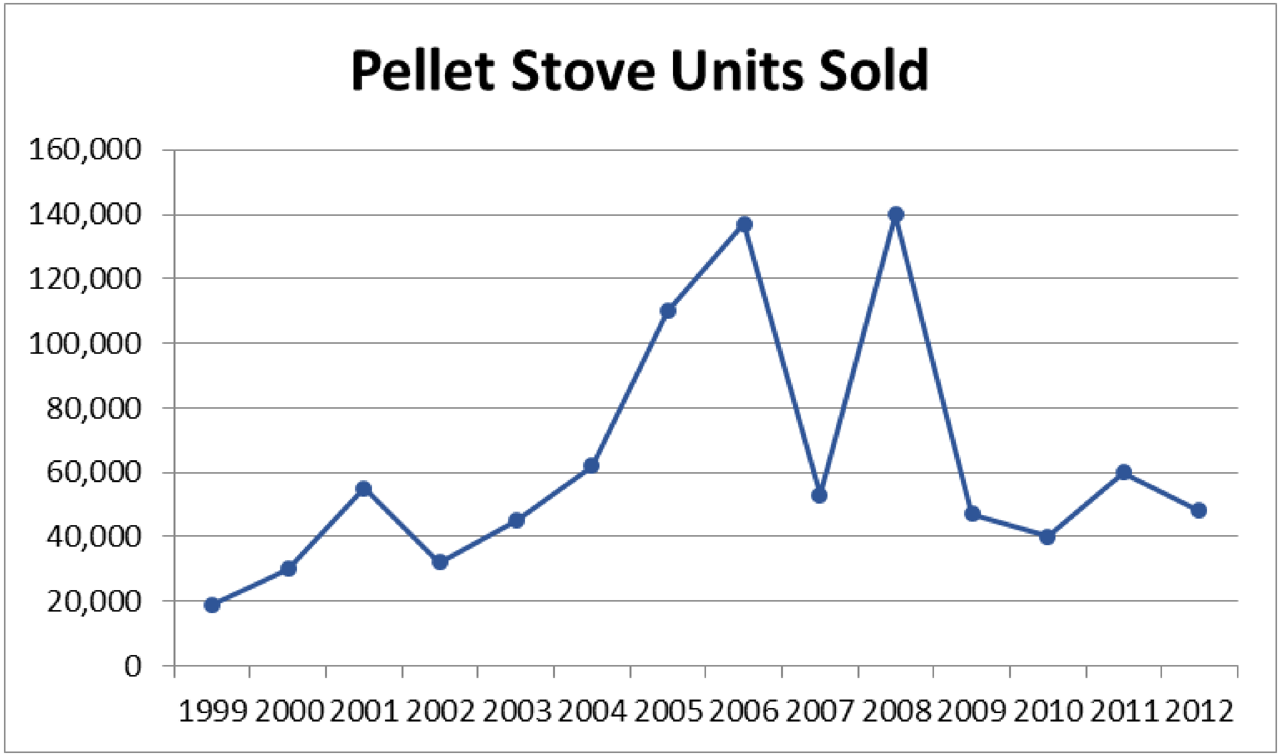
DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	50	50	50	50	50	50	50	50	50	50	50	50
Efficiency (HHV)	65	70	76	87	76	87	77	87	78	88	79	89
Annual Electricity Consumption (kWh)	600	600	600	600	600	600	600	600	600	600	600	600
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	3,300	3,300	3,300	4,000	3,300	4,000	3,400	4,000	3,500	4,100	3,600	4,200
Total Installed Cost ($)	4,700	4,700	4,700	5,400	4,700	5,400	4,800	5,400	4,900	5,500	5,000	5,600
Annual Maintenance Cost ($)	260	260	260	260	260	260	260	260	260	260	260	260

* EPA Certified Default Level removed because 2015 EPA rule requires that manufacturers test and report the efficiency of their stoves. Therefore, manufacturers no longer have the option to report the default value.
** Efficiency includes combustion and heat transfer efficiency and is based on the higher heating value (HHV) of the fuel.
*** Installed cost includes cost of hearth and vent pipe - materials and labor.

- In 2015, EPA published an update to its New Source Performance Standards (NSPS), limiting emissions for wood pellet stoves to 4.5 g/hr. Prior to the 2015 EPA rule, most pellet stoves were exempt from EPA's NSPS requirements. The new rule did not institute efficiency standards, but required that manufacturers test and certify the efficiency of their stoves. This standard took full effect on January 1, 2016.
- The 2015 EPA rule stipulates that, in 2020, emissions requirements for wood stoves will be lowered to 2.5 or 2.0 g/hr (depending on the test method used).
- EPA notes in its 2015 rule that efficiency requirements may be included in a future rulemaking.
- Prior to the 2015 rule, manufacturers could either submit efficiency data from laboratory testing or use a default efficiency value designated by EPA (78% for pellet stoves). Under this system, few manufacturers submitted efficiency test data to EPA.
- Some states still have emissions requirements that are more stringent than the EPA's standard (e.g., Washington).
- A federal tax credit for efficient wood stoves was offered from 2009 to 2016 and retroactively for 2017. Some states offered tax credits through 2017 (e.g., Oregon).

- Multiple test standards are commonly used to assess stove efficiency and data from product literature does not generally identify the efficiency test method.
- It's not possible to determine performance trends based on construction or configuration (e.g., cast iron vs. plate steel, powered blowers vs. no blowers, etc.) trends in specific equipment type or construction based on published efficiencies. Further, EPA certification data shows no significant relationship between emissions and heating efficiency.
- Wood pellet stoves may be able to be direct vented to the outdoors, eliminating the need for a chimney. This reduces the overall system cost as compared to a cord wood stove. However, they do use electricity to power the pellet feeder, the combustion air fan, and the blower. In the event of a power outage, a pellet stove can not operate without some back-up source of electricity (e.g., battery) .

Wood pellet stove shipments grew substantially in the 2005 – 2008 time period, but have averaged only 40,000 – 60,000 units since that time.



Source: HPBA, no post-2012 sales data was publicly available at time of publication.

- On December 29, 2016, the metric for the current Federal standard was translated from Energy Factor (EF) to Uniform Energy Factor (UEF)[1].

- The UEF test procedure is conceptually similar to the EF test procedure in that it is a 24-hour simulated-use test of how the water heater would be expected to perform in the field.
  - The EF test procedure consists of one draw pattern for all models.
  - The UEF test procedure consists of 4 possible draw patterns.
    - The particular draw pattern a water heater is tested to is determined through a delivery capacity test (first-hour rating or maximum GPM).
    - A draw pattern is a set of instructions specifying when, how fast (flow rate), and how much (volume) hot water is removed from the water heater.
    - Therefore, a water heater designed to deliver a small amount of hot water is not tested the same as a water heater designed to deliver a large amount of hot water.

[1]Test Procedures for Consumer and Commercial Water Heaters; Final rule. 81 FR 96204.

Typical efficiency level and product costs increase to ENERGY STAR levels.
Increased high efficiency product with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Uniform Energy Factor (UEF)*	0.58	0.58	0.61	0.63	0.66	0.81	0.63	0.81	0.66	0.81	0.66	1.3	0.66	1.3
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	500	500	700	750	800	1,850	750	1,850	800	1,850	800	1,850	800	1,850
	550	550	1,000	1,200	1,350	2,100	1,200	2,100	1350	2,100	1350	2,100	1350	2,100
Total Installed Cost (2017$)**	1,050	1,050	1,350	1,400	1,500	2,450	1,400	2,450	1500	2,450	1500	2,450	1500	2,450
	1,050	1,050	2,300	2,450	2,550	3,700	2,450	3,700	2550	3,700	2550	3,700	2550	3,700
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-	-	-

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.60 EF. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market.

** Installed cost reflects differences in installation cost between typical and high efficiency products. Typical efficiency products are non-condensing, whereas the high efficiency products are condensing and require different installation. Furthermore, higher UEF can be achieved by additional insulation, which also increases the size of the unit and the associated installation cost.

*** Maintenance costs are negligible.

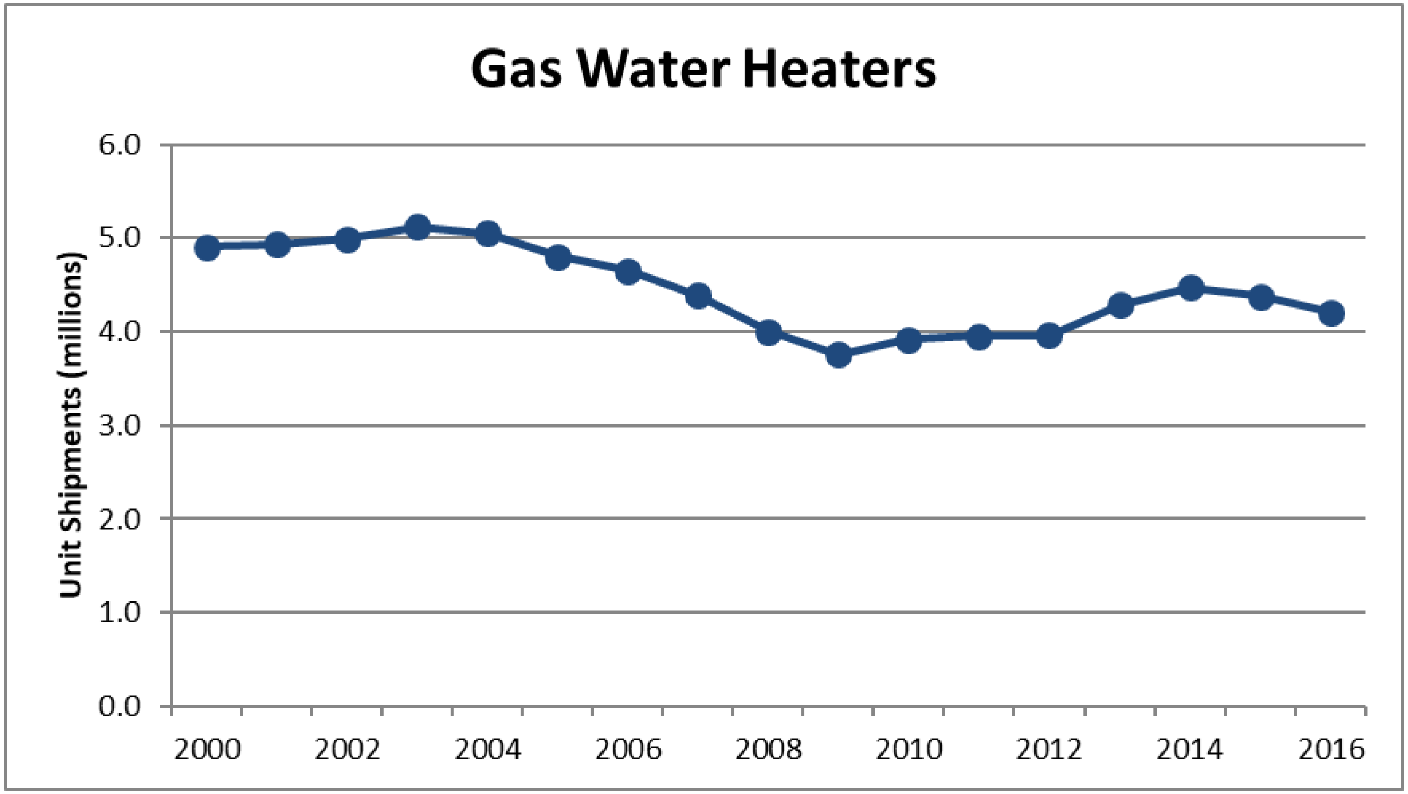
- The equations for the revised Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.3456-(0.002*Gal)	No models on the market	N/A
	Low	UEF=0.5982-(0.0019*Gal)	0.54 for a 29-gallon water heater	N/A
	Medium	UEF=0.6483-(0.0017*Gal)	0.58 for a 38-gallon water heater	0.64
	High	UEF=0.692-(0.0013*Gal)	0.64 for a 48-gallon water heater	0.68
> 55 gal and ≤ 100 gal	Very Small	UEF=0.647-(0.0006*Gal)	No models on the market	N/A
	Low	UEF=0.7689-(0.0005*Gal)	No models on the market	N/A
	Medium	UEF=0.7897-(0.0004*Gal)	No models on the market	0.78
	High	UEF=0.8072-(0.0003*Gal)	No models on the market	0.80

- There are currently no models on the market above 55 gallons due to the high UEF which would require using condensing or gas-fired heat pump (e.g., absorption) technology to achieve.
- The ENERGY STAR UEF levels for models with storage volume ≤ 55 gallons are typically achievable through the use of a power vent or flue damper.
- The cost of installation is typically $600 to $1200, which exceeds that of electric water heaters. This difference can be attributed to multiple differences, gas-fired heaters require an extra 1.5 hours of labor for 2 plumbers that is required for gas units.
- Condensing units are high efficiency and use PVC venting instead of stainless-steel. High efficiency condensing units also use an electrical supply for electronic ignition and power venting. Some building codes require condensate neutralizer filters.
- Advanced Case: Increased incentives move typical efficiency products to ENERGY STAR levels by 2030. The current typical efficiency product is at 0.63 UEF, while ENERGY STAR is at 0.66 UEF with only a small difference in costs. It is expected that with more market incentives, manufacturers will produce more products that can be ENERGY STAR certified at the 0.66 UEF level. Furthermore, high efficiency gas absorption heat pump water heaters are expected to enter the market by 2040, which will dramatically increase maximum achievable UEF.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Shipments were flat at 5 million units per year through 2004, then declined gradually over 5 years to a new plateau at 4 million units until rising again to a max of 4.5 million units in 2014.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Residential-Storage-Water-Heaters-Historical-Data.aspx*

Same as reference case

DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	30	32	32	32	32	32	32	32	32	32	32	32	32
Uniform Energy Factor (UEF)*	0.51	0.51	0.64	0.67	0.69	0.67	0.69	0.67	0.69	0.67	0.69	0.67	0.69
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	1,350	1,350	1,500	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
	1,450	1,450	1,900	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050	2,050
Total Installed Cost (2017$)	2,000	2,000	2,100	2,250	2,200	2,250	2,200	2,250	2,200	2,250	2,200	2,250	2,200
	2,100	2,100	2,700	2,850	2,850	2,850	2,850	2,850	2,850	2,850	2,850	2,850	2,850
Annual Maintenance Cost (2017$)	180	180	180	180	180	180	180	180	180	180	180	180	180

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.50 EF. Analysis is based on an average of medium and high draw pattern units, as this is most reflective of the market

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- The equations for the Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≤ 50 gal	Very Small	UEF=0.2509-(0.0012*Gal)	No models on the market	N/A
	Low	UEF=0.533-(0.0016*Gal)	No models on the market	N/A
	Medium	UEF=0.6078-(0.0016*Gal)	No models on the market	N/A
	High	UEF=0.6815-(0.0014*Gal)	0.64 for a 29-gallon water heater	N/A

- There are no ENERGY STAR levels for oil-fired storage water heaters.
- Annual shipments of residential oil-fired storage water heaters are approximately 40,000, which is ~1% of shipments of residential gas-fired storage water heaters.
- Oil-fired storage water heaters often have smaller tanks with larger input ratings relative to natural gas-fired and electric storage water heaters.
- No condensing residential oil-fired storage water heaters currently exist in the U.S. market. The highest efficiencies currently on the market are at near-condensing levels.
- Residential oil-fired water heaters utilize power burners and have at least some level of electrical power consumption.
- The max-tech model on the market uses a proprietary "turbo-flue" design to increase heat transfer to water.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Electric Resistance Storage Water Heaters

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Same as reference case

DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50	50	50	50
Uniform Energy Factor (UEF)*	0.88	0.88	0.92	0.93	0.95	0.93	0.95	0.93	0.95	0.93	0.95	0.93	0.95
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	300	250	250	300	700	300	700	300	700	300	700	300	700
	350	450	500	550	900	550	900	550	900	550	900	550	900
Total Installed Cost (2017$)**	600	500	550	600	1,000	600	1,000	600	1,000	600	1,000	600	1,000
	650	800	1,000	1,100	1,450	1,100	1,450	1,100	1,450	1,100	1,450	1,100	1,450
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-	-

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.90 EF. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market

** Installed cost reflects differences in installation cost between typical and high efficiency products. The high UEF products have a larger size (due to insulation differences) and therefore require more installation work.

*** Maintenance costs are negligible.

- The equations for the Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
≥ 20 gal and ≤ 55 gal	Very Small	UEF=0.8808-(0.0008*Gal)	No models on the market	2.00
	Low	UEF=0.9254-(0.0003*Gal)	0.91 for a 27-gallon water heater	2.00
	Medium	UEF=0.9307-(0.0002*Gal)	0.92 for a 36-gallon water heater	2.00
	High	UEF=0.9349-(0.0001*Gal)	0.93 for a 45-gallon water heater	2.00
> 55 gal and ≤ 120 gal	Very Small	UEF=1.9236-(0.0011*Gal)	No models on the market	2.20
	Low	UEF=2.0440-(0.0011*Gal)	No models on the market	2.20
	Medium	UEF=2.1171-(0.0011*Gal)	2.03 for a 77-gallon water heater	2.20
	High	UEF=2.2418-(0.0011*Gal)	2.15 for a 82-gallon water heater	2.20

- The federal standards for residential electric storage water heaters apply to both electric resistance storage water heaters and integrated heat pump water heaters (HPWHs; heat pump module and storage tank combined in one unit).
  - The Federal standard levels for the ≤55 gallon range are achievable through electric resistance and heat pump technology.
  - The Federal standards for the >55 gallon range and all ENERGY STAR levels are only achievable through heat pump technology. There are no HPWHs on the market that cannot meet the applicable Federal standard level.
- Typical storage volumes range from 25-55 gallons for electric resistance storage water heaters and 45-80 gallons for HPWHs.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Heat Pump Water Heaters

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Same as reference case

DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	50	50	50	50	50	50	50	50	50	50	50	50	50
Uniform Energy Factor (UEF)*	2.05	2.05	3.28	2.00	3.55	3.28	3.55	3.28	3.55	3.28	3.55	3.28	3.55
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6
	20	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost (2017$)	1,550	1,100	1,200	1,050	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200
	1,900	1,400	1,500	1,350	2,300	1,500	2,300	1,500	2,300	1,500	2,300	1,500	2,300
Total Installed Cost (2017$)	1,700	1,450	1,600	1,400	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
	2,450	2,500	2,550	2,400	3,350	2,550	3,350	2,550	3,350	2,550	3,350	2,550	3,350
Annual Maintenance Cost (2017$)	20	20	20	20	20	20	20	20	20	20	20	20	20

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 2.00 EF. Analysis is based on an average of low and medium draw pattern units, as this is most reflective of the market

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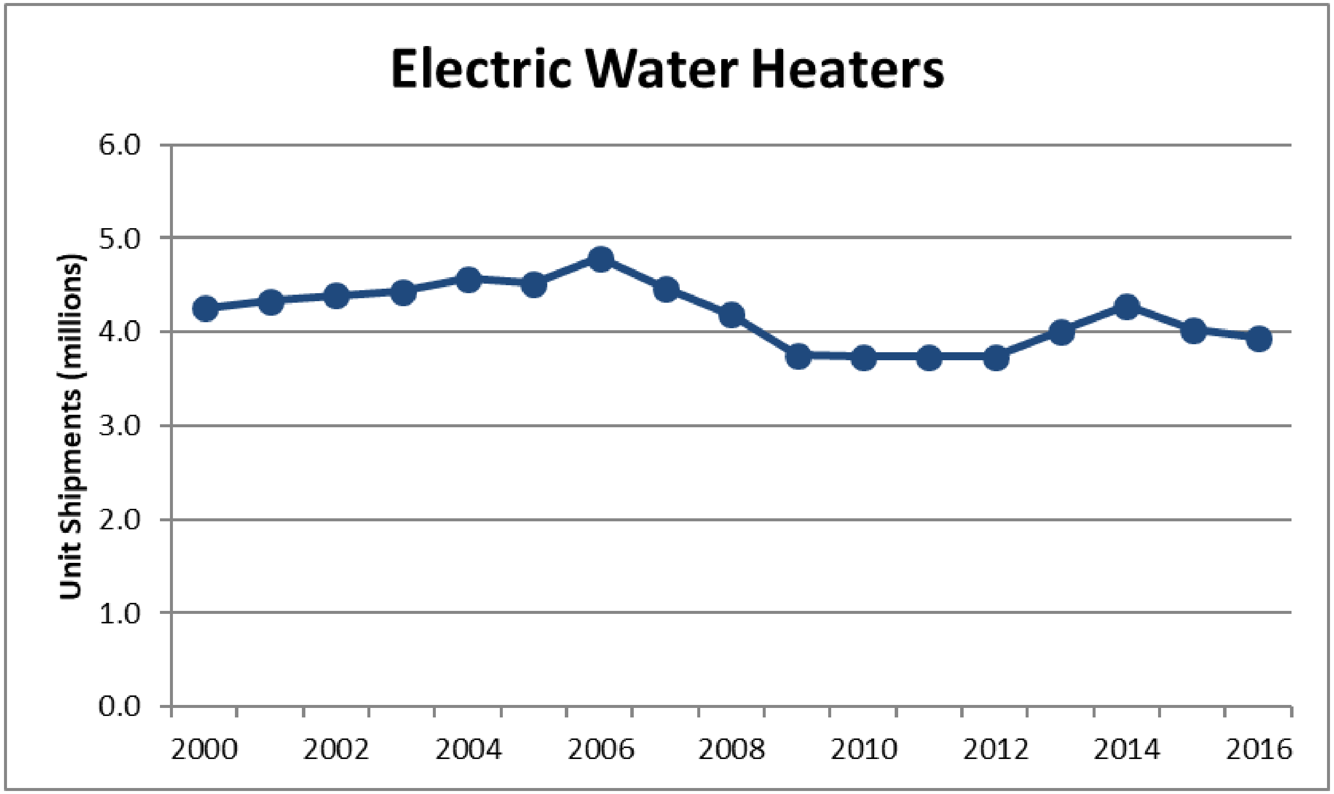
- Technology improvements have advanced efficiency and reliability, but the high first-cost and lack of awareness among consumers and contractors still precludes high-volume market penetration. Although there is an installed base listed for 2009, the market penetration of heat pump water heaters (HPWHs) was quite low at that time.
- New Federal standards that came into effect in April 2015 effectively mandate heat pump technology for electric storage water heaters with storage volume > 55 gallons.
- Integrated models are the most common configuration for residential HPWHs. Several major water heater manufacturers produce such models, and other competitors offer integrated or add-on units (for existing electric or indirect storage water heaters).
- Sales are estimated to be driven partly by rebates and tax credits at the utility, local, state, and Federal level.
- Resistive heating elements are virtually 100% efficient, but there is a jump in efficiency when heat pump technology is adopted because heat pumps' Coefficient of Performance (COP) are usually between 2.5 and 4.
- Heat pumps raise the water temperature more slowly than resistive heating elements, so most models use backup resistive elements along with the heat pump when hot water demand is high. Most HPWHs allow the consumer to control whether resistive elements are used in periods of high demand (e.g., "hybrid mode" or "heat pump only mode").

Shipments peaked in 2006 then dropped a total of 22 percent over three years and leveled off between 3.7 and 4.3 million units per year.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Residential-Storage-Water-Heaters-Historical-Data.aspx*

Residential Solar Water Heaters

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Same as reference case

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical / ENERGY STAR**	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	42	42	42	42	42	42	42
	63	65	65	65	65	65	65
Solar Fraction (SF)	0.5	0.5	0.56	0.56	0.56	0.56	0.56
Solar Energy Factor (SEF)	2.5	2.5	2.7	2.7	2.7	2.7	2.7
Average Life (yrs)	15	15	15	15	15	15	15
	30	30	30	30	30	30	30
Retail Equipment Cost* (2017$)	3,500	4,800	4,800	4,800	4,800	4,800	4,800
	5,400	8,300	8,300	8,300	8,300	8,300	8,300
Total Installed Cost* (2017$)	7,800	7,100	7,100	7,100	7,100	7,100	7,100
	10,200	11,000	11,000	11,000	11,000	11,000	11,000
Annual Maintenance Cost (2017$)	25	25	25	25	25	25	25

* Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.
** ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

- Solar water heaters (SWHs) are not subject to federal energy conservation standards, the ENERGY STAR requirements are:

Applicable Products	Backup Fuel	ENERGY STAR Requirement	Test Method
Whole-home solar units	Gas	SEF ≥ 1.2	SRCC – OG-300: Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems
	Electric	SEF ≥ 1.8	

- Solar water heaters can be either active or passive. An active system uses an electric pump to circulate the heat transfer fluid; a passive system has no pump. Most solar water heaters in the United States are the active type.
- Solar water heaters are also characterized as open loop (also called "direct") or closed loop (also called "indirect"). An open-loop system circulates household (potable) water through the collector. A closed-loop system uses a heat transfer fluid (water or diluted antifreeze, for example) to collect heat and a heat exchanger to transfer the heat to household water.
- Solar fraction represents the fraction of total annual water heating energy met by the solar water heater. A backup water heating system is required with SWHs, and it is typically most economical to size the system to provide about 50% of water heating energy (solar fraction = 0.5).
- Solar Energy Factor (SEF) is defined by the Solar Rating and Certification Corporation (SRCC) as the useful energy delivered by the system divided by the total electrical and/or fossil fuel required for backup heating, pumping, and controls (the free solar energy input is neglected).
- Over 2/3 of the current SWH market is in the southern or western US (including Hawaii). A collector area of 42 ft^2 would be typical for these areas. Colder areas of the US would require a larger collector (e.g. 65 ft^2).
- Installed costs are higher for colder areas where larger collectors are required. Costs also vary widely depending on collector quality, type of system, and site-specific characteristics.

Residential Gas-fired Instantaneous Water Heaters

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/hr)	185	199	199	199	199	199	199	199	199	199	199	199	199	199
Uniform Energy Factor (UEF)*	0.81	0.81	0.81	0.89	0.87	0.97	0.93	0.97	0.93	0.97	0.93	0.97	0.93	0.97
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Retail Equipment Cost (2017$)	1,150	1,200	700	1,000	850	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050
	1,300	1,500	1,200	1,200	1,200	1,650	1,200	1,650	1,200	1,650	1,200	1,650	1,200	1,650
Total Installed Cost (2017$)	1,750	2,200	1,500	1,500	1,550	1,600	1,500	1,600	1,500	1,600	1,500	1,600	1,500	1,600
	1,850	3,250	3,200	2,850	3,050	3,300	2,850	3,300	2,850	3,300	2,850	3,300	2,850	3,300
Annual Maintenance Cost (2017$)	90	130	130	130	130	130	130	130	130	130	130	130	130	130

*Beginning in 2016, the efficiency metric for water heaters changed from EF to UEF based on DOE test procedures. The UEF values for installed base 2009 and 2015 are converted values equivalent to 0.82 EF. Analysis is based on an average of low, medium, and high draw pattern units, as this is most reflective of the market

- The Federal standards are:

Volume Range	Draw Pattern	Federal standard[1]	Federal minimum UEF for typical sizes	ENERGY STAR
<2 gal and >50,000 Btu/h	Very Small	UEF=0.80	No models on the market	0.87
	Low	UEF=0.81	No models on the market	0.87
	Medium	UEF=0.81	0.81	0.87
	High	UEF=0.81	0.81	0.87

- The ENERGY STAR levels require the use of condensing technology.
- Navien and Bosch manufacture the highest efficiency high draw pattern models currently available on the market, which have a UEF of 0.97. Navien manufactures the highest efficiency medium draw pattern models currently available on the market, which have a UEF of 0.96. These levels are achieved through the use of electronic ignition, power-direct venting, and condensing the flue gases.
- All of the major water heater manufacturers now offer an instantaneous model.
- The maintenance costs include cleaning the water inlet filter and the heat exchanger of mineral deposits and replacing the water valve approximately once every five years for all instantaneous water heaters.
- When replacing a storage water heater with an instantaneous water heater, there are significant additional costs to upsize the gas supply line to ¾ inch from the typical ½ inch and change the venting.
- Advanced Case: Increased market incentives is expected to drive further adoption of condensing products, thereby raising the typical efficiency, while increased R&D is expected to improve cost.

[1]Energy Conservation Standards for Residential Water Heaters. 10 CFR 430.32(d).

Residential Refrigerator-Freezers (Top)

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/yr)***	657	512	405	389	364	358	389	358	364	358	362	358	361	358
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost (2017$)	580	570	700	750	850	880	750	880	750	880	750	880	750	880
Total Installed Cost (2017$)	580	570	700	750	850	880	750	880	750	880	750	880	750	880
Annual Maintenance Cost (2017$)****	10	10	10	10	10	10	10	10	10	10	10	10	10	10

* Product Class 3 is used for this analysis (Refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost)
** The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 21 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics)

Residential Refrigerator-Freezers (Side)

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Energy Consumption (kWh/yr)***	1,146	893	705	671	635	509	671	509	635	509	604	509	572	509
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost (2017$)	1,200	1,190	1,310	1,420	1,550	1,980	1,420	1,980	1,420	1,980	1,420	1,980	1,420	1,980
Total Installed Cost (2017$)	1,200	1,190	1,310	1,420	1,550	1,980	1,420	1,980	1,420	1,980	1,420	1,980	1,420	1,980
Annual Maintenance Cost (2017$)****	25	25	25	25	25	25	25	25	25	25	25	25	25	25

* Product Class 7 is used for this analysis (Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service)
** The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 32 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics, ice maker), not replaceable components (e.g., water filters)

Residential Refrigerator-Freezers (Bottom)

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	21	19	19	19	19	19	19	19	19	19	19	19	19	19
Energy Consumption (kWh/yr)***	651	547	521	480	469	469	480	469	476	469	472	469	469	469
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12	12
	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Retail Equipment Cost (2017$)	980	1,010	1,030	1,120	1,160	1,160	1,120	1,160	1,120	1,160	1,120	1,160	1,120	1,160
Total Installed Cost (2017$)	980	1,010	1,030	1,120	1,160	1,160	1,120	1,160	1,120	1,160	1,120	1,160	1,120	1,160
Annual Maintenance Cost (2017$)*****	25	25	25	25	25	25	25	25	25	25	25	25	25	25

* Product Class 5 is used for this analysis (Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service)
** The volume shown here is the nominal total volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 25 ft^3 for 2009 and 23 ft3 for all other years. All values represent use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics)

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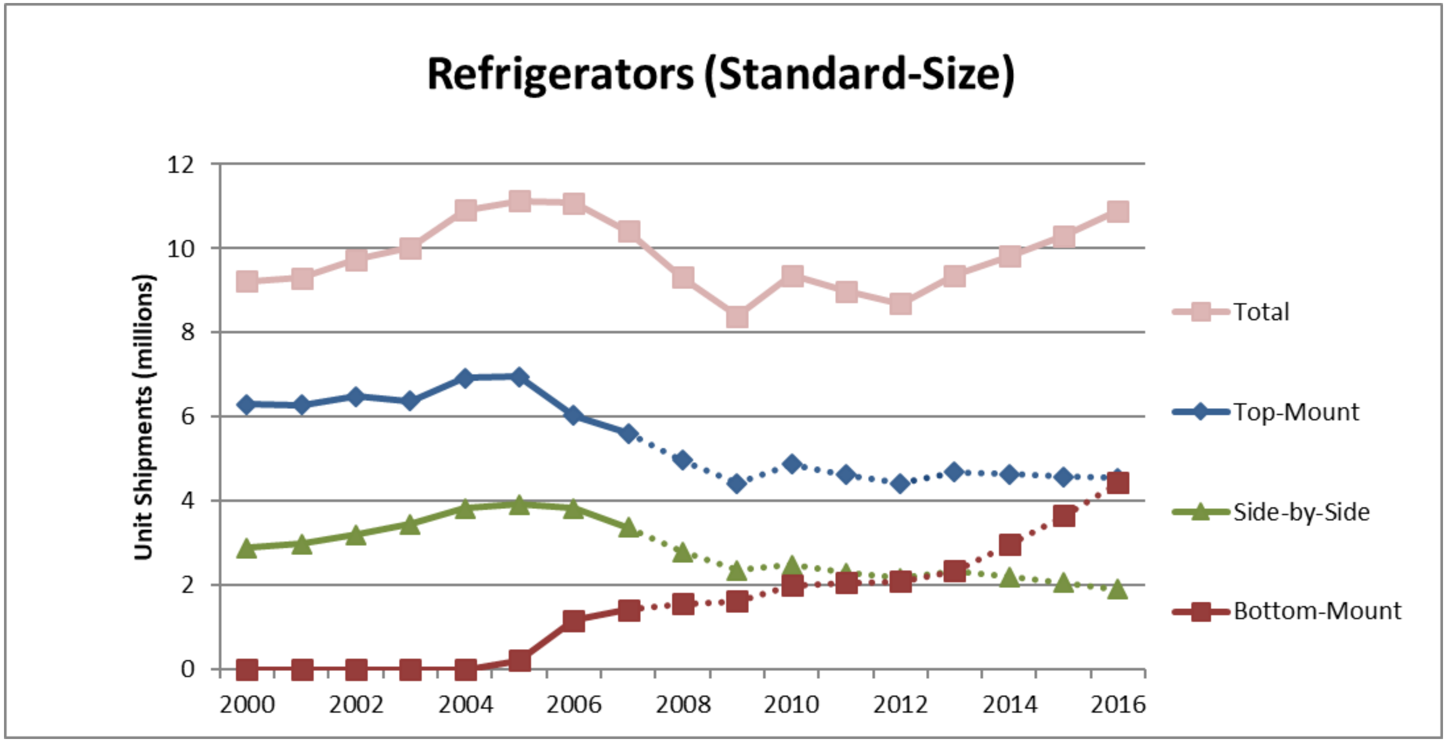
- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014.
  - Models divided into 32 product classes based on size (standard or compact), location of freezer (top, bottom, or side), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence and configuration (through-the-door or inside cabinet) of automatic icemaker
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
  - New product classes for built-in units
  - Amount by which standards are tightened varies by product class
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard.
- Current analysis focuses on the three representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating
- Advanced Case: Increased market incentives will push product sales towards the ENERGY STAR level, but the technologies used to meet ENERGY STAR are already well-known and prices will likely not rise as manufacturing volumes increase at higher efficiencies.

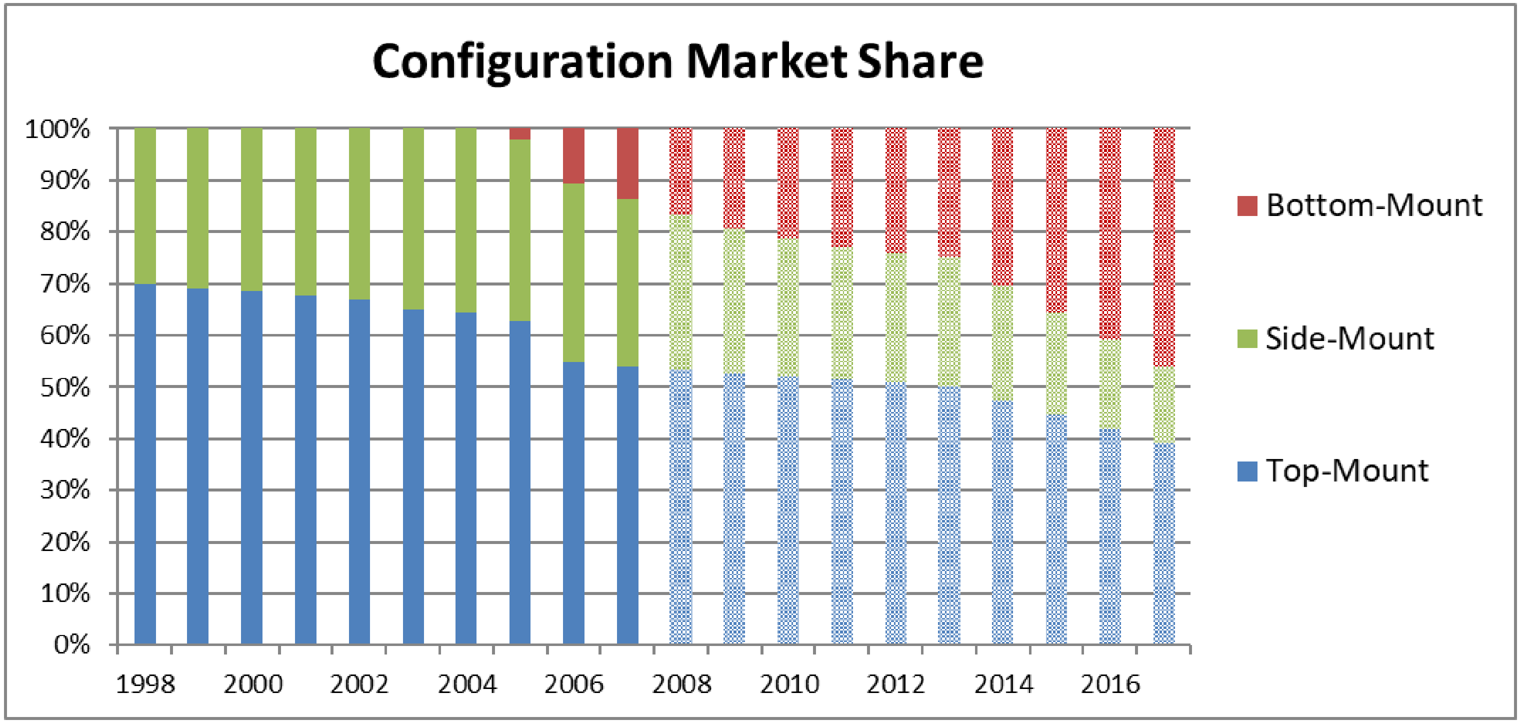
[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume).

Annual shipment volumes have rebounded from a sharp decline between 2006 and 2009, reaching approximately 10.9 million units in 2016.



Source: *Appliance Magazine*; DOE's Compliance and Certification Database (as of December 2017); Navigant analysis. Dashed lines indicate interpolated data.

Side-mount units continue to gain market share, surpassing top-mount units in 2017.



Sources: August 2011 Refrigerator Final Rule TSD; DOE's Compliance Certification Database (as of December 2017); Navigant analysis. Dashed bars (2008 to 2017) indicate interpolated data.

Residential Freezers (Chest)

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	17	16	16	16	16	16	16	16	16	16	16	16	16	16
Energy Consumption (kWh/yr)***	428	360	300	297	277	275	297	275	290	275	283	275	276	275
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	420	430	500	500	550	540	500	540	500	540	500	540	500	540
Total Installed Cost (2017$)	420	430	500	500	550	540	500	540	500	540	500	540	500	540
Annual Maintenance Cost (2017$)****	5	5	5	5	5	5	5	5	5	5	5	5	5	5

* Product Class 10 is used for this analysis (Chest freezers and all other freezers except compact freezers)
** The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 26 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics)

Residential Freezers (Upright)

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Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

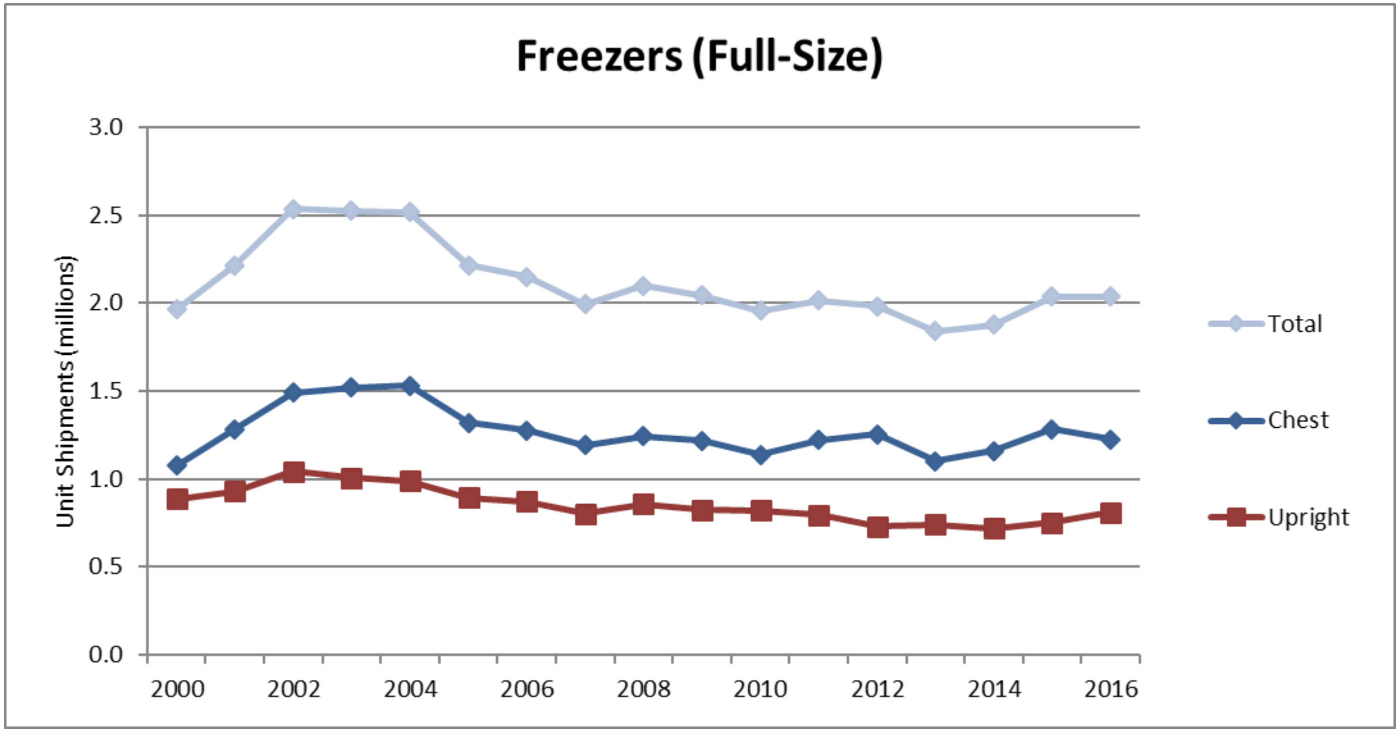
DATA*	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)**	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Energy Consumption (kWh/yr)***	763	615	477	446	430	419	446	419	439	419	432	419	425	419
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Retail Equipment Cost (2017$)	580	590	690	750	790	810	750	810	750	810	750	810	750	810
Total Installed Cost (2017$)	580	590	690	750	790	810	750	810	750	810	750	810	750	810
Annual Maintenance Cost (2017$)****	5	5	5	5	5	5	5	5	5	5	5	5	5	5

* Product Class 9 is used for this analysis (Upright freezers with automatic defrost)
** The volume shown here is the nominal volume, not the adjusted volume, which is used to determine compliance with standards. The adjusted volume is equal to the fresh food internal volume (zero for freezers) plus the freezer internal volume times an adjustment factor, which depends on the product type.
*** Based on an adjusted volume of 29 ft^3 and use of the test procedure established by the 2014 Test Procedures for Refrigerators, Refrigerator-Freezers, and Freezers Final Rule. The 2009 value has been adjusted from previous versions to account for the updated test procedure.
**** Maintenance costs include cost of repairing integral components (e.g., compressor, evaporator fan, electronics)

- Current Federal standards[1]:
  - Compliance required beginning September 15, 2014
  - Models divided into 10 product classes based on size (standard or compact), orientation (chest or upright), type of defrost (automatic or manual), installation configuration (freestanding or built-in), and presence of automatic icemaker
  - Limits on annual electricity consumption expressed as functions of adjusted volume[2]
- ENERGY STAR criteria limit annual electricity consumption to 10% less than the Federal standard.
- Current analysis focuses on the two representative product classes analyzed in the recent rulemaking.
- Energy efficiency opportunities include:
  - Higher efficiency and/or variable-speed compressor systems
  - Larger heat exchangers
  - Permanent-magnet fan motor systems (vs. SPM and PSC fan motors)
  - Demand defrost systems
  - Vacuum-insulated panels
  - Thicker insulation (though at a loss of consumer utility)
  - Refrigerants (Isobutane vs. R134a)
  - Variable anti-sweat heating
  - Use of forced convection condenser (for upright freezers)
- Advanced Case: Increased market incentives will push product sales towards the ENERGY STAR level, but the technologies used to meet ENERGY STAR are already well-known and prices will likely not rise as manufacturing volumes increase at higher efficiencies.

[1]Energy Conservation Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers. 10 CFR 430.32(a).
[2]Adjusted Volume (AV) = (Fresh Volume) + 1.76 × (Freezer Volume).

Shipment volumes have held steady since 2007 at about 2 million units per year. Chest freezers represent about 60% of the market.



Source: *Appliance Magazine.*

Residential Natural Gas Cooktops

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Same as reference case

DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	9	9	9	9	9	9	9	9	9	9	9	9
	23	23	23	23	23	23	23	23	23	23	23	23
Integrated Annual Energy Consumption (kbtu/yr)*	1,105	1,061	914	730	914	730	914	730	914	730	914	730
Cooking Efficiency (%)	39	40	45	52	45	52	45	52	45	52	45	52
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9	9
	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2017$)**	250	250	260	260	260	260	260	260	260	260	260	260
Total Installed Cost (2017$)**	360	360	370	370	370	370	370	370	370	370	370	370
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-

* Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to Integrated Annual Energy Consumption (kBtu/yr) based on the 2016 Energy Conservation Standards for Residential Conventional Cooking Products
** Equipment and installed costs are for stand-alone cooktops only (not stoves).
*** Maintenance costs are negligible.

Residential Natural Gas Ovens

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Same as reference case

DATA	2009	2015	2017		2020		2030		2040		2050	
	Installed Base	Installed Base	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	16	16	16	16	16	16	16	16	16	16	16	16
	18	18	18	18	18	18	18	18	18	18	18	18
Typical Cavity Volume (ft^3)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Integrated Annual Energy Consumption (kbtu/yr)*	2,077	2,038	1,915	1,660	1,915	1,660	1,915	1,660	1,915	1,660	1,915	1,660
Cooking Efficiency (%)	6.5	6.6	7.0	7.8	7.0	7.8	7.0	7.8	7.0	7.8	7.0	7.8
Average Life (yrs)	9	9	9	9	9	9	9	9	9	9	9	9
	15	15	15	15	15	15	15	15	15	15	15	15
Retail Equipment Cost (2017$)**	510	510	560	610	560	610	560	610	560	610	560	610
Total Installed Cost (2017$)**	620	620	680	720	680	720	680	720	680	720	680	720
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-

* Although there is no performance standard in effect, the test procedure metric has changed from Cooking Efficiency (%) to Integrated Annual Energy Consumption (kBtu/yr) based on the 2016 Energy Conservation Standards for Residential Conventional Cooking Products

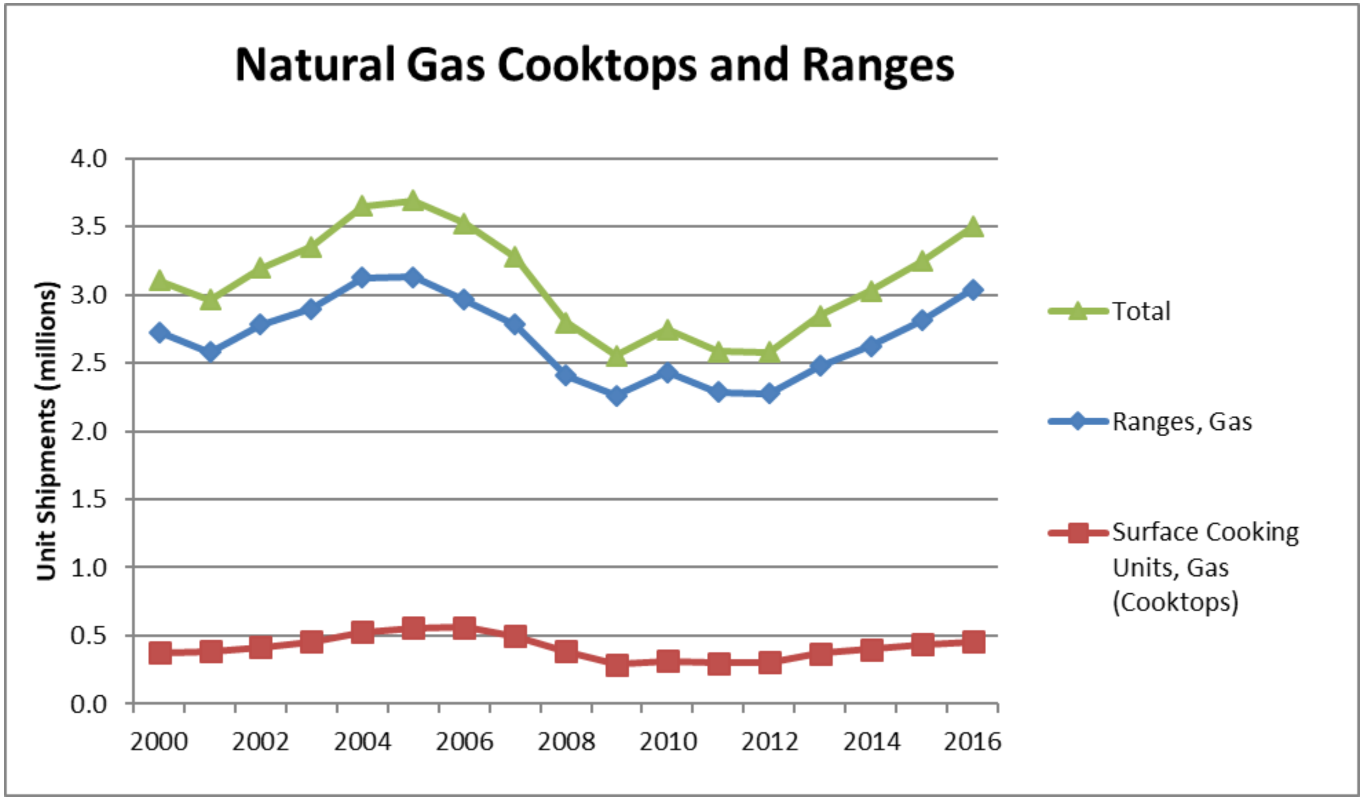
** Equipment and installed costs are for ovens only (not combined ranges). Furthermore, they are reflective of freestanding oven units, which represent 90% of the market.

*** Maintenance costs are negligible.

- DOE analyzes cooktops and ovens separately, although they are often sold together in a single unit that combines both a cooktop and an oven into a product referred to as a range.
- Since January 1, 1990, gas cooking products *with* an electrical supply cord have been required to not be equipped with a constant burning pilot light. This requirement extended to gas cooking products *without* an electrical supply cord, as of April 9, 2012.
- DOE final rule published in 2009[1]: no standard for cooking efficiency is cost-justified.
- DOE initiated a standards rulemaking in 2014 to consider amended standards for cooking products, including gas cooktops and ovens[2].
  - Most recently, on September 2, 2016, DOE proposed performance-based standards for gas cooktops and ovens that would take effect in 2020 if adopted.
- DOE established a new metric called integrated annual energy consumption (kBtu/year) to replace cooking efficiency (%).

[1]Energy Conservation Standards for Certain Consumer Products (Dishwashers, Dehumidifiers, Microwave Ovens, and Electric and Gas Kitchen Ranges and Ovens) and for Certain Commercial and Industrial Equipment (Commercial Clothes Washers); Final Rule. 74 FR 16040.
[2]Energy Conservation Standards for Residential Conventional Cooking Products; Supplemental notice of proposed rulemaking (SNOPR). 81 FR 60784.

Shipments have been rising since 2012 and are approaching the peak reached in 2005.



Note: Excludes separate ovens, which were categorized as "built-in" units prior to 2007 and represent a relatively negligible portion of the market. For example, between 2012-2014 an average of 32,000 standalone gas ovens, 360,000 gas cooktops, and 4.46 million ranges were sold per year.
Source: *Appliance Magazine.*

Higher typical efficiency product with the same costs as ref. case despite increased efficiency.

DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7	7	7
Combined Energy Factor (lb/kWh)*	3.55	3.59	3.73	3.74	4.50	3.74	4.50	3.89	4.50	3.97	4.50	4.04	4.50
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2017$)	410	410	420	430	650	430	650	430	650	430	650	430	650
Total Installed Cost (2017$)	520	520	530	540	770	540	770	540	770	540	770	540	770
Annual Maintenance Cost (2017$)**	-	-	-	-	-	-	-	-	-	-	-	-	-

*The efficiency metric changed from energy factor (EF) to combined energy factor (CEF) in 2015. The CEF value for installed base 2009 is a converted value equivalent to 3.01 EF

** Maintenance costs are negligible.

Residential Clothes Dryers (Gas)

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Same as reference case

DATA	2009	2015	2017			2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	7	7	7	7	7	7	7	7	7	7	7	7	7
Combined Energy Factor (lb/kWh)*	3.14	3.18	3.30	3.32	3.49	3.32	3.49	3.32	3.61	3.32	3.61	3.32	3.61
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8
	18	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost (2017$)	460	460	480	500	610	500	610	500	640	500	640	500	640
Total Installed Cost (2017$)	630	630	650	660	770	660	770	660	810	660	810	660	810
Annual Maintenance Cost (2017$)**	-	-	-	-	-	-	-	-	-	-	-	-	-

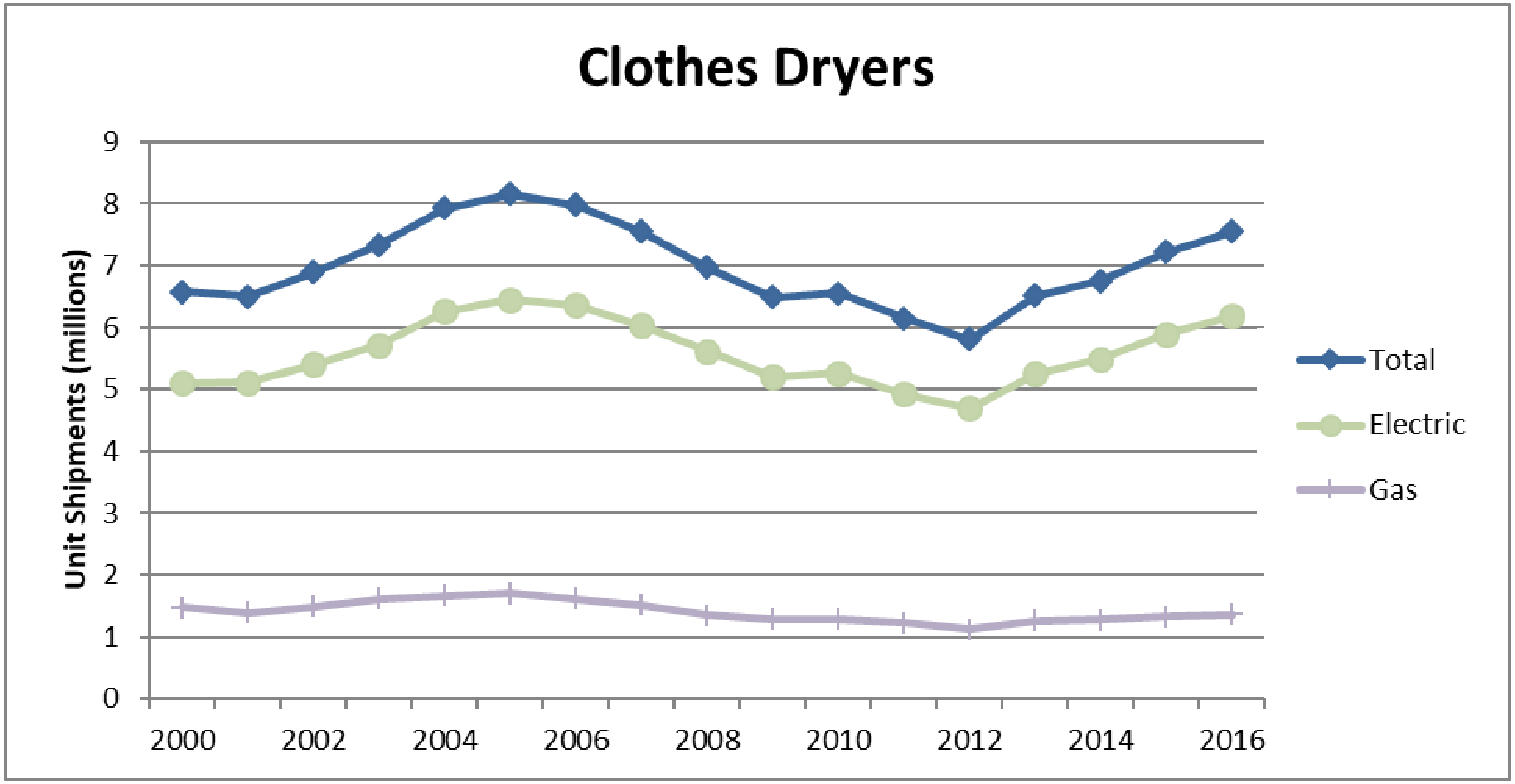
*The efficiency metric changed from energy factor (EF) to combined energy factor (CEF) in 2015. The CEF value for installed base 2009 is a converted value equivalent to 2.67 EF

** Maintenance costs are negligible.

- Current standards[1] in effect since 2015:
  - For standard-size electric units : CEF ≥ 3.73 lb/kWh
  - For gas units: CEF ≥ 2.30 lb/kWh
- Remaining efficiency improvement opportunities include:
  - Multi-step or modulating heat
  - Higher efficiency drum motors
  - Inlet air pre-heat
  - Better control systems for cycle termination
  - Heat pump (for electric clothes dryers)
  - Ultrasonic drying (prototype in development at Oak Ridge National Lab)
- EPA developed an ENERGY STAR program for residential clothes dryers, which became effective in 2015. In addition, EPA developed an Emerging Technology Award in 2014 to recognize advanced high-efficiency clothes dryers introduced to the U.S. market.
- Standard-size heat pump clothes dryers with CEF of 4.5 currently available in the U.S. market. High initial cost and longer drying times have limited market penetration, but some utilities are offering rebates to support market penetration.
- Advanced Case: Due to increases in market incentives, the residential electric clothes dryers market will see an increase in adoption of heat pump dryers that improve the typical efficiency products.

[1]Energy Conservation Standards for Consumer Clothes Dryers. 10 CFR 430.32(h).

Shipment volumes have been on the rise since 2012. Gas dryers continue to account for about one-fifth of the market.



Source: *Appliance Magazine*.

Residential Clothes Washers (Front)

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Same as reference case

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3.09	3.66	3.41	4.5	4.2	4.5	4.5	5.6	4.5	5.6	4.5	5.6	4.5	5.6
Integrated Modified Energy Factor (ft^3/kWh/cycle)*	1.67	2.16	1.84	2.76	2.38	2.92	2.76	3.10	2.92	3.10	2.92	3.10	2.92	3.10
Integrated Water Factor (gal/cycle/ft^3)**	6.5	4.7	4.7	3.2	3.7	2.9	3.2	2.7	2.9	2.7	2.9	2.7	2.9	2.7
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	20	17	16	14	16	13	14	15	13	15	13	15	13	15
Hot Water Energy (kWh/cycle)	0.68	0.21	0.36	0.17	0.24	0.14	0.17	0.15	0.14	0.15	0.14	0.15	0.14	0.15
Machine Energy (kWh/cycle)	0.15	0.17	0.15	0.21	0.29	0.17	0.21	0.28	0.17	0.28	0.17	0.28	0.17	0.28
Dryer Energy (kWh/cycle)	1.02	1.31	1.34	1.22	1.19	1.22	1.22	1.37	1.22	1.37	1.22	1.37	1.22	1.37
Retail Equipment Cost (2017$)	550	550	600	600	600	600	600	600	700	700	700	700	700	700
	700	700	1,000	1,100	1,000	1,200	1,100	1,200	1,200	1,300	1,200	1,300	1,200	1,300
Total Installed Cost (2017$)	700	700	750	750	750	750	750	1350	750	1350	750	1350	750	1350
	850	850	1150	1250	1150	1350	1250	1350	1350	1350	1350	1350	1350	1350
Annual Maintenance Cost (2017$)	10	10	10	10	10	10	10	10	10	10	10	10	10	10

*2009 installed base value is equivalent to 2.07 Modified Energy Factor (MEF). The efficiency metric changed from Modified Energy Factor to Integrated Modified Energy Factor (IMEF) in 2015.
**2009 installed base value is equivalent to 6.2 Water Factor (WF). The efficiency metric changed from Water Factor to Integrated Water Factor (IWF) in 2015.

Same as reference case

DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (ft^3)	3	3.28	3.3	3.3	4.5	4.9	3.9	4.9	4.5	4.9	4.5	4.9	4.5	4.9
Integrated Modified Energy Factor (ft^3/kWh/cycle)*	0.78	1.14	1.29	1.29	2.06	2.76	1.57	2.76	2.06	2.76	2.06	2.76	2.06	2.76
Integrated Water Factor (gal/cycle/ft^3)**	12.4	9.2	8.4	8.4	4.3	3.5	6.5	3.5	4.3	3.5	4.3	3.5	4.3	3.5
Average Life (yrs)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Water Consumption (gal/cycle)	37	30	28	28	19	17	25	17	19	17	19	17	19	17
Hot Water Energy (kWh/cycle)	2.25	0.90	0.77	0.77	0.36	0.18	0.71	0.18	0.36	0.18	0.36	0.18	0.36	0.18
Machine Energy (kWh/cycle)	0.28	0.25	0.26	0.26	0.15	0.12	0.24	0.12	0.15	0.12	0.15	0.12	0.15	0.12
Dryer Energy (kWh/cycle)	1.31	1.73	1.50	1.50	1.65	1.46	1.51	1.46	1.65	1.46	1.65	1.46	1.65	1.46
Retail Equipment Cost (2017$)	550	450	400	400	600	750	400	750	500	750	500	750	500	750
	700	550	600	600	1,000	1,200	600	1,200	700	1,200	700	1,200	700	1,200
Total Installed Cost (2017$)	700	600	550	550	750	900	550	900	650	900	650	900	650	900
	850	700	750	750	1150	1350	750	1350	850	1350	850	1350	850	1350
Annual Maintenance Cost (2017$)	10	10	10	10	10	10	10	10	10	10	10	10	10	10

*2009 installed base value is equivalent to 1.2 Modified Energy Factor (MEF). The efficiency metric changed from Modified Energy Factor to Integrated Modified Energy Factor (IMEF) in 2015.

**2009 installed base value is equivalent to 12 Water Factor (WF). The efficiency metric changed from Water Factor to Integrated Water Factor (IWF) in 2015.

- The analysis treats front- and top-loading models separately due to their different energy use characteristics.
- Federal standards[1] for standard-capacity clothes washers (≥ 1.6 cubic feet):

	Integrated Modified Energy Factor		Integrated Water Factor	
	Top-Loading	Front-Loading	Top-Loading	Front-Loading
Current DOE Standard (effective 3/7/2015)	≥ 1.29	≥ 1.84	≤ 8.4	≤ 4.7
Current ENERGY STAR (effective 3/7/2015)	≥ 2.06	≥ 2.38	≤ 4.3	≤ 3.7
Future DOE Standard (effective 1/1/2018)	≥ 1.57	≥ 1.84 (no change)	≤ 6.5	≤ 4.7 (no change)
Future ENERGY STAR (effective 1/1/2018)	≥ 2.06 (no change)	≥ 2.76	≤ 4.3 (no change)	≤ 3.2

- In 2017, around 30% of top-loading models and almost all front-loading models achieve the ENERGY STAR level.
- Energy efficiency improvement opportunities include:
  - Higher efficiency motors and higher spin speeds
  - Better load sensing for adaptive water fill control
  - Reduced water temperature and quantity, while providing equivalent cleaning and rinsing performance
- Maintenance costs include replacement or repair of the drain pump, control board, motor, rubber gaskets, or control panel knobs.
- The products on the market with the highest Integrated Modified Energy Factor have significantly larger capacity and therefore use more energy per cycle than typical, smaller capacity products but still perform more efficiently on a per volume basis.

[1]Energy Conservation Standards for Consumer Clothes Washers. 10 CFR 430.32(g).

Shipment volumes have returned to pre-housing boom levels. Front-loaders' market share peaked in 2010 at just under 50% and has since declined to around 40%.

Sources: *Appliance Magazine;* Residential Clothes Washer Direct Final Rule TSD, EERE, April 2012; ENERGY STAR shipments data 2015-2016. Dashed lines indicate extrapolated/interpolated data.

Residential Dishwashers

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Same as reference case

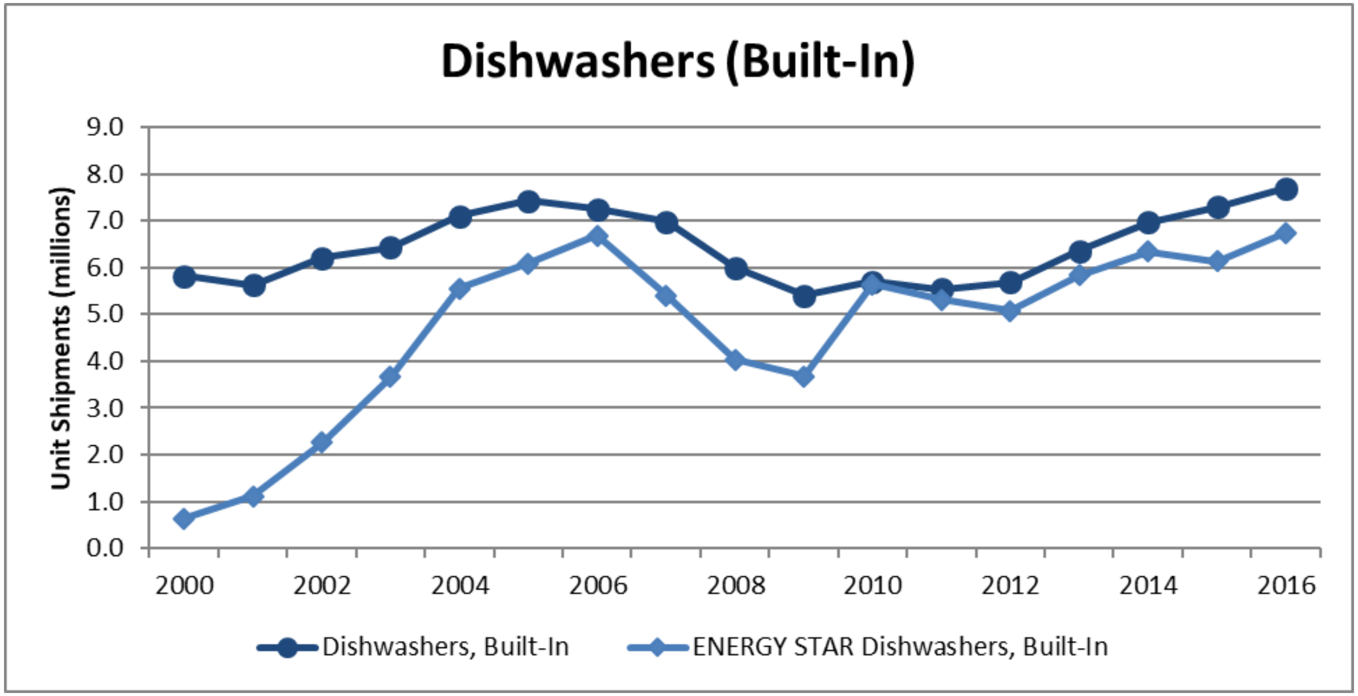
DATA	2009	2015	2017				2020		2030		2040		2050	
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Annual Energy Use (kWh/yr)	383	347	307	270	270	225	270	225	270	225	270	225	270	225
Water Consumption (gal/cycle)	6.88	6.23	5.00	3.50	3.50	2.40	3.50	2.40	3.50	2.40	3.50	2.40	3.50	2.40
Water Heating Energy Use (kWh/yr)*	249	226	176	125	125	86	125	86	125	86	125	86	125	86
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Retail Equipment Cost (2017$)**	365	370	260	320	320	390	320	390	320	390	320	390	320	390
Total Installed Cost (2017$)**	705	710	425	485	485	555	485	555	485	555	485	555	485	555
Annual Maintenance Cost (2017$)***	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Refers to that portion of "Typical Annual Energy Use" that is the energy used to heat water in a separate water heater before it enters the dishwasher. The energy used to heat water inside the dishwasher cannot be disaggregated from the total.
** Equipment and installation cost estimates changed significantly between the 2012 DOE analysis, the source for installed base costs, and the 2016 DOE analysis, the source for costs in 2017 and later.
*** Maintenance costs are negligible.
Note: All values in table reflect 215 cycles/year, as dictated by the test procedure.

- Performance criteria for standard-capacity dishwashers (assumes 215 cycles/year[1]):
  - Federal Standards:
    - Jan. 1, 2010: ≤ **355** kWh/yr, ≤ **6.5** gal/cycle (EISA 2007)
    - May 30, 2013: ≤ **307** kWh/yr, ≤ **5.0** gal/cycle (DOE Direct Final Rule, published May 2012)
  - ENERGY STAR Criteria:
    - Aug. 11, 2009 : ≤ **324** kWh/yr, ≤ **5.8** gal/cycle (version 4.0, announced Nov. 2008)
    - Jan. 20, 2012: ≤ **295** kWh/yr, ≤ **4.25** gal/cycle (version 5.0, announced April 2011)
    - Jan. 29, 2016: ≤ **270** kWh/yr (5% allowance for connected), ≤ **3.5** gal/cycle (version 6.0, announced April 2015)
- ENERGY STAR has maintained a very high market share for several years, so sales-weighted-average efficiency has tracked ENERGY STAR levels.
- Test procedures:
  - Accounts for motor, dryer, booster heater (if present), and hot water from separate water heater
  - Amended test procedure, which took effect May 30, 2013, includes standby and off-mode energy
  - ENERGY STAR established a cleaning performance test method; however, cleaning performance reporting is currently optional.
- Efficiency improvement opportunities include:
  - Better soil sensing
  - Water distribution (small pipes, fine filter, small sump, alternating water use) and controls (flow meter, temperature sensor)
  - Inline water heater (to minimize sump volume)
  - Separate drain pump, high-efficiency, variable-speed circulation pump motor
  - Condensation drying (rather than power dry)

[1] 215 cycles/year is assumed in the current test procedure and current standard. In the 2016 DOE “Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers” the energy use and economic analyses were updated to include RECS 2009 data which resulted in a value of 207 cycles/year.

Shipments peaked in 2005 during the housing boom, dropped during the 2008-2009 recession, and reached a new high in 2016.



Sources: *DOE Residential Dishwashers Final Rule Technical Support Document (Table 3.9.2); ENERGY STAR Unit Shipment and Market Penetration Report, Calendar Year 2016 Summary; Appliance Magazine*

Higher typical efficiency in 2020.

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400	400	400	400	400	400
Thermal Efficiency (%)*	80	80	80	95	81	95	81	95	81	95	81	95
Average Life (yrs)	23	23	23	23	23	23	23	23	23	23	23	23
Retail Equipment Cost ($)	1,050	1,050	1,050	2,450	1,050	2,450	1,050	2,450	1,050	2,450	1,050	2,450
Total Installed Cost ($)	2,150	2,150	2,150	3,950	2,200	3,950	2,200	3,950	2,200	3,950	2,200	3,950
Annual Maintenance Cost ($)**	170	170	170	180	170	180	170	180	170	180	170	180

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.
**In 2023, the new Energy Conservation Standards for Commercial Warm Air Furnaces will take effect. These projections reflect the 2023 minimum thermal efficiency requirement for gas-fired furnaces, 81%.

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- Current Federal standard requires minimum 80% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applies to all units manufactured on or after January 1, 1994 with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increases to 81% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial furnaces are typically non-condensing with thermal efficiencies ranging from 80% to 82%. Recently condensing commercial furnaces have been introduced, which achieve up to 95% thermal efficiency. However, condensing models currently make up a very small portion of the market.
- Besides capacity, commercial units can differ from residential furnaces in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.
- Advanced Case: Slightly increased typical efficiency products in 2020 due to market incentives. No significant changes otherwise.

Commercial Oil-Fired Furnaces

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Same as reference case

DATA	2012	2017			2020	2030**	2040	2050
	Installed Base	Current Standard	Typical	High	Typical	Typical	Typical	Typical
Typical Input Capacity (kBtu/h)	400	400	400	400	400	400	400	400
Thermal Efficiency (%)*	81	81	82	85	82	82	82	82
Average Life (yrs)	23	23	23	23	23	23	23	23
Retail Equipment Cost ($)	4,650	4,650	4,700	5,050	4,700	4,700	4,700	4,700
Total Installed Cost ($)	6,550	6,550	6,600	6,750	6,600	6,600	6,600	6,600
Annual Maintenance Cost ($)**	300	300	300	300	300	300	300	300

* DOE's efficiency metric for commercial furnaces accounts only for flue losses, not jacket losses.
**In 2023, the new Energy Conservation Standards for Commercial Warm Air Furnaces will take effect. These projections reflect the 2023 minimum thermal efficiency requirement for oil-fired furnaces, 82%.

- Current Federal standard requires minimum 81% thermal efficiency. This metric, more commonly called "combustion efficiency" in other contexts, accounts only for flue losses, not jacket losses.
  - The Federal standard applies to all units manufactured on or after January 1, 1994 with maximum rated heat input ≥ 225,000 Btu per hour.
  - On January 1, 2023, the minimum Federal standard increases to 82% thermal efficiency.
- ASHRAE Standard 90.1, which is used as a commercial building code in many states, stipulates that furnaces that are not within the conditioned space shall not have jacket losses exceeding 0.75% of the input rating.
- Commercial oil-fired furnaces have thermal efficiencies ranging from 81% to 85% and are non-condensing (i.e., not designed for condensation of flue gases).
- Besides capacity, commercial units can differ in terms of the control system (i.e. integration with a Building Management System, twinning, or other staging strategies). Commercial systems may also use a heat recovery system to pre-heat inlet air.
- The maintenance cost estimate assumes two cleanings per year.

Commercial Electric Resistance Heaters

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Same as reference case

DATA	2012		2017		2020		2030		2040		2050	
	Installed Base: Small	Installed Base: Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
Typical Capacity (kBtu/h)*	17	170	17	170	17	170	17	170	17	170	17	170
Efficiency (%)	100	100	100	100	100	100	100	100	100	100	100	100
Average Life (yrs)	18	18	18	18	18	18	18	18	18	18	18	18
Retail Equipment Cost ($)	850	5,375	850	5,375	850	5,375	850	5,375	850	5,375	850	5,375
Total Installed Cost ($)	1,050	6,350	1,050	6,350	1,050	6,350	1,050	6,350	1,050	6,350	1,050	6,350
Annual Maintenance Cost ($)**	-	-	-	-	-	-	-	-	-	-	-	-

* Capacity is *output*
** Annual Maintenance Cost is negligible

- This analysis examined electric unit heaters.
- Electric unit heaters range in capacity from 2 to 100 kW (7 to 340 kBtu/hr), with 5 to 50 kW (17 to 170 kBtu/hr) being the most typical units on the market.
- Electric resistance heaters are considered near 100% efficient because there is no heat loss through ducts or combustion.
- Installation time and costs are estimated to be minimal.

Commercial Electric Boilers

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Same as reference case

DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (kW)*	165	165	165	165	165	165
Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($)	9,875	9,850	9,850	9,850	9,850	9,850
Total Installed Cost ($)	14,875	11,750	11,750	11,750	11,750	11,750
Annual Maintenance Cost ($)	145	110	110	110	110	110

* Capacity is *output*

- There are currently no federal standards associated with electric boilers.
- The costs shown are for one 165kW unit, which would equate to a steady load of approximately 550,000 Btu/hr.
- Service life is determined mainly by water quality. Water conditioning (e.g., filters, softeners, de-alkizers, chemical feeders) may be necessary for a given application.
- Annual maintenance in a typical application would include draining the unit for removal of any accumulated scale or sludge buildup.
- Minor end-use inefficiencies for electric boilers result from heat loss through the boiler (jacket losses).

Commercial Gas-Fired Boilers

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Higher typical efficiencies with corresponding cost increases.

DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard *	Typical	Mid-Range	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	800	800	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)**	77	80	85	93	99	85	99	94	99	95	99	95	99
Average Life (yrs)	30	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	13,150	16,600	22,700	33,250	37,500	22,700	37,500	33,700	37,500	34,250	37,500	34,250	37,500
Total Installed Cost ($)	20,825	25,800	32,450	42,650	46,750	32,450	46,750	43,100	46,750	43,600	46,750	43,600	46,750
Annual Maintenance Cost ($)***	1,445	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800

* The standard level shown here is for small (300 kBtu/h to 2500 kBtu/h) gas-fired hot water commercial packaged boilers, the most common type of boiler available on the market.
** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.
*** The updated maintenance costs for 2017 and post-2017 are based on the recently issued commercial packaged boilers final rule. The annualized maintenance costs estimated in the final rule are based on 2016 RS Means data and differ for condensing vs non-condensing boilers. Appendix 8E of the 2016 final rule TSD for commercial packaged boilers provides additional information on how the values are calculated. The cost values in the table are for gas-fired hot water CPBs.

Note: In December of 2016, EREE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. As of October 2017, this rule has not yet been published and therefore these standards are not reflected in the values shown above.

- Commercial packaged gas-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
  - Draft type (natural draft or not) – for steam boilers
- Most common type is small gas-fired hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- Federal standards require thermal efficiency ≥ 77%, 79%, or 80%, depending on type.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Large gas-fired hot water boilers i.e., boilers with rated heat input greater than 2,500,000 Btu/h are required to have *combustion* efficiency ≥ 82%.
- Similar technologies to the those used in the residential market can be leveraged in the commercial arena. The higher efficiency units typically include electronic ignition, power burners, and improved heat exchangers. Some also condense water vapor from the flue gases to improve heating efficiency.
- DOE issued a Final Rule for Energy Conservation Standards for Commercial Packaged Boilers on December 28, 2016 that would update the efficiency ratings of gas-fired commercial packaged boilers.
- Advanced Case: Condensing gas-fired boilers are expected to dominate the market by 2030, with corresponding price increases.

Commercial Oil-Fired Boilers

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017		2020		2030		2040		2050			
	Installed Base	Current Standard*	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Input Capacity (kBtu/h)	1,200	800	800	800	800	800	800	800	800	800	800	800
Thermal Efficiency (%)**	81	82	85	97	85	97	92	97	92	97	92	97
Average Life (yrs)	30	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($)	14,250	19,800	22,850	44,550	22,850	44,550	22,850	44,550	22,850	44,550	22,850	44,550
Total Installed Cost ($)	18,625	28,000	31,500	53,250	31,500	53,250	31,500	53,250	31,500	53,250	31,500	53,250
Annual Maintenance Cost ($)***	1445	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300

* The standard level shown here is for small (300 kBtu/h -2500 kBtu/h) oil-fired hot water commercial packaged boilers, the most common type of oil-fired boiler available on the market.

** DOE's efficiency metric for most types of boilers now accounts for both flue and jacket losses; previously it did not. DOE continues to uses a combustion efficiency metric instead for hot water boilers with heat input > 2,500,000 Btu/h.

*** The updated maintenance costs for 2017 and post-2017 are based on the recently issued commercial packaged boilers final rule. The annualized maintenance costs estimated in the final rule are based on 2016 RS Means data and differ for condensing vs non-condensing boilers. Appendix 8E of the 2016 final rule TSD for commercial packaged boilers provides additional information on how the values are calculated. The cost values in the table are for oil-fired hot water CPBs.

Note: In December of 2016 EREE issued a final rule titled Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers. As of October 2017, this rule has not yet been published and therefore these standards are not reflected in the values shown above.

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- Commercial packaged oil-fired boilers are classified by:
  - Heat input capacity
  - Produce steam or hot water
- Most common type is small hot water boilers, those with 300,000-2,500,000 Btu/h rated heat input.
- DOE's efficiency metric, thermal efficiency, now aligns with ASHRAE 90.1 and accounts for both flue and jacket losses.
- Federal standards require thermal efficiency ≥ 81% for steam boilers and ≥ 82% for hot water boilers.
- Exception is large hot water boilers, which must have *combustion* efficiency ≥ 84%.
- The higher efficiency units typically include improved heat exchangers, and multi-step or variable-output power burners.
- Based on current shipment trends, projected shipments of oil-fired CPBs post-2017 are expected to decrease with time.
- DOE issued a Final Rule for Energy Conservation Standards for Commercial Packaged Boilers on December 28, 2016 that would update the efficiency ratings of oil-fired commercial packaged boilers.
- Advanced Case: Increased adoption of condensing oil-fired boilers by 2030. However, due to low demand and a shrinking market, costs are expected to remain the same.

Commercial Centrifugal Chillers (Water Cooled)

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Higher efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	ASHRAE 90.1**	Typical***	High***	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)*	400	400	400	400	400	400	400	400	400	400	400	400
	600	600	600	600	600	600	600	600	600	600	600	600
Efficiency [full-load] (kW/ton)	0.66	0.56	0.53	0.45	0.48	0.43	0.44	0.40	0.41	0.39	0.40	0.38
Efficiency [IPLV] (kW/ton)	0.61	0.50	0.37	0.30	0.35	0.28	0.34	0.26	0.33	0.24	0.32	0.23
COP [full-load]	5.4	6.3	6.6	7.8	7.3	8.2	8.0	8.7	8.5	8.9	8.7	9.2
COP [IPLV]	5.9	7.0	9.5	11.7	10.0	12.4	10.5	13.6	10.8	14.7	11.1	15.3
Average Life (yrs)	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost ($/ton)	325	400	425	575	425	575	425	575	425	575	425	575
Total Installed Cost ($/ton)	375	450	475	625	475	625	475	625	475	625	475	625
	425	475	500	650	500	650	500	650	500	650	500	650
Annual Maintenance Cost ($/ton)	25	25	25	25	25	25	25	25	25	25	25	25
	35	35	35	35	35	35	35	35	35	35	35	35

* Capacity is *output*

**ASHRAE 90.1 data here are for units larger than 400 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

***2017 typical and high efficiency levels determined base on the range of products currently available on the market.

Note: For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

- ASHRAE 90.1-2016 stipulates minimum efficiencies for centrifugal chillers separately from positive displacement water-cooled chillers. They are separated into 5 size categories, with categories divided at: 150, 300, 400, and 600 tons; ASHRAE 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly high full-load consumption in exchange for much lower part-load consumption. For example, for a 600 Ton unit:
  - Path A: ≥ 0.56 kW/ton full load and ≥0.50 kW/ton IPLV
  - Path B: ≥ 0.585 kW/ton full load and ≥.38 kW/ton IPLV
- Federal Energy Management Program (FEMP) recommendations, last updated in Aug 2016, match ASHRAE 90.1-2016.
- The highest efficiency centrifugal chillers incorporate some of the following:
  - Variable speed drive (VSD) compressors
  - Dedicated heat recovery (heat pump chiller)
  - Magnetic bearing technology (oil-free operation)
  - Greater heat exchanger surface areas; enhanced tube configurations (counterflow)
  - Optimized fluid flow velocities
  - High efficiency electric motors
  - Improved turbomachinery design, resulting in higher compressor efficiency
  - Better piping and valving, including electronic expansion valves
  - Evaporative condenser for the heat rejection equipment
- Installed costs vary widely depending on equipment needed for installation (e .g. crane) and size of system. This is a mature market with centrifugal chillers representing 75% of commercial chiller sales larger than 200 tons.
- Water cooled chiller ratings do not include energy consumption of the cooling tower and therefore are not directly comparable to rating for air-cooled chillers.
- Advanced Case: Due to increases in R&D, improvements in current technology are expected to increase efficiency without substantially increasing costs.

Commercial Reciprocating Chillers (Air Cooled Only)

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Same as reference case

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	ASHRAE 90.1[2]	Typical[3]	High[3]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[4]	100	100	100	100	100	100	100	100	100	100	100	100
	200	200	200	200	200	200	200	200	200	200	200	200
Efficiency [full-load] (kW/ton)[1]	1.26	1.19	1.19	1.00	1.15	1.00	1.15	1.00	1.15	1.00	1.15	1.00
Efficiency [IPLV] (kW/ton)[1]	1.13	0.86	0.86	0.79	0.80	0.79	0.80	0.79	0.80	0.79	0.80	0.79
COP [full-load][1]	2.8	3.0	3.0	3.5	3.1	3.5	3.1	3.5	3.1	3.5	3.1	3.5
COP [IPLV] [1]	3.1	4.1	4.1	4.5	4.4	4.5	4.4	4.5	4.4	4.5	4.4	4.5
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	725	750	750	875	750	875	750	875	750	875	750	875
	600	650	650	750	650	750	650	750	650	750	650	750
Total Installed Cost ($/ton)	800	850	850	1000	850	1000	850	1000	850	1000	850	1000
	700	700	700	925	700	925	700	925	700	925	700	925
Annual Maintenance Cost ($/ton)	45	45	45	45	45	45	45	45	45	45	45	45
	25	25	25	25	25	25	25	25	25	25	25	25

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

[2] ASHRAE 90.1 data here are for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

[3] 2017 typical and high efficiency levels determined base on the range of products currently available on the market.

[4] Capacity is *output*

- Reciprocating chillers are most cost effective for small loads (30-150 ton range). However, reciprocating chiller market share continues to be supplanted by screw and scroll chillers. This trend has accelerated with the phase out of R-22, which was the refrigerant of choice for reciprocating products, which has in turn driven major manufacturers to replace their reciprocating product lines with scroll products (rather than redesign reciprocating products for new refrigerants). As a result, product options are very limited.
- Reciprocating chillers can be used in either air-cooled or water cooled applications. Reciprocating chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2016 stipulates minimum efficiencies for all air-cooled chillers together, including reciprocating chillers, while water-cooled chillers are separated by positive displacement (e.g., reciprocating) versus centrifugal models. Air cooled chiller efficiencies are further split by size for more and less than 150 tons. ASHRAE 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100 Ton unit:
  - Path A: ≥10.1 EER full load and ≥13.7 IPLV EER
  - Path B: ≥9.7 EER full load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated August 2016) are:
  - Path A (<150 tons): ≥10.4 EER full load and ≥13.7 IPLV EER
  - Path B (<150 tons): ≥9.7 EER full load and ≥15.8 IPLV EER (same as 90.1-2016)
- The highest efficiency reciprocating chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers

Commercial Screw Chillers (Air Cooled Only)

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Higher efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	ASHRAE 90.1[2]	Typical[3]	High[3]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[4]	100	100	100	100	100	100	100	100	100	100	100	100
	300	300	300	300	300	300	300	300	300	300	300	300
Efficiency [full-load] (kW/ton)[1]	1.26	1.19	1.18	0.94	1.11	0.91	0.99	0.86	0.93	0.77	0.89	0.73
Efficiency [IPLV] (kW/ton)[1]	1.13	0.86	0.84	0.57	0.77	0.53	0.65	0.49	0.61	0.43	0.59	0.39
COP [full-load][1]	2.8	3.0	3.0	3.7	3.2	3.9	3.6	4.1	3.8	4.6	3.9	4.8
COP [IPLV] [1]	3.1	4.1	4.2	6.2	4.5	6.6	5.4	7.2	5.7	8.2	6.0	9.0
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	525	725	725	800	725	800	725	800	725	800	725	800
	650	825	825	900	825	900	825	900	825	900	825	900
Total Installed Cost ($/ton)	725	800	800	900	800	900	800	900	800	900	800	900
	775	975	975	1,050	975	1,050	975	1,050	975	1,050	975	1,050
Annual Maintenance Cost ($/ton)	20	20	20	20	20	20	20	20	20	20	20	20
	45	45	45	45	45	45	45	45	45	45	45	45

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

[2] ASHRAE 90.1 data here are for units larger than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

[3] 2017 typical and high efficiency levels determined base on the range of products currently available on the market.

[4] Capacity is *output*

- Screw chillers are common in 150 - 500 ton capacities, but are most cost effective for small (<300 tons) loads; screw chillers dominate the current market for small to mid-size chillers.
- Screw chillers can be used in either air-cooled or water cooled applications. Screw chillers shown in the data are air-cooled. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2016 stipulates minimum efficiencies for all air-cooled chillers together, including screw chillers, while water cooled chillers are separated by positive displacement (e.g., screw) versus centrifugal models. Air cooled chiller efficiencies are further split by size for more and less than 150 tons. 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100 Ton unit:
  - Path A: ≥10.1 EER full load and ≥13.7 IPLV EER
  - Path B: ≥9.7 EER full load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated August 2016) are:
  - Path A (<150 tons): ≥10.4 EER full load and ≥13.7 IPLV EER
  - Path B (<150 tons): ≥9.7 EER full load and ≥15.8 IPLV EER (same as 90.1-2016)
- The highest efficiency screw chillers incorporate some of the following:
  - Variable speed compressors and/or multiple compressors
  - Economizers
  - Improved heat-exchangers
- Advanced Case: Due to increases in R&D, improvements in current technology are expected to increase efficiency without substantially increasing costs.

Commercial Scroll Chillers (Air-Cooled Only)

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Higher efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	ASHRAE 90.1[2]	Typical[3]	High[3]	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (tons)[4]	50	50	50	50	50	50	50	50	50	50	50	50
	140	140	140	140	140	140	140	140	140	140	140	140
Efficiency [full-load] (kW/ton)[1]	1.23	1.19	1.16	1.10	1.14	1.08	1.08	1.03	1.04	0.99	0.99	0.94
Efficiency [IPLV] (kW/ton)[1]	0.99	0.88	0.77	0.72	0.75	0.70	0.71	0.66	0.69	0.63	0.67	0.60
COP [full-load][1]	2.9	3.0	3.0	3.2	3.1	3.3	3.3	3.4	3.4	3.6	3.6	3.7
COP [IPLV] [1]	3.7	4.0	4.6	4.9	4.7	5.0	5.0	5.3	5.1	5.6	5.3	5.8
Average Life (yrs)	20	20	20	20	20	20	20	20	20	20	20	20
Retail Equipment Cost ($/ton)	475	650	700	800	700	800	700	800	700	800	700	800
	575	800	850	950	850	950	850	950	850	950	850	950
Total Installed Cost ($/ton)	725	775	825	925	825	925	825	925	825	925	825	925
	825	975	1,025	1,125	1,025	1,125	1,025	1,125	1,025	1,125	1,025	1,125
Annual Maintenance Cost ($/ton)	35	35	35	35	35	35	35	35	35	35	35	35
	50	50	50	50	50	50	50	50	50	50	50	50

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value.

[2] ASHRAE 90.1 data here are for units smaller than 150 tons and for full-load optimized applications (Path A in ASHRAE 90.1-2016)

[3] 2017 typical, mid, and high efficiency levels determined base on the range of products currently available on the market.

[4] Capacity is *output*

- Scroll chillers range in size from ~20 tons to ~200 tons and can be used in either air-cooled or water cooled applications. They are the most common type of chiller for small chiller plants. The scroll chillers shown in the data are air-cooled, which is most common. Air-cooled chillers are less efficient than the water-cooled models. Listed efficiencies include matched condensers and their associated energy use.
- ASHRAE 90.1-2016 stipulates minimum efficiencies for all air-cooled chillers together, including scroll chillers, while water cooled chillers are separated by positive displacement (e.g., scroll) versus centrifugal models. Air cooled chiller efficiencies are distinct for more and less than 150 tons. 90.1-2016 also distinguishes between whether the unit will be optimized for full load (Path A) or part load operation (Path B). Data here are for Path A; a Path B chiller may have slightly lower full-load efficiency in exchange for much higher part-load efficiency. For example, for a 100 Ton unit:
  - Path A: ≥10.1 EER full load and ≥13.7 IPLV EER
  - Path B: ≥9.7 EER full load and ≥ 15.8 IPLV EER
- FEMP recommendations for air-cooled chillers (updated Aug. 2016) are:
  - Path A (<150 tons): ≥10.4 EER full load and ≥13.7 IPLV EER
  - Path B (<150 tons): ≥9.7 EER full load and ≥15.8 IPLV EER (same as 90.1-2016)
- The highest efficiency scroll chillers incorporate some of the following:
  - Multiple compressors for staged capacity control
  - Improved heat-exchangers
  - Variable speed compressor (or other modulation controls)
- With the phase out of R-22, manufacturers have replaced many of their small reciprocating chiller products with equivalent scroll products, making them a primary choice for small tonnage applications.
- Advanced Case: Due to increases in R&D, improvements in current technology are expected to increase efficiency without substantially increasing costs.

Commercial Gas-Fired Chillers (Water-Cooled, Direct-Fired Only)

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Same as reference case

DATA	2012		2017				2020		2030		2040		2050	
	Installed Base: Absorption	Installed Base: Engine-Driven	ASHRAE 90.1 Absorption	CA Title 24 - Engine	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven	Absorption	Engine-Driven
Typical Capacity (tons)[2]	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400	1,500	400
COP [full-load]	1.1	1.7	1.0	1.2	1.2	1.7	1.3	1.8	1.4	1.8	1.4	1.8	1.4	1.8
COP [IPLV]	NA	NA	1.0	2.0	1.6	2.6	1.6	2.6	1.6	2.6	1.6	2.6	1.6	2.6
Average Life (yrs)	23	25	23	25	23	25	23	25	23	25	23	25	23	25
Retail Equipment Cost ($/ton)	750	750	750	750	750	750	750	750	750	750	750	750	750	750
	900	850	850	850	900	850	900	850	900	850	900	850	900	850
Total Installed Cost ($/ton)	850	850	850	850	850	850	850	850	850	850	850	850	850	850
	1,100	1,050	975	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050	1,000	1,050
Annual Maintenance Cost ($/ton)	20	35	20	35	20	35	20	35	20	35	20	35	20	35
	35	50	35	50	35	50	35	50	35	50	35	50	35	50

[1] For most chillers (including those in single-chiller applications and for peaking units in multi-chiller applications, the seasonal performance (represented by the integrated part-load value; IPLV) is more indicative of annual expected performance than the full-load performance; performance of baseload chillers in multi-chiller applications, which typically operate at full load, are well represented by the full load efficiency value. For the 2012 analysis, IPLV was not evaluated and is therefore not available (NA).

[2] Capacity is *output*

- Gas-fired chillers are available as either air-cooled (~25-50 tons) or water-cooled (150+ tons). This analysis covers only water-cooled chillers of two varieties: absorption and engine-driven vapor compression (direct-fired only; indirect steam or hot water driven units are excluded).
- Direct gas firing provides high enough temperatures to operate double effect absorption chillers, which operate at a 50-60% higher COP than single effect systems. Triple effect chillers, though not commercially available, can boost cooling COP 30-50% beyond double effect chillers. York, Trane, and others have worked on prototype direct-fired triple effect absorption chillers, but prohibitively high cost of advanced high heat/corrosion-resistant materials required for triple effect absorption chillers suggest that this technology will not likely have an impact on the market in the near-term.
- Gas-fired engine-driven chillers pair conventional vapor compression systems(typically screw or centrifugal compressors) with natural gas powered-reciprocating engines. They exhibit higher peak cooling COP than absorbers, and engine modulation results in better part load performance. Future efficiency improvements for engine-driven chillers are not anticipated. Engine driven chillers allow the opportunity to recover waste heat for useful purposes.
- Maintenance costs for engine driven chillers are higher than for other chillers are they include all the typical components of a vapor compression chiller in addition to an engine; The engine maintenance costs vary depending on the annual run hours of the unit.
- Limited sales data suggest that the U.S. market for gas-fired chillers is very limited and is mostly for replacement units, not for new installations. Recent increases in electric chiller efficiency has narrowed the operating cost differential with gas chillers. Asia has the majority of the global gas-fired chiller market.
- Gas-fired chiller installations are particularly valuable in locations where electric rates are high and gas prices are low (i.e., low spark spread), where digester or landfill gas sources are available, or where waste heat sources are available (e.g., an industrial process or microturbine CHP system) that could be used with a hybrid direct/indirect-fired absorption chiller to offset the use of natural gas.

Commercial Rooftop Air Conditioners

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Higher efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017				2020***		2030****		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR**	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Output Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	10.6	11.2	11.3	11.7	12.8	11.8	12.8	12.2	12.8	12.4	12.8	12.6	12.8
Part Load Efficiency (IEER)*	12.4	-	11.6	11.8	21.5	13.1	21.5	16.0	21.5	16.5	21.5	17.5	21.5
Average Life (yrs)	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost ($)	6,600	6,600	6,600	6,650	10,350	7,150	10,350	7,150	10,350	7,150	10,350	7,150	10,350
Total Installed Cost ($)	8,800	8,800	8,800	9,400	14,900	10,250	14,900	10,250	14,900	10,250	14,900	10,250	14,900
Annual Maintenance Cost ($)	310	310	310	310	310	310	310	310	310	310	310	310	310

* Values shown are for air-cooled units with either electric resistance heating or no heating within the same enclosure.
** In 2018 the ENERGY STAR levels will change to 12.2 EER and 14.0 IEER.
*** In 2018, new energy conservation standards for Small (<135 kBtu/h) Commercial Packaged Air Conditioning and Heating Equipment will take effect. At this time the DOE-regulated metric will change from EER to IEER, and the minimum IEER will be 12.9.
**** In 2023, new energy conservation standards for Small (<135 kBtu/h) Commercial Packaged Air Conditioning and Heating Equipment will take effect. These projections reflect the 2023 minimum efficiency requirement, 14.8 IEER.

Air-Cooled Commercial Packaged Air Conditioners

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010 Min. EER	ENERGY STAR version 2.2 Effective 1/1/2011	
			Min. EER	Min. IEER
Small (≥ 65 and < 135)	Electric resistance or none	11.2	11.7	11.8
	Any other type	11.0	11.5	11.6
Large (≥ 135 and < 240)	Electric resistance or none	11.0	11.7	11.8
	Any other type	10.8	11.5	11.6

- This analysis focused on small air-cooled commercial packaged rooftop air conditioners (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial air conditioners.
- Amended standards in terms of IEER for all equipment classes will take effect in 2018. More stringent standards in terms of IEER for all equipment classes will take effect in 2023.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners

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Same as reference case

DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (tons)	18	11	11	11	11	11
Heating COP	1.4	1.4	1.4	1.4	1.4	1.4
Cooling COP	0.9	1.2	1.2	1.2	1.2	1.2
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost ($/ton)	2,850	2,400	2,400	2,400	2,400	2,400
	3,450	3,000	3,000	3,000	3,000	3,000
Total Installed Cost ($/ton)	3,250	2,800	2,800	2,800	2,800	2,800
	4,250	3,800	3,800	3,800	3,800	3,800
Annual Maintenance Cost ($)	62	62	62	62	62	62

* Only one product available in 2012, market has grown slightly in years since. Typical capacity and COP for 2017 and later are averages of units currently available.

Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners/Heat Pumps

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- There are only a few gas-fired engine-driven rooftop units currently available in the US market. The first unit was introduced in 2010. It is an 11 ton packaged heat pump with dual scroll compressors, variable refrigerant flow, and a variable speed supply fan. Engine coolant heat recovery improves the heating mode COP.
- There are currently no Federal requirements on gas-fired engine-driven rooftop air conditioners or heat pumps.
- Annual sales of the engine-driven rooftop heat pump are estimated at less than 5,000 units per year.

Commercial Rooftop Heat Pumps

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Higher efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017				2020***		2030****		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR**	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	90	90	90	90	90	90	90	90	90	90	90	90	90
Efficiency (EER)*	10.2	11.0	11.2	11.3	13.1	11.2	13.1	11.7	13.1	11.9	13.1	12.1	13.1
Part Load Efficiency (IEER)	12.0	-	11.3	11.4	20.3	12.4	20.3	15.0	20.3	15.5	20.3	16.5	20.3
COP (Heating)	3.3	3.3	3.3	3.4	3.7	3.3	3.7	3.4	3.7	3.4	3.7	3.5	3.7
Average Life (yrs)	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost ($)	6,050	7,000	7,100	7,150	11,000	7,750	11,000	8,750	11,000	8,750	11,000	8,750	11,000
Total Installed Cost ($)	7,550	9,900	10,100	10,200	16,050	11,150	16,050	12,750	16,050	12,750	16,050	12,750	16,050
Annual Maintenance Cost ($)	310	310	310	310	310	310	310	310	310	310	310	310	310

* Values shown are for air-cooled units with either electric resistance heating or no heating within the same enclosure.
** In 2018 the ENERGY STAR levels will change to 11.8 EER, 12.8 IEER, and 3.4 COP.
*** These efficiency levels reflect DOE's energy conservation standards for Small Commercial Packaged Air Conditioning and Heating Equipment with a 2018 compliance deadline. In 2018 the DOE-regulated metric will switch from EER to IEER, and the minimum IEER will be set at 12.2.
**** In 2023, new energy conservation standards for Small Commercial Packaged Air Conditioning and Heating Equipment will take effect. These projections reflect the 2023 minimum efficiency requirements IEER of 14.1 and COP of 3.4.

Air-Cooled Commercial Packaged Heat Pumps

Cooling Capacity (kBtu/h)	Heating Type	Federal Standard Effective 1/1/2010		ENERGY STAR version 2.2 Effective 1/1/2011		
		Min. EER	Min. COP at 47°F	Min. EER	Min. IEER	Min. COP at 47°F
Small (≥ 65 and < 135)	Electric resistance or none	11.0	3.3	11.3	11.4	3.35
	Any other type	10.8	3.3	–	–	–
Large (≥ 135 and < 240)	Electric resistance or none	10.6	3.2	10.9	11.0	3.25
	Any other type	10.4	3.2	–	–	–

- This analysis focused on small air-cooled commercial packaged rooftop heat pumps (90 kBtu/h or 7.5 tons), though there are also standards for many other types of commercial heat pumps.
- Amended standards in terms of IEER for all equipment classes will take effect in 2018. More stringent standards in terms of IEER for all equipment classes will take effect in 2023.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Higher efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	Mid	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	48	48	48	48	48	48	48	48	48	48	48	48	48
COP (Heating)*	3.1	3.2	3.7	3.8	4.0	3.7	4.0	3.7	4.0	3.7	4.0	3.8	4.0
EER (Cooling)**	12.7	14.1	17.4	19.7	22.1	17.4	22.1	18.0	22.1	18.5	22.1	19.0	22.1
Average Life (yrs)	8	8	8	8	8	8	8	8	8	8	8	8	8
	21	21	21	21	21	21	21	21	21	21	21	21	21
Retail Equipment Cost ($)	8,500	4,750	5,550	6,100	6,700	5,550	6,700	5,550	6,700	5,550	6,700	5,550	6,700
Total Installed Cost ($)	16,500	14,750	15,550	16,100	16,700	15,550	16,700	15,550	16,700	15,550	16,700	15,550	16,700
	37,500	21,750	22,550	23,100	23,700	22,550	23,700	22,550	23,700	22,550	23,700	22,550	23,700
Annual Maintenance Cost ($)	150	150	150	150	150	150	150	150	150	150	150	150	150

* COP values listed are assessed at a "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a "water loop" test condition. The AHRI directory lists COP ratings at both sets of test conditions and is used to convert between them where necessary.

** EER values listed are assessed at a full-load "ground loop" test condition, which is representative of closed loop GSHP operating conditions. However, DOE sets standards at a full-load "water loop" test condition. The AHRI directory lists EER ratings at all sets of test conditions and is used to convert between them where necessary.

Note: Residential and commercial GSHPs are very similar - the main difference in data presented is the different capacity (3-ton vs 4-ton) and slightly higher installation costs for commercial. DOE does not distinguish between residential and commercial units in its regulations.

- The most common commercial ground source heat pump systems are closed-loop in which water or anti-freeze solution is circulated through plastic pipes buried underground. Commercial water-to-air heat pumps (WAHPs) range in size from 1 ton or less to over 500 tons depending on whether a distributed or centralized architecture is used. Distributed systems are more prevalent.
- Most geothermal WAHPs are rated for capacity and efficiency based on the ISO 13256-1 standard. Heating and cooling efficiency measurements under this standard include input energy for fans and pumps on a proportional basis that only includes that power required to transport air and liquid through the heat pump. The reason for this method is to simplify comparisons between heat pumps and to allow equipment to be optimized for real world conditions without suffering rating penalties. Real world energy use will exceed ratings predictions as a result of higher fluid static pressure requirements.
- ISO 13256-1 cooling rating conditions call for 77F entering water temperature and 80.6F entering air temperature. More typical peak design criteria would be 80-90F entering water temperature and 75F entering air temperature. As a result, ISO 13256-1 rated cooling efficiency would be higher than typical design peak operation.
- Some WAHPs include efficiency data for a part load operating condition as allowed by ISO 13256-1 for multiple stage or variable speed compressors. No seasonal energy efficiency metric (analogous to SEER or IEER) currently applies to WAHPs. The annual performance of a geothermal WAHP system can vary more widely than for other system types due to the large influence of ground loop design and characteristics.
- The ENERGY STAR® criteria for ground source heat pumps apply only to residential applications.
- Installation cost is for a closed loop system and includes necessary accessories. The ground loop heat exchanger and distribution pumping systems represent a majority of the installation cost.
- Low end WAHPs utilize single stage compressors. Higher efficiency units incorporate multiple stage or variable speed compressor controls to improve efficiency as well as humidity and temperature control. Variable speed electronically commutated (EC) fan motors also improve overall energy efficiency.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more advanced compressors, fan motors) are expected to increase efficiency without substantially increasing costs.

Commercial Gas-Fired Storage Water Heaters

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Higher typical efficiencies with the same equipment costs as ref. case despite increased efficiency. Installation costs are higher for condensing than for non-condensing in replacement installations.

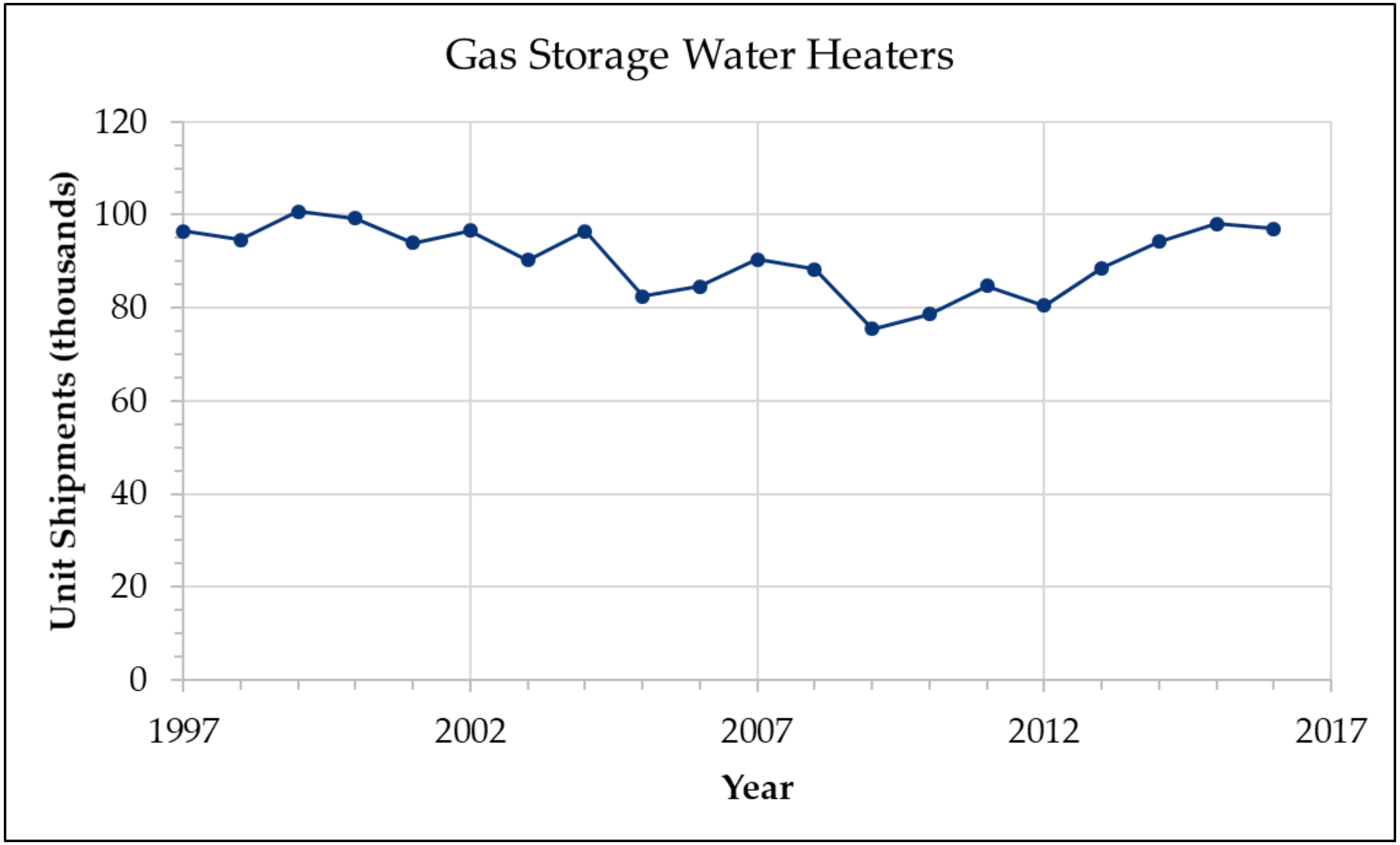
DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	100	100	100	100	100	100	100	100	100	100	100	100	100
Typical Input Capacity (kBtu/h)	199	199	199	199	199	199	199	199	199	199	199	199	199
Thermal Efficiency (%)	81	80	82	94	99	82	99	92	99	95	99	96	99
Average Life (yrs)	13	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2017$)**	3,400	3,300	3,450	3,950	4,050	3,450	4,050	3,300	4,050	3,300	4,050	3,300	4,050
	4,200	4,100	4,300	4,850	4,950	4,300	4,950	4,100	4,950	4,100	4,950	4,100	4,950
Total Installed Cost (2017$)**	4,200	4,150	4,300	5,450	5,550	4,300	5,550	4,350	5,550	4,350	5,550	4,350	5,550
	6,050	5,950	6,150	6,500	6,600	6,150	6,600	6,150	6,600	6,150	6,600	6,150	6,600
Annual Maintenance Cost (2017$)	270	270	270	270	270	270	270	270	270	270	270	270	270

*Different levels of standby loss were not included in this analysis.
**The range of retail and installed costs represent the range from replacement market to new construction market.

- Input capacity ≥ 75,000 Btu/h, and < 4,000 Btu/h per gallon of stored water
- Federal standard[1]:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h) : Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
  - Maximum standby loss (Btu/h): 0.84 × [(Input Rate/800) + 110 × (Rated Volume)$^{1/2}$]
- Baseline units are typically constructed similarly to residential units, though with higher input capacities (and often higher storage volumes).
- High-efficiency units include condensing heat exchangers (typically stainless or enameled steel) to extract additional heat by condensing water vapor in flue gases. Condensing units also include an inducer fan system or power burner. The heat exchanger is typically contained within the tank, but some designs consist of an external heating module attached to a storage tank.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $270 per year for annual maintenance.
- Advanced Case: Increasing adoption of condensing technology from 2020 to 2030 due to market incentives, with costs adjusting so that the condensing units in 2030 will not be higher in price due to technology advances and increased economies of scale. However, market will experience an increase in installation cost due to the adoption of condensing units. In replacement installations, installation costs are higher for condensing units than non-condensing units.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Annual shipments have fluctuated from 99,000 units in 2000 to 80,000 units in 2012, back to 99,000 units in 2016.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Commercial-Storage-Water-Heaters-Historical-Data.aspx*

Commercial Electric Resistance Storage Water Heaters

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Same as reference case

DATA	2012	2017		2020	2030	2040	2050
	Installed Base	Current Standard	Typical	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	119	119	119	119	119	119	119
Typical Input Capacity (kW)	18	18	18	18	18	18	18
Thermal Efficiency (%)	98	98	98	98	98	98	98
Average Life (yrs)	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)**	2,700	2,700	2,700	2,700	2,700	2,700	2,700
	3,200	3,200	3,200	3,200	3,200	3,200	3,200
Total Installed Cost (2017$)**	3,800	3,800	3,800	3,800	3,800	3,800	3,800
	3,950	3,950	3,950	3,950	3,950	3,950	3,950
Annual Maintenance Cost (2017$)	50	50	50	50	50	50	50

*Different levels of standby loss were not included in this analysis.
**The range of retail equipment and installed costs represents the range from replacement market to new construction market.

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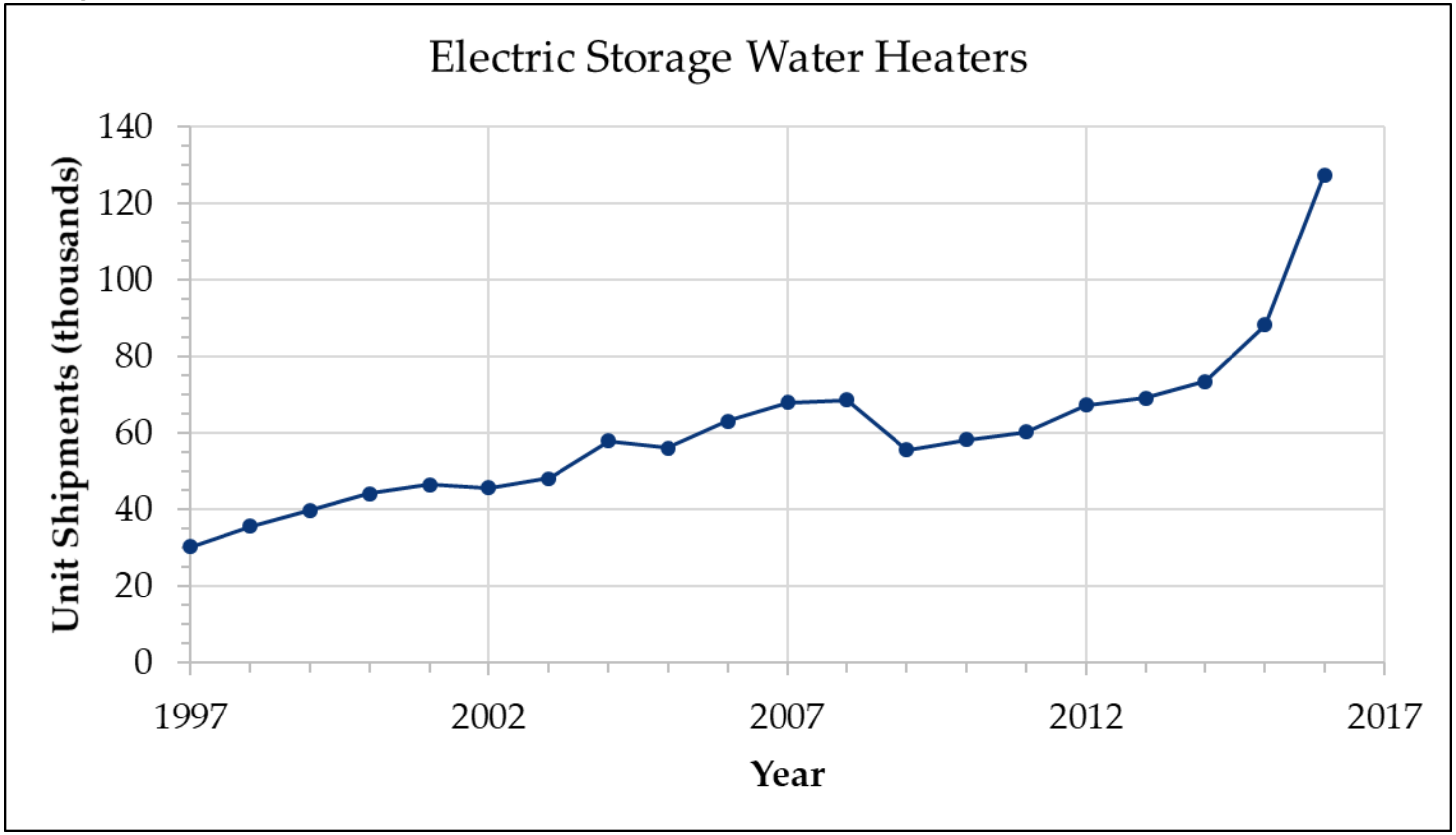
- Federal standard[1]:
  - Maximum standby loss (%/h) : 0.30 + 27/Measured Storage Volume
  - Minimum thermal efficiency: no standard, but all units ≥ 98% anyway
- Storage capacity: typically 50 to 120 gallons, though smaller and larger units exist for specialized applications
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- There is very little variation in thermal efficiency on the market; variation in standby loss is typically due to tank design and insulation thickness.
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $50 for annual maintenance.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Annual shipments increased more than 50 percent over 12 years from 44 thousand units in 2000 to 67 thousand units in 2012. Since 2012, shipments have increased by 89%, with the largest increase of 44% occurring in 2016.



Source: *http://www.ahrinet.org/Resources/Statistics/Historical-Data/Commercial-Storage-Water-Heaters-Historical-Data.aspx*

Commercial Heat Pump Water Heaters

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Water Flow Rate (gal/min)	34	34	34	34	34	34
Typical Input Capacity (kBtu/h)	171	171	171	171	171	171
Coefficient of Performance (COP)	3.9	3.9	3.9	4	4.2	4.4
Average Life (yrs)	15	15	15	15	15	15
Retail Equipment Cost (2017$)	47,100	47,100	47,100	47,100	47,100	47,100
Total Installed Cost (2017$)	50,950	50,950	50,950	50,950	50,950	50,950
Annual Maintenance Cost (2017$)	100	100	100	100	100	100

- There are no integrated commercial HPWHs (CHPWHs) on the market (i.e., heat pump module and storage tank combined in one unit); all units are add-on units which are typically designed to be used with a storage tank(s).
- CHPWHs serve only a small portion of the commercial water heating (CWH) market. Three manufacturers (including only one major CWH manufacturer) sell CHPWHs.
- CHPWHs can extract heat from either air or water for heating potable water ("air-source" or "water-source"). The capacity of air-source CHPWHs falls at lower ambient air temperatures.
- Air-source CHPWHs cool the surrounding air, which can be desirable when installed indoors in applications with a year-round cooling load (e.g., a commercial kitchen).
- Output capacities for CHPWHs range from 17 kW to over 70 kW for air-source units and over 600 kW for water-source units.
- Some commercial applications require water as hot as 180 °F, such as dishwashing; however, most CHPWHs cannot deliver hot water at temperatures higher than 150 °F.
- There are no current Federal standards for CHPWHs, but DOE prescribes a test procedure for determining COP_h for CHPWHs.
- ENERGY STAR levels for CWH equipment are under revision. The public final draft of the updated specification includes a COP_h level of 3.0 for CHPWHs.
- Advanced Case: Due to increases in R&D, improvements in current technology (e.g., more cost-effective variable speed technology) are expected to increase efficiency without substantially increasing costs.

Commercial Oil-Fired Storage Water Heaters

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Same as reference case

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Storage Capacity (gal)	70	85	85	85	85	85	85	85	85	85	85	85
Typical Input Capacity (kBtu/h)	300	300	300	300	300	300	300	300	300	300	300	300
Thermal Efficiency (%)	79	80	81	82	81	82	81	82	81	82	81	82
Average Life (yrs)	13	13	13	13	13	13	13	13	13	13	13	13
Retail Equipment Cost (2017$)	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650	4,650
Total Installed Cost (2017$)	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200	5,200
Annual Maintenance Cost (2017$)	168	168	168	168	168	168	168	168	168	168	168	168

*Different levels of standby loss were not included in this analysis.

- Input capacity ≥ 105,000 Btu/h, and < 4,000 Btu/h per gallon of stored water
- Federal standard[1]:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h): Input Rate/800 + 110 × (Rated Volume)$^{1/2}$
- Condensing units do not exist, thus the highest thermal efficiency on the market is 86%.
- Commercial units are typically constructed similar to residential units, though with higher input capacities (and often higher storage volumes).
- Maintenance consists of sediment and scale removal once or twice per year. Estimated cost of $100–$200 per year for one or two cleanings performed by a plumber.
- The market for commercial oil-fired storage water heaters is very small; shipments are approximately 3% of shipments for commercial gas-fired storage water heaters.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Commercial Electric Booster Water Heaters

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Same as reference case

DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Capacity (gal)	6	6	6	6	6	6
	16	16	16	16	16	16
Thermal Efficiency (%)	98	98	98	98	98	98
Average Life (yrs)	3	3	3	3	3	3
	10	10	10	10	10	10
Retail Equipment Cost (2017$)	1,300	1,300	1,300	1,300	1,300	1,300
	2,800	3,000	3,000	3,000	3,000	3,000
Total Installed Cost (2017$)	1,500	1,500	1,500	1,500	1,500	1,500
	3,000	3,200	3,200	3,200	3,200	3,200
Annual Maintenance Cost (2017$)*	-	-	-	-	-	-

* Maintenance costs negligible.

Commercial Gas-fired Booster Water Heaters

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Same as reference case

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (gal)	3	3	3	3	3	3	3	3	3	3	3	3
	5	5	5	5	5	5	5	5	5	5	5	5
Thermal Efficiency (%)	80	80	80	91	80	91	80	91	80	91	80	91
Average Life (yrs)	5	5	5	5	5	5	5	5	5	5	5	5
	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost (2017$)	4,700	4,900	4,900	8,000	4,900	8,000	4,900	8,000	4,900	8,000	4,900	8,000
	6,800	7,700	7,700	9,500	7,700	9,500	7,700	9,500	7,700	9,500	7,700	9,500
Total Installed Cost (2017$)	5,000	5,200	5,200	8,300	5,200	8,300	5,200	8,300	5,200	8,300	5,200	8,300
	7,100	8,000	8,000	9,800	8,000	9,800	8,000	9,800	8,000	9,800	8,000	9,800
Annual Maintenance Cost (2017$)	160	160	160	160	160	160	160	160	160	160	160	160

- Booster water heaters are installed, often at the point of use, in series with the main service water heating system to boost service water temperatures. The main service water heating system may provide 110-140 °F water, and the booster water heater may increase that temperature to 180-195 °F. Typical commercial applications for booster water heaters include commercial dishwashers, laundromats, hospitals, and car washes.
- Commercial booster water heaters are regulated by DOE as either storage or instantaneous water heaters, depending on the ratio of input capacity to storage volume. Units with input capacity < 4,000 Btu/h per gallon of stored water are storage water heaters; all other units are instantaneous water heaters.
- DOE's regulations do not currently include standards for electric instantaneous water heaters, but standards are included for electric storage water heaters, gas-fired instantaneous water heaters, and gas-fired storage water heaters.
- Booster water heaters typically have short lifetimes because of high usage and extreme temperatures.
- Shipments are small due to the limited number of applications.

Higher typical efficiencies with the same equipment costs as ref. case despite increased efficiency. Installation costs are higher for condensing than for non-condensing in replacement installations.

DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Typical Capacity (kBtu/h)	250	250	250	250	250	250	250	250	250	250	250	250	250
	399	399	399	399	399	399	399	399	399	399	399	399	399
Thermal Efficiency (%)	80	80	92	94	98	92	98	92	98	94	98	96	98
Average Life (yrs)	17	17	17	17	17	17	17	17	17	17	17	17	17
	25	25	25	25	25	25	25	25	25	25	25	25	25
Retail Equipment Cost (2017$)*	1,900	1,900	2,200	2,250	2,300	2,200	2,300	2,200	2,300	2,200	2,300	2,200	2,300
	4,800	4,800	8,450	8,800	9,150	8,450	9,150	8,450	9,150	8,450	9,150	8,450	9,150
Total Installed Cost (2017$)*	2,550	2,550	3,700	3,750	3,800	3,700	3,800	3,700	3,800	3,700	3,800	3,700	3,800
	11,000	11,000	11,300	11,650	12,050	11,300	12,050	11,300	12,050	11,300	12,050	11,300	12,050
Annual Maintenance Cost (2017$)*	40	40	100	100	110	100	110	100	110	100	110	100	110

*Commercial gas-fired instantaneous water heaters are categorized into two groups: tankless water heater and hot water supply boiler. Tankless units are similar in design to residential tankless units. The hot water supply boiler has a much higher input and is similar in design to boilers. The large variation of total input capacity and design causes a large range of costs. The low and high range of retail and installed costs represent the differences in design, as well as the cost ranges arising from replacement versus new construction markets.

- Input capacity ≥ 200,000 Btu/h, and ≥ 4,000 Btu/h per gallon of stored water
- Federal standard[1]:
  - Minimum thermal efficiency: 80%
  - Maximum standby loss (Btu/h): Input Rate/800 + 110 x (Rated Volume)$^{1/2}$
- ENERGY STAR requirements:
  - Minimum thermal efficiency: 94%
- Wall-mounted ("tankless") units typically top out at ~400,000 Btu/h and are similar in design to residential tankless units. Floor-mounted units ("circulating" or "volume" water heaters) are similar in design to boilers and can have input capacities in the millions of Btu/h. Floor-mounted units are typically installed with a storage tank.
- Despite high available input capacities, some installations use multiple units staged together, which may have reliability and/or efficiency benefits.
- Similar to storage water heaters, higher efficiencies are achieved with condensing operation, which requires a condensing heat exchanger and inducer fan or power burner. Some units include both non-condensing and condensing heat exchangers, while others include a single condensing heat exchanger.
- When replacing a storage water heater with an instantaneous water heater, there may be significant additional costs to upsize the gas supply line and change the venting.
- Advanced Case: Increasing adoption of condensing technology from 2020 to 2030, with costs adjusting so that the condensing units in 2030 will not be higher in price due to technology advances and increased economies of scale. However, market will experience an increase in installation cost due to the adoption of condensing units. In replacement installations, installation costs are higher for condensing units than non-condensing units.

[1] Energy Efficiency Program for Certain Commercial and Industrial Equipment: Commercial Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks. 10 CFR 430.32(h).

Commercial Solar Water Heaters

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Same as reference case

DATA	2012	2017	2020	2030	2040	2050
	Installed Base	Typical / ENERGY STAR**	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	83	83	83	83	83	83
Solar Fraction (SF)	0.5	0.56	0.56	0.56	0.56	0.56
Solar Energy Factor (SEF)	2.5	2.7	2.7	2.7	2.7	2.7
Average Life (yrs)	20	20	20	20	20	20
Retail Equipment Cost (2017$)*	8,300	8,300	8,300	8,300	8,300	8,300
	9,500	9,500	9,500	9,500	9,500	9,500
Total Installed Cost (2017$)*	11,000	11,000	11,000	11,000	11,000	11,000
	13,100	13,100	13,100	13,100	13,100	13,100
Annual Maintenance Cost (2017$)	25	25	25	25	25	25

* Costs are for an indirect (active closed loop) system, including tank and backup heater. Smaller capacity/cost systems are typical for southern & western states (>2/3 of the current market). Higher capacity/cost systems are required in colder/cloudier regions.
** ENERGY STAR requires OG-300 rating from SRCC. Most installations use SRCC rated collectors; a high efficiency option is not applicable.

- Solar water heaters are not subject to federal energy conservation standards, the ENERGY STAR requirements are:

Applicable Products	Backup Fuel	ENERGY STAR Requirement	Test Method
Whole-home solar units	Gas	SEF ≥ 1.2	SRCC – OG-300: Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems
	Electric	SEF ≥ 1.8	

- Commercial solar water heaters are typically custom designed for a specific installation.
- One major CWH manufacturer sells a commercial integrated solar water heater similar to residential designs that includes an indirect solar water heat exchanger and a gas-fired backup heat exchanger, and this model is certified to the Solar Rating and Certification Corporation (SRCC)'s OG-300, "Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems."
- Commercial solar water heaters may include backup heating, from sources such as electric resistance or hydronic heat (supplied from a gas-fired boiler or geothermal heat pump).
- Storage volumes of tanks for commercial solar water heaters can span from 140 gallons to over 2,000 gallons.
- SRCC's OG-300 can be used to certify commercial systems, but most commercial systems are larger and unique, so this certification program is mostly used for residential solar water heaters.
  — Many incentive programs require that solar collectors for commercial systems be certified to SRCC's certification program for collectors, OG-100.

Commercial Natural Gas Ranges with Griddle and Ovens

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Typical	ENERGY STAR*	High	Typical	High	Typical	High	Typical	High	Typical	High
Total Input Capacity (kBtu)	275	275	275	275	275	275	275	275	275	275	275	275
Griddle - Cooking Energy Efficiency (%)	30	30	38	52	30	52	33	52	36	52	40	52
Oven - Cooking Energy Efficiency (%)	35	35	46	50	35	50	39	50	42	50	47	50
Range - Cooking Energy Efficiency (%)	30	30	N/A	40	30	40	33	40	36	40	39	40
Griddle - Normalized Idle Energy Rate (Btu/h/ft^2)	3,000	3,000	2,650	1,080	3,000	1,180	2,700	1,180	2,450	1,180	2,200	1,180
Oven - Idle Energy Rate (Btu/h)	18,000	18,000	12,000	7,180	18,000	7,180	16,200	7,180	14,600	7,180	13,150	7,180
Range - Idle Energy Rate (Btu/h)	3,600	3,600	N/A	1,900	3,600	1,900	3,250	1,900	2,950	1,900	2,650	1,900
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)**	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450	7,450
Total Installed Cost (2017$)	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600	7,600
Annual Maintenance Cost (2017$)*	–	–	–	–	–	–	–	–	–	–	–	–

*ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
** Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
*** Maintenance costs are negligible.

Commercial Electric Ranges with Griddle and Ovens

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Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017			2020		2030		2040		2050	
	Installed Base	Typical	ENERGY STAR*	High	Typical	High	Typical	High	Typical	High	Typical	High
Total Input Capacity (kW)	20	20	20	20	20	20	20	20	20	20	20	20
Griddle - Cooking Energy Efficiency (%)	65	70	70	86	70	86	72	86	74	86	76	86
Oven - Cooking Energy Efficiency (%)	65	65	N/A	80	65	80	67	80	69	80	71	80
Range - Cooking Energy Efficiency (%)	75	75	N/A	85	75	85	77	85	80	85	82	85
Griddle - Normalized Idle Energy Rate (kW/ft^2)	0.44	0.34	0.32	0.20	0.34	0.20	0.32	0.20	0.29	0.20	0.27	0.20
Oven - Idle Energy Rate (kW)	1.50	1.50	1.00	0.90	1.50	0.90	1.40	0.90	1.30	0.90	1.21	0.90
Range - Idle Energy Rate (kW)**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)***	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550	9,550
Total Installed Cost (2017$)	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700	9,700
Annual Maintenance Cost (2017$)****	–	–	–	–	–	–	–	–	–	–	–	–

*ENERGY STAR does not cover combination products that include griddles, ranges, and ovens in one single package. The ENERGY STAR levels provided here reflect specifications for individual products. Range tops are not covered by ENERGY STAR.
**No data on electric range top idle energy rates.
*** Products in the commercial cooking market generally do not scale in price with relation to cooking efficiency. Distributors also do not provide this information.
**** Maintenance costs are negligible.

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- Combined product that typically includes 2-6 range tops, a 24 in. x 24 in. griddle surface, and one or two half- or full-size ovens.
- Combined product is not covered by ENERGY STAR. However, the individual product ENERGY STAR specifications are provided below.

Product	ENERGY STAR Requirements	Gas	Electric
Griddle	Cooking Energy Efficiency	≥ 38%	≥ 70%
	Normalized Idle Energy Rate	≤ 2,650 Btu/h per ft^2	≤ 0.320 kW per ft^2
Oven	Cooking Energy Efficiency	≥ 46%	≥ 71%
	Idle Energy Rate	≤ 12,000 Btu/h	Half size: ≤1.00 kW Full size: ≤1.60 kW

- ENERGY STAR does not provide certification for range tops.
- There are no Federal standards for commercial cooking products.
- Product pricing in this market does not scale with efficiency, but rather depend on a number of other factors such as brand name, aesthetics, and additional features.
- Advanced Case: Increased market incentives are expected to drive efficiency improvements. However, because cost does not scale with efficiency, there is no significant expected change in cost.

Higher typical efficiencies with the same costs as ref. case despite increased efficiency.

DATA	2012	2017				2020		2030		2040		2050	
	Installed Base	State Standards	Typical	ENERGY STAR	High	Typical	High	Typical	High	Typical	High	Typical	High
Interior Volume (ft^3)	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4	21.4
Maximum Idle Energy Rate (W)	900	856	856	297	154	856	154	685	154	548	154	438	154
Average Life (yrs)	12	12	12	12	12	12	12	12	12	12	12	12	12
Retail Equipment Cost (2017$)	2,500	3,850	3,850	4,200	5,500	3,850	5,500	3,850	5,500	3,850	5,500	3,850	5,500
Total Installed Cost (2017$)	2,500	3,850	3,850	4,200	5,500	3,850	5,500	3,850	5,500	3,850	5,500	3,850	5,500
Annual Maintenance Cost (2017$)*	–	–	–	–	–	–	–	–	–	–	–	–	–

* Maintenance costs are negligible.

- Used in commercial kitchens to keep food warm until it is served.
- Many shapes and sizes, but interior volumes around 21.4 ft^3 typical in many settings.
- Annual unit energy consumption can range from < 1,000 to > 30,000 kWh/y, depending on size, efficiency, and usage.
- Energy performance metric is "Idle Energy Consumption Rate" in Watts, measured using ASTM Standard F2140-11.
- No Federal standards, but eight identical State standards, first took effect in California in 2006, now considered the typical or "baseline" product. ENERGY STAR version 2.0 took effect October 1, 2011.
- Maximum Idle Energy Consumption Rate for products $12 \leq V < 28$:
  - State standards: **$\leq 40 \times V$** (baseline)
  - ENERGY STAR: **$\leq 2.0 \times V + 254$** (about 65% below baseline)

  where V is interior volume in ft^3.
- The most efficient products are about 80% below baseline.
- Energy savings achieved with insulation, automatic door closers, magnetic door gaskets, and Dutch doors (half-doors).
- Advanced Case: Increased market incentives are expected to drive efficiency improvements. However, because cost does not scale with efficiency, there is no significant expected change in cost.

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Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19 St. NW, Suite 700
Washington, D.C. 20036
(202) 973-2400

www.navigantconsulting.com

North & Rest of Country

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th>2015</th><th colspan="4">2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR (North)</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>Navigant</td><td>Navigant</td><td colspan="4">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>AFUE (%)</td><td>Navigant</td><td>Navigant</td><td>EERE</td><td>EERE</td><td>ENERGY STAR v4.1</td><td>AHRI</td></tr>
<tr><td>Electric Consumption (kWh/yr)</td><td rowspan="5">EERE/ Navigant</td><td colspan="5" rowspan="5">EERE 2015</td></tr>
<tr><td>Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td></tr>
</table>

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Input Capacity (kBtu/h)	Navigant		EERE							
AFUE (%)	Navigant		EERE	Navigant	ENERGY STAR v4.1	AHRI				
Electric Consumption (kWh)	EERE	EERE 2011								
Average Life (yrs)	EERE	EERE 2015					Navigant			
Retail Equipment Cost ($)	EERE	EERE 2011								
Total Installed Cost ($)	EERE	EERE 2011								
Annual Maintenance Cost ($)	EERE	EERE 2011								

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th>2015</th><th colspan="4">2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>EERE 2007</td><td colspan="5">EERE 2015 (Section 5.4.1 of the TSD)</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>AFUE (%)</td><td>EERE 2007/ Navigant</td><td>EERE 2007</td><td>EERE 2007</td><td>AHRI Database</td><td>ENERGY STAR v3.0</td><td>AHRI Database</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>EERE 2007</td><td colspan="5" rowspan="2">EERE 2015 (LCC Analysis Spreadsheet "Statistics" tab)</td></tr>
<tr><td>Total Installed Cost ($)</td><td>EERE 2007</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE 2007</td><td colspan="5">EERE 2015 (Section 8.2.2.4 of the TSD)</td></tr>
</table>

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Input Capacity (kBtu/h)	EERE	EERE 2015 (Section 5.4.1 of the TSD)					Navigant			
AFUE (%)	EERE / Navigant	EERE 2007	EERE 2007	AHRI Database	ENERGY STAR v3.0	EERE 2007				
Average Life (yrs)	EERE	EERE								
Retail Equipment Cost ($)	EERE	EERE 2015 (LCC Analysis Spreadsheet "Statistics" tab)								
Total Installed Cost ($)	EERE	EERE 2015 (LCC Analysis Spreadsheet "Statistics" tab)								
Annual Maintenance Cost ($)	EERE	EERE 2015 (Section 8.2.2.4 of the TSD)								

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical			
Typical Capacity (kBtu/h)	Distributors			Navigant			
Efficiency (%)	DOE/ASHRAE						
Average Life (yrs)	Distributors						
Retail Equipment Cost ($)	RS Means 2017						
Total Installed Cost ($)	RS Means 2017						
Annual Maintenance Cost ($)	Navigant						

Data Sources » Residential Electric Resistance Heaters

DATA	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical			
Typical Capacity (kBtu/h)	Distributors			Navigant			
Efficiency (%)	Navigant						
Average Life (yrs)	Navigant						
Retail Equipment Cost ($)	2017 RS Means						
Total Installed Cost ($)	2017 RS Means						
Annual Maintenance Cost ($)	Navigant						

South (Hot-Dry and Hot-Humid)

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td>EERE</td><td colspan="5">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>SEER</td><td rowspan="6">EERE / Navigant</td><td>EERE / Navigant</td><td>eCFR</td><td>EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5" rowspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
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North (Rest of Country)

<table>
<tr><th rowspan="2">SOURCES</th><th>2009</th><th>2015</th><th colspan="4">2017</th><th>2020</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td>EERE</td><td colspan="5">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>SEER</td><td rowspan="6">EERE / Navigant</td><td>EERE / Navigant</td><td>eCFR</td><td>EERE</td><td>ENERGY STAR</td><td>EERE</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5" rowspan="5">EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

Data Sources » Residential Air Source Heat Pumps

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (kBtu/h)	EERE / AHRI	EERE					Navigant			
SEER (Cooling)	EERE / Navigant	EERE / Navigant	eCFR	EERE	ENERGY STAR	EERE				
HSPF (Heating)		EERE								
Average Life (yrs)										
Retail Equipment Cost ($)										
Total Installed Cost ($)										
Annual Maintenance Cost ($)										

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<tr><td>Typical Capacity (kBtu/h)</td><td>AHRI/Navigant</td><td colspan="5">EERE</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>COP (Heating)</td><td>Navigant</td><td>AHRI Database</td><td rowspan="2">ASHRAE 90.1-2016</td><td>AHRI Database</td><td>ENERGY STAR</td><td>AHRI Database</td></tr>
<tr><td>EER (Cooling)</td><td>Navigant</td><td>AHRI Database</td><td>AHRI Database</td><td>ENERGY STAR</td><td>AHRI Database</td></tr>
<tr><td>Average Life (yrs)</td><td>Navigant / EERE</td><td colspan="5" rowspan="4">Navigant / EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td>Distributors/IGSHPA/EERE 2009/Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td><td>Distributors/IGSHPA/EERE 2009/Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>Navigant</td></tr>
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SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (kBtu/hr)	Distributors		AHAM				Navigant			
EER and CEER	Navigant		EERE	CCMS	ENERGY STAR	CCMS				
Average Life (yrs)	Appliance Magazine, 2012									
Retail Equipment Cost (2017$)	EERE									
Total Installed Cost (2017$)										
Annual Maintenance Cost (2017$)	Navigant		Navigant							

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<tr><td>Typical Capacity (kBtu/hr)</td><td colspan="4" rowspan="6">EERE</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>CEER</td></tr>
<tr><td>Average Life (yrs)</td></tr>
<tr><td>Retail Equipment Cost ($)</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

SOURCES	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical	Typical			
Typical Capacity (kBtu/h)	Manufacturer			Navigant			
Heating (COP)	Product Literature						
Cooling (COP)	Product Literature						
Annual Electric Use (kWh/yr)	Product Literature						
Average Life (yrs)	Navigant						
Retail Equipment Cost ($)	PERC						
Total Installed Cost ($)	Navigant						
Annual Maintenance Cost ($)	Navigant						

Data Sources » Residential Cord Wood Stoves

SOURCES	2009	2015	2017		2020	2030	2040	2050
	Installed Base	Installed Base	Typical	High	Typical / High			
Typical Capacity (kBtu/h)	Distributors / Product Literature				Navigant			
Efficiency (Non-Catalytic) (HHV)	Navigant / Literature	EPA Default / Literature / Navigant	EPA Certified Wood Heater List August 2016					
Efficiency (Catalytic) (HHV)								
Average Life (yrs)	Navigant							
Retail Equipment Cost ($)	Product Lit. / Dealers	Product Literature/Dealers						
Total Installed Cost ($)	Dealers	Dealers/Navigant						
Annual Maintenance Cost ($)	Dealers / Navigant							

Data Sources » Residential Wood Pellet Stoves

<table>
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<tr><td>Typical Capacity (kBtu/h)</td><td colspan="4">Distributors / Product Literature</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>Efficiency (HHV)</td><td>Navigant/ Literature</td><td>EPA Default/Literature/Navigant</td><td colspan="2">EPA Default/EPA Certified Wood Heater List August 2016/Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">Navigant</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="4">Product Literature/ Dealers</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="2">Dealers</td><td colspan="3" rowspan="2">Dealers/Navigant</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
</table>

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (gal)	AHRI / Distributors	Navigant	EERE 2010/AHRI				Navigant			
Uniform Energy Factor (UEF)	Navigant		EERE 2016	CCMS	ENERGY STAR	AHRI/CCMS				
Average Life (yrs)	EERE 2010									
Retail Equipment Cost (2017$)	Distributors		EERE 2010			Distributors				
Total Installed Cost (2017$)	Distributors / RS Means 2010		EERE 2010							
Annual Maintenance Cost (2017$)	EERE 2010									

<table>
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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td rowspan="2">Navigant</td><td colspan="3">EERE 2010/AHRI</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>Uniform Energy Factor (UEF)</td><td>Navigant</td><td>EERE 2016</td><td colspan="2">AHRI/CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE 2010</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td>Distributors</td><td colspan="4" rowspan="2">EERE 2010</td></tr>
<tr><td>Total Installed Cost (2017$)</td><td>Distributors / RS Means 2007</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="5">EERE 2010</td></tr>
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Data Sources » Residential Electric Resistance Storage Water Heaters

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<tr><td>Typical Capacity (gal)</td><td>AHRI / Distributors</td><td>AHRI</td><td colspan="3">EERE 2010/AHRI</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>Uniform Energy Factor (UEF)</td><td colspan="2">Navigant</td><td>EERE 2016</td><td>AHRI/CCMS</td><td>AHRI</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE 2010</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td>Distributors</td><td>EERE 2010</td><td colspan="2">EERE 2010</td><td>Distributors</td></tr>
<tr><td>Total Installed Cost (2017$)</td><td>Distributors / RS Means 2010</td><td colspan="4">EERE 2010</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="5">EERE 2010</td></tr>
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SOURCES	2009	2015	2017			2020	2030	2040	2050
	Installed Base	Installed Base	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (gal)	AHRI	Navigant	AHRI			Navigant			
Uniform Energy Factor (UEF)	Navigant	Navigant	CCMS	ENERGY STAR	AHRI/CCMS				
Average Life (yrs)	EERE 2010								
Retail Equipment Cost (2017$)	RS Means 2010 / ACEEE 2007	EERE 2010	Distributors	EERE 2010	Distributors				
Total Installed Cost (2017$)		EERE 2010							
Annual Maintenance Cost (2017$)	EERE 2010								

SOURCES	2009	2015	2017	2020	2030	2040	2050
	Installed Base	Installed Base	Typical / ENERGY STAR**	Typical	Typical	Typical	Typical
Typical Capacity (sq. ft.)	SRCC / Navigant			Navigant			
Overall Efficiency (Solar Fraction)	DOE / SRCC / Navigant						
Solar Energy Factor	SRCC / Navigant						
Average Life (yrs)	DOE / Navigant						
Retail Equipment Cost1 (2017$)	RS Means Online 2017						
Total Installed Cost1 (2017$)	RS Means Online 2017						

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SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (kBtu/hr)	EERE	AHRI	EERE 2010/AHRI				Navigant			
Uniform Energy Factor (UEF)	Navigant	Navigant	EERE 2016	CCMS	ENERGY STAR	CCMS				
Average Life (yrs)	EERE 2010									
Retail Equipment Cost (2017$)	Distributors / RS Means 2010	EERE 2010								
Total Installed Cost (2017$)	DEER 2008									
Annual Maintenance Cost (2017$)	Navigant									

SOURCES	2009	2015	2017				2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (ft^3)	EERE 2011 / Navigant						Navigant			
Energy Consumption (kWh/yr)	Navigant		EERE 2011	Navigant	ENERGY STAR	Navigant				
Average Life (yrs)	EERE 2011 / Navigant									
Retail Equipment Cost (2017$)										
Total Installed Cost (2017$)										
Annual Maintenance Cost (2017$)										

<table>
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<tr><th>Installed Base</th><th>Installed Base</th><th>Typical</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="4">Distributors / Product Literature</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Integrated Annual Energy Consumption (kBtu/yr)</td><td>EERE</td><td>Navigant</td><td colspan="2">EERE</td></tr>
<tr><td>Cooking Efficiency (%)</td><td colspan="4">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4" rowspan="3">EERE</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="4">Navigant / EERE</td></tr>
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<tr><td>Typical Capacity (ft3)</td><td colspan="5">Navigant / CCMS</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>CEF (lb/kWh)</td><td colspan="2">EERE / Navigant</td><td colspan="2">EERE</td><td>CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="2">EERE</td><td colspan="3" rowspan="4">EERE</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td colspan="2" rowspan="2">EERE / Navigant</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
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SOURCES	2009	2015	2017			2020	2030	2040	2050
	Installed Base	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Capacity (ft^3)	EERE / Navigant		CCMS			Navigant			
CEF (lb/kWh)			EERE		CCMS				
Average Life (yrs)	EERE		EERE						
Retail Equipment Cost (2017$)	EERE / Navigant								
Total Installed Cost (2017$)									
Annual Maintenance Cost (2017$)	EERE								

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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (ft^3)</td><td rowspan="3">Navigant</td><td>Navigant</td><td>CCMS</td><td rowspan="3">CCMS</td><td>CCMS</td><td rowspan="3">CCMS</td><td colspan="4" rowspan="11">Navigant</td></tr>
<tr><td>Integrated Modified Energy Factor (ft^3/kWh/cycle)</td><td rowspan="2">AHAM / Navigant</td><td rowspan="2">EERE</td><td>ENERGY STAR</td></tr>
<tr><td>Integrated Water Factor (gal/cycle/ft^3)</td><td>ENERGY STAR</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Water Consumption (gal/cycle)</td><td colspan="6">Navigant / EERE</td></tr>
<tr><td>Hot Water Energy (kWh/cycle)</td><td colspan="6" rowspan="3">Navigant</td></tr>
<tr><td>Machine Energy (kWh/cycle)</td></tr>
<tr><td>Dryer Energy (kWh/cycle)</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td colspan="6">EERE / Distributors</td></tr>
<tr><td>Total Installed Cost (2017$)</td><td colspan="6">Navigant / RS Means 2016</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="6">EERE</td></tr>
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<tr><td>Typical Capacity (ft^3)</td><td rowspan="3">Navigant</td><td>Navigant</td><td>CCMS</td><td rowspan="3">CCMS</td><td>CCMS</td><td rowspan="3">CCMS</td><td rowspan="11" colspan="4">Navigant</td></tr>
<tr><td>Integrated Modified Energy Factor (ft^3/kWh/cycle)</td><td rowspan="2">AHAM / Navigant</td><td rowspan="2">EERE</td><td rowspan="2">ENERGY STAR</td></tr>
<tr><td>Integrated Water Factor (gal/cycle/ft^3)</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE</td></tr>
<tr><td>Water Consumption (gal/cycle)</td><td colspan="6">Navigant / EERE</td></tr>
<tr><td>Hot Water Energy (kWh/cycle)</td><td colspan="6" rowspan="3">Navigant</td></tr>
<tr><td>Machine Energy (kWh/cycle)</td></tr>
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<tr><td>Retail Equipment Cost (2017$)</td><td colspan="6">EERE / Distributors</td></tr>
<tr><td>Total Installed Cost (2017$)</td><td colspan="6">Navigant / RS Means 2016</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="6">EERE</td></tr>
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<tr><th>Installed Base</th><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Annual Energy Use (kWh/yr)</td><td colspan="2" rowspan="3">AHAM 2014 / EERE 2012</td><td rowspan="2">CFR</td><td rowspan="2">Navigant / CCMS / ENERGY STAR</td><td rowspan="2">ENERGY STAR</td><td rowspan="2">EERE 2016</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Water Consumption (gal/cycle)</td></tr>
<tr><td>Water Heating Energy Use (kWh/yr)</td><td colspan="4">EERE 2016</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="6">EERE 2016 / Navigant</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td colspan="2" rowspan="2">EERE 2012</td><td colspan="4" rowspan="2">EERE 2016</td></tr>
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<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="6">Navigant</td></tr>
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<tr><td>Thermal Efficiency (%)</td><td>AHRI</td><td>10 CFR 431.77</td><td colspan="2">DOE CCMS</td></tr>
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<tr><td>Retail Equipment Cost ($)</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
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Data Sources » Commercial Oil-Fired Furnaces

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<tr><td>Efficiency (%)</td><td colspan="4">Navigant</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="4">Technology Cost and Performance File for Commercial Model for AEO2010</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td colspan="4" rowspan="2">RS Means 2017</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="4">Navigant</td></tr>
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SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	**Typical**	**Typical**			
Typical Capacity (kW)	BSRIA		Navigant			
Efficiency (%)	EERE / Navigant					
Average Life (yrs)	ASHRAE 2007 HVAC Applications	ASHRAE 2015 HVAC Applications				
Retail Equipment Cost ($)	RS Means 2013/Navigant	RS Means 2017				
Total Installed Cost ($)						
Annual Maintenance Cost ($)						

SOURCES	2012	2017				2020		2030	2040	2050
	Installed Base	Current Standard*	Typical	Mid-Range	High	Typical	High	Typical/High		
Typical Input Capacity (kBtu/h)	Navigant	EERE Issued Final Rule				Navigant		Navigant		
Thermal Efficiency (%)	ASHRAE Standard 90.1-2004 / Navigant	EERE Issued Final Rule				Navigant				
Average Life (yrs)	EERE	EERE Issued Final Rule				Navigant				
Retail Equipment Cost ($)	RS Means 2011	EERE Issued Final Rule				Navigant				
Total Installed Cost ($)	RS Means 2011	EERE Issued Final Rule				Issued Final Rule				
Annual Maintenance Cost ($)	Navigant	EERE Issued Final Rule				Navigant				

Data Sources » Commercial Oil-Fired Boilers

<table>
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<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>Navigant</td><td colspan="3" rowspan="6">Issued Final Rule
(Energy Conservation Program: Energy Conservation Standards for Commercial Packaged Boilers)</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>ASHRAE Standard 90.1-2004</td></tr>
<tr><td>Average Life (yrs)</td><td>EERE</td></tr>
<tr><td>Retail Equipment Cost ($)</td><td rowspan="2">RS Means 2011 / Navigant</td></tr>
<tr><td>Total Installed Cost ($)</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td>EERE</td></tr>
</table>

Data Sources » Commercial Centrifugal Chillers

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	ASHRAE 90.1	Typical	High	Typical / High			
Typical Capacity (tons)	IPCC/ARB/TEAP/Navigant				Navigant			
Efficiency (kW/ton)	ASHRAE 90.1-2010/FEMP/ eSource/Product Literature	ASHRAE 90.1-2016 (>400 TR)	Product Lit	Progress Energy Data Sheet				
COP								
Average Life (yrs)	2007 ASHRAE Applications Handbook	2015 ASHRAE Applications Handbook A37 Table 4						
Retail Equipment Cost ($/ton)	RS Means/Distributors/Navigant	RS Means 2017/Navigant						
Total Installed Cost ($/ton)								
Annual Maintenance Cost ($/ton)	Navigant/Alabama Power							

Data Sources » Commercial Reciprocating Chillers

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	ASHRAE 90.1	Typical	High	Typical / High			
Typical Capacity (tons)	BSRIA/DEER				Navigant			
Efficiency (kW/ton)	ASHRAE 90.1-2010/DEER/FEMP/Product Literature	ASHRAE 90.1-2016 (>150 TR)	ASHRAE 90.1-2016 (>150 TR)	Product Lit				
COP								
Average Life (yrs)	Manufacturers	2015 ASHRAE Applications Handbook A37 Table 4						
Retail Equipment Cost ($/ton)	RS Means/ Distributors/ Navigant	RS Means 2017/Navigant						
Total Installed Cost ($/ton)								
Annual Maintenance Cost ($/ton)	Navigant/Alabama Power							

Data Sources » Commercial Screw Chillers

<table>
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<tr><th>Installed Base</th><th>ASHRAE 90.1</th><th>Typical</th><th>High</th><th colspan="4">Typical / High</th></tr>
<tr><td>Typical Capacity (tons)</td><td colspan="4">Navigant</td><td colspan="4" rowspan="7">Navigant</td></tr>
<tr><td>Efficiency (kW/ton)</td><td rowspan="2">Navigant</td><td rowspan="2">ASHRAE 90.1-2016 (>150 TR)</td><td rowspan="2">ASHRAE 90.1-2016 (>150 TR)</td><td rowspan="2">Product Lit</td></tr>
<tr><td>COP</td></tr>
<tr><td>Average Life (yrs)</td><td>Manufacturers</td><td colspan="3">FacilitiesNet</td></tr>
<tr><td>Retail Equipment Cost ($/ton)</td><td rowspan="2">RS Means 2013/Distributors/Navigant</td><td colspan="3" rowspan="2">RS Means 2017/Navigant</td></tr>
<tr><td>Total Installed Cost ($/ton)</td></tr>
<tr><td>Annual Maintenance Cost ($/ton)</td><td colspan="4">Navigant/Alabama Power</td></tr>
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Data Sources » Commercial Scroll Chillers

SOURCE	2012	2017			2020	2030	2040	2050
	Installed Base	**ASHRAE 90.1**	**Typical**	**High**	**Typical / High**			
Typical Capacity (tons)	Navigant/Manufacturers				Navigant			
Efficiency [full-load/IPLV] (kW/ton)	Navigant	ASHRAE 90.1-2016 (>150TR)	Product Lit/Navigant	Product Lit				
COP [full-load/IPLV]								
Average Life (yrs)	Manufacturers							
Retail Equipment Cost ($/ton)	Manufacturers/RS Means 2013/Navigant	RS Means 2017/Navigant						
Total Installed Cost ($/ton)								
Annual Maintenance Cost ($/ton)	Navigant /Alabama Power							

Data Sources » Commercial Gas-Fired Chillers

SOURCES	2012		2017				2020	2030	2040	2050
	Installed Base: Absorption	Installed Base: Engine-Driven	ASHRAE 90.1 absorption	CA Title 24 - engine	Absorption	Engine-Driven	Absorption / Engine-Driven			
Typical Capacity (tons)	BSRIA/Distributors						Navigant			
COP [full-load]	Product Literature/Navigant		ASHRAE 90.1-2016 direct-fired double effect	CA Title 24 gas Engine standard	Product Lit					
COP [IPLV]										
Average Life (yrs)	2007 ASHRAE Applications Handbook/Distributors		2015 ASHRAE Applications Handbook A37 Table 4							
Retail Equipment Cost ($/ton)	Manufacturer/Distributors/RS Means 2013/GIT/Navigant		RS Means 2017/Navigant							
Total Installed Cost ($/ton)										
Annual Maintenance Cost ($/ton)	Navigant/Alabama Power									

Data Sources » Commercial Rooftop Air Conditioners

SOURCES	2012	2017				2020	2030	2040	2050
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Output Capacity (kBtu/h)	AHRI / Navigant	EERE				Navigant			
Efficiency (EER)	Distributors / Navigant	eCFR	EERE	ENERGY STAR	EERE				
Part Load Efficiency (IEER)	EERE	N/A							
Average Life (yrs)	EERE								
Retail Equipment Cost ($)	Distributors / Navigant / DEER, 2008	EERE							
Total Installed Cost ($)									
Annual Maintenance Cost ($)	EERE								

Data Sources » Commercial Gas-Fired Engine-Driven Rooftop Air Conditioners/Heat Pumps

SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical			
Typical Capacity (tons)	Product Literature/Navigant		Navigant			
Heating COP						
Cooling COP						
Average Life (yrs)	Manufacturer/RS Means 2017/Navigant					
Retail Equipment Cost ($/ton)	Abuheiba 2017/Manufacturer/RS Means 2017/Navigant					
Total Installed Cost ($/ton)	Manufacturer/RS Means 2017/Navigant					
Annual Maintenance Cost ($)						

Data Sources » Commercial Rooftop Heat Pumps

SOURCES	2012	2017				2020	2030	2040	2050
	Installed Base	Current Standard	Typical	ENERGY STAR	High	Typical / High			
Typical Capacity (kBtu/h)	EERE					Navigant			
Efficiency (EER)	ASHRAE Standard 90.1-2004 / Navigant	eCFR	EERE / Navigant	ENERGY STAR	EERE / Navigant				
Part Load Efficiency	EERE	N/A	EERE		EERE				
COP (Heating)	EERE / Navigant	eCFR							
Average Life (yrs)	Distributors / RS Means 2010 / DEER / Navigant	EERE							
Retail Equipment Cost ($)									
Total Installed Cost ($)									
Annual Maintenance Cost ($)									

Data Sources » Commercial Ground Source Heat Pumps

SOURCES	2012	2017				2020	2030	2040	2050
	Installed Base	Current Standard	Typical	Mid	High	Typical / High			
Typical Capacity (kBtu/h)	US DOE/EIA	EERE				Navigant			
COP (Heating)	Navigant	ASHRAE 90.1-2016	AHRI Database						
EER (Cooling)									
Average Life (yrs)	Navigant / EERE	Navigant / EERE							
Retail Equipment Cost ($)	Distributors/Navigant								
Total Installed Cost ($)	US DOD/IGSHPA/MA DOER/CEFIA/ASHRAE								
Annual Maintenance Cost ($)	Geothermal Heat Pump Consortium, Inc. (US DOE Contract DE-FG07-95ID13347)								

<table>
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<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENERGY STAR</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Storage Capacity (gal)</td><td>Arthur D. Little / Distributors / AHRI</td><td colspan="4" rowspan="2">CCMS</td><td colspan="8" rowspan="7">Navigant</td></tr>
<tr><td>Typical Input Capacity (kBtu/h)</td><td>AHRI</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>EERE / ASHRAE Standard 90.1-2004 / Navigant</td><td>CFR</td><td>CCMS</td><td>ENERGY STAR</td><td>CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td>EERE 2001</td><td colspan="4" rowspan="3">EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td rowspan="2">Distributors / CEC / Navigant</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="5">EERE/Distributors</td></tr>
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SOURCES	2012	2017		2020	2030	2040	2050
	Installed Base	Current Standard	Typical	Typical			
Typical Storage Capacity (gal)	Navigant / Product Literature	EERE 2016		Navigant			
Typical Input Capacity (kW)	Product Literature						
Thermal Efficiency (%)	Navigant						
Average Life (yrs)	EERE 2016						
Retail Equipment Cost (2017$)	EERE 2016 /Navigant	EERE 2016					
Total Installed Cost (2017$)							
Annual Maintenance Cost (2017$)							

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SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical	Typical	Typical	Typical
Typical Storage Capacity (gal)	Distributors/Navigant		Navigant			
Typical Input Capacity (kBtu/h)						
Coefficient of Performance (COP)	Distributors					
Average Life (yrs)	EERE/Navigant					
Retail Equipment Cost (2017$)	RS Means Online2017					
Total Installed Cost (2017$)						
Annual Maintenance Cost (2017$)	Navigant					

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Storage Capacity (gal)	AHRI / Navigant	CCMS/Navigant			Navigant			
Typical Input Capacity (kBtu/h)								
Thermal Efficiency (%)	Navigant	CFR	CCMS					
Average Life (yrs)	EERE 2001							
Retail Equipment Cost (2017$)	Distributors / Navigant							
Total Installed Cost (2017$)								
Annual Maintenance Cost (2017$)								

SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical	Typical			
Typical Capacity (gal)	Product Literature / Navigant	Product Literature	Navigant			
Thermal Efficiency (%)	Product Literature					
Average Life (yrs)						
Retail Equipment Cost (2017$)	Distributors/Navigant					
Total Installed Cost (2017$)						
Annual Maintenance Cost (2017$)						

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Current Standard	Typical	High	Typical / High			
Typical Capacity (gal)	Distributors/Navigant				Navigant			
Thermal Efficiency (%)	Product Literature/ Navigant	CFR	Product Literature/ Navigant					
Average Life (yrs)	Product Literature/Navigant							
Retail Equipment Cost (2017$)	Distributors/Navigant							
Total Installed Cost (2017$)								
Annual Maintenance Cost (2017$)								

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<tr><th>Installed Base</th><th>Current Standard</th><th>Typical</th><th>ENEGRY STAR</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Typical Capacity (kBtu/h)</td><td colspan="5">CCMS</td><td colspan="8" rowspan="6">Navigant</td></tr>
<tr><td>Thermal Efficiency (%)</td><td>Navigant</td><td colspan="2">CCMS</td><td>ENERGY STAR</td><td>CCMS</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">EERE 2016</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td rowspan="3">EERE 2016 /Navigant</td><td colspan="4" rowspan="3">EERE 2016</td></tr>
<tr><td>Total Installed Cost (2017$)</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td></tr>
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SOURCES	2012	2017	2020	2030	2040	2050
	Installed Base	Typical / ENERGY STAR	Typical			
Typical Capacity (sq. ft.)	SRCC / Navigant		Navigant			
Overall Efficiency (Solar Fraction)	DOE / SRCC / Navigant					
Solar Energy Factor	SRCC / Navigant					
Average Life (yrs)	DOE / Navigant					
Retail Equipment Cost (2017$)	RS Means Online 2017					
Total Installed Cost (2017$)	RS Means Online 2017					

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Typical	ENERGY STAR	High	Typical / High			
Total Input Capacity (kBtu)	Distributors							
Griddle - Cooking Energy Efficiency (%)			ENERGY STAR					
Oven - Cooking Energy Efficiency (%)	Navigant	FSTC	N/A	FSTC				
Range Burner - Cooking Energy Efficiency (%)								
Griddle - Normalized Idle Energy Rate (Btu/h/ft²)			ENERGY STAR					
Oven - Idle Energy Rate (Btu/h)	FEMP				Navigant			
Range - Idle Energy Rate (Btu/h)	FSTC		-	FSTC				
Average Life (yrs)	FSTC							
Retail Equipment Cost (2017$)**	Distributors							
Total Installed Cost (2017$)	FSTC / Navigant							
Annual Maintenance Cost (2017$)*	FSTC							

SOURCES	2012	2017			2020	2030	2040	2050
	Installed Base	Typical	ENERGY STAR	High	Typical / High			
Total Input Capacity (kW)	Distributors				Navigant			
Griddle - Cooking Energy Efficiency (%)	Navigant	FSTC	ENERGY STAR	FSTC				
Oven - Cooking Energy Efficiency (%)	Navigant	FSTC	-	FSTC				
Range Top - Cooking Energy Efficiency (%)	Navigant	FSTC	-	FSTC				
Griddle - Normalized Idle Energy Rate (W/ft^2)	Navigant	FSTC	ENERGY STAR	FSTC				
Oven - Idle Energy Rate (kW)	Navigant	FSTC	ENERGY STAR	FSTC				
Range Top - Idle Energy Rate (kW)	N/A							
Average Life (yrs)	FSTC							
Retail Equipment Cost (2017$)	Distributors							
Total Installed Cost (2017$)	FSTC / Navigant							
Annual Maintenance Cost (2017$)*	FSTC							

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<tr><td>Interior Volume (ft³)</td><td colspan="5">FEMP</td><td colspan="4" rowspan="6">Navigant</td></tr>
<tr><td>Maximum Idle Energy Rate (W)</td><td>CEE / Navigant</td><td colspan="4">FEMP</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="5">FEMP</td></tr>
<tr><td>Retail Equipment Cost (2017$)</td><td colspan="5">Distributors / ENERGY STAR Savings Calculator / Navigant</td></tr>
<tr><td>Total Installed Cost (2017$)</td><td colspan="5">Navigant</td></tr>
<tr><td>Annual Maintenance Cost (2017$)</td><td colspan="5">FSTC</td></tr>
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Appendix B
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www.navigantconsulting.com

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APPENDIX C

Final

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case

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DISCLAIMER

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Final

Objective

- The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment.

  - 2003/2012 (commercial) and 2009 (residential) baselines, as well as today's (2015)
    - Review of literature, standards, installed base, contractor, and manufacturer information.
    - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
  - Forecast of technology improvements that are projected to be available through 2040
    - Review of trends in standards, product enhancements, and Research and Development (R&D).
    - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

- Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.
  - Technology forecasting involves many uncertainties.
  - Technology developments impact performance and cost forecasts.
  - Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.

- The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (for commercial products) and 2009 (for residential) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.
  - Installed Base: the installed and "in use" equipment for that year. Represents the installed stock of equipment, but does NOT represent sales.
  - Current Standard: the minimum efficiency (or maximum energy use) required (allowed) by current DOE standards, when applicable.
  - ENERGY STAR: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable. Presented performance data represents certified products just meeting current ENERGY STAR specifications.
  - Low: The minimum available efficiency product or product mix available on the market. This typically reflects minimal compliance with DOE standards.
  - Typical: the average, or "typical," product being sold in the particular timeframe.
  - High: the product with the highest efficiency available in the particular timeframe.
  - Lumens: All reported lumens are initial lumens.
  - Correlated Color Temperature (CCT): a specification of the color appearance of the light emitted by a lamp.
  - Color Rendering Index (CRI): a scale from 0 to 100 percent indicating how accurate a "given" light source is at rendering color when compared to a "reference" light source. The higher the CRI, the better the color rendering ability.

- The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric
  - **Lighting**
    - **System Wattage** = (Lamp Wattage * Ballast Factor) / Ballast Efficiency
    - **System Lumens** = Lamp Lumens * Ballast Factor
    - **Lamp Efficacy** = Lamp Lumens / Lamp Wattage
    - **System Efficacy** = System Lumens / System Wattage
    - **Lamp Cost ($/klm)** = Lamp Cost / (Lamp Lumens / 1000)
    - **Total Equipment Cost** = Lamp Cost + Fixture (including ballast) Cost
    - **System Cost ($/klm)** = Total Equipment Cost / (System Lumens / 1000)
    - **Total Installed Cost** = Total Equipment Cost + Labor Installation Cost
    - **BLE** = A/(1+B*Avg Total Lamp Arc Power^(-C))
  - **Commercial Refrigeration**
    - **Nominal Capacity over Average Input (Btu in / Btu out)** = (Cooling or Heat Rejection Capacity)*24*365/(Annual Energy Consumption * 3412)
    - **Total Installed Cost** = Retail Equipment Cost + Labor Installation Cost
    - **Total Installed Cost ($/kBtu/hr)** = Total Installed Cost*1000 / (Cooling or Heat Rejection Capacity)
    - **Annual Maintenance Cost ($/kBtu/hr)** = Annual Maintenance Cost * 1000 / (Cooling or Heat Rejection Capacity)
  - **Ventilation**
    - **CFM out / Btu in / hr** = System Airflow / (System Fan Power * 3412)
    - **Total Installed Cost ($/1000 CFM)** = Total Installed Cost * 1000 / System Airflow
    - **Annual Maintenance Cost ($/1000 CFM)** = Annual Maintenance Cost * 1000 / System Fan Power

- The market for the reviewed products has changed since the analysis was performed in 2012. These changes are noted and reflected in the efficiency and cost characteristics.
  - DOE issued Federal minimum efficiency standards that have or will soon go into effect for General Service Fluorescent Lamps (effective 2012), Incandescent Reflector Lamps (July 2012), Fluorescent Lamp Ballasts (2014), Refrigerated Beverage Vending Machines (2012), Automatic Commercial Ice Makers (2018), Walk-In Coolers and Freezers (2017) and Commercial Refrigeration Equipment (2017). DOE published a Final Rule updating energy conservation standards for Refrigerated Beverage Vending Machines at the end of 2015, effective in 2018.

Residential Lighting

The residential general service lamps characterized in this report are a 60 watt and a 75 watt medium screw based A-type incandescent lamp and their halogen, CFL, and LED equivalents. A standard 60 watt incandescent lamp produces approximately 800 lumens. A standard 75 watt incandescent lamp produces approximately 1100 lumens (ENERGY STAR Program).

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 652 hours/year for residential general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60 watt general service lamps effective in 2014 and 75 watt lamps effective in 2013. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. California's Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent, halogen, and CFL technologies.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts ENERGY STAR performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- Beginning in 2017, California's Title 24 will require all light sources to be high efficacy. All general service lamps with medium screw bases must meet the following requirements: initial efficacy ≥45 lm/W, power factor ≥0.90, CCT ≤3000K, CRI ≥90, rated life ≥15,000 hours.
- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage <15W and ≥15W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Residential General Service Incandescent Lamps (60 watt)

DATA	2009	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	14.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$0.25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$0.16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$0.29	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 60 watt incandescent lamps as of January 1, 2014. Starting in 2014, 60 watt incandescent lamps were replaced by halogen lamps.

Performance/Cost Characteristics » Residential General Service Incandescent Lamps (75 watt)

DATA	2009	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1170	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	15.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.

DATA	2009	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	44	N/A	43	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	750	N/A	750	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	16.9	N/A	17.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$2.05	N/A	$1.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$2.73	N/A	$2.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$2.05	N/A	$1.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$1.38	N/A	$1.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$2.73	N/A	$2.65	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$1.83	N/A	$1.73	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for 60 watt incandescent lamps as of January 1, 2014. Starting in 2014, 60 watt incandescent lamps were replaced by halogen lamps.
2. In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards cannot be met with existing commercialized halogen lamp technologies and current trends in industry lead us to believe they will not be met.

DATA	2009	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	55	N/A	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1050	N/A	1050	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	19.2	N/A	19.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	652	N/A	652	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$1.38	N/A	$1.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$1.32	N/A	$1.24	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.
2. In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards cannot be met with existing commercialized halogen lamp technologies and current trends in industry lead us to believe they will not be met.

Performance/Cost Characteristics » Residential General Service Compact Fluorescent Lamps

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	13	14	13	13	14	13	13	12	12	11	11
Lamp Lumens	825	850	897	926	800	897	926	897	926	897	926
Lamp Efficacy (lm/W)	63.5	60.7	68.9	71.2	58.0	70.6	73.0	74.2	76.7	78.0	80.6
CRI	82	82	82	82	82	82	82	82	82	82	82
Correlated Color Temperature (CCT)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	10.0	10.0	10.0	10.0	10.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	652	652	652	652	N/A	652	652	652	652	652	652
Lamp Price ($)	$2.15	$2.74	$2.03	$5.49	N/A	$1.98	$5.35	$1.89	$5.09	$1.79	$4.84
Lamp Cost ($/klm)	$2.61	$3.22	$2.27	$5.93	N/A	$2.21	$5.78	$2.10	$5.50	$2.00	$5.23
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Installation (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($/klm)	$2.15	$2.74	$2.03	$5.49	N/A	$1.98	$5.35	$1.89	$5.09	$1.79	$4.84
Annual Maintenance Cost ($)	$0.14	$0.18	$0.13	$0.36	N/A	$0.13	$0.34	$0.11	$0.31	$0.10	$0.28
Total Installed Cost ($/klm)	$2.61	$3.22	$2.27	$5.93	N/A	$2.21	$5.78	$2.10	$5.50	$2.00	$5.23
Annual Maintenance Cost ($/klm)	$0.17	$0.21	$0.15	$0.39	N/A	$0.14	$0.37	$0.13	$0.33	$0.12	$0.30

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential General Service LED Lamps (60 Watt Equivalent)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	8	7	6	5	5	4
Lamp Lumens	800	850	837	865	800	840	840	840	840	840	840
Lamp Efficacy (lm/W)	44	64	93	104	59	102	123	131	171	161	219
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	652	652	652	652	652	652	652	652	652	652	652
Lamp Price ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$5.89	$5.89	$3.00	$3.00	$2.00	$2.00
Lamp Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$5.89	$5.89	$3.00	$3.00	$2.00	$2.00
Annual Maintenance Cost ($)	$2.22	$0.63	$0.20	$0.13	$0.31	$0.08	$0.08	$0.04	$0.04	$0.03	$0.03
Total Installed Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Annual Maintenance Cost ($/klm)	$2.77	$0.74	$0.23	$0.15	$0.39	$0.10	$0.09	$0.05	$0.05	$0.03	$0.03

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available, and meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Reflector Lamps

The residential reflector lamps characterized in this report are directional lamps that emit between approximately 550-750 lumens. Multiple baseline reflector lamps were analyzed, including: 65W Incandescent BR30, Halogen PAR30, Halogen Infrared Reflector (HIR) PAR30, CFL BR30, LED BR30, LED PAR38.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 642 hours/year for residential reflector lamps (DOE SSL Program, 2012a).

Legislation:

- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA 2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008. The 65W BR30, a large majority of the incandescent reflector lamp market is still exempted. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for directional lamps with CRI ≥ 90 and 70 lm/W for directional lamps with CRI < 90 (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Residential Reflector Lamps (65W BR30 Incandescent)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	65	N/A	65	N/A	N/A	64	N/A	63	N/A	62	N/A
Lamp Lumens	620	N/A	637	N/A	N/A	637	N/A	637	N/A	637	N/A
Lamp Efficacy (lm/W)	9.5	N/A	9.8	N/A	N/A	9.9	N/A	10.1	N/A	10.3	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2700	N/A	2700	N/A	N/A	2700	N/A	2700	N/A	2700	N/A
Average Lamp Life (1000 hrs)	2.0	N/A	2.0	N/A	N/A	2.1	N/A	2.2	N/A	2.3	N/A
Annual Operating Hours (hrs/yr)	642	N/A	642	N/A	N/A	642	N/A	642	N/A	642	N/A
Lamp Price ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Lamp Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Annual Maintenance Cost ($)	$0.44	N/A	$1.08	N/A	N/A	$1.03	N/A	$0.93	N/A	$0.84	N/A
Total Installed Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Annual Maintenance Cost ($/klm)	$0.71	N/A	$1.70	N/A	N/A	$1.61	N/A	$1.46	N/A	$1.32	N/A

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	50	N/A	47	N/A	N/A	46	N/A	44	N/A	42	N/A
Lamp Lumens	660	N/A	660	N/A	N/A	660	N/A	660	N/A	660	N/A
Lamp Efficacy (lm/W)	13.2	N/A	14.0	N/A	N/A	14.4	N/A	15.1	N/A	15.9	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	1.4	N/A	1.5	N/A	N/A	1.5	N/A	1.6	N/A	1.7	N/A
Annual Operating Hours (hrs/yr)	642	N/A	642	N/A	N/A	642	N/A	642	N/A	642	N/A
Lamp Price ($)	$4.19	N/A	$5.71	N/A	N/A	$5.57	N/A	$5.30	N/A	$5.04	N/A
Lamp Cost ($/klm)	$6.35	N/A	$8.65	N/A	N/A	$8.44	N/A	$8.02	N/A	$7.63	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$4.19	N/A	$5.71	N/A	N/A	$5.57	N/A	$5.30	N/A	$5.04	N/A
Annual Maintenance Cost ($)	$1.92	N/A	$2.44	N/A	N/A	$2.32	N/A	$2.10	N/A	$1.90	N/A
Total Installed Cost ($/klm)	$6.35	N/A	$8.65	N/A	N/A	$8.44	N/A	$8.02	N/A	$7.63	N/A
Annual Maintenance Cost ($/klm)	$2.91	N/A	$3.70	N/A	N/A	$3.52	N/A	$3.18	N/A	$2.88	N/A

Performance/Cost Characteristics » Residential Reflector Lamps (PAR30 Halogen Infrared Reflector (HIR)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	40	N/A	39	N/A	N/A	38	N/A	36	N/A	34	N/A
Lamp Lumens	650	N/A	650	N/A	N/A	650	N/A	650	N/A	650	N/A
Lamp Efficacy (lm/W)	16.2	N/A	16.7	N/A	N/A	17.1	N/A	18.0	N/A	18.9	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	3.9	N/A	4.0	N/A	N/A	4.1	N/A	4.3	N/A	4.5	N/A
Annual Operating Hours (hrs/yr)	642	N/A	642	N/A	N/A	642	N/A	642	N/A	642	N/A
Lamp Price ($)	$12.76	N/A	$12.38	N/A	N/A	$12.07	N/A	$11.48	N/A	$10.92	N/A
Lamp Cost ($/klm)	$19.63	N/A	$19.05	N/A	N/A	$18.57	N/A	$17.67	N/A	$16.80	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$12.76	N/A	$12.38	N/A	N/A	$12.07	N/A	$11.48	N/A	$10.92	N/A
Annual Maintenance Cost ($)	$2.11	N/A	$1.99	N/A	N/A	$1.89	N/A	$1.71	N/A	$1.55	N/A
Total Installed Cost ($/klm)	$19.63	N/A	$19.05	N/A	N/A	$18.57	N/A	$17.67	N/A	$16.80	N/A
Annual Maintenance Cost ($/klm)	$3.24	N/A	$3.05	N/A	N/A	$2.91	N/A	$2.63	N/A	$2.38	N/A

Performance/Cost Characteristics » Residential Reflector Lamps (BR30 CFL)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	16	14	15	15	15	14	15	14	14	13	13
Lamp Lumens	750	600	700	750	650	700	750	700	750	700	750
Lamp Efficacy (lm/W)	46.9	42.9	47.4	50.0	43.3	48.6	51.3	51.1	53.9	53.7	56.6
CRI	82	82	82	82	82	82	82	82	82	82	82
Correlated Color Temperature (CCT)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	8.0	10.0	10.0	10.0	10.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	642	642	642	642	N/A	642	642	642	642	642	642
Lamp Price ($)	$5.87	$6.98	$5.46	$5.60	N/A	$5.32	$5.46	$5.06	$5.19	$4.82	$4.94
Lamp Cost ($/klm)	$7.82	$11.63	$7.80	$7.47	N/A	$7.61	$7.28	$7.24	$6.93	$6.88	$6.59
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($)	$5.87	$6.98	$5.46	$5.60	N/A	$5.32	$5.46	$5.06	$5.19	$4.82	$4.94
Annual Maintenance Cost ($)	$0.47	$0.45	$0.35	$0.36	N/A	$0.33	$0.34	$0.30	$0.31	$0.27	$0.28
Total Installed Cost ($/klm)	$7.83	$11.63	$7.80	$7.47	N/A	$7.61	$7.28	$7.24	$6.93	$6.88	$6.59
Annual Maintenance Cost ($/klm)	$0.63	$0.75	$0.50	$0.48	N/A	$0.48	$0.46	$0.43	$0.41	$0.39	$0.37

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Reflector LED BR30

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	18	11	10	8	12	8	6	6	5	5	4
Lamp Lumens	600	670	794	699	605	700	700	700	700	700	700
Lamp Efficacy (lm/W)	33	59	78	89	50	91	109	117	153	144	196
CRI	80	95	84	82	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	5000	2700	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$8.63	$8.63	$4.90	$4.90	$2.80	$2.80
Lamp Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$8.63	$8.63	$4.90	$4.90	$2.80	$2.80
Annual Maintenance Cost ($)	$3.16	$0.33	$0.38	$0.54	$1.91	$0.11	$0.11	$0.06	$0.06	$0.04	$0.04
Total Installed Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Annual Maintenance Cost ($/klm)	$5.26	$0.50	$0.48	$0.77	$3.16	$0.16	$0.16	$0.09	$0.09	$0.05	$0.05

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Reflector LED PAR38

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	28	18	16	17	20	15	13	12	9	10	7
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	91	109	117	153	144	196
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Annual Maintenance Cost ($)	$5.26	$0.66	$0.64	$0.94	$0.88	$0.23	$0.23	$0.13	$0.13	$0.07	$0.07
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Annual Maintenance Cost ($/klm)	$5.26	$0.56	$0.48	$0.48	$0.84	$0.16	$0.16	$0.09	$0.09	$0.05	$0.05

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. The LED luminaire is more efficient and cost effective for new installations or fixture retrofits.
- Labor costs for lamp changes are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore annual maintenance costs are the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 684 hours/year for residential linear systems(DOE SSL Program, 2012a).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized residential ballasts have a minimum BLE = 0.993 / (1 + 0.41 * Avg Total Lamp Arc power ^ (- 0.25)). Residential ballasts also must have a minimum power factor of 0.5.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR residential fixtures require ≥ 65 lm/W per lamp-ballast platform before September 1, 2013 and ≥ 70 lm/W per lamp-ballast platform thereafter (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T12	0%	0%	-0.5%	Limited as the technology is mature.
T8	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Residential Linear Fluorescent Lamp T12

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	2860	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens	3890	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	78%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	4100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours	684	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.92	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price ($)	$11.22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$25.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$9.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$68.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hr)	0.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$35.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$1.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$9.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.41	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Performance/Cost Characteristics » Residential Linear Fluorescent Lamp T8

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	32	32	32	28	32	32	28	31	27	30	27
Lamp Lumens	2520	2725	2770	2590	2800	2770	2590	2770	2590	2770	2590
Lamp Efficacy (lm/W)	79	85	87	93	88	87	93	89	95	91	97
System Wattage	65	61	61	54	60	60	53	59	52	58	51
System Lumens	4435	4796	4875	4558	4410	4875	4558	4875	4558	4875	4558
System Efficacy (lm/W)	69	79	80	85	74	81	86	82	88	84	89
Ballast Efficiency (BLE)	87%	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
CRI	75	83	85	85	80	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	3000	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	24	21	24	10	22	25	23	26	24	27
Annual Operating Hours	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$0.85	$4.99	$5.51	$8.23	$4.79	$5.37	$8.03	$5.11	$7.63	$4.86	$7.26
Ballast Price ($)	$9.94	$16.10	$16.10	$16.10	N/A	$15.70	$15.70	$14.93	$14.93	$14.20	$14.20
Fixture Price ($)	$25.01	$24.64	$24.64	$24.64	$24.98	$24.03	$24.03	$22.86	$22.86	$21.74	$21.74
Lamp Cost ($/klm)	$0.34	$1.83	$1.99	$3.18	$1.71	$1.94	$3.10	$1.85	$2.95	$1.75	$2.80
System (l/b/f) Cost ($/klm)	$14.55	$18.61	$18.69	$22.09	$12.34	$18.22	$21.54	$17.33	$20.49	$16.49	$19.48
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$98.62	$123.37	$125.20	$134.78	$88.53	$122.95	$132.28	$118.60	$127.48	$114.47	$122.92
Annual Maintenance Cost ($)	$0.06	$0.28	$0.36	$0.47	$0.66	$0.34	$0.45	$0.31	$0.40	$0.28	$0.37
Total Installed Cost ($/klm)	$22.24	$25.72	$25.68	$29.57	$20.08	$25.22	$29.02	$24.33	$27.97	$23.48	$26.97
Annual Maintenance Cost ($/klm)	$0.01	$0.06	$0.07	$0.10	$0.15	$0.07	$0.10	$0.06	$0.09	$0.06	$0.08

1. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential Linear Fluorescent Lamp T5

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	28	28	28	28	28	28	27	27	27	27
Lamp Lumens	2660	2446	2697	2898	2900	2697	2898	2697	2898	2697	2898
Lamp Efficacy (lm/W)	95	87	96	104	104	97	105	99	107	101	109
System Wattage	63	61	61	61	56	60	60	59	59	58	58
System Lumens	5320	4892	5394	5796	4350	5394	5796	5394	5796	5394	5796
System Efficacy (lm/W)	84	80	89	95	78	90	96	91	98	93	100
Ballast Efficiency (BLE)	89%	92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
CRI	85	85	85	85	80	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	3500	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	30	30	30	10	31	31	32	32	34	34
Annual Operating Hours	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$3.18	$4.10	$5.94	$7.06	$7.20	$5.79	$6.89	$5.51	$6.55	$5.24	$6.23
Ballast Price ($)	$20.94	$26.28	$26.28	$26.28	N/A	$25.63	$25.63	$24.38	$24.38	$23.18	$23.18
Fixture Price ($)	$94.07	$92.67	$92.67	$92.67	$79.97	$90.38	$90.38	$85.96	$85.96	$81.76	$81.76
Lamp Cost ($/klm)	$0.60	$1.68	$2.20	$2.44	$2.48	$2.15	$2.38	$2.04	$2.26	$1.94	$2.15
System (l/b/f) Cost ($/klm)	$45.63	$51.98	$48.51	$45.92	$32.54	$47.31	$44.78	$45.00	$42.59	$42.80	$40.51
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$276.83	$288.40	$295.76	$300.24	$175.66	$289.29	$293.65	$276.81	$280.96	$264.94	$268.90
Annual Maintenance Cost ($)	$0.22	$0.19	$0.27	$0.32	$0.98	$0.26	$0.31	$0.23	$0.28	$0.21	$0.25
Total Installed Cost ($/klm)	$52.04	$58.95	$54.83	$51.80	$40.38	$53.63	$50.67	$51.32	$48.48	$49.12	$46.39
Annual Maintenance Cost ($/klm)	$0.04	$0.04	$0.05	$0.06	$0.23	$0.05	$0.05	$0.04	$0.05	$0.04	$0.04

1. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential Linear LED Replacement Lamp 2 Lamp System*

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	19	18	18	N/A	15	14	13	11	11	9
Lamp Lumens	1355	1743	2151	2309	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	75	92	116	132	N/A	136	151	164	199	192	230
System Wattage	36	38	37	35	N/A	31	28	26	21	22	18
System Lumens	2304	3103	3829	4110	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	64	82	104	117	N/A	128	142	158	191	184	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	70	80	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	4000	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	35	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	684	684	684	684	N/A	684	684	684	684	684	684
Lamp Price ($)	$135.83	$22.19	$34.42	$38.30	N/A	$22.76	$22.76	$10.44	$10.44	$4.79	$4.79
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$100.25	$12.73	$16.00	$16.59	N/A	$10.84	$10.84	$4.97	$4.97	$2.28	$2.28
System (l/b/f) Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor System Installation (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$271.67	$44.38	$68.84	$76.60	N/A	$45.51	$45.51	$20.88	$20.88	$9.58	$9.58
Annual Maintenance Cost ($)	$5.31	$0.61	$1.05	$1.05	N/A	$0.64	$0.64	$0.29	$0.29	$0.13	$0.13
Total Installed Cost ($/klm)	$200.49	$25.46	$32.00	$33.17	N/A	$21.67	$21.67	$9.94	$9.94	$4.56	$4.56
Annual Maintenance Cost ($/klm)	$3.92	$0.35	$0.49	$0.45	N/A	$0.30	$0.30	$0.14	$0.14	$0.06	$0.06

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

Performance/Cost Characteristics » Residential Linear LED Luminaire

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	46	48	57	40	55	37	30	28	22	22	22
System Lumens	3395	4044	5697	4918	4000	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	67	84	100	122	73	137	164	181	230	225	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	87	83	83	83	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
Average Lamp Life (1000 hrs)	50	60	56	50	36	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$731.04	$439.00	$176.61	$513.45	$139.00	$98.98	$98.98	$52.60	$52.60	$27.96	$27.96
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)[5]	$215.34	$108.56	$31.00	$104.41	$34.75	$19.80	$19.80	$10.52	$10.52	$5.59	$5.59
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr) [5]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$765.14	$473.10	$210.71	$547.55	$173.10	$133.08	$133.08	$86.70	$86.70	$62.06	$62.06
Annual Maintenance Cost ($)	$10.46	$5.39	$2.57	$7.49	$3.29	$0.94	$0.94	$0.59	$0.59	$0.42	$0.42
Total Installed Cost ($/klm)	$225.38	$116.99	$36.99	$111.35	$43.28	$26.62	$26.62	$17.34	$17.34	$12.41	$12.41
Annual Maintenance Cost ($/klm)	$3.08	$1.33	$0.45	$1.52	$0.82	$0.19	$0.19	$0.12	$0.12	$0.08	$0.08

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Residential Outdoor Lamps

- The residential outdoor lamps characterized in this report include reflector and general service lamps used for security and/or porch lighting that can be switched on from inside the home (i.e. parking lot/garage and outdoor common area lighting at multifamily buildings are excluded) with lumen outputs of approximately 1000-1400 lumens. Multiple baseline lamps were analyzed according to estimates of installed base average lumens by lamp type, including:

Security (Reflector Lamps)	Porch (General Service Lamps)
Incandescent BR30	Incandescent A-Type
Halogen PAR38	Halogen A-Type
Halogen Infrared Reflector (HIR) PAR38	CFL Bare Spiral
CFL PAR38	LED A-Type Lamp
LED PAR38	

- In 2010, it was estimated that over 96% of residential outdoor lamps were incandescent, halogen, or CFL technologies. Approximately, 51% of residential outdoor lamps were general service and 24% were reflector lamps. The remaining share was made up of primarily decorative and miscellaneous lamp types (DOE, 2012(3)).

Performance:

- 65W BR30 is the only viable incandescent reflector lamp due to exemption from EISA 2007. The lumen output of this lamp type is well below other reflector lamp technologies characterized for residential outdoor spaces, thus its use is limited for this application.
- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 1059 hours/year for residential reflector lamps (DOE SSL Program, 2012b).

Legislation:

- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for directional lamps with CRI ≥ 90 and 70 lm/W for directional lamps with CRI < 90 (ENERGY STAR).
- Additionally, all lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent Omnidirectional	0%	+0.5%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Incandescent Directional	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: Incandescent BR30)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	65	N/A	65	N/A	N/A	64	N/A	63	N/A	62	N/A
Lamp Lumens	620	N/A	637	N/A	N/A	637	N/A	637	N/A	637	N/A
Lamp Efficacy (lm/W)	9.5	N/A	9.8	N/A	N/A	9.9	N/A	10.1	N/A	10.3	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2700	N/A	2700	N/A	N/A	2700	N/A	2700	N/A	2700	N/A
Average Lamp Life (1000 hrs)	2.0	N/A	2.0	N/A	N/A	2.1	N/A	2.2	N/A	2.3	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Lamp Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$1.37	N/A	$3.37	N/A	N/A	$3.29	N/A	$3.13	N/A	$2.97	N/A
Annual Maintenance Cost ($)	$0.73	N/A	$1.78	N/A	N/A	$1.70	N/A	$1.54	N/A	$1.39	N/A
Total Installed Cost ($/klm)	$2.21	N/A	$5.29	N/A	N/A	$5.16	N/A	$4.91	N/A	$4.67	N/A
Annual Maintenance Cost ($/klm)	$1.17	N/A	$2.80	N/A	N/A	$2.66	N/A	$2.41	N/A	$2.18	N/A

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: Halogen PAR38)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	90	N/A	72	N/A	N/A	70	N/A	67	N/A	63	N/A
Lamp Lumens	1320	N/A	1350	N/A	N/A	1350	N/A	1350	N/A	1350	N/A
Lamp Efficacy (lm/W)	14.7	N/A	18.8	N/A	N/A	19.3	N/A	20.3	N/A	21.3	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2900	N/A	2900	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	2.4	N/A	2.4	N/A	N/A	2.5	N/A	2.6	N/A	2.7	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$4.47	N/A	$5.61	N/A	N/A	$5.47	N/A	$5.20	N/A	$4.95	N/A
Lamp Cost ($/klm)	$3.39	N/A	$4.16	N/A	N/A	$4.05	N/A	$3.85	N/A	$3.67	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$4.47	N/A	$5.61	N/A	N/A	$5.47	N/A	$5.20	N/A	$4.95	N/A
Annual Maintenance Cost ($)	$1.97	N/A	$2.47	N/A	N/A	$2.35	N/A	$2.13	N/A	$1.93	N/A
Total Installed Cost ($/klm)	$3.39	N/A	$4.16	N/A	N/A	$4.05	N/A	$3.85	N/A	$3.67	N/A
Annual Maintenance Cost ($/klm)	$1.50	N/A	$1.83	N/A	N/A	$1.74	N/A	$1.58	N/A	$1.43	N/A

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	70	N/A	70	N/A	N/A	68	N/A	65	N/A	62	N/A
Lamp Lumens	1358	N/A	1453	N/A	N/A	1453	N/A	1453	N/A	1453	N/A
Lamp Efficacy (lm/W)	19.4	N/A	20.8	N/A	N/A	21.3	N/A	22.4	N/A	23.6	N/A
CRI	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	3.4	N/A	4.4	N/A	N/A	4.5	N/A	4.7	N/A	5.0	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$13.63	N/A	$9.16	N/A	N/A	$8.93	N/A	$8.50	N/A	$8.08	N/A
Lamp Cost ($/klm)	$10.04	N/A	$6.30	N/A	N/A	$6.15	N/A	$5.85	N/A	$5.56	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$13.63	N/A	$9.16	N/A	N/A	$8.93	N/A	$8.50	N/A	$8.08	N/A
Annual Maintenance Cost ($)	$4.24	N/A	$2.20	N/A	N/A	$2.10	N/A	$1.90	N/A	$1.72	N/A
Total Installed Cost ($/klm)	$10.04	N/A	$6.30	N/A	N/A	$6.15	N/A	$5.85	N/A	$5.56	N/A
Annual Maintenance Cost ($/klm)	$3.12	N/A	$1.52	N/A	N/A	$1.44	N/A	$1.31	N/A	$1.18	N/A

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: CFL PAR38)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	19	N/A	23	N/A	23	22	N/A	21	N/A	20	N/A
Lamp Lumens	1300	N/A	1300	N/A	1300	1300	N/A	1300	N/A	1300	N/A
Lamp Efficacy (lm/W)	54.9	N/A	56.5	N/A	56.5	57.9	N/A	60.9	N/A	64.0	N/A
CRI	82	N/A	82	N/A	82	82	N/A	82	N/A	82	N/A
Correlated Color Temperature (CCT)	2700	N/A	2700	N/A	2700	2700	N/A	2700	N/A	2700	N/A
Average Lamp Life (1000 hrs)	9.7	N/A	10.0	N/A	10.0	10.3	N/A	10.8	N/A	11.3	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	1059	N/A	1059	N/A	1059	N/A
Lamp Price ($)	$7.18	N/A	$6.97	N/A	N/A	$6.80	N/A	$6.47	N/A	$6.15	N/A
Lamp Cost ($/klm)	$5.53	N/A	$5.36	N/A	N/A	$5.23	N/A	$4.97	N/A	$4.73	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	$0.00	N/A	$0.00	N/A	$0.00	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	0	N/A	0	N/A	0	N/A
Total Installed Cost ($)	$7.18	N/A	$6.97	N/A	N/A	$6.80	N/A	$6.47	N/A	$6.15	N/A
Annual Maintenance Cost ($)	$0.78	N/A	$0.74	N/A	N/A	$0.70	N/A	$0.64	N/A	$0.57	N/A
Total Installed Cost ($/klm)	$5.53	N/A	$5.36	N/A	N/A	$5.23	N/A	$4.97	N/A	$4.73	N/A
Annual Maintenance Cost ($/klm)	$0.60	N/A	$0.57	N/A	N/A	$0.54	N/A	$0.49	N/A	$0.44	N/A

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: LED PAR38[1])

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	18	16	17	20	15	13	12	9	10	7
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	91	109	117	153	144	196
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Annual Maintenance Cost ($)	$8.68	$1.09	$1.05	$1.55	$1.46	$0.37	$0.37	$0.21	$0.21	$0.12	$0.12
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
Annual Maintenance Cost ($/klm)	$8.68	$0.93	$0.79	$0.79	$1.39	$0.27	$0.27	$0.15	$0.15	$0.08	$0.08

1. Data based on an indoor LED PAR38 lamp with adjustments for annual operating hours.
2. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: Incandescent A19)

DATA	2009	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1170	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	15.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$0.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$0.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$0.32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$0.45	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: Halogen A19)

DATA	2009	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	55	N/A	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1050	N/A	1050	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	19.2	N/A	19.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	1059	N/A	1059	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	N/A	$0.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	0	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$2.06	N/A	$2.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$2.25	N/A	$2.12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$1.96	N/A	$1.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$2.14	N/A	$2.02	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 (EISA 2007) prescribes standards for current 75 watt incandescent lamps as of January 1, 2013. Starting in 2013, 75 watt incandescent lamps were replaced by halogen lamps.
2. In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized halogen lamp technologies and current trends in industry lead us to believe they will not be met.

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: CFL Bare Spiral)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	19	19	19	18	20	18	18	17	17	16	16
Lamp Lumens	1216	1200	1216	1300	1200	1216	1300	1216	1300	1216	1300
Lamp Efficacy (lm/W)	63.5	63.2	65.4	72.2	60.0	67.1	74.0	70.5	77.8	74.1	81.8
CRI	82	82	82	82	82	82	82	82	82	82	82
Correlated Color Temperature (CCT)	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	10	10.0	10.0	10.0	10.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	N/A	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$3.32	$3.24	$3.22	$6.49	N/A	$3.14	$6.33	$2.99	$6.02	$2.84	$5.73
Lamp Cost ($/klm)	$2.73	$2.70	$2.65	$4.99	N/A	$2.58	$4.87	$2.46	$4.63	$2.34	$4.40
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($)	$3.32	$3.24	$3.22	$6.49	N/A	$3.14	$6.33	$2.99	$6.02	$2.84	$5.73
Annual Maintenance Cost ($)	$0.36	$0.34	$0.34	$0.69	N/A	$0.32	$0.65	$0.29	$0.59	$0.27	$0.54
Total Installed Cost ($/klm)	$2.73	$2.70	$2.65	$4.99	N/A	$2.58	$4.87	$2.46	$4.63	$2.34	$4.40
Annual Maintenance Cost ($/klm)	$0.30	$0.29	$0.28	$0.53	N/A	$0.27	$0.50	$0.24	$0.45	$0.22	$0.41

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: LED A-Type[1])

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	9	8	7	6	6	4
Lamp Lumens	964	964	964	964	964	964	964	964	964	964	964
Lamp Efficacy (lm/W)	44	64	93	104	71	102	123	131	171	161	219
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$6.76	$6.76	$3.44	$3.44	$2.30	$2.30
Lamp Cost ($/klm)	$85.00	$24.90	$9.00	$5.18	$12.43	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$6.76	$6.76	$3.44	$3.44	$2.30	$2.30
Annual Maintenance Cost ($)	$3.60	$1.02	$0.37	$0.21	$0.51	$0.15	$0.15	$0.07	$0.07	$0.05	$0.05
Total Installed Cost ($/klm)	$70.54	$24.90	$9.00	$5.18	$12.43	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
Annual Maintenance Cost ($/klm)	$3.73	$1.05	$0.38	$0.22	$0.53	$0.15	$0.15	$0.08	$0.08	$0.05	$0.05

1. Data based on an indoor 100W Equivalent LED A-type lamp, scaled to lumen output reported for the building exterior low-output technologies in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)
2. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Commercial Lighting

Performance/Cost Characteristics » Commercial General Service Lamps in Recessed Can Fixtures

This section characterizes commercial omnidirectional incandescent, halogen, CFL, and LED screw based general service lamps emitting approximately 1600 lumens (equivalent to a 100W incandescent lamp) used in recessed can fixtures. A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, an omnidirectional lamp is not well suited for use in such fixtures, as light that emits upwards and out of the sides must be reflected downwards and out of the fixture and some light is absorbed in the process. A fixture efficiency of 61% is used to characterize these lumen losses for all omnidirectional lamps. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3868 hours/year for commercial general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. California's Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent, halogen, and CFL technologies.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts ENERGY STAR performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- For ENERGY STAR qualification, general service, omnidirectional lamps, must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥15 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

DATA	2003	2012[1]	2015[1]				2020[1]		2030[1]		2040[1]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1620	1620	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	16.2	16.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens	988	988	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	9.9	9.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	0.8	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	3868	3868	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$0.37	$0.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$0.23	$0.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$17.07	$20.81	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hr)	1.0	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0.05	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$82.22	$97.61	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$18.78	$22.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$83.20	$98.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$19.00	$23.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 prescribes standards for current 100 watt incandescent lamps as of January 1, 2012. Starting in 2012, 100-watt incandescent lamps will be replaced by halogen lamps.

Performance/Cost Characteristics » Commercial General Service Halogen Lamp (100W Incandescent Equivalent) in Recessed Can Fixture

DATA	2003	2012[1]	2015[1]				2020[2]		2030[2]		2040[2]	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	90	72	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	1620	1490	N/A	1490	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	18.0	20.7	N/A	20.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	90	72	N/A	72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Lumens	988	909	N/A	909	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Efficacy (lm/W)	11.0	12.6	N/A	12.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Correlated Color Temperature (CCT)	2850	2850	N/A	2850	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average Lamp Life (1000 hrs)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Operating Hours (hrs/yr)	3868	3868	N/A	3868	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Price ($)	$8.07	$1.97	N/A	$2.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	$22.56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$4.98	$1.32	N/A	$1.35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$24.86	$24.17	N/A	$27.03	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	$81.95	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor System Installation (hr)	1.0	1.0	N/A	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0.05	0.05	N/A	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$89.92	$99.02	N/A	$106.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($)	$43.85	$22.51	N/A	$23.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($/klm)	$90.99	$108.94	N/A	$117.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Annual Maintenance Cost ($/klm)	$44.37	$24.77	N/A	$25.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

1. The Energy Independence and Security Act of 2007 prescribes standards for current 100 watt incandescent lamps as of January 1, 2012. Starting in 2012, 100-watt incandescent lamps will be replaced by halogen lamps.
2. In 2020, EISA 2007 sets a minimum efficacy for general service lamps of 45 lm/W. These standards can not be met with existing commercialized halogen lamp technologies and current trends in industry lead us to believe they will not be met.

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[1]	Typical	High	Typical	High	Typical	High
Lamp Wattage	26	25	27	23	23	26	23	22	22	21	21	20
Lamp Lumens	1750	1680	1700	1611	1640	1686	1611	1640	1611	1640	1611	1640
Lamp Efficacy (lm/W)	67.3	68.1	63.7	68.9	71.3	65.0	70.7	73.1	74.3	76.8	78.1	80.8
System Wattage	26	25	27	23	23	26	23	22	22	21	21	20
System Lumens	1068	1025	1037	983	1000	1028	983	1000	983	1000	983	1000
System Efficacy (lm/W)	41.1	41.6	38.9	42.7	43.5	39.6	43.1	44.6	45.3	46.9	47.6	49.3
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	82	82	82	82	82	81	82	82	82	82	82	82
Correlated Color Temperature (CCT)	3000	3000	3000	3000	3000	2700	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	10.0	10.0	10.0	10.0	10.0	12.0	10.3	10.3	10.8	10.8	11.3	11.3
Annual Operating Hours (hrs/yr)	3868	3868	3868	3868	3868	N/A	3868	3868	3868	3868	3868	3868
Lamp Price ($)	$7.02	$2.60	$3.30	$3.33	$3.50	N/A	$3.24	$3.41	$3.08	$3.24	$2.93	$3.08
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	$22.56	$22.56	$22.56	N/A	$22.00	$22.00	$20.93	$20.93	$19.90	$19.90
Lamp Cost ($/klm)	$4.01	$1.55	$1.94	$2.06	$2.13	N/A	$2.01	$2.08	$1.91	$1.98	$1.82	$1.88
System (l/b/f) Cost ($/klm)	$22.02	$22.05	$24.94	$26.34	$26.04	N/A	$25.69	$25.40	$24.43	$24.16	$23.24	$22.98
Labor Cost ($/hr)	$65.35	$77.05	$81.95	$81.95	$81.95	N/A	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)	1.0	1.0	1.0	1.0	1.0	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr)	0.05	0.05	0.05	0.05	0.05	N/A	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost ($)	$88.87	$99.65	$107.81	$107.84	$108.01	N/A	$107.19	$107.36	$105.96	$106.12	$104.79	$104.94
Annual Maintenance Cost ($)	$3.98	$2.50	$2.86	$2.87	$2.94	N/A	$2.77	$2.83	$2.58	$2.63	$2.40	$2.45
Total Installed Cost ($/klm)	$83.21	$97.22	$103.96	$109.73	$107.96	N/A	$109.07	$107.32	$107.82	$106.08	$106.62	$104.89
Annual Maintenance Cost ($/klm)	$3.73	$2.44	$2.76	$2.92	$2.94	N/A	$2.82	$2.83	$2.62	$2.63	$2.44	$2.45

1. Meets criteria outlined in ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs): Eligibility Criteria Version 1.1 (Rev. August 2014)

Performance/Cost Characteristics » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	27	17	15	16	23	12	11	9	8	7	7
Lamp Lumens	N/A	1600	1580	1646	1710	1600	1600	1600	1600	1600	1600	1600
Lamp Efficacy (lm/W)	N/A	60	92	108	110	71	137	150	176	209	216	230
System Wattage	N/A	27	17	15	16	23	12	11	9	8	7	7
System Lumens	N/A	976	964	1004	1043	976	976	976	976	976	976	976
System Efficacy (lm/W)	N/A	36.6	56.4	66.2	67.3	43.4	83.3	91.6	107.4	127.4	131.6	140.3
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	80	84	83	81	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	3000	3000	2700	2700	3000	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	N/A	22	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868
Lamp Price ($)	N/A	$40.00	$14.71	$15.30	$15.99	$22.99	$11.22	$11.22	$5.71	$5.71	$3.81	$3.81
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$25.00	$9.31	$9.30	$9.35	$14.37	$7.02	$7.02	$3.57	$3.57	$2.38	$2.38
System (l/b/f) Cost ($/klm)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost ($)	N/A	$43.85	$18.81	$19.40	$20.09	$27.09	$15.32	$15.32	$9.81	$9.81	$7.91	$7.91
Annual Maintenance Cost ($)	N/A	$7.71	$2.91	$3.00	$3.11	$4.19	$1.23	$1.21	$0.76	$0.76	$0.61	$0.61
Total Installed Cost ($/klm)	N/A	$44.93	$19.51	$19.33	$19.26	$27.75	$15.70	$15.70	$10.05	$10.05	$8.10	$8.10
Annual Maintenance Cost ($/klm)	N/A	$7.90	$3.02	$2.99	$2.98	$4.29	$1.27	$1.24	$0.78	$0.78	$0.63	$0.63

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For new installations or retrofits where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

This section characterizes commercial halogen, Halogen infrared reflector (HIR), and LED screw based reflector lamps emitting approximately 1400 lumens used in recessed can fixtures.

- HIR lamps contain a tungsten halogen capsule with a film coating on the inside of the capsule. The coating reflects infrared radiation back into the lamp filament, which forces the filament to burn at a higher temperature. This increases the efficacy of the lamp, without reducing operating life.
- A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, a reflector lamp, which employs reflective coating to direct light out in only one direction, is well suited for use in such fixtures. However, some light is not able to escape the fixture, and a fixture efficiency of 93% is used to characterize these minimal lumen losses. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3860 hours/year for commercial reflector lamps (DOE SSL Program, 2012a).

Legislation:

- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for omnidirectional lamps with CRI ≥ 90 and 70 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Performance/Cost Characteristics » Commercial Reflector Lamps in Recessed Can Fixtures

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
HIR	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	90	90	N/A	72	N/A	N/A	70	N/A	67	N/A	63	N/A
Lamp Lumens	1314	1323	N/A	1350	N/A	N/A	1350	N/A	1350	N/A	1350	N/A
Lamp Efficacy (lm/W)	14.6	14.7	N/A	18.8	N/A	N/A	19.3	N/A	20.3	N/A	21.3	N/A
System Wattage	90	90	N/A	72	N/A	N/A	70	N/A	67	N/A	63	N/A
System Lumens	1222	1230	N/A	1256	N/A	N/A	1256	N/A	1256	N/A	1256	N/A
System Efficacy (lm/W)	13.5	13.7	N/A	17.5	N/A	N/A	17.9	N/A	18.8	N/A	19.8	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2900	2900	N/A	2900	N/A	N/A	2900	N/A	2900	N/A	2900	N/A
Average Lamp Life (1000 hrs)	2.4	2.4	N/A	2.4	N/A	N/A	2.5	N/A	2.6	N/A	2.7	N/A
Annual Operating Hours (hrs/yr)	3860	3860	N/A	3860	N/A	N/A	3860	N/A	3860	N/A	3860	N/A
Lamp Price ($)	$6.54	$3.78	N/A	$5.61	N/A	N/A	$5.47	N/A	$5.20	N/A	$4.95	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	$22.56	N/A	N/A	$22.00	N/A	$20.93	N/A	$19.90	N/A
Lamp Cost ($/klm)	$4.98	$2.86	N/A	$4.16	N/A	N/A	$4.05	N/A	$3.85	N/A	$3.67	N/A
System (l/b/f) Cost ($/klm)	$18.86	$19.33	N/A	$22.44	N/A	N/A	$21.88	N/A	$20.81	N/A	$19.79	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	$81.95	N/A	N/A	$81.95	N/A	$81.95	N/A	$81.95	N/A
Labor System Installation (hr)	1.0	1.0	N/A	1.0	N/A	N/A	1.0	N/A	1.0	N/A	1.0	N/A
Labor Lamp Change (hr)	0.0615	0.0615	N/A	0.0615	N/A	N/A	0.0615	N/A	0.0615	N/A	0.0615	N/A
Total Installed Cost ($)	$88.39	$100.83	N/A	$110.12	N/A	N/A	$109.42	N/A	$108.08	N/A	$106.80	N/A
Annual Maintenance Cost ($)	$16.99	$13.71	N/A	$17.13	N/A	N/A	$16.49	N/A	$15.29	N/A	$14.18	N/A
Total Installed Cost ($/klm)	$72.33	$81.95	N/A	$87.71	N/A	N/A	$87.15	N/A	$86.08	N/A	$85.07	N/A
Annual Maintenance Cost ($/klm)	$13.90	$11.14	N/A	$13.64	N/A	N/A	$13.13	N/A	$12.18	N/A	$11.30	N/A

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	70	70	N/A	70	N/A	N/A	68	N/A	65	N/A	62	N/A
Lamp Lumens	1260	1407	N/A	1453	N/A	N/A	1453	N/A	1453	N/A	1453	N/A
Lamp Efficacy (lm/W)	18.0	20.1	N/A	20.8	N/A	N/A	21.3	N/A	22.4	N/A	23.6	N/A
System Wattage	70	70	N/A	70	N/A	N/A	68	N/A	65	N/A	62	N/A
System Lumens	1172	1309	N/A	1351	N/A	N/A	1351	N/A	1351	N/A	1351	N/A
System Efficacy (lm/W)	16.7	18.7	N/A	19.3	N/A	N/A	19.8	N/A	20.8	N/A	21.9	N/A
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	100	100	N/A	100	N/A	N/A	100	N/A	100	N/A	100	N/A
Correlated Color Temperature (CCT)	2850	2850	N/A	2850	N/A	N/A	2850	N/A	2850	N/A	2850	N/A
Average Lamp Life (1000 hrs)	3.0	3.6	N/A	4.4	N/A	N/A	4.5	N/A	4.7	N/A	5.0	N/A
Annual Operating Hours (hrs/yr)	3860	3860	N/A	3860	N/A	N/A	3860	N/A	3860	N/A	3860	N/A
Lamp Price ($)	$8.52	$15.66	N/A	$9.16	N/A	N/A	$8.93	N/A	$8.50	N/A	$8.08	N/A
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)	$16.50	$20.00	N/A	$22.56	N/A	N/A	$22.00	N/A	$20.93	N/A	$19.90	N/A
Lamp Cost ($/klm)	$6.76	$11.13	N/A	$6.30	N/A	N/A	$6.15	N/A	$5.85	N/A	$5.56	N/A
System (l/b/f) Cost ($/klm)	$21.35	$27.25	N/A	$23.47	N/A	N/A	$22.89	N/A	$21.77	N/A	$20.71	N/A
Labor Cost ($/hr)	$65.35	$77.05	N/A	$81.95	N/A	N/A	$81.95	N/A	$81.95	N/A	$81.95	N/A
Labor System Installation (hr)	1.0	1.0	N/A	1.0	N/A	N/A	1.0	N/A	1.0	N/A	1.0	N/A
Labor Lamp Change (hr)	0.0615	0.0615	N/A	0.0615	N/A	N/A	0.0615	N/A	0.0615	N/A	0.0615	N/A
Total Installed Cost ($)	$90.37	$112.71	N/A	$113.67	N/A	N/A	$112.88	N/A	$111.37	N/A	$109.93	N/A
Annual Maintenance Cost ($)	$16.13	$21.87	N/A	$12.46	N/A	N/A	$11.96	N/A	$11.02	N/A	$10.16	N/A
Total Installed Cost ($/klm)	$77.11	$86.14	N/A	$84.12	N/A	N/A	$83.54	N/A	$82.42	N/A	$81.35	N/A
Annual Maintenance Cost ($/klm)	$13.76	$16.72	N/A	$9.22	N/A	N/A	$8.85	N/A	$8.16	N/A	$7.52	N/A

Performance/Cost Characteristics » Commercial LED Reflector Lighting (PAR38)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	17	18	16	17	20	13	12	10	9	8	7
Lamp Lumens	N/A	1045	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	N/A	61	64	83	116	53	105	116	136	162	167	209
System Wattage	N/A	17	18	16	17	20	13	12	10	9	8	7
System Lumens	N/A	972	1090	1235	1821	977	1302	1302	1302	1302	1302	1302
System Efficacy (lm/W)	N/A	57	59	78	108	49	98	108	127	151	156	194
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	83	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	N/A	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	N/A	22	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860
Lamp Price ($)	N/A	$52.25	$25.68	$27.89	$36.59	$34.47	$17.26	$17.26	$9.80	$9.80	$5.60	$5.60
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$50.00	$21.92	$21.00	$18.69	$32.83	$12.33	$12.33	$7.00	$7.00	$4.00	$4.00
System (l/b/f) Cost ($/klm)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total Installed Cost ($)	N/A	$56.99	$30.72	$32.93	$41.63	$39.51	$22.30	$22.30	$14.84	$14.84	$10.64	$10.64
Annual Maintenance Cost ($)	N/A	$10.00	$4.74	$4.54	$6.43	$6.10	$1.76	$1.76	$1.15	$1.15	$0.82	$0.82
Total Installed Cost ($/klm)	N/A	$58.64	$28.19	$26.66	$22.86	$40.46	$17.13	$17.13	$11.40	$11.40	$8.17	$8.17
Annual Maintenance Cost ($/klm)	N/A	$10.29	$4.35	$3.68	$3.53	$6.25	$1.35	$1.35	$0.88	$0.88	$0.63	$0.63

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For new installations or retrofits where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

Performance/Cost Characteristics » Commercial 4-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4055 hours/year for commercial 4ft linear systems (DOE SSL Program, 2012a).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2012).

Performance/Cost Characteristics » Commercial 4-foot Linear 2-Lamp Lighting Systems

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F32 Commodity	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F32 High Efficiency/High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5 F28	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial 4-ft T8 F32 Commodity in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	32	32	32	32	32	N/A	32	32	31	31	30	30
Lamp Lumens	2520	2725	2725	2770	2915	N/A	2770	2915	2770	2915	2770	2915
Lamp Efficacy (lm/W)	79	85	85	87	91	N/A	87	92	89	94	91	96
System Wattage	65	56	55	55	55	N/A	55	55	54	54	53	53
System Lumens	3282	4796	4349	4421	4652	N/A	4421	4652	4421	4652	4421	4652
System Efficacy (lm/W)	50	86	79	80	84	N/A	81	85	82	87	84	88
Ballast Efficiency (BLE)	86%	91%	92%	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	75	83	83	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	24	24	21	24	N/A	22	25	23	26	24	27
Annual Operating Hours	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	$0.96	$6.58	$4.99	$5.51	$9.54	N/A	$5.37	$9.30	$5.11	$8.85	$4.86	$8.42
Ballast Price ($)	$17.25	$16.49	$16.10	$16.10	$16.10	N/A	$15.70	$15.70	$14.93	$14.93	$14.20	$14.20
Fixture Price ($)	$26.17	$25.02	$24.64	$24.64	$24.64	N/A	$24.03	$24.03	$22.86	$22.86	$21.74	$21.74
Lamp Cost ($/klm)	$0.38	$2.41	$1.83	$1.99	$3.27	N/A	$1.94	$3.19	$1.85	$3.04	$1.75	$2.89
System (l/b/f) Cost ($/klm)	$13.81	$20.06	$18.61	$18.69	$20.52	N/A	$18.22	$20.01	$17.33	$19.04	$16.49	$18.10
Labor Cost ($/hr)	$57.34	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	N/A	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.4	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	$74.00	$80.64	$79.83	$80.35	$84.38	N/A	$79.21	$83.14	$77.00	$80.74	$74.90	$78.46
Annual Maintenance Cost ($)	$3.03	$6.59	$6.26	$7.35	$7.80	N/A	$7.12	$7.53	$6.68	$7.02	$6.27	$6.55
Total Installed Cost ($/klm)	$22.55	$16.81	$18.36	$18.18	$18.14	N/A	$17.92	$17.87	$17.42	$17.35	$16.94	$16.86
Annual Maintenance Cost ($/klm)	$0.92	$1.37	$1.44	$1.66	$1.68	N/A	$1.61	$1.62	$1.51	$1.51	$1.42	$1.41

Performance/Cost Characteristics » Commercial 4-ft T8 F32 High-efficiency/High-output in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	28	N/A	28	N/A	N/A	28	N/A	27	N/A	27	N/A
Lamp Lumens	N/A	2560	N/A	2590	N/A	N/A	2590	N/A	2590	N/A	2590	N/A
Lamp Efficacy (lm/W)	N/A	91	N/A	93	N/A	N/A	93	N/A	95	N/A	97	N/A
System Wattage	N/A	50	N/A	50	N/A	N/A	49	N/A	48	N/A	47	N/A
System Lumens	N/A	4506	N/A	4229	N/A	N/A	4229	N/A	4229	N/A	4229	N/A
System Efficacy (lm/W)	N/A	90	N/A	85	N/A	N/A	86	N/A	88	N/A	89	N/A
Ballast Efficiency (BLE)	N/A	91%	N/A	92%	N/A	N/A	92%	N/A	92%	N/A	92%	N/A
CRI	N/A	85	N/A	85	N/A	N/A	85	N/A	85	N/A	85	N/A
Correlated Color Temperature (CCT)	N/A	4100	N/A	4100	N/A	N/A	4100	N/A	4100	N/A	4100	N/A
Average Lamp Life (1000 hrs)	N/A	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours	N/A	4055	N/A	4055	N/A	N/A	4055	N/A	4055	N/A	4055	N/A
Lamp Price ($)	N/A	$9.42	N/A	$8.23	N/A	N/A	$8.03	N/A	$7.63	N/A	$7.26	N/A
Ballast Price ($)	N/A	$16.49	N/A	$16.10	N/A	N/A	$15.70	N/A	$14.93	N/A	$14.20	N/A
Fixture Price ($)	N/A	$25.02	N/A	$24.64	N/A	N/A	$24.03	N/A	$22.86	N/A	$21.74	N/A
Lamp Cost ($/klm)	N/A	$3.68	N/A	$3.18	N/A	N/A	$3.10	N/A	$2.95	N/A	$2.80	N/A
System (l/b/f) Cost ($/klm)	N/A	$23.57	N/A	$22.09	N/A	N/A	$21.54	N/A	$20.49	N/A	$19.48	N/A
Labor Cost ($/hr)	N/A	$65.10	N/A	$68.20	N/A	N/A	$68.20	N/A	$68.20	N/A	$68.20	N/A
Labor System Installation (hr)	N/A	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Labor Lamp Change (hr)	N/A	0.4	N/A	0.4	N/A	N/A	0.4	N/A	0.4	N/A	0.4	N/A
Total Installed Cost ($)	N/A	$83.48	N/A	$83.07	N/A	N/A	$81.86	N/A	$79.52	N/A	$77.30	N/A
Annual Maintenance Cost ($)	N/A	$7.55	N/A	$7.35	N/A	N/A	$7.10	N/A	$6.64	N/A	$6.20	N/A
Total Installed Cost ($/klm)	N/A	$18.53	N/A	$19.64	N/A	N/A	$19.36	N/A	$18.80	N/A	$18.28	N/A
Annual Maintenance Cost ($/klm)	N/A	$1.67	N/A	$1.74	N/A	N/A	$1.68	N/A	$1.57	N/A	$1.47	N/A

Performance/Cost Characteristics » Commercial 4-ft T5 F28 in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	28	28	28	28	N/A	28	28	27	27	27	27
Lamp Lumens	2660	2697	2446	2697	2898	N/A	2697	2898	2697	2898	2697	2898
Lamp Efficacy (lm/W)	95	96	87	96	104	N/A	97	105	99	107	101	109
System Wattage	66	60	60	60	60	N/A	60	60	59	59	57	57
System Lumens	4698	5394	4892	5394	5796	N/A	5394	5796	5394	5796	5394	5796
System Efficacy (lm/W)	71	89	81	89	96	N/A	90	97	92	99	94	101
Ballast Efficiency (BLE)	89%	92%	92%	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	85	85	85	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	30	30	30	30	N/A	31	31	32	32	34	34
Annual Operating Hours	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	$4.08	$5.51	$4.10	$5.94	$7.06	N/A	$5.79	$6.89	$5.51	$6.55	$5.24	$6.23
Ballast Price ($)	$28.17	$26.93	$26.28	$26.28	$26.28	N/A	$25.63	$25.63	$24.38	$24.38	$23.18	$23.18
Fixture Price ($)	$98.42	$94.07	$92.67	$92.67	$92.67	N/A	$90.38	$90.38	$85.96	$85.96	$81.76	$81.76
Lamp Cost ($/klm)	$1.53	$2.04	$1.68	$2.20	$2.44	N/A	$2.15	$2.38	$2.04	$2.26	$1.94	$2.15
System (l/b/f) Cost ($/klm)	$28.68	$48.95	$51.98	$48.51	$45.92	N/A	$47.31	$44.78	$45.00	$42.59	$42.80	$40.51
Labor Cost ($/hr)	$60.42	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	N/A	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)	0.4	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	$164.95	$159.06	$157.15	$158.99	$160.11	N/A	$155.90	$156.99	$149.94	$150.98	$144.28	$145.27
Annual Maintenance Cost ($)	$2.81	$4.98	$4.77	$5.26	$5.57	N/A	$5.09	$5.38	$4.78	$5.04	$4.48	$4.71
Total Installed Cost ($/klm)	$35.11	$29.49	$32.12	$29.48	$27.62	N/A	$28.90	$27.09	$27.80	$26.05	$26.75	$25.06
Annual Maintenance Cost ($/klm)	$0.60	$0.92	$0.97	$0.98	$0.96	N/A	$0.94	$0.93	$0.89	$0.87	$0.83	$0.81

Performance/Cost Characteristics » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	21	19	18	18	N/A	15	14	13	11	11	9
Lamp Lumens	N/A	2091	1743	2151	2303	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	N/A	101	92	116	132	N/A	136	151	164	199	192	230
System Wattage	N/A	42	38	37	35	N/A	31	28	26	21	22	18
System Lumens	N/A	3555	3102	3829	4099	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	N/A	85	82	104	117	N/A	128	142	158	191	184	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	86	80.1	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	4100	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	N/A	50	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	N/A	$234.66	$22.19	$34.42	$38.30	N/A	$22.76	$22.76	$10.44	$10.44	$4.79	$4.79
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$112.20	$12.73	$16.00	$16.63	N/A	$10.84	$10.84	$4.97	$4.97	$2.28	$2.28
System (l/b/f) Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	$495.15	$71.43	$95.90	$103.65	N/A	$49.81	$49.81	$37.49	$37.49	$31.84	$31.84
Annual Maintenance Cost ($)	N/A	$40.16	$5.79	$8.64	$8.41	N/A	$4.12	$4.12	$3.04	$3.04	$2.58	$2.58
Total Installed Cost ($/klm)	N/A	$236.76	$40.98	$44.57	$45.01	N/A	$23.72	$23.72	$17.85	$17.85	$15.16	$15.16
Annual Maintenance Cost ($/klm)	N/A	$19.20	$3.32	$4.02	$3.65	N/A	$1.96	$1.96	$1.45	$1.45	$1.23	$1.23

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

Performance/Cost Characteristics » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems*

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	51	48	57	40	N/A	37	30	28	22	22	22
System Lumens	548	4818	4044	5697	4918	N/A	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	15	94	84	100	122	N/A	137	164	181	230	225	230
Ballast Efficiency (BLE) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	84	82.7	83	83	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	N/A	3500	3500	3500	3500	3500	3500
Average Lamp Life (1000 hrs)	50	67	60	56	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp Price ($)	$215.19	$610.32	$439.00	$176.61	$513.45	N/A	$98.98	$98.98	$52.60	$52.60	$27.96	$27.96
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$108.56	$31.00	$104.41	N/A	$19.80	$19.80	$10.52	$10.52	$5.59	$5.59
Labor Cost ($/hr)	$110.50	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	N/A	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$642.87	$473.10	$210.71	$547.55	N/A	$133.08	$133.08	$86.70	$86.70	$62.06	$62.06
Annual Maintenance Cost ($)	21.934591	$38.91	$31.98	$15.26	$44.41	N/A	$5.56	$5.56	$3.52	$3.52	$2.52	$2.52
Total Installed Cost ($/klm)	$493.50	$133.43	$116.99	$36.99	$111.35	N/A	$26.62	$26.62	$17.34	$17.34	$12.41	$12.41
Annual Maintenance Cost ($/klm)	40.026627	$8.08	$7.91	$2.68	$9.03	N/A	$1.11	$1.11	$0.70	$0.70	$0.50	$0.50

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

This section characterizes commercial linear fixtures that house 2 8ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4147 hours/year for commercial 8ft linear systems (DOE SSL Program, 2012a).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F59 Typical Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F59 High Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F96 High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial 8-ft T8 F59 Typical Efficiency in a 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	60	59	59	59	59	N/A	58	58	57	57	56	56
Lamp Lumens	5214	5430	5220	5490	5650	N/A	5490	5650	5490	5650	5490	5650
Lamp Efficacy (lm/W)	87	92	88	93	96	N/A	94	97	96	99	98	101
System Wattage	113	107	107	107	107	N/A	105	105	103	103	101	101
System Lumens	8300	9448	9083	9553	9831	N/A	9553	9831	9553	9831	9553	9831
System Efficacy (lm/W)	73	88	85	90	92	N/A	91	93	92	95	94	97
Ballast Efficiency (BLE)	89%	93%	93%	93%	93%	N/A	93%	93%	93%	93%	93%	93%
CRI	75	82	80	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	15	24	24	24	24	N/A	25	25	26	26	27	27
Annual Operating Hours (hrs/yr)	4147	4147	4147	4147	4147	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	$4.16	$12.39	$10.48	$11.74	$14.18	N/A	$11.45	$13.83	$10.89	$13.15	$10.36	$12.51
Ballast Price ($)	$20.51	$19.61	$19.14	$19.14	$19.14	N/A	$18.67	$18.67	$17.75	$17.75	$16.89	$16.89
Fixture Price ($)	$23.99	$22.93	$22.59	$22.59	$22.59	N/A	$22.03	$22.03	$20.95	$20.95	$19.93	$19.93
Lamp Cost ($/klm)	$0.80	$2.28	$2.01	$2.14	$2.51	N/A	$2.09	$2.45	$1.98	$2.33	$1.89	$2.21
System (l/b/f) Cost ($/klm)	$6.36	$12.40	$12.01	$11.88	$12.40	N/A	$11.58	$12.10	$11.02	$11.51	$10.48	$10.94
Labor Cost ($/hr)	$57.31	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.9	0.9	0.9	0.9	0.9	N/A	0.9	0.9	0.9	0.9	0.9	0.9
Labor Lamp Change (hr)	0.3	0.3	0.3	0.3	0.3	N/A	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost ($)	$105.35	$114.60	$114.72	$115.98	$118.42	N/A	$114.66	$117.04	$112.11	$114.37	$109.68	$111.84
Annual Maintenance Cost ($)	$4.39	$7.43	$6.92	$7.36	$8.20	N/A	$7.08	$7.88	$6.55	$7.28	$6.07	$6.73
Total Installed Cost ($/klm)	$12.69	$12.13	$12.63	$12.14	$12.05	N/A	$12.00	$11.91	$11.74	$11.63	$11.48	$11.38
Annual Maintenance Cost ($/klm)	$0.53	$0.79	$0.76	$0.77	$0.83	N/A	$0.74	$0.80	$0.69	$0.74	$0.64	$0.68

Performance/Cost Characteristics » Commercial 8-ft T8 F59 High Efficiency in a 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	60	59	59	59	59	N/A	58	58	57	57	56	56
Lamp Lumens	5892	5430	5220	5490	5650	N/A	5490	5650	5490	5650	5490	5650
Lamp Efficacy (lm/W)	98	92	88	93	96	N/A	94	97	96	99	98	101
System Wattage	100	107	105	94	94	N/A	93	93	91	91	89	89
System Lumens	8311	9448	9083	8455	8701	N/A	8455	8701	8455	8701	8455	8701
System Efficacy (lm/W)	83	88	86	90	93	N/A	91	94	93	95	95	97
Ballast Efficiency (BLE)	89%	93%	94%	94%	94%	N/A	94%	94%	94%	94%	94%	94%
CRI	85	82	80	85	85	N/A	85	85	85	85	85	85
Correlated Color Temperature (CCT)	4100	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	18	24	24	24	24	N/A	25	25	26	26	27	27
Annual Operating Hours (hrs/yr)	4147	4147	4147	4147	4147	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	$7.27	$12.39	$10.48	$11.74	$14.18	N/A	$11.45	$13.83	$10.89	$13.15	$10.36	$12.51
Ballast Price ($)	$20.51	$19.61	$19.14	$19.14	$19.14	N/A	$18.67	$18.67	$17.75	$17.75	$16.89	$16.89
Fixture Price ($)	$23.85	$22.79	$22.45	$22.45	$22.45	N/A	$21.90	$21.90	$20.83	$20.83	$19.81	$19.81
Lamp Cost ($/klm)	$1.23	$2.28	$2.01	$2.14	$2.51	N/A	$2.09	$2.45	$1.98	$2.33	$1.89	$2.21
System (l/b/f) Cost ($/klm)	$7.09	$12.37	$11.98	$11.85	$12.38	N/A	$11.56	$12.07	$10.99	$11.48	$10.46	$10.92
Labor Cost ($/hr)	$57.64	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.9	0.9	0.9	0.9	0.9	N/A	0.9	0.9	0.9	0.9	0.9	0.9
Labor Lamp Change (hr)	0.3	0.3	0.3	0.3	0.3	N/A	0.3	0.3	0.3	0.3	0.3	0.3
Total Installed Cost ($)	$111.74	$114.47	$114.59	$115.85	$118.29	N/A	$114.53	$116.91	$111.99	$114.25	$109.57	$111.72
Annual Maintenance Cost ($)	$4.22	$7.43	$6.92	$7.36	$8.20	N/A	$7.08	$7.88	$6.55	$7.28	$6.07	$6.73
Total Installed Cost ($/klm)	$13.44	$12.12	$12.62	$13.70	$13.60	N/A	$13.55	$13.44	$13.25	$13.13	$12.96	$12.84
Annual Maintenance Cost ($/klm)	$0.51	$0.79	$0.76	$0.87	$0.94	N/A	$0.84	$0.91	$0.78	$0.84	$0.72	$0.77

Performance/Cost Characteristics » Commercial 8-ft T8 F96 High-Output in a 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	86	86	85	86	N/A	85	85	83	83	81	82
Lamp Lumens	N/A	7600	7342	7600	7800	N/A	7600	7800	7600	7800	7600	7800
Lamp Efficacy (lm/W)	N/A	88	85	89	91	N/A	90	92	92	93	93	95
System Wattage	N/A	148	179	172	179	N/A	170	178	167	174	163	171
System Lumens	N/A	12026	13949	14000	14820	N/A	14000	14820	14000	14820	14000	14820
System Efficacy (lm/W)	N/A	81	78	82	83	N/A	82	83	84	85	86	87
Ballast Efficiency (BLE)	N/A	92%	92%	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	N/A	78	78	78	78	N/A	78	78	78	78	78	78
Correlated Color Temperature (CCT)	N/A	4100	4100	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	N/A	18	18	18	18	N/A	18	18	19	19	20	20
Annual Operating Hours (hrs/yr)	N/A	4147	4147	4147	4147	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	N/A	$17.05	$8.63	$13.19	$16.61	N/A	$12.86	$16.20	$12.23	$15.41	$11.64	$14.65
Ballast Price ($)	N/A	$15.64	$17.49	$17.49	$17.49	N/A	$17.06	$17.06	$16.22	$16.22	$15.43	$15.43
Fixture Price ($)	N/A	$22.93	$22.59	$22.59	$22.59	N/A	$22.03	$22.03	$20.95	$20.95	$19.93	$19.93
Lamp Cost ($/klm)	N/A	$2.24	$1.18	$1.74	$2.13	N/A	$1.69	$2.08	$1.61	$1.98	$1.53	$1.88
System (l/b/f) Cost ($/klm)	N/A	$9.56	$7.81	$8.74	$9.40	N/A	$8.53	$9.16	$8.11	$8.72	$7.71	$8.29
Labor Cost ($/hr)	N/A	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	N/A	1.0	1.0	1.0	1.0	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr)	N/A	0.4	0.4	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	$120.72	$116.91	$121.47	$124.89	N/A	$120.15	$123.48	$117.61	$120.78	$115.19	$118.21
Annual Maintenance Cost ($)	N/A	$13.48	$9.87	$11.97	$13.55	N/A	$11.53	$13.03	$10.70	$12.05	$9.93	$11.16
Total Installed Cost ($/klm)	N/A	$10.04	$8.38	$8.68	$8.43	N/A	$8.58	$8.33	$8.40	$8.15	$8.23	$7.98
Annual Maintenance Cost ($/klm)	N/A	$1.12	$0.71	$0.85	$0.91	N/A	$0.82	$0.88	$0.76	$0.81	$0.71	$0.75

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical[1]	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	36	N/A	N/A	31	28	26	21	22	17
Lamp Lumens	N/A	N/A	N/A	3975	N/A	N/A	4000	4000	4000	4000	4000	4000
Lamp Efficacy (lm/W)	N/A	N/A	N/A	111	N/A	N/A	130	144	157	190	183	230
System Wattage	N/A	N/A	N/A	71	N/A	N/A	61	56	51	42	44	35
System Lumens	N/A	N/A	N/A	7076	N/A	N/A	7520	7520	7680	7680	7680	7680
System Efficacy (lm/W)	N/A	N/A	N/A	99	N/A	N/A	122	135	150	182	176	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	80	N/A	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	N/A	N/A	N/A	5000	N/A	N/A	5000	5000	5000	5000	5000	5000
Average Lamp Life (1000 hrs)	N/A	N/A	N/A	50	N/A	N/A	50	50	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	N/A	N/A	N/A	$75.53	N/A	N/A	$51.47	$51.47	$23.61	$23.61	$10.83	$10.83
Ballast Price ($)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	N/A	N/A	$19.00	N/A	N/A	$12.87	$12.87	$5.90	$5.90	$2.71	$2.71
System (l/b/f) Cost ($/klm)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	N/A	N/A	0.4	N/A	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	N/A	N/A	$176.63	N/A	N/A	$128.52	$128.52	$72.80	$72.80	$48.72	$48.72
Annual Maintenance Cost ($)	N/A	N/A	N/A	$14.65	N/A	N/A	$10.66	$10.66	$6.04	$6.04	$4.04	$4.04
Total Installed Cost ($/klm)	N/A	N/A	N/A	$44.43	N/A	N/A	$32.13	$32.13	$18.20	$18.20	$12.18	$12.18
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$3.69	N/A	N/A	$2.66	$2.66	$1.51	$1.51	$1.01	$1.01

1. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
2. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical[1]	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	N/A	N/A	N/A	73	N/A	N/A	58	46	44	35	36	35
System Lumens	N/A	N/A	N/A	8000	N/A	N/A	8000	8000	8000	8000	8000	8000
System Efficacy (lm/W)	N/A	N/A	N/A	110	N/A	N/A	137	173	181	230	225	230
Ballast Efficiency (BLE) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	90	N/A	N/A	90	90	90	90	90	90
Correlated Color Temperature (CCT)	N/A	N/A	N/A	4000	N/A	N/A	4000	4000	4000	4000	4000	4000
Average Lamp Life (1000 hrs)	N/A	N/A	N/A	75	N/A	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp Price ($)	N/A	N/A	N/A	$640.00	N/A	N/A	$408.70	$408.70	$217.21	$217.21	$115.44	$115.44
Ballast Price ($) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	N/A	N/A	N/A	$80.00	N/A	N/A	$51.09	$51.09	$27.15	$27.15	$14.43	$14.43
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	N/A	N/A	N/A	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr) [2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	N/A	N/A	N/A	$708.20	N/A	N/A	$476.90	$476.90	$285.41	$285.41	$183.64	$183.64
Annual Maintenance Cost ($)	N/A	N/A	N/A	$39.16	N/A	N/A	$20.39	$20.39	$11.84	$11.84	$7.62	$7.62
Total Installed Cost ($/klm)	N/A	N/A	N/A	$88.53	N/A	N/A	$59.61	$59.61	$35.68	$35.68	$22.95	$22.95
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$4.89	N/A	N/A	$2.55	$2.55	$1.48	$1.48	$0.95	$0.95

1. Based on the CREE CS18-80LHE found on Grainger online of 11/20/15.
2. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

The commercial low bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits between 6,000 and 10,000 system lumens. Low bay lighting is defined as "interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor"(IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial Mercury Vapor Low-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	175	175	N/A	174	N/A	N/A	172	N/A	169	N/A	165	N/A
Lamp Lumens	6825	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
Lamp Efficacy (lm/W)	39	42	N/A	43	N/A	N/A	43	N/A	44	N/A	45	N/A
System Wattage	208	206	N/A	205	N/A	N/A	203	N/A	199	N/A	195	N/A
System Lumens	5176	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
System Efficacy (lm/W)	25	36	N/A	36	N/A	N/A	37	N/A	37	N/A	38	N/A
Ballast Efficiency (BLE)	85%	85%	N/A	85%	N/A	N/A	85%	N/A	85%	N/A	85%	N/A
CRI	15	33	N/A	33	N/A	N/A	33	N/A	33	N/A	33	N/A
Correlated Color Temperature (CCT)	3000	3700	N/A	3700	N/A	N/A	3700	N/A	3700	N/A	3700	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours (hrs/yr)	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$14.96	$11.77	N/A	$11.59	N/A	N/A	$11.31	N/A	$10.75	N/A	$10.23	N/A
Ballast Price ($)	$45.77	$43.76	N/A	$43.11	N/A	N/A	$42.04	N/A	$39.98	N/A	$38.03	N/A
Fixture Price ($)	$34.15	$32.65	N/A	$32.16	N/A	N/A	$31.37	N/A	$29.83	N/A	$28.37	N/A
Lamp Cost ($/klm)	$2.19	$1.59	N/A	$1.57	N/A	N/A	$1.53	N/A	$1.45	N/A	$1.38	N/A
System (l/b/f) Cost ($/klm)	$35.80	$11.92	N/A	$11.74	N/A	N/A	$11.45	N/A	$10.89	N/A	$10.36	N/A
Labor Cost ($/hr)	$95.69	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	0.5	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Total Installed Cost ($)	$328.83	$197.24	N/A	$190.35	N/A	N/A	$188.20	N/A	$184.06	N/A	$180.12	N/A
Annual Maintenance Cost ($)	$3.93	$10.09	N/A	$9.71	N/A	N/A	$9.38	N/A	$8.75	N/A	$8.17	N/A
Total Installed Cost ($/klm)	$63.53	$26.65	N/A	$25.72	N/A	N/A	$25.43	N/A	$24.87	N/A	$24.34	N/A
Annual Maintenance Cost ($/klm)	$0.76	$1.36	N/A	$1.31	N/A	N/A	$1.27	N/A	$1.18	N/A	$1.10	N/A

Performance/Cost Characteristics » Commercial Metal Halide Low-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	175	175	N/A	174	N/A	N/A	170	N/A	161	N/A	154	N/A
Lamp Lumens	8803	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
Lamp Efficacy (lm/W)	50	42	N/A	43	N/A	N/A	44	N/A	46	N/A	48	N/A
System Wattage	210	199	N/A	198	N/A	N/A	193	N/A	183	N/A	175	N/A
System Lumens	6669	7400	N/A	7400	N/A	N/A	7400	N/A	7400	N/A	7400	N/A
System Efficacy (lm/W)	32	37	N/A	37	N/A	N/A	38	N/A	40	N/A	42	N/A
Ballast Efficiency (BLE)	88%	88%	N/A	88%	N/A	N/A	88%	N/A	88%	N/A	88%	N/A
CRI	65	80	N/A	80	N/A	N/A	80	N/A	80	N/A	80	N/A
Correlated Color Temperature (CCT)	3000	4000	N/A	4000	N/A	N/A	4000	N/A	4000	N/A	4000	N/A
Average Lamp Life (1000 hrs)	10	15	N/A	15	N/A	N/A	15	N/A	16	N/A	17	N/A
Annual Operating Hours (hrs/yr)	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$24.17	$20.39	N/A	$20.09	N/A	N/A	$19.59	N/A	$18.63	N/A	$17.72	N/A
Ballast Price ($)	$51.12	$48.87	N/A	$48.14	N/A	N/A	$46.95	N/A	$44.66	N/A	$42.47	N/A
Fixture Price ($)	$34.15	$32.65	N/A	$32.16	N/A	N/A	$31.37	N/A	$29.83	N/A	$28.37	N/A
Lamp Cost ($/klm)	$2.75	$2.76	N/A	$2.71	N/A	N/A	$2.65	N/A	$2.52	N/A	$2.39	N/A
System (l/b/f) Cost ($/klm)	$26.17	$13.77	N/A	$13.57	N/A	N/A	$13.23	N/A	$12.58	N/A	$11.97	N/A
Labor Cost ($/hr)	$95.78	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	0.5	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Total Installed Cost ($)	$318.18	$210.98	N/A	$203.88	N/A	N/A	$201.39	N/A	$196.60	N/A	$192.05	N/A
Annual Maintenance Cost ($)	$4.81	$20.78	N/A	$20.12	N/A	N/A	$19.36	N/A	$17.94	N/A	$16.63	N/A
Total Installed Cost ($/klm)	$47.71	$28.51	N/A	$27.55	N/A	N/A	$27.22	N/A	$26.57	N/A	$25.95	N/A
Annual Maintenance Cost ($/klm)	$0.72	$2.81	N/A	$2.72	N/A	N/A	$2.62	N/A	$2.42	N/A	$2.25	N/A

Performance/Cost Characteristics » Commercial Sodium Vapor Low-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	70	100	N/A	99	N/A	N/A	97	N/A	92	N/A	88	N/A
Lamp Lumens	5453	8550	N/A	8550	N/A	N/A	8550	N/A	8550	N/A	8550	N/A
Lamp Efficacy (lm/W)	78	86	N/A	86	N/A	N/A	88	N/A	93	N/A	97	N/A
System Wattage	93	128	N/A	127	N/A	N/A	124	N/A	118	N/A	112	N/A
System Lumens	4130	8550	N/A	8550	N/A	N/A	8550	N/A	8550	N/A	8550	N/A
System Efficacy (lm/W)	64	67	N/A	67	N/A	N/A	69	N/A	72	N/A	76	N/A
Ballast Efficiency (BLE)	78%	78%	N/A	78%	N/A	N/A	78%	N/A	78%	N/A	78%	N/A
CRI	22	22	N/A	22	N/A	N/A	22	N/A	22	N/A	22	N/A
Correlated Color Temperature (CCT)	3000	2000	N/A	2000	N/A	N/A	2000	N/A	2000	N/A	2000	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours (hrs/yr)	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$16.94	$45.56	N/A	$44.88	N/A	N/A	$43.77	N/A	$41.63	N/A	$39.59	N/A
Ballast Price ($)	$49.50	$47.33	N/A	$46.62	N/A	N/A	$45.47	N/A	$43.25	N/A	$41.13	N/A
Fixture Price ($)	$112.99	$108.03	N/A	$106.42	N/A	N/A	$103.78	N/A	$98.71	N/A	$93.88	N/A
Lamp Cost ($/klm)	$3.11	$5.33	N/A	$5.25	N/A	N/A	$5.12	N/A	$4.87	N/A	$4.63	N/A
System (l/b/f) Cost ($/klm)	$41.15	$23.50	N/A	$23.15	N/A	N/A	$22.58	N/A	$21.47	N/A	$20.42	N/A
Labor Cost ($/hr)	$95.27	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	0.5	0.5	N/A	0.5	N/A	N/A	0.5	N/A	0.5	N/A	0.5	N/A
Total Installed Cost ($)	$312.86	$309.98	N/A	$301.40	N/A	N/A	$296.51	N/A	$287.07	N/A	$278.09	N/A
Annual Maintenance Cost ($)	$3.93	$21.47	N/A	$20.92	N/A	N/A	$20.04	N/A	$18.40	N/A	$16.90	N/A
Total Installed Cost ($/klm)	$75.75	$36.26	N/A	$35.25	N/A	N/A	$34.68	N/A	$33.58	N/A	$32.53	N/A
Annual Maintenance Cost ($/klm)	$0.95	$2.51	N/A	$2.45	N/A	N/A	$2.34	N/A	$2.15	N/A	$1.98	N/A

Performance/Cost Characteristics » Commercial LED Low-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	68	104	71	46	N/A	56	47	44	34	36	30
System Lumens	548	4877	8410	7042	6294	N/A	7000	7000	7000	7000	7000	7000
System Efficacy (lm/W)	15	72	81	100	136	N/A	125	150	160	207	194	230
Ballast Efficiency (BLE)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	85	75	81	84	N/A	81	81	81	81	81	81
Correlated Color Temperature (CCT)	4000	4000	5000	4000	4000	N/A	4000	4000	4000	4000	4000	4000
Average Lamp Life (1000 hrs)	50	50	100	60	100	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp Price ($)	$215.19	$761.95	$447.31	$267.59	$332.80	N/A	$169.86	$169.86	$90.28	$90.28	$47.98	$47.98
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$156.23	$53.19	$38.00	$52.88	N/A	$24.27	$24.27	$12.90	$12.90	$6.85	$6.85
Labor Cost ($/hr)	$36.83	$68.99	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.20	$68.20
Labor System Installation (hr)	1.5	1.5	1.5	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$865.44	$550.80	$371.08	$436.29	N/A	$273.35	$273.35	$193.76	$193.76	$150.28	$150.28
Annual Maintenance Cost ($)	$0.07	$69.95	$22.26	$25.00	$17.63	N/A	$11.39	$11.39	$7.83	$7.83	$6.07	$6.07
Total Installed Cost ($/klm)	$493.50	$177.44	$65.49	$52.70	$69.32	N/A	$39.05	$39.05	$27.68	$27.68	$21.47	$21.47
Annual Maintenance Cost ($/klm)	$0.13	$14.34	$2.65	$3.55	$2.80	N/A	$1.63	$1.63	$1.12	$1.12	$0.87	$0.87

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18//15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. LED Low-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

The commercial high-bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits greater than 10,000 system lumens. High-bay lighting is defined as "interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor" (IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
T5 4xF54 HO Linear System	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial Mercury Vapor High-Bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	400	400	N/A	398	N/A	N/A	394	N/A	386	N/A	378	N/A
Lamp Lumens	14400	15800	N/A	15800	N/A	N/A	15800	N/A	15800	N/A	15800	N/A
Lamp Efficacy (lm/W)	36	40	N/A	40	N/A	N/A	40	N/A	41	N/A	42	N/A
System Wattage	453	449	N/A	447	N/A	N/A	442	N/A	434	N/A	425	N/A
System Lumens	13061	15800	N/A	15800	N/A	N/A	15800	N/A	15800	N/A	15800	N/A
System Efficacy (lm/W)	29	35	N/A	35	N/A	N/A	36	N/A	36	N/A	37	N/A
Ballast Efficiency (BLE)	89%	89%	N/A	89%	N/A	N/A	89%	N/A	89%	N/A	89%	N/A
CRI	50	50	N/A	50	N/A	N/A	50	N/A	50	N/A	50	N/A
Correlated Color Temperature (CCT)	3100	3900	N/A	3900	N/A	N/A	3900	N/A	3900	N/A	3900	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$16.70	$20.07	N/A	$19.77	N/A	N/A	$19.28	N/A	$18.34	N/A	$17.44	N/A
Ballast Price ($)	$48.84	$46.70	N/A	$46.00	N/A	N/A	$44.86	N/A	$42.67	N/A	$40.58	N/A
Fixture Price ($)	$94.03	$89.91	N/A	$88.56	N/A	N/A	$86.37	N/A	$82.15	N/A	$78.13	N/A
Lamp Cost ($/klm)	$1.16	$1.27	N/A	$1.25	N/A	N/A	$1.22	N/A	$1.16	N/A	$1.10	N/A
System (l/b/f) Cost ($/klm)	$11.06	$9.92	N/A	$9.77	N/A	N/A	$9.53	N/A	$9.06	N/A	$8.62	N/A
Labor Cost ($/hr)	$95.28	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	1.5	1.5	N/A	1.5	N/A	N/A	1.5	N/A	1.5	N/A	1.5	N/A
Labor Lamp Change (hr)	1.0	1.0	N/A	1.0	N/A	N/A	1.0	N/A	1.0	N/A	1.0	N/A
Total Installed Cost ($)	$287.32	$265.74	N/A	$257.82	N/A	N/A	$254.00	N/A	$246.64	N/A	$239.64	N/A
Annual Maintenance Cost ($)	$3.93	$19.00	N/A	$18.28	N/A	N/A	$17.67	N/A	$16.51	N/A	$15.44	N/A
Total Installed Cost ($/klm)	$22.00	$16.82	N/A	$16.32	N/A	N/A	$16.08	N/A	$15.61	N/A	$15.17	N/A
Annual Maintenance Cost ($/klm)	$0.30	$1.20	N/A	$1.16	N/A	N/A	$1.12	N/A	$1.05	N/A	$0.98	N/A

Performance/Cost Characteristics » Commercial Metal Halide High-Bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	250	400	N/A	398	N/A	N/A	388	N/A	369	N/A	351	N/A
Lamp Lumens	13500	32000	N/A	32000	N/A	N/A	32000	N/A	32000	N/A	32000	N/A
Lamp Efficacy (lm/W)	54	80	N/A	80	N/A	N/A	83	N/A	87	N/A	91	N/A
System Wattage	293	443	N/A	440	N/A	N/A	430	N/A	409	N/A	389	N/A
System Lumens	12245	32000	N/A	32000	N/A	N/A	32000	N/A	32000	N/A	32000	N/A
System Efficacy (lm/W)	42	72	N/A	73	N/A	N/A	75	N/A	78	N/A	82	N/A
Ballast Efficiency (BLE)	90%	90%	N/A	90%	N/A	N/A	90%	N/A	90%	N/A	90%	N/A
CRI	65	80	N/A	80	N/A	N/A	80	N/A	80	N/A	80	N/A
Correlated Color Temperature (CCT)	3100	4000	N/A	4000	N/A	N/A	4000	N/A	4000	N/A	4000	N/A
Average Lamp Life (1000 hrs)	10	15	N/A	15	N/A	N/A	15	N/A	16	N/A	17	N/A
Annual Operating Hours	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$17.67	$29.46	N/A	$29.63	N/A	N/A	$28.90	N/A	$27.48	N/A	$26.14	N/A
Ballast Price ($)	$48.84	$46.70	N/A	$46.00	N/A	N/A	$44.86	N/A	$42.67	N/A	$40.58	N/A
Fixture Price ($)	$94.03	$89.91	N/A	$88.56	N/A	N/A	$86.37	N/A	$82.15	N/A	$78.13	N/A
Lamp Cost ($/klm)	$1.31	$0.92	N/A	$0.93	N/A	N/A	$0.90	N/A	$0.86	N/A	$0.82	N/A
System (l/b/f) Cost ($/klm)	$12.83	$5.19	N/A	$5.13	N/A	N/A	$5.00	N/A	$4.76	N/A	$4.53	N/A
Labor Cost ($/hr)	$71.47	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	2.0	2.0	N/A	2.0	N/A	N/A	2.0	N/A	2.0	N/A	2.0	N/A
Labor Lamp Change (hr)	1.4	1.4	N/A	1.4	N/A	N/A	1.4	N/A	1.4	N/A	1.4	N/A
Total Installed Cost ($)	$300.09	$311.48	N/A	$302.18	N/A	N/A	$298.11	N/A	$290.28	N/A	$282.84	N/A
Annual Maintenance Cost ($)	$4.81	$43.12	N/A	$41.82	N/A	N/A	$40.40	N/A	$37.73	N/A	$35.25	N/A
Total Installed Cost ($/klm)	$24.51	$9.73	N/A	$9.44	N/A	N/A	$9.32	N/A	$9.07	N/A	$8.84	N/A
Annual Maintenance Cost ($/klm)	$0.39	$1.35	N/A	$1.31	N/A	N/A	$1.26	N/A	$1.18	N/A	$1.10	N/A

Performance/Cost Characteristics » Commercial Sodium Vapor High-Bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	150	250	N/A	249	N/A	N/A	242	N/A	231	N/A	219	N/A
Lamp Lumens	13500	24300	N/A	24300	N/A	N/A	24300	N/A	24300	N/A	24300	N/A
Lamp Efficacy (lm/W)	90	97	N/A	98	N/A	N/A	100	N/A	105	N/A	111	N/A
System Wattage	190	297	N/A	295	N/A	N/A	288	N/A	274	N/A	261	N/A
System Lumens	10754	24300	N/A	24300	N/A	N/A	24300	N/A	24300	N/A	24300	N/A
System Efficacy (lm/W)	57	82	N/A	82	N/A	N/A	84	N/A	89	N/A	93	N/A
Ballast Efficiency (BLE)	84%	84%	N/A	84%	N/A	N/A	84%	N/A	84%	N/A	84%	N/A
CRI	22	22	N/A	22	N/A	N/A	22	N/A	22	N/A	22	N/A
Correlated Color Temperature (CCT)	3100	2100	N/A	2100	N/A	N/A	2100	N/A	2100	N/A	2100	N/A
Average Lamp Life (1000 hrs)	24	24	N/A	24	N/A	N/A	25	N/A	26	N/A	27	N/A
Annual Operating Hours	4042	4042	N/A	4042	N/A	N/A	4042	N/A	4042	N/A	4042	N/A
Lamp Price ($)	$62.80	$45.28	N/A	$44.60	N/A	N/A	$43.50	N/A	$41.37	N/A	$39.35	N/A
Ballast Price ($)	$79.49	$76.00	N/A	$74.87	N/A	N/A	$73.02	N/A	$69.45	N/A	$66.05	N/A
Fixture Price ($)	$247.51	$236.65	N/A	$233.11	N/A	N/A	$227.34	N/A	$216.23	N/A	$205.66	N/A
Lamp Cost ($/klm)	$4.65	$1.86	N/A	$1.84	N/A	N/A	$1.79	N/A	$1.70	N/A	$1.62	N/A
System (l/b/f) Cost ($/klm)	$30.96	$14.73	N/A	$14.51	N/A	N/A	$14.15	N/A	$13.46	N/A	$12.80	N/A
Labor Cost ($/hr)	$241.44	$72.71	N/A	$68.99	N/A	N/A	$68.99	N/A	$68.99	N/A	$68.99	N/A
Labor System Installation (hr)	2.0	2.0	N/A	2.0	N/A	N/A	2.0	N/A	2.0	N/A	2.0	N/A
Labor Lamp Change (hr)	1.4	1.4	N/A	1.4	N/A	N/A	1.4	N/A	1.4	N/A	1.4	N/A
Total Installed Cost ($)	$815.84	$503.35	N/A	$490.57	N/A	N/A	$481.84	N/A	$465.03	N/A	$449.04	N/A
Annual Maintenance Cost ($)	$3.93	$32.28	N/A	$31.18	N/A	N/A	$30.05	N/A	$27.92	N/A	$25.96	N/A
Total Installed Cost ($/klm)	$75.86	$20.71	N/A	$20.19	N/A	N/A	$19.83	N/A	$19.14	N/A	$18.48	N/A
Annual Maintenance Cost ($/klm)	$0.37	$1.33	N/A	$1.28	N/A	N/A	$1.24	N/A	$1.15	N/A	$1.07	N/A

Performance/Cost Characteristics » Commercial T5 4xF54 HO High-bay

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	54	54	N/A	54	54	N/A	53	53	52	52	51	51
Lamp Lumens	4752	4850	N/A	4273	4750	N/A	4273	4750	4273	4750	4273	4750
Lamp Efficacy (lm/W)	88	90	N/A	79	88	N/A	80	89	82	91	83	92
System Wattage	240	240	N/A	240	240	N/A	238	238	233	233	228	228
System Lumens	18060	19400	N/A	17092	19000	N/A	17092	19000	17092	19000	17092	19000
System Efficacy (lm/W)	75	81	N/A	71	79	N/A	72	80	73	82	75	83
Ballast Efficiency (BLE)	92%	92%	N/A	92%	92%	N/A	92%	92%	92%	92%	92%	92%
CRI	85	86	N/A	86	86	N/A	86	86	86	86	86	86
Correlated Color Temperature (CCT)	4100	4100	N/A	4100	4100	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	20	24	N/A	25	25	N/A	26	26	27	27	28	28
Annual Operating Hours	4042	4042	N/A	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp Price ($)	$5.06	$7.12	N/A	$5.66	$9.48	N/A	$5.52	$9.25	$5.25	$8.79	$4.99	$8.36
Ballast Price ($)	$29.47	$28.18	N/A	$27.51	$27.51	N/A	$26.83	$26.83	$25.52	$25.52	$24.27	$24.27
Fixture Price ($)	$113.97	$108.94	N/A	$107.32	$107.32	N/A	$104.66	$104.66	$99.54	$99.54	$94.68	$94.68
Lamp Cost ($/klm)	$1.06	$1.47	N/A	$1.32	$2.00	N/A	$1.29	$1.95	$1.23	$1.85	$1.17	$1.76
System (l/b/f) Cost ($/klm)	$8.50	$8.54	N/A	$9.21	$9.09	N/A	$8.98	$8.87	$8.55	$8.43	$8.13	$8.02
Labor Cost ($/hr)	$45.81	$65.10	N/A	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.7	0.7	N/A	0.7	0.7	N/A	0.7	0.7	0.7	0.7	0.7	0.7
Labor Lamp Change (hr)	0.4	0.4	N/A	0.4	0.4	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	$184.10	$187.64	N/A	$185.95	$189.77	N/A	$182.48	$186.20	$175.78	$179.32	$169.41	$172.78
Annual Maintenance Cost ($)	$2.81	$6.93	N/A	$6.39	$7.62	N/A	$6.19	$7.36	$5.80	$6.87	$5.45	$6.41
Total Installed Cost ($/klm)	$10.19	$9.67	N/A	$10.88	$9.99	N/A	$10.68	$9.80	$10.28	$9.44	$9.91	$9.09
Annual Maintenance Cost ($/klm)	$0.16	$0.36	N/A	$0.37	$0.40	N/A	$0.36	$0.39	$0.34	$0.36	$0.32	$0.34

Performance/Cost Characteristics » Commercial LED High-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	212	189	183	101	N/A	128	107	100	77	82	70
System Lumens	548	18915	15070	18722	13640	N/A	16000	16000	16000	16000	16000	16000
System Efficacy (lm/W)	15	89	80	102	135	N/A	125	150	160	207	194	230
Ballast Efficiency (BLE) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	74	73	80	83	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	5000	5000	5000	4000	4100	N/A	4000	4000	4000	4000	4000	4000
Average Lamp Life (1000 hrs)	50	70	50	60	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp Price ($)	$215.19	$2,395.94	$398.34	$711.42	$297.76	N/A	$388.26	$388.26	$206.35	$206.35	$109.67	$109.67
Ballast Price ($) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$26.43	$38.00	$21.83	N/A	$24.27	$24.27	$12.90	$12.90	$6.85	$6.85
Labor Cost ($/hr)	$36.83	$72.71	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.99	$68.99
Labor System Installation (hr)	1.5	1.5	1.5	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr) [4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$2,505.00	$501.83	$814.90	$401.25	N/A	$491.75	$491.75	$309.83	$309.83	$213.15	$213.15
Annual Maintenance Cost ($)	$0.07	$144.63	$40.56	$54.89	$32.43	N/A	$20.49	$20.49	$12.52	$12.52	$8.61	$8.61
Total Installed Cost ($/klm)	$493.50	$132.44	$33.30	$43.53	$29.42	N/A	$30.73	$30.73	$19.36	$19.36	$13.32	$13.32
Annual Maintenance Cost ($/klm)	$0.13	$7.65	$2.69	$2.93	$2.38	N/A	$1.28	$1.28	$0.78	$0.78	$0.54	$0.54

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. LED High-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Additional Technologies of Interest: Lighting

Final

- Tables were not provided for technologies of interest utilizing occupancy sensors and other controls due to lack of available data and currently small market presence.
    - Lighting controls can save energy by either reducing input wattage or limiting hours of operation.
    - The following table indicates prevalence of various lighting controls in 2010 (DOE SSL Program, 2012a).
    - Leading experts claim that controls penetration remains low, particularly for integrated/advanced controls (DOE Connected Lighting Systems Meeting, November 2015).
    - As a result, there is not enough information to determine the price and performance impacts of controls on current lighting technologies or to project improvements going forward.

Prevalence of Lighting Controls by Sector and Lamp Type

		None	Dimmer	Light Sensor	Motion Detector	Timer	EMS	Total
Residential	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%
Commercial	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%

EMS: Energy Management System
HID: High Intensity Discharge:
CFL: Compact Fluorescent Lamp

Refrigeration

Commercial Compressor Rack Systems

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,050	1,200	1,200	1,190	930	N/A	830	816	818	715	818	715
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	180	162	162	160	125	N/A	104	102	94	82	82	78
Energy Use (MWh/yr) [2]	1,618	1,497	1,497	1,484	1,160	N/A	1,033	1,016	934	816	934	816
Indexed Annual Efficiency [3]	1.00	1.08	1.08	1.09	1.40	N/A	1.57	1.59	1.73	1.98	1.73	1.98
Average Life (yrs)	15	15	15	15	15	N/A	15	15	15	15	15	15
Total Installed Cost ($1000) [4]	$630	$630	$630	$625	$488	N/A	$452	$444	$388	$339	$388	$339
Total Installed Cost ($/kBtu/hr)	$600	$525	$525	$525	$525	N/A	$545	$544	$474	$474	$474	$474
Annual Maintenance Cost ($1000) [5]	$33	$34	$34	$34	$34	N/A	$34	$34	$34	$34	$34	$34
Annual Maintenance Cost ($/kBtu/hr)	$31.14	$28.33	$28.33	$28.57	$36.56	N/A	$40.96	$41.67	$41.54	$47.55	$41.54	$47.55

[1] The total capacity represents the nominal compressor capacity required for the entire refrigeration system of a typical supermarket. This usually includes two low temperature racks and two medium temperature racks. For 2012 a 1,200 MBtu/hr total cooling capacity is based on a 100 ton estimate for total capacity – 80 tons for the medium temperature racks and 20 tons for the low temperature racks. Beyond 2012, estimates are based on data provided by a supermarket refrigeration efficiency consultant.

[2] Capacity and Annual energy consumption for 2012 and beyond are based on interviews with supermarket refrigeration consultants

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[4] The total installed cost for 2003 is based on the entire supermarket compressor rack system (two medium temperature racks and two low temperature racks). The equipment purchase price for an entire supermarket compressor rack system is approximately $130,000, the installation cost (including piping, electrical, startup and commissioning) is approximately $400,000, and the rack defrost and lighting controls are approximately $100,000. Therefore the total installed cost for a typical supermarket compressor rack system is approximately $630,000. Total installed cost for 2012 and beyond is based on updated Navigant estimates. Note the decrease in cost over time as required capacity is decreased.

[5] Maintenance cost includes oil changes, bearing lubrication, filter replacement, and system functionality checks.

Commercial Compressor Rack Systems

- Commercial compressor rack systems that serve commercial supermarket display cases and walk-ins consist of a number of parallel-connected compressors located in a separate machine room. By modulating compressor capacity, these integrated systems provide higher efficiency and mechanical longevity.
- Rack integrators generally supply a packaged compressor rack for which much of the necessary piping, insulation, components, and controls are pre-assembled.
- A typical supermarket will have 10 to 20 compressors mounted in racks in the 3-hp to 15-hp size range. Usually there are 3 to 5 compressors per rack serving a series of loads with nearly identical evaporator temperature.
- The duty cycle for compressors is usually in the range 60% to 70%.
- Approximately 34 percent of the total annual electricity consumption for a typical supermarket is attributable to compressors. (NCI, 2009)
- There are an estimated 140,000 compressor rack systems installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- Installed cost, power draw, and capacity are all expected to decrease in the future due to the reduced load of supermarket display cases

Commercial Condensers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,680	1,680	1,680	1,666	1,302	N/A	1,121	1,102	1,004	877	1,004	877
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	25	25	24	22	18	N/A	14	14	12	10	12	10
Energy Use (MWh/yr)	138	120	115	106	86	N/A	67	66	58	51	58	48
Indexed Annual Efficiency[2]	1.00	1.15	1.20	1.30	1.60	N/A	2.06	2.10	2.38	2.72	2.38	2.87
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Total Installed Cost ($1000)	$47	$54	$54	$53	$51	N/A	$51	$51	$51	$51	$51	$51
Total Installed Cost ($/kBtu/hr)	$27.87	$32.14	$32.14	$31.81	$39.17	N/A	$45.50	$46.28	$50.80	$58.13	$50.80	$58.15
Annual Maintenance Cost[3]	$817	$954	$954	$954	$954	N/A	$956	$956	$956	$956	$956	$956
Annual Maintenance Cost ($/kBtu/hr)	$0.49	$0.57	$0.57	$0.57	$0.73	N/A	$0.85	$0.87	$0.95	$1.09	$0.95	$1.09

[1] Total capacity is the total heat rejected (THR) of condensers comprised of two low temperature condensers (THRL = 240 MBtu/hr each, suction temperature = -25°F, condensing temperature 110°F) and two medium temperature (THRM = 520 MBtu/hr each, suction temperature = 15°F, condensing temperature = 115°F) condensers; ambient temperature = 95°F. (NCI, 2009). For 2012 and beyond, capacity was estimated based on consultation with a supermarket refrigeration expert.

[2] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[3] Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks. Note a slight expected increase in maintenance costs due to the expected implementation of hybrid condenser systems.

Commercial Condensers

- Condensers are designed with multiple methods of cooling: air-cooled, water-cooled, and evaporative. These units can be single-circuit or a multiple circuit.
- Commercial condensers are remotely located, typically installed on the roof of a supermarket.
- For use with parallel compressors in supermarkets, air-cooled units are the most commonly used condensers. This analysis is based on multiple air-cooled condensers connected to a supermarket refrigeration system comprised of two low temperature condensers and two medium temperature condensers, using R-404A refrigerant.
- Each compressor rack has a dedicated condenser or a separate circuit of a single common condenser. Condenser temperatures of multiple racks are often different.
- The duty cycle for condensers is usually in the range 50 - 70%.
- Approximately 5 percent of the total annual electricity consumption for a typical supermarket is attributable to condensers. (NCI, 2009)
- There are an estimated 140,000 condensers installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- Total installed cost is expected to decrease over time due to an expected reduction in required capacity due to more efficient display cases

Commercial Supermarket Display Cases

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	20,000	17,623	17,623	17,623	17,623	N/A	17,623	17,623	17,623	17,623	17,623	17,623
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Case Length (ft)	12	12	12	12	12	N/A	12	12	12	12	12	12
Energy Use (kWh/yr) [1,2]	21,000	13,497	13,497	12,565	11,746	N/A	11,787	11,586	10,467	9,146	9,146	8,689
Energy Use (kWh/ft)	1,750	1,125	1,125	1,047	979	N/A	982	966	872	762	762	724
Indexed Annual Efficiency[3]	1.00	1.56	1.56	1.67	1.79	N/A	1.78	1.81	2.01	2.30	2.30	2.42
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$4,371	$8,510	$8,510	$8,940	$9,601	N/A	$9,356	$9,806	$9,453	$9,550	$9,550	$9,806
Total Installed Cost	$6,452	$10,811	$10,811	$11,241	$11,902	N/A	$11,657	$12,107	$11,754	$11,851	$11,851	$12,107
Total Installed Cost ($/kBtu/hr)	323	613	613	638	675	N/A	661	687	667	672	672	687
Annual Maintenance Cost[4]	$657	$940	$940	$940	$940	N/A	$940	$940	$940	$940	$940	$940
Annual Maintenance Cost ($/kBtu/hr)	$32.85	$53.34	$53.34	$53.34	$53.34	N/A	$53.34	$53.34	$53.34	$53.34	$53.34	$53.34

[1] DOE's Federal energy conservation standards for Commercial Refrigeration Equipment (CRE) went into effect on January 1, 2012. The 2012 typical and 2015 low efficiency values are based on minimal compliance with this standard. For 2015 and beyond, energy consumption and cost values were estimated using shipments-weighted averages reported in DOE's 2014 CRE Final Rule TSD for equipment commonly used as display cases. DOE's updated conservation standard goes into effect in 2017, so units sold in 2020 are assumed to comply with this standard.

[2] **For consistency with DOE rulemaking practices, Supermarket Display Case Energy Use reported above includes energy use of the compressor racks and condensers. To avoid double counting, do not add Energy Use from the Compressor Rack or Condenser Systems tabs if calculating total energy consumption.**

[3] **Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).**

[4] Maintenance cost includes preventative maintenance costs such as cleaning evaporator coils, drain pans, fans, and intake screens as well as lamp replacements and other lighting maintenance activities. After 2012, these values are based on a reported maintenance and repair cost of $220 per unit for preventative maintenance plus approximately $60 per linear foot for additional repair and maintenance

Commercial Supermarket Display Cases

- DOE set Federal energy efficiency standards for Commercial Refrigeration Equipment (CRE) in 2009. These standards set maximum daily energy consumption levels, in kWh/day, for display cases manufactured and/or sold in the United States on or after January 1, 2012.
- DOE updated its Energy Conservation Standards for Commercial Refrigeration Equipment in 2014, for equipment sold on or after March 27, 2017.
- The table below lists equipment used as supermarket display cases and their corresponding Energy Conservation Standard levels. The maximum allowable daily energy consumption for each equipment class is a linear function of Total Display Area (TDA)

Equipment Description	DOE Designation	Standards Equation (2012)	Standards Equation (2017)
Vertical Open Cooler	VOP.RC.M	0.82xTDA+4.07	0.64xTDA+4.07
Semi vertical Open Cooler	SVO.RC.M	0.83xTDA+3.18	0.66xTDA+3.18
Horizontal Open Cooler	HZO.RC.M	0.35xTDA+2.88	0.35xTDA+2.88
Transparent-Doored Cooler	VCT.RC.M	0.22xTDA+1.95	0.15xTDA+1.95
Deli Display Cooler	SOC.RC.M	0.51xTDA+0.11	0.44xTDA+0.11
Transparent-Doored Freezer	VCT.RC.L	0.56xTDA+2.61	0.49xTDA+2.61
Horizontal Open Freezer	HZO.RC.L	0.57xTDA+6.88	0.55xTDA+6.88

Commercial Supermarket Display Cases

- The Food Marketing Institute reported the median total supermarket size in 2003 was 44,000 sq. ft., and in 2013, the last year reported in the study, it was listed as 46,500 sq. ft.
- Unit energy consumption for 2012 and beyond is estimated using a shipments weighted average by efficiency level and equipment class, using data in DOE's 2014 CRE Final Rule TSD and Engineering Spreadsheet. The equipment classes analyzed are listed in the table on the previous slide.
- Supermarket refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks
- A typical supermarket display case contains lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- Approximately 20% of total annual electricity consumption for a typical supermarket is directly attributable to display cases (this does not include the energy consumed by compressors and condensers necessary to cool the display cases). (NCI, 2009)
- The efficiency of supermarket display cases can be increased through the use of improved evaporator coils, larger evaporators, higher efficiency evaporator fan blades, high efficiency doors, LED lighting, and improved insulation.
- Unit energy consumption for supermarket display cases is expected to decrease over time as a result of DOE's updated energy conservation standards
- In addition, a transition from open to transparent-doored display cases is expected to occur as supermarkets increase focus on energy efficiency.

Commercial Reach-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	3,000	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	3,800	2,340	2,665	2,033	1,394	1,394	1,448	1,340	1,259	1,150	1,221	1,117
Energy Use (kWh/yr/ft^3) [1]	79	48	54	41	28	28	30	27	26	23	25	23
Indexed Annual Efficiency[3]	1.00	1.62	1.43	1.87	2.73	2.73	2.62	2.84	3.02	3.31	3.11	3.40
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,810	$2,624	$2,728	$2,780	$3,021	$3,021	$2,947	$3,001	$3,214	$2,934	$3,280	$2,959
Total Installed Cost[4]	$2,966	$3,454	$3,591	$3,643	$3,884	$3,884	$3,810	$3,864	$4,077	$3,797	$4,143	$3,822
Total Installed Cost ($/kBtu/hr)	$989	$1,179	$1,226	$1,244	$1,326	$1,326	$1,301	$1,319	$1,392	$1,296	$1,415	$1,305
Annual Maintenance Cost[5]	$143	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185
Annual Maintenance Cost ($/kBtu/hr)	$48	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63

[1] EPACT 2005 energy standards went into effect in 2010. 2015 low efficiency cost and energy consumption values are based on minimum compliance with this standard. Unless otherwise noted, all other cases are based on shipments-weighted averages of solid and transparent doored units reported in the 2014 CRE TSD. DOE's updated Energy Conservation standards go into effect in 2017; therefore, compliance with this standard is assumed for 2020 and beyond.

[2] The Energy Star category is based on a shipments weighted average of solid and transparent-doored units that are minimally compliant with Energy Star v3, effective October 1, 2014. Units compliant with Energy Star are found to be the most efficient reach-in refrigeration equipment on the market in 2015

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based DOE's CRE Final Rule, which assumes a installation cost of $863 for self-contained equipment.

[5] Maintenance costs after 2003 are based on DOE's CRE Final Rule TSD, which reports $35 annual preventative maintenance, per unit, per year, plus approximately $40 per linear foot, per year of additional repair and maintenance costs for the units characterized

Commercial Reach-In Refrigerators

- The Energy Policy Act of 2005 (EPACT 2005) set maximum daily energy consumption levels, in kWh/day, for commercial reach-in refrigerators that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
- In 2014, DOE updated its energy conservation standards for Reach-in refrigerators, effective March 27, 2017. Both standards are reported in the table below.

Equipment Class	EPCA Standard Level (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.M)	0.10xV+2.04	0.05xV + 1.36
Glass Door (VCT.SC.M)	0.12xV+3.34	0.1xV+0.86

- In 2013, EPA updated its Energy Star® for Reach-in refrigerators, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit.

Reach-In Refrigerator Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.M)	0.02xV+1.60	0.09xV+0.55	0.01xV+2.95	0.06xV+0.45
Glass Door (VCT.SC.M)	0.10xV+1.07	0.15xV+0.32	0.06xV+3.02	0.08xV+2.02

Commercial Reach-In Refrigerators

- Unit energy consumption for 2012 and beyond was estimated based on shipment-weighted averages by efficiency level and equipment class for 49 ft^3 VCS.SC.M and VCT.SC.M units reported in DOE's 2014 CRE Final Rule TSD. These units were estimated to comprise approximately 85% and 15% of total reach-in refrigerator shipments, respectively.
- The efficiency of commercial reach-in refrigerators can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- Unit energy consumption is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to compliance with EPA SNAP
- After 2020, the high efficiency cases are based on solid doored units rather than shipment-weighted averages due to the assumption that stakeholders will increasingly value energy conservation.

Commercial Reach-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[3]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr) [1]	9,392	6,023	7,658	5,592	4,563	4,763	4,453	4,417	4,417	3,975	3,776	3,587
Energy Use (kWh/yr/ft^3)	192	123	156	114	93	97	91	90	90	81	77	69
Indexed Annual Efficiency[4]	1.00	1.56	1.23	1.68	2.06	1.97	2.11	2.13	2.13	2.36	2.49	2.62
Average Life (yrs)	8	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,498	$2,886	$3,002	$3,033	$3,186	$3,118	$3,395	$3,389	$3,230	$3,588	$3,617	$3,812
Total Installed Cost[5]	$2,654	$3,749	$3,865	$3,896	$4,049	$3,981	$4,258	$4,252	$4,093	$4,451	$4,480	$4,675
Total Installed Cost ($/kBtu/hr)	$611	$864	$890	$897	$933	$917	$981	$979	$943	$1,025	$1,032	$1,077
Annual Maintenance Cost[6]	$140	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181
Annual Maintenance Cost ($/kBtu/hr)	$32.25	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70

1 EPACT 2005 energy standards went into effect in 2010. The 2015 low energy consumption and cost values are based on minimal compliance with this standard.

2 A 49 ft^3 unit was characterized, as this was the representative size selected for DOE's rulemaking analysis.

3 The Energy Star category was based on a solid doored unit that is minimally compliant with Energy Star v3, effective October 1, 2014

4 **Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).**

5 Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based on DOE's on-going CRE rulemaking which assumes a cost of $863 for self-contained equipment.

6 Maintenance costs are calculated based on a $35 per unit annual preventative maintenance cost, plus an additional $45 per linear foot repair and maintenance cost estimated based on values reported in the in the CRE TSD

Commercial Reach-In Freezers

- EPACT 2005 set maximum daily energy consumption levels, in kWh/day, for commercial reach-in freezers that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
- In December of 2014, DOE updated its energy conservation standards for commercial refrigeration equipment, including reach-in freezers. Both the EPCA and DOE standards are reported in the table below.

Equipment Class	EPCA (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.L)	0.4xV+1.38	0.22xV+1.38
Transparent Door (VCT.SC.L)	0.75xV+4.10	0.29xV+2.95

- In 2013, EPA updated its Energy Star standards for reach-in freezers, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit

Reach-In Freezer Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.L)	0.25xV+1.55	0.20xV+2.30	0.25xV+0.80	0.14xV+6.30
Glass Door (VCT.SC.L)	0.56xV+1.61	0.30xV+5.50	0.55xV+2.00	0.32xV+9.49

Commercial Reach-In Freezers

- The commercial reach-in freezer characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 49 cubic ft. solid two-door unit with a nominal compressor size 4,341 Btu/hr.
- The efficiency of commercial reach-in freezers can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- Unit energy consumption for reach-in freezers is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to EPA SNAP compliance.

Commercial Walk-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	37,820	37,820	37,820	37,820	37,820	N/A	37,820	37,820	37,820	37,820	37,820	37,820
Size (ft^2) [1]	305	305	305	305	305	N/A	305	305	305	305	305	305
Energy Use (kWh/yr) [2]	53,756	30,689	31,892	30,689	27,571	N/A	16,014	15,855	15,214	15,063	14,453	14,310
Energy Use (kWh/ft^2/yr)	176	101	105	101	90	N/A	53	52	50	49	47	47
Indexed Annual Efficiency[3]	1.00	1.75	1.69	1.75	1.95	N/A	3.36	3.39	3.53	3.57	3.72	3.76
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$19,607	$23,598	$23,583	$23,598	$23,644	N/A	$24,290	$24,473	$24,290	$24,473	$24,290	$24,473
Total Installed Cost[4]	$23,846	$27,012	$26,997	$27,012	$27,057	N/A	$27,703	$27,886	$27,703	$27,886	$27,703	$27,886
Total Installed Cost($/kBtu/hr)	$631	$714	$714	$714	$715	N/A	$733	$737	$733	$737	$733	$737
Annual Maintenance Cost[5]	$573	$716	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$15.15	$18.93	$19.59	$19.59	$19.59	N/A	$19.59	$19.59	$19.59	$19.59	$19.59	$19.59

[1] Estimated based on analysis from the 2014 WICF TSD, which reports the average size of a walk in cooler as 305 ft^2

[2] EISA 2007 includes prescriptive standards for walk-in refrigerators that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. In 2014, DOE updated energy conservation standards for walk-ins. All units 2015 and beyond use data from this rulemaking, and all units 2020 and beyond are assumed to comply with DOE's updated standards.

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $4,163 and $4,891 respectively. Installation cost for 2012 and beyond is based on DOE's Walk-In TSD

[5] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

Commercial Walk-In Refrigerators

- The unit characterized in 2003 was a walk-in cooler with merchandising doors, which was also characterized in the ADL 1996 and NCI, 2009 reports. For 2012 and beyond, the unit characterized was walk-in storage cooler, based on DOE's WICF TSD
- A typical walk-in refrigerator includes:
  - insulated floor and wall panels
  - merchandising doors, shelving, and lighting (not included in cost estimate)
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.

Commercial Walk-In Refrigerators

- The Energy Independence and Security Act (EISA) of 2007 included prescriptive standards for walk-in refrigerators (coolers) that went into effect in 2009. These prescriptive standards, which are included in the analysis for all units for 2012 and beyond, state that all walk-in refrigerators manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–25, except for glazed portions of doors and structural members
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in refrigerator is not occupied by people.

Commercial Walk-In Refrigerators

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Walk-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	22,114	22,114	22,114	22,114	22,114	N/A	22,114	22,114	22,114	22,114	22,114	22,114
Size (ft^2) [1]	172	172	172	172	172	N/A	172	172	172	172	172	172
Energy Use (kWh/yr) [2]	33,540	22,862	23,610	22,862	20,878	N/A	13,421	13,303	12,750	12,637	12,113	12,006
Energy Use (kWh/ft^2/yr)	195	133	137	133	121	N/A	78	77	74	73	70	70
Indexed Annual Efficiency[3]	1.00	1.47	1.42	1.47	1.61	N/A	2.50	2.52	2.63	2.65	2.77	2.79
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$16,333	$22,008	$21,993	$22,008	$22,054	N/A	$22,793	$23,452	$22,793	$23,452	$22,793	$23,452
Total Installed Cost[4]	$18,570	$24,058	$24,043	$24,058	$24,103	N/A	$24,843	$25,501	$24,843	$25,501	$24,843	$25,501
Total Installed Cost ($/kBtu/hr)	$840	$1,088	$1,087	$1,088	$1,090	N/A	$1,123	$1,153	$1,123	$1,153	$1,123	$1,153
Annual Maintenance Cost[5]	$573	$741	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$25.91	$33.51	$33.51	$33.51	$33.51	N/A	$33.51	$33.51	$33.51	$33.51	$33.51	$33.51

[1] Based on DOE's 2014 WICF Final Rule TSD which states the average floor area for a walk-in storage freezer as 172 ft^2

[2] EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. Units for 2015 and beyond are characterized using data from DOE's 2014 WICF rulemaking. All units 2020 and beyond are assumed to comply with this standard

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $1,040. Installation cost for 2012 and beyond is based on DOE's WICF TSD.

[5] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils

Commercial Walk-In Freezers

- The commercial walk-in freezer characterized in this report is a walk-in storage freezer with an area of 172 ft^2
- A typical walk-in freezer includes:
  - insulated floor, door, and wall panels
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.

Commercial Walk-In Freezers: EISA 2007

- EISA 2007 included prescriptive standards for walk-in freezers that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in freezers manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–32, except for glazed portions of doors and structural members
  - contain floor insulation of at least R–28
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in freezer is not occupied by people.

Commercial Walk-In Freezers: DOE 2014 Standards

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Ice Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[5]	Typical	High	Typical	High	Typical	High
Output (lbs/day) [1]	300	300	300	300	300	300	300	300	300	300	300	300
Cooling Capacity (Btu/hr)[2]	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963
Water Use (gal/100 lbs)	20	20	20	20	20	20	20	20	20	20	20	20
Energy Use (kWh/100 lbs)	8.4	7.7	7.7	6.7	6.1	6.7	6.1	6.0	6.0	5.7	5.7	5.7
Energy Use (kWh/yr)[3]	3,833	3,185	3,185	3,078	3,009	3,078	2,901	2,901	2,658	2,640	2,525	2,508
Normalized Annual Efficiency[4]	1.00	1.20	1.20	1.25	1.27	1.25	1.32	1.32	1.44	1.45	1.52	1.53
Average Life (yrs)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Retail Equipment Cost	$1,374	$2,146	$2,189	$2,284	$2,392	$2,284	$2,392	$2,427	$2,427	$2,786	$2,786	$2,786
Total Installed Cost (with Bin)	$1,499	$2,441	$2,484	$2,579	$2,687	$2,579	$2,687	$2,722	$2,722	$3,081	$3,081	$3,081
Total Installed Cost ($/kBtu/hr)	$763	$1,244	$1,265	$1,314	$1,369	$1,314	$1,369	$1,387	$1,387	$1,570	$1,570	$1,570
Annual Maintenance Cost[6]	$639	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826
Annual Maintenance Cost ($/kBtu/hr)	$326	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421

[1] Based on the Final Rule shipment data from DOE's Automatic Ice Maker rulemaking which states the most common equipment type is a small air cooled unit with an integrated ice making head with a representative capacity of 300 lbs/day.

[2] Defined as the average heat load to remove the latent and sensible heat required to freeze the daily output capacity of ice

[3] EPACT 2005 energy standards went into effect in 2010. The 2015 Low values are based on this standard. In 2014, DOE set new standards for commercial ice machines, with compliance required by 2018. The unit characterized for 2012 and beyond use data from this rulemaking. All units 2020 and beyond are assumed to comply with the updated standard.

[4] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[5] The Energy Star category is based on minimum compliance with the Energy Star v2.0 standard, which went into effect on February 1, 2013. According to this analysis, Energy Star certification is typical for the small air-cooled IMH unit characterized.

[6] Maintenance cost includes cleaning and maintaining refrigerant levels, replacing filters, checking water distribution lines for leaks, cleaning, sanitizing, and descaling the bin and water system. Maintenance cost decreases as the size of the ice machine (i.e. output) decreases.

Commercial Ice Machines

- The commercial ice machine characterized in this report is an air-cooled, ice maker head unit with an approximate output of 300 lbs/day. Commercial ice machines are typically integrated with an insulated ice storage bin or mounted on top of a separate storage bin. The retail equipment cost includes the ice making head and the integrated storage bin. Commercial ice machine condensers are either air-cooled or water-cooled. Approximately 90% of all units are the air-cooled type.
- Commercial ice machine maintenance includes periodic cleaning (every 2 to 6 weeks) to remove lime and scale, and sanitizing to kill bacteria. Some ice machines are self-cleaning/sanitizing.
- ENERGY STAR® updated its maximum energy consumption levels, in KWh/100 lbs ice, for air cooled ice machines that went into effect on February 1, 2013. These efficiency levels are based on the harvest rate, in lbs/24 hrs. (H). Water cooled ice machines are not eligible for Energy Star certification.

ENERGY STAR Requirements for Air-Cooled Batch-Type Ice Makers			
Equipment Type	Applicable Ice Harvest Rate Range (lbs of ice/24 hrs)	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$200 \leq H \leq 1600$	$\leq 37.72 * H^{-0.298}$	≤ 20.0
RCU	$400 \leq H \leq 1600$	$\leq 22.95 * H^{-0.258} + 1.00$	≤ 20.0
	$1600 \leq H \leq 4000$	$\leq -0.00011 * H + 4.60$	≤ 20.0
SCU	$50 \leq H \leq 450$	$\leq 48.66 * H^{-0.326} + 0.08$	≤ 25.0

ENERGY STAR Requirements for Air-Cooled Continuous-Type Ice Makers		
Equipment Type	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$\leq 9.18 * H^{-0.057}$	≤ 15.0
RCU	$\leq 6.00 * H^{-0.162} + 3.50$	≤ 15.0
SCU	$\leq 59.45 * H^{-0.349} + 0.08$	≤ 15.0

Commercial Ice Machines: EPACT 2005

- EPACT 2005 issued standard levels for commercial ice machines with capacities between 50 and 2500 pounds per 24-hour period that are manufactured and/or sold in the United States on or after January 1, 2010. The energy

Equipment Type	Type of Cooling	Harvest Rate (lbs ice/24 hrs)	Maximum Energy Use (kWh/100 lbs ice)	Maximum Condenser Water Use (gal/100 lbs ice)
Ice Making Head	Water	<500	7.80-0.0055 H	200-0.022 H
		≥500 and <1436	5.58-0.0011 H	200-0.022 H
		≥1436	4.0	200-0.022 H
	Air	<450	10.26-0.0086 H	Not Applicable
		≥450	6.89-0.0011 H	Not Applicable
Remote Condensing (but not remote compressor)	Air	<1000	8.85-0.0038 H	Not Applicable
		≥1000	5.10	Not Applicable
Remote Condensing and Remote Compressor	Air	<934	8.85-0.0038 H	Not Applicable
		≥934	5.3	Not Applicable
Self Contained	Water	<200	11.40-0.019 H	191-0.0315 H
		≥200	7.60	191-0.0315 H
	Air	<175	18.0-0.0469 H	Not Applicable
		≥175	9.80	Not Applicable

Water use is for the condenser only and does not include potable water used to make ice.

Commercial Ice Machines: 2014 DOE Standards

Energy Conservation Standards for Batch Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<300	6.88 - 0.0055H	200 - 0.022H
		300 and <850	5.80 - 0.00191H	200 - 0.022H
		850 and <1,500	4.42 - 0.00028H	200 - 0.022H
		1500 and <2,500	4.0	200 - 0.022H
		2500 and <4,000	4.0	145
Ice-Making Head	Air	<300	10 - 0.01233H	Not Applicable
		300 and <800	7.05 - 0.0025H	Not Applicable
		800 and <1500	5.55 - 0.00063H	Not Applicable
		1500 and <4,000	4.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	50 and <1,000	7.97 - 0.00342H	Not Applicable
		1,000 and <4,000	4.55	Not Applicable
Remote Condensing and Remote Compressor	Air	<942	7.97 - 0.00342H	Not Applicable
		942 and <4,000	4.75	Not Applicable
Self-Contained	Water	<200	9.5 - 0.019H	191 - 0.0315H
		200 and <2,500	5.7	191 - 0.0315H
		2500 and <4,000	5.7	112
Self-Contained	Air	<110	14.79 - 0.0469H	Not Applicable
		110 and <200	12.42 - 0.02533H	Not Applicable
		200 and <4,000	7.35	Not Applicable

Energy Conservation Standards for Continuous Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<801	6.48 - 0.00267H	180 - 0.0198H
		801 and <2,500	4.34	180 - 0.0198H
		2,500 and <4,000	4.34	130.5
Ice-Making Head	Air	<310	9.19 - 0.00629H	Not Applicable
		310 and <820	8.23 - 0.0032H	Not Applicable
		820 and <4,000	5.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	<800	9.7 - 0.0058H	Not Applicable
		800 and <4,000	5.06	Not Applicable
Remote Condensing and Remote Compressor	Air	<800	9.9 - 0.0058H	Not Applicable
		800 and <4,000	5.26	Not Applicable
Self-Contained	Water	<900	7.6 - 0.00302H	153 - 0.0252H
		900 and <2,500	4.88	153 - 0.0252H
		2500 and <4,000	4.88	90
Self-Contained	Air	<200	14.22 - 0.03H	Not Applicable
		200 and <700	9.47 - 0.00624H	Not Applicable
		700 and <4,000	5.1	Not Applicable

Commercial Beverage Merchandisers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27	27
Energy Use (kWh/yr)	3,900	1,829	2,523	1,781	1,694	1,694	1,380	1,369	1,369	1,329	1,318	1,186
Energy Use (kWh/ft^3/yr)[1]	144	68	93	66	63	63	51	51	51	49	49	44
Indexed Annual Efficiency[3]	1.00	2.13	1.55	2.19	2.30	2.30	2.83	2.85	2.85	2.94	2.96	3.29
Average Life (yrs)	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Retail Equipment Cost	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$2,839	$2,972	$3,078	$3,232
Total Installed Cost[4]	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$2,839	$2,972	$3,078	$3,232
Total Installed Cost ($/kBtu/hr)	$311	$508	$496	$555	$560	$560	$599	$605	$605	$634	$656	$689
Annual Maintenance Cost[5]	$84	$108	$108	$98	$95	$95	$95	$95	$95	$95	$95	$95
Annual Maintenance Cost ($/kBtu/hr)	$17.91	$23.03	$23.03	$20.79	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15

[1] EPACT 2005 energy conservation standards went into effect in 2010. The 2015 Low values are based on this standard. In 2015, DOE updated its energy conservation standards for commercial refrigeration equipment, including transparent-doored refrigerators with pull-down capability. Compliance with this standard is required by 2017. Units characterized for 2012 and beyond use data reported in this rulemaking's TSD. Units 2020 and beyond are assumed to comply with this updated standard.

[2] The Energy Star category characterizes a unit that is compliant with Energy Star v3, effective October 1, 2014. This standard does not separately define units with pull-down capability

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Beverage merchandisers are shipped ready to be plugged in, so installation costs are assumed to be negligible

[5] Maintenance costs are estimated based on CRE Final Rule TSD data. Note that maintenance costs decrease slightly for more efficient units, which are assumed to include LED lighting with lower associated maintenance costs

Commercial Beverage Merchandisers

- EPACT 2005 sets maximum daily energy consumption levels, in kWh/day, for commercial refrigerators with a self-contained condensing unit designed for pull-down temperature applications and transparent doors (i.e., beverage merchandisers) that went into effect on January 1, 2010.
- In 2014, DOE updated its energy consumption standards for commercial refrigeration equipment, including beverage merchandisers, effective March 27, 2015. Both the DOE and EPCA standards are reported below.

Equipment Type	EPCA (2010)	DOE Standards (2017)
Beverage Merchandisers (PD.SC.M)	0.126xV + 3.51	0.11xV+0.81

- In 2013, EPA updated its Energy Star standards for glass doored commercial refrigerators, which can be used as beverage merchandisers, effective October 1, 2014. These standards are also based on the volume of the unit (V). Note that Energy Star does not have a separate equipment class for units with pull-down capability.

Beverage Merchandiser Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Glass Door	0.118*V + 1.382	≤ 0.140*V + 1.050	≤ 0.088*V + 2.625	≤ 0.110*V + 1.500

Commercial Beverage Merchandisers

- The beverage merchandiser characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a nominal compressor size of 4,689 Btu/hr.
- The efficiency of beverage merchandisers can be increased through the use of more efficient compressors, fluorescent lighting with electronic ballasts, and improved insulation.
- Beverage merchandisers have an estimated installed base of 920,000 units in 2008. Of those beverage merchandisers 460,000 are one-door units, which represents the most common type of beverage merchandiser.
- Unit energy consumption of beverage merchandisers is expected to decrease as a result of DOE's updated Energy Conservation Standards, as well as a transition from R-134a to more efficient propane refrigerant due to EPA SNAP compliance
- By 2040, beverage merchandisers with vapor-compression refrigeration systems are expected to have reached the limit of possible improvements to energy efficiency.

Commercial Refrigerated Vending Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810
Can Capacity	500	470	470	470	470	470	470	470	470	470	470	470
Size (ft^3)	26	26	26	26	26	26	26	26	26	26	26	26
Energy Use (kWh/yr) [1]	3,000	1,632	1,718	1,632	1,504	1,504	1,360	1,292	1,319	1,253	1,293	1,228
Energy Use (kWh/ft^3/yr)	115	63	66	63	58	58	52	50	51	48	50	47
Indexed Annual Efficiency[3]	1.00	1.84	1.75	1.84	1.99	1.99	2.21	2.32	2.27	2.39	2.32	2.44
Average Life (yrs)	14	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Retail Equipment Cost	$1,769	$3,209	$3,187	$3,209	$3,276	$3,276	$3,551	$3,738	$3,661	$3,854	$3,736	$3,933
Total Installed Cost	$1,844	$3,320	$3,298	$3,320	$3,387	$3,387	$3,662	$3,849	$3,772	$3,965	$3,847	$4,044
Total Installed Cost ($/kBtu/hr)	$1,019	$1,834	$1,822	$1,834	$1,872	$1,872	$2,023	$2,127	$2,084	$2,191	$2,125	$2,234
Annual Maintenance Cost[4]	$209	$270	$270	$270	$250	$250	$250	$250	$250	$250	$250	$250
Annual Maintenance Cost ($/kBtu/hr)	$115	$149	$149	$149	$138	$138	$138	$138	$138	$138	$138	$138

[1] Energy use for 2012 and beyond is estimated based on DOE's 2015 BVM Final Rule

[2] The Energy Star category assumes units that are compliant with the Energy Star v3 standard, since combination units are currently not separately defined by Energy Star. This standard went into effect on March 1, 2013. Our analysis finds Energy Star certified equipment to be the most efficient currently available on the market

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils and also includes an annualized cost for refurbishments/remanufacturing.

Commercial Refrigerated Vending Machines

- DOE set Federal energy efficiency standards for refrigerated vending machines. These standards set maximum daily energy consumption levels, in kWh/day, for commercial refrigerated vending machines manufactured and/or sold in the United States on or after August 31, 2012. The daily energy consumption is based on the volume of the unit (V).
  - Refrigerated Vending Machines that are fully-cooled (Type A) ≤ 0.055*V + 2.56
  - Refrigerated Vending Machines that are zone-cooled (Type B) ≤ 0.073*V + 3.16
- Energy Star® updated its maximum daily energy consumption efficiency levels, also in KWh/day, for refrigerated vending machines that went into effect on March 1, 2013. These efficiency levels are based on refrigerated volume.

Equipment Type	Maximum Daily Energy Consumption	Low Power Mode Requirement
Class A (Transparent-Front)	MDEC= 0.0523 x V + 2.432	Hard-wired controls and/or software capable of placing the machine into a low power mode during periods of extended inactivity while still connected to its power source
Class B (Solid-Front)	MDEC = 0.0657 x V + 2.844	

- DOE is currently engaged in rulemaking for refrigerated vending machines, which will separately define combination vending machines with a separate, partitioned volume for unrefrigerated products. Data for characterizing units 2012 and beyond is drawn from this NOPR TSD.

Commercial Refrigerated Vending Machines

- In December 2015, DOE updated its energy conservation standards for beverage vending machines, and defined two new product classes for combination vending machines Compliance with these standards is required by 2019. For this analysis, compliance with these updated standards is assumed for equipment sold in 2020 and beyond. The updated standards and DOE equipment definitions are listed in the table below.

Equipment Class	Maximum daily energy consumption (kilowatt hours per day)
Class A – a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.052 x V + 2.43
Class B – any refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine	MDEC = 0.052 x V + 2.20
Combination A – a combination vending machine where 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.086 x V + 2.66
Combination B – a combination vending machine that is not considered to be Combination A	MDEC = 0.111 x V + 2.04

Commercial Ventilation

Commercial Constant Air Volume

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4,5]	Typical[4,6]	High[4,7]	Energy Star	Typical[4,7]	High[4,8]	Typical[4,7,9]	High[4,8,9]	Typical[4,7,9]	High[4,8,9]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	11.80	11.56	11.56	11.56	11.56	N/A	11.56	11.56	10.98	10.98	9.83	9.83
Specific Fan Power (W/CFM)	0.787	0.771	0.771	0.771	0.771	N/A	0.771	0.771	0.732	0.732	0.655	0.655
Annual Fan Energy Use (kWh/yr)[1]	44,858	43,924	23,038	20,018	15,226	N/A	15,226	11,155	14,465	10,597	12,942	9,482
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$68,539	$68,539	$68,979	$68,979	$74,178	N/A	$74,178	$74,778	$74,178	$74,778	$74,178	$74,778
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$4,569	$4,569	$4,599	$4,599	$4,945	N/A	$4,945	$4,985	$4,945	$4,985	$4,945	$4,985
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

[1] Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 15,000 CFM CAV AHU and hypothetical supply ductwork layout.

[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

[4] ASHRAE 90.1-2010 & 2013 Section 6.5.3.2 require minimum 2-speed fan control (no longer always constant volume).

[5] Two-speed motor.

[6] Two-speed VFD.

[7] Modulating VFD (66-100%).

[8] Modulating VFD (50-100%).

[9] High aerodynamic efficiency fan.

Commercial Constant Air Volume

- Constant air volume (CAV) ventilation systems are common, inexpensive, air-side HVAC systems that operate in response to a single control zone. Historically, these systems provide a constant flow rate of air (typically a mix of recirculated and outside air) and adjust the supply temperature of that air in order to maintain space temperature setpoint. Recent energy efficiency standard changes (ASHRAE 90.1-2013) now mandate at least two fan speed settings with the requirement of a maximum 40% power at 66% flow. Systems with variable speed fans are increasingly popular, making the term "constant air volume" somewhat of a misnomer for this system type. This analysis examines only the fan energy of the CAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for CAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the CAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- The unit characterized in this report is a 15,000 CFM CAV system. The average commercial building is approximately 15,000 square feet (CBECS 2003 and BED 2007). Assuming 1 CFM is needed per square foot of floor area results in a 15,000 CFM air handling unit.
- A 15,000 CFM CAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $60,722 (RS Means 2016). Ductwork would cost approximately $7,817 additional ($68,539 total). A 2-speed motor (estimated $440 incremental cost) and variable frequency drive (estimated $5,639) add cost.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP) for CAV systems. The 2007 version of Standard 90.1 was used to represent the 2012 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, motor efficiency, and speed/flow control.

Commercial Variable Air Volume

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4]	Typical[5]	High[6]	Energy Star	Typical[6]	High[6,7]	Typical[6,7]	High[6,7]	Typical[6,7]	High[6,7]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	16.72	15.99	15.99	15.99	15.99	N/A	15.99	15.19	15.19	14.39	14.39	13.59
Specific Fan Power (W/CFM)	1.115	1.066	1.066	1.066	1.066	N/A	1.066	1.013	1.013	0.959	0.959	0.906
Annual Fan Energy Use (kWh/yr)[1]	25,839	24,699	24,699	18,181	16,425	N/A	16,425	15,604	15,604	14,783	14,783	13,961
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$88,207	$88,207	$88,207	$93,846	$94,346	N/A	$94,446	$94,946	$94,446	$94,946	$94,446	$94,946
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$5,880	$5,880	$5,880	$6,256	$6,290	N/A	$6,296	$6,330	$6,296	$6,330	$6,296	$6,330
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

[1] Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 15,000 CFM VAV AHU, VFD, (10) VAV boxes, and hypothetical supply ductwork layout.

[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

[4] ASHRAE 90.1-2010 Section 6.5.3.2 minimum power-flow requirement.

[5] ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 50%-100% flow.

[6] ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 30%-100% flow.

[7] High aerodynamic efficiency fan.

Commercial Variable Air Volume

- Variable air volume (VAV) ventilation systems are the most common multi-zone system type specified today for conditioning commercial buildings. These systems provide conditioned air to multiple zone terminal units (VAV boxes) that use dampers to modulate the amount of cool air to each zone. An individual zone thermostat controls the VAV box damper to allow more or less cooling. If a zone requires heating then the VAV box provides the minimum flow rate and typically includes a reheat coil to meet space temperature setpoint. As VAV box dampers close in the system, a variable frequency drive reduces fan speed and flow continuously to meet current requirements.
- This analysis examines only the fan energy of the VAV system. VAV systems vary fan speed/flow to meet space conditioning requirements; minimum flow settings apply for DX cooling stages and gas furnace heating stages. Most hours of operation are much lower than full speed, and fan power varies with the cube of fan speed according to fan affinity laws. The 2012 ASHRAE Handbook: HVAC Systems and Equipment (p. 45.11) provided the typical flow profile used for this analysis. The unit characterized in this report is a 15,000 CFM VAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for VAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the VAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- A 15,000 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $69,100 (RS Means 2016). Ductwork and (10) VAV boxes with reheat would cost approximately $19,107 additional ($88,207 total). A 20 hp variable frequency drive (estimated $5,639) is an additional cost.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power for VAV systems (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2012 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor VFD efficiency.

Commercial Fan Coil Units

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[5]	Low[3]	Typical[5]	High[6]	Energy Star	Typical[4,6]	High[4,7]	Typical[4,7]	High[4,8]	Typical[4,8]	High[4,8,9]
System Airflow (CFM)	800	800	800	800	800	N/A	800	800	800	800	800	800
System Fan Power (kW)	0.315	0.241	0.748	0.241	0.148	N/A	0.148	0.148	0.148	0.148	0.148	0.141
Specific Fan Power (W/CFM)	0.394	0.302	0.935	0.301	0.185	N/A	0.185	0.185	0.185	0.185	0.185	0.176
Annual Fan Energy Use (kWh/yr)[1]	709	543	1,683	543	333	N/A	333	152	152	94	94	89
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$2,429	$2,429	$2,429	$2,429	$2,753	N/A	$2,753	$2,995	$2,753	$2,995	$2,753	$2,995
Annual Maintenance Cost ($)	$100	$100	$100	$100	$100	N/A	$100	$100	$100	$100	$100	$100
Total Installed Cost ($/1000 CFM)	$3,036	$3,036	$3,036	$3,036	$3,441	N/A	$3,441	$3,744	$3,441	$3,744	$3,441	$3,744
Annual Maintenance Cost ($/1000 CFM)	$125	$125	$125	$125	$125	N/A	$125	$125	$125	$125	$125	$125

[1] Based on 2250 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.

[3] Based on ASHRAE 90.1-2010 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

[4] Based on ASHRAE 90.1-2013 Section 6.5.3.5 requirement of electronically commutated or 70+% efficient fan motor.

[5] Permanent split capacitor fan motor.

[6] Electronically commutated fan motor (single speed).

[7] Electronically commutated fan motor (two-speed).

[8] Electronically commutated fan motor (variable speed).

[9] High aerodynamic efficiency fan.

Commercial Fan Coil Units

- Commercial fan coil units (FCUs) are self-contained, mass-produced assemblies that provide cooling, heating, or cooling and heating, but do not include the source of cooling or heating. The unit characterized in this report is a cooling only (2-pipe), horizontal unit with housing and controls. Fan coil units are typically installed in or adjacent to the space being served and have no (or very limited) ductwork.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons. This analysis examines only the fan energy of FCUs.
- Fan coil unit fan motors can be shaded pole, a single phase AC motor with offset start winding and no capacitor; PSC, a single phase AC motor with offset start winding with capacitor; or ECM, an AC electronically commutated permanent magnet DC motor. PSC motors are currently the most common motor type in FCUs, but most manufacturers offer ECM as an option. ASHRAE 90.1-2013 requires an electronically commutated fan motor (or minimum motor efficiency of 70%) for this system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for FCUs. Fan power can be minimized through good design practice and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including small systems such as the FCU considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- Fan coil units have higher maintenance costs than central air systems due to the distributed nature of the system. For each unit the filters must be changed and drain systems must be flushed periodically.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2012 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type configuration, filter and coil pressure drops, motor efficiency, and fan speed control.

Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

SAIC
8301 Greensboro Drive
McLean, VA 22102

Residential Lighting

Data Sources » Residential General Service Incandescent Lamps (60 watt)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Ref. Case	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)	DOE, 2008										
Average Lamp Life (1000 hrs)	2012 EIA Ref. Case										
Annual Operating Hours (hrs/yr)	DOE, 2012(3)										
Lamp Price ($)	2012 EIA Ref. Case										
Lamp Cost ($/klm)											
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential General Service Incandescent Lamps (75 watt)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Ref. Case	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)	DOE, 2008										
Average Lamp Life (1000 hrs)	2012 EIA Ref. Case										
Annual Operating Hours (hrs/yr)	DOE, 2012(3)										
Lamp Price ($)	2012 EIA Ref. Case										
Lamp Cost ($/klm)											
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential General Service Halogen Lamps (60 watt Incandescent Equivalent)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated										
Lamp Lumens	Product Catalogs										
Lamp Efficacy (lm/W)	Calculated; NCI, 2014(1)		Product Catalogs								
CRI	Product Catalogs										
Correlated Color Temperature (CCT)	DOE, 2008		DOE, 2008								
Average Lamp Life (1000 hrs)	Calculated; NCI, 2014(1)		Product Catalogs								
Annual Operating Hours (hrs/yr)	DOE, 2012(3)	N/A	DOE, 2012(3)	N/A							
Lamp Price ($)	Calculated; NCI, 2014(1)		Distributor Websites								
Lamp Cost ($/klm)			Calculated								
Labor Cost ($/hr)	N/A		N/A								
Labor Installation (hr)											
Total Installed Cost ($)											
Annual Maintenance Cost ($)	Calculated		Calculated								
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources» Residential General Service Halogen Lamps (75 watt Incandescent Equivalent)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	N/A	Product Catalogs	N/A							
Lamp Lumens	Product Catalogs										
Lamp Efficacy (lm/W)	Calculated; NCI, 2014(1)										
CRI	Product Catalogs										
Correlated Color Temperature (CCT)	DOE, 2008		DOE, 2008								
Average Lamp Life (1000 hrs)	Calculated; NCI, 2014(1)		Product Catalogs								
Annual Operating Hours (hrs/yr)	DOE, 2012(3)		DOE, 2012(3)								
Lamp Price ($)	Calculated; NCI, 2014(1)		Distributor Websites								
Lamp Cost ($/klm)			Calculated								
Labor Cost ($/hr)	N/A		N/A								
Labor Installation (hr)											
Total Installed Cost ($)	Calculated		Calculated								
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="4">2012 EIA Ref. Case</td><td colspan="3" rowspan="2">Product Catalogs</td><td rowspan="6">TCP 1ES134AMO, Lowest performing product in the Energy Star Light Bulb product database downloaded 11-10-15</td><td colspan="6" rowspan="6">NCI, 2014(1)</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="3">Calculated</td></tr>
<tr><td>CRI</td><td colspan="3" rowspan="3">Product Catalogs</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>Product Catalogs</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2012 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="11">DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">2012 EIA Ref. Case</td><td colspan="3">Distributor Websites</td><td rowspan="8">N/A</td><td colspan="6" rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3">Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="4" rowspan="2">N/A</td><td colspan="6" rowspan="2">N/A</td></tr>
<tr><td>Labor Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="4" rowspan="4">Calculated</td><td colspan="6" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Residential General Service LED Lamps (60 Watt Equivalent)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Calculated from 2015 Values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged From 2015 Typical					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	SSL R&D Plan Table 2.1 (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	SSL R&D Plan Table 2.1 +adjustment (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="4">2012 EIA Ref. Case</td><td rowspan="9">N/A</td><td rowspan="6">Product Catalogs</td><td rowspan="9" colspan="2">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE, 2012(1)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2012 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated; NCI 2014(1)</td><td>Distributor Websites</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2" colspan="11">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4" colspan="11">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
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<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="4">2012 EIA Ref. Case</td><td rowspan="9">N/A</td><td rowspan="6">Product Catalogs</td><td rowspan="9">N/A</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td><td rowspan="6">NCI, 2014(1)</td><td rowspan="9">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td>DOE, 2012(1)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td>2012 EIA Ref. Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td><td>DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Calculated; NCI 2014(1)</td><td>Distributor Websites</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td><td rowspan="2">NCI, 2014(1)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Calculated</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="11" rowspan="2">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td colspan="11" rowspan="4">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

Data Sources » Residential Reflector Lamps (PAR30 Halogen Infrared Reflector (HIR)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	N/A	Product Catalogs	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Lamp Lumens	Product Catalogs	N/A	Product Catalogs	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Lamp Efficacy (lm/W)	Calculated; NCI, 2014(1)	N/A	Product Catalogs	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
CRI	Product Catalogs	N/A	Product Catalogs	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Correlated Color Temperature (CCT)	Product Catalogs	N/A	Product Catalogs	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Average Lamp Life (1000 hrs)	Calculated; NCI, 2014(1)	N/A	Product Catalogs	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Annual Operating Hours (hrs/yr)	DOE, 2012(3)	N/A	DOE, 2012(3)	N/A	N/A	DOE, 2012(3)	N/A	DOE, 2012(3)	N/A	DOE, 2012(3)	N/A
Lamp Price ($)	Calculated; NCI, 2014(1)	N/A	Distributor Websites	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Lamp Cost ($/klm)	Calculated; NCI, 2014(1)	N/A	Calculated	N/A	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Labor Cost ($/hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Installation (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated
Annual Maintenance Cost ($)	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated
Total Installed Cost ($/klm)	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated
Annual Maintenance Cost ($/klm)	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated	Calculated

Data Sources » Residential Reflector Lamps (BR30 CFL)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Ref. Case	Product Catalogs			EcoSmart CFL 15W BR30 158-653, Lowest performing product in the Energy Star Light Bulb product database downloaded 11-10-15	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A	NCI, 2014(1)	N/A
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)	DOE, 2012(1)										
Average Lamp Life (1000 hrs)	2012 EIA Ref. Case										
Annual Operating Hours (hrs/yr)	DOE, 2012(3)				N/A	DOE, 2012(3)		DOE, 2012(3)		DOE, 2012(3)	
Lamp Price ($)	2012 EIA Ref. Case	Distributor Websites				NCI, 2014(1)		NCI, 2014(1)		NCI, 2014(1)	
Lamp Cost ($/klm)		Calculated									
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Reflector LED BR30

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Adjusted based on PAR38 values					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)					Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
CRI	Adjusted based on PAR38 values				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Lamp Cost ($/klm)	Adjusted based on PAR38 values	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Linear Fluorescent Lamp T12

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage											
Lamp Lumens	DOE GSFL and IRL Energy Conservation Standard, 2009										
Lamp Efficacy (lm/W)											
System Wattage											
System Lumens											
System Efficacy (lm/W)	Calculated										
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011										
CRI	DOE GSFL and IRL Energy Conservation Standard, 2009										
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013										
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009										
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					N/A					
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009										
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011										
Fixture Price ($)											
Lamp Cost ($/klm)											
System (l/b/f) Cost ($/klm)											
Labor Cost ($/hr)											
Labor System Installation (hr)											
Labor Lamp Change (hr)											
Total Installed Cost ($)											
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)	Calculated										

Data Sources » Residential Linear Fluorescent Lamp T8

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	Calculated					
Lamp Lumens						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	Calculated	Calculated				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Final Rule TSD (DOE, 2015)			Energy Star Light Bulb product database (downloaded 11-4-15)						
System Lumens											
System Efficacy (lm/W)		Calculated									
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011	GSFL IRL Final Rule TSD (DOE, 2015)			Assume same as other 2015 data	Assume Unchanged from 2015					
CRI	DOE GSFL and IRL Energy Conservation Standard, 2009				Energy Star Light Bulb product database (downloaded 11-4-15)						
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013										
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011				N/A						
Fixture Price ($)	Assume Same as Commercial Fixture				Retailer Websites						
Lamp Cost ($/klm)	Calculated	Calculated									
System (l/b/f) Cost ($/klm)											
Labor Cost ($/hr)		GSFL IRL Final Rule TSD (DOE, 2015)									
Labor System Installation (hr)											
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	Calculated					
Lamp Lumens						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage	Calculated	GSFL IRL Final Rule TSD (DOE, 2015)			Energy Star Light Bulb product database (downloaded 11-4-15)						
System Lumens											
System Efficacy (lm/W)		Calculated									
Ballast Efficiency (BLE)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011	GSFL IRL Final Rule TSD (DOE, 2015)			Asssume Constant	Assume Unchanged from 2015					
CRI	DOE GSFL and IRL Energy Conservation Standard, 2009				Energy Star Light Bulb product database (downloaded 11-4-15)						
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013										
Average Lamp Life (1000 hrs)	DOE GSFL and IRL Energy Conservation Standard, 2009					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE GSFL and IRL Energy Conservation Standard, 2009	GSFL IRL Final Rule TSD (DOE, 2015)			Retailer Websites	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)	DOE Fluorescent Lamp Ballast Energy Conservation Standard, 2011										
Fixture Price ($)	Assume Same as Commercial Fixture				Retailer Websites						
Lamp Cost ($/klm)	Calculated	Calculated									
System (l/b/f) Cost ($/klm)											
Labor Cost ($/hr)		GSFL IRL Final Rule TSD (DOE, 2015)									
Labor System Installation (hr)	Assume same as 2015										
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Linear LED Replacement Lamp 2 Lamp System*

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)			N/A	Calculated					
Lamp Lumens						Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage	Calculated					Calculated					
System Lumens	DOE SSL Program R&D Plan (DOE SSL Program, 2015)					DOE SSL Program R&D Plan (DOE SSL Program, 2015)					
System Efficacy (lm/W)	Calculated					Calculated					
Ballast Efficiency (BLE)	N/A					N/A					
CRI	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List Downloaded 11/17/15	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)		Retailer Websites	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A					N/A					
Fixture Price ($)*											
Lamp Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*	N/A					N/A					
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor System Installation (hr)*											
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A										
Lamp Lumens											
Lamp Efficacy (lm/W)											
System Wattage	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 10/31/15)	DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
System Lumens		Calculated		Calculated		Adjusted for 2015 Typical Lumen Output					
System Efficacy (lm/W)		DLC Qualified Product List (Downloaded 11/18/15)		DLC Qualified Product List (Downloaded 11/18/15)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Efficiency (BLE)	N/A										
CRI	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 10/31/15)	DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lifetime (1000 hrs)			DOE SSL Program R&D Plan (DOE SSL Program, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp/Luminaire Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites	Retailer Websites	Calculated					
Ballast Price ($)	N/A										
Fixture Price ($)											
Lamp Cost ($/klm)											
System (l/b/f) Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	Assume Same as T5										
Labor System Installation (hr)											
Labor Lamp Change (hr)	N/A										
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Security: BR30 Incandescent)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="6">Same as indoor Residential Incandescent Reflector</td><td rowspan="9">N/A</td><td rowspan="6">Same as indoor Residential Incandescent Reflector</td><td rowspan="9" colspan="2">N/A</td><td rowspan="6">Same as indoor Residential Incandescent Reflector</td><td rowspan="9">N/A</td><td rowspan="6">Same as indoor Residential Incandescent Reflector</td><td rowspan="9">N/A</td><td rowspan="6">Same as indoor Residential Incandescent Reflector</td><td rowspan="9">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>DOE, 2012(2)</td><td>DOE, 2012(2)</td><td>DOE, 2012(2)</td><td>DOE, 2012(2)</td><td>DOE, 2012(2)</td></tr>
<tr><td>Lamp Price ($)</td><td rowspan="2">Same as indoor Residential Incandescent Reflector</td><td rowspan="2">Same as indoor Residential Incandescent Reflector</td><td rowspan="2">Same as indoor Residential Incandescent Reflector</td><td rowspan="2">Same as indoor Residential Incandescent Reflector</td><td rowspan="2">Same as indoor Residential Incandescent Reflector</td></tr>
<tr><td>Lamp Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="2" colspan="11">N/A</td></tr>
<tr><td>Labor Lamp Installation (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4" colspan="11">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Interpolated from Commercial PAR38 Halogen	N/A	Same as Commercial PAR38 Halogen	N/A		Same as Commercial PAR38 Halogen					
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE, 2012(2)		DOE, 2012(2)			DOE, 2012(2)					
Lamp Price ($)	Interpolated from Commercial PAR38 Halogen		Same as Commercial PAR38 Halogen			Same as Commercial PAR38 Halogen					
Lamp Cost ($/klm)											
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Interpolated from Commercial PAR38 HIR	N/A	Same as Commercial PAR38 HIR	N/A		Same as Commercial PAR38 HIR					
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE, 2012(2)		DOE, 2012(2)			DOE, 2012(2)					
Lamp Price ($)	Interpolated from Commercial PAR38 HIR		Same as Commercial PAR38 HIR			Same as Commercial PAR38 HIR					
Lamp Cost ($/klm)											
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Security: CFL PAR38)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	N/A	Product Catalogs	N/A	Product Catalogs; Distributor Websites (Distributor websites claim ENERGY STAR certification for nearly all lamp models but no PAR38 CFLs listed on ENERGY STAR product list)	NCI, 2014(1)					
Lamp Lumens	Same as outdoor halogen reflector										
Lamp Efficacy (lm/W)	Calculated; NCI, 2014(1)										
CRI	Product Catalogs										
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)	Calculated; NCI, 2014(1)										
Annual Operating Hours (hrs/yr)	DOE, 2012(2)		DOE, 2012(2)		N/A	DOE, 2012(2)					
Lamp Price ($)	Calculated		Distributor Websites			NCI, 2014(1)					
Lamp Cost ($/klm)	Calculated; NCI, 2014(1)		Calculated								
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Security: LED PAR38)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Porch: A19 Incandescent)

DATA SOURCES	2009	2015*				2020*		2030*		2040*	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential General Service 75W Incandescent	N/A									
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE, 2012(2)										
Lamp Price ($)	Same as Residential General Service 75W Incandescent										
Lamp Cost ($/klm)											
Labor Cost ($/hr)											
Labor Lamp Installation (hr)											
Total Installed Cost ($)											
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Porch: Halogen A-Type)

DATA SOURCES	2009	2015*				2020**		2030**		2040**	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Same as Residential General Service 75W Equivalent Halogen	N/A	Same as Residential General Service 75W Equivalent Halogen	N/A							
Lamp Lumens											
Lamp Efficacy (lm/W)											
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE, 2012(2)		DOE, 2012(2)								
Lamp Price ($)	Same as Residential General Service 75W Equivalent Halogen		Same as Residential General Service 75W Equivalent Halogen								
Lamp Cost ($/klm)											
Labor Cost ($/hr)											
Labor Lamp Installation (hr)											
Total Installed Cost ($)											
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Porch: CFL Bare Spiral)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	Product Catalogs			Energy Star Light Bulb product database downloaded 11-10-15	NCI, 2014(1)					
Lamp Lumens	Same as 2015 Typical										
Lamp Efficacy (lm/W)	Calculated; NCI, 2014(1)	Calculated									
CRI	Product Catalogs	Product Catalogs									
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)	Calculated; NCI, 2014(1)										
Annual Operating Hours (hrs/yr)	DOE, 2012(2)				N/A	DOE, 2012(2)					
Lamp Price ($)	Calculated; NCI, 2014(1)	Distributor Websites				NCI, 2014(1)					
Lamp Cost ($/klm)		Calculated									
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Final

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star*	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated										
Lamp Lumens	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Lamp Efficacy (lm/W)	Scaled based on 60W Residential A-type Lamp										
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE SSL Program, Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates (DOE SSL Program, 2012)										
Lamp Price ($)	Calculated										
Lamp Cost ($/klm)	Scaled based on 60W Residential A-type Lamp										
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Commercial Lighting

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Reference Case		N/A									
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage												
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI												
Correlated Color Temperature (CCT)	DOE, 2008											
Average Lamp Life (1000 hrs)	2012 EIA Reference Case											
Annual Operating Hours (hrs/yr)	DOE, 2012(3)											
Lamp Price ($)	2012 EIA Reference Case; Calculated											
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	2016 RSMeans Online											
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	Calculated											
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial General Service Halogen Lamp (100W Incandescent Equivalent) in Recessed Can Fixture

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Lamp Wattage</td><td colspan="2" rowspan="8">2012 EIA Reference Case</td><td rowspan="23">N/A</td><td rowspan="10">Product Catalogs</td><td colspan="8" rowspan="23">N/A</td></tr>
<tr><td>Lamp Lumens</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td></tr>
<tr><td>System Wattage</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td></tr>
<tr><td>CRI</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td colspan="2">DOE, 2008</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="2">2012 EIA Reference Case</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="2">DOE, 2012(3)</td><td>DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td colspan="2" rowspan="5">2012 EIA Reference Case; Calculated</td><td rowspan="2">Distributor Websites</td></tr>
<tr><td>Ballast Price ($)</td></tr>
<tr><td>Fixture Price ($)</td><td>NCI, 2014(2)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="2" rowspan="3">2016 RSMeans Online</td><td rowspan="3">2016 RSMeans Online</td></tr>
<tr><td>Labor System Installation (hr)</td></tr>
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<tr><td>Total Installed Cost ($)</td><td colspan="2" rowspan="4">Calculated</td><td rowspan="4">Calculated</td></tr>
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<tr><td>Lamp Wattage</td><td colspan="2" rowspan="8">2012 EIA Reference Case</td><td colspan="3" rowspan="10">Product Catalogs</td><td rowspan="10">GE FLE26HT3/2/SXE/SW, Lowest Performing product in the Energy Star Light Bulb product database downloaded 11-10-15</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td colspan="6">Held Constant 2015-2040</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="6">NCI, 2014(1)</td></tr>
<tr><td>System Wattage</td><td colspan="6">Same as lamp wattage</td></tr>
<tr><td>System Lumens</td><td colspan="6" rowspan="3">Calculated; 2012 EIA Reference Case</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td></tr>
<tr><td>CRI</td><td colspan="6">2012 EIA Reference Case</td></tr>
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<tr><td>Annual Operating Hours (hrs/yr)</td><td colspan="5">DOE, 2012(3)</td><td rowspan="13">N/A</td><td colspan="6">DOE, 2012(3)</td></tr>
<tr><td>Lamp Price ($)</td><td colspan="2" rowspan="5">2012 EIA Reference Case; Calculated</td><td colspan="3" rowspan="2">Distributor Websites</td><td colspan="6" rowspan="5">Calculated; Distributor Websites; NCI, 2014(1)</td></tr>
<tr><td>Ballast Price ($)</td></tr>
<tr><td>Fixture Price ($)</td><td colspan="3">NCI, 2014(2)</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td colspan="3" rowspan="2">Calculated</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)</td></tr>
<tr><td>Labor Cost ($/hr)</td><td colspan="5" rowspan="3">2016 RSMeans Online</td><td colspan="6" rowspan="3">2016 RSMeans Online</td></tr>
<tr><td>Labor System Installation (hr)</td></tr>
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<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
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DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A	DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage		Calculated										
System Lumens*												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)			Retailer Websites	Assume Same as A19 60W equiv	Retailer Websites							
Average Lamp Life (1000 hrs)		Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	Calculated				Calculated	
System (l/b/f) Cost ($/klm)		N/A										
Labor Cost ($/hr)		Same as for CFL										
Labor System Installation (hr)**												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated										
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Halogen Reflector Lamp (PAR38) in Recessed Can Fixture

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<tr><td>Lamp Lumens</td><td colspan="6">Held Constant 2015-2040</td></tr>
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<tr><td>System Wattage</td><td colspan="6">Same as lamp wattage</td></tr>
<tr><td>System Lumens</td><td colspan="6" rowspan="3">Calculated; 2012 EIA Reference Case</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td></tr>
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</table>

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2012 EIA Reference Case		N/A	Product Catalogs	N/A		Calculated					
Lamp Lumens							Held Constant 2015-2040					
Lamp Efficacy (lm/W)							NCI, 2014(1)					
System Wattage							Same as lamp wattage					
System Lumens							Calculated; 2012 EIA Reference Case					
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI							2012 EIA Reference Case					
Correlated Color Temperature (CCT)	Product Catalogs						Product Catalogs					
Average Lamp Life (1000 hrs)	2012 EIA Reference Case						Calculated; Product Catalogs; NCI, 2014(1)					
Annual Operating Hours (hrs/yr)	DOE, 2012(3)			DOE, 2012(3)			DOE, 2012(3)					
Lamp Price ($)	2012 EIA Reference Case; Calculated			Distributor Websites			Calculated; Distributor Websites; NCI, 2014(1)					
Ballast Price ($)												
Fixture Price ($)				NCI, 2014(2)								
Lamp Cost ($/klm)				Calculated								
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	2016 RSMeans Online			2016 RSMeans Online			2016 RSMeans Online					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	Calculated			Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial LED Reflector Lighting (PAR38)

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)				Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage		Calculated										
System Lumens*												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)		N/A										
CRI		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)		Calculated	Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)**		N/A										
Labor Cost ($/hr)		Same as for Halogen										
Labor System Installation (hr)**												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated										
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft T8 F32 Commodity in 2-Lamp System

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)			N/A	Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)	Calculated											
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated										
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft T8 F32 High-efficiency/High-output in 2-Lamp System

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	N/A	GSFL IRL Final Rule TSD (DOE, 2015)	N/A	N/A	Calculated					
Lamp Lumens							Assume Unchanged					
Lamp Efficacy (lm/W)		Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)		Calculated		Calculated								
Ballast Efficiency (BLE)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			Assume Unchanged					
CRI												
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)							Calculated					
Fixture Price ($)		Calculated		Calculated								
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			Assume Unchanged					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated - See Chapter 8; Section 8.2.2 of GSFL IRL Preliminary Analysis TSD (DOE, 2013)		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)	Calculated											
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated										
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
Labor System Installation (hr)	Assume unchanged											
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage		DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)				Calculated					
Lamp Lumens							Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage		Calculated					Calculated					
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI		DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)				Assume Unchanged					
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)			Retailer Websites	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)	N/A	N/A				N/A	N/A					
Fixture Price ($)*												
Lamp Cost ($/klm)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*		N/A					N/A					
Labor Cost ($/hr)		Calculated	Assume Same as Analgous Conventional Tech				Assume Unchanged					
Labor System Installation (hr)*		N/A										
Labor Lamp Change (hr)		Calculated										
Total Installed Cost ($)		Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems*

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)												
Average Lifetime (1000 hrs)	Calculated						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Website	Calculated	Retailer Website		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case	Calculated									Assume Unchanged	
Labor System Installation (hr)	2008 EIA Reference Case											
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft T8 F59 Typical Efficiency in a 2-Lamp System

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)			N/A	Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)	Calculated											
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated										
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft T8 F59 High Efficiency in a 2-Lamp System

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)			N/A	Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)	Calculated											
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated										
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft T8 F96 High-Output in a 2-Lamp System

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Calculated					
Lamp Lumens							Assume Unchanged from 2015					
Lamp Efficacy (lm/W)		Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)									
System Lumens												
System Efficacy (lm/W)		Calculated										
Ballast Efficiency (BLE)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.				N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)		Calculated										
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)		GSFL IRL Preliminary Analysis TSD (DOE, 2013)	GSFL IRL Final Rule TSD (DOE, 2015)				Assume Unchanged from 2015					
Labor System Installation (hr)												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System*

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<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>High</th><th>Energy Star</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th><th>Typical</th><th>High</th></tr>
<tr><td>Lamp Wattage</td><td rowspan="23" colspan="3">N/A</td><td rowspan="3">LED Lighting Facts Qualified Product List (Downloaded 11/17/15)</td><td rowspan="23" colspan="2">N/A</td><td colspan="6">Calculated</td></tr>
<tr><td>Lamp Lumens</td><td colspan="6">Nominal Lumen output based on 2015 values</td></tr>
<tr><td>Lamp Efficacy (lm/W)</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>System Wattage</td><td rowspan="3">Calculated</td><td rowspan="3" colspan="6">Calculated</td></tr>
<tr><td>System Lumens</td></tr>
<tr><td>System Efficacy (lm/W)</td></tr>
<tr><td>Ballast Efficiency (BLE)</td><td>N/A</td><td rowspan="3" colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>CRI</td><td>Calculated from LED Lighting Facts Qualified Product List Downloaded 11/17/15</td></tr>
<tr><td>Correlated Color Temperature (CCT)</td><td rowspan="2">DOE SSL Program R&D Plan (DOE SSL Program, 2015)</td></tr>
<tr><td>Average Lamp Life (1000 hrs)</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Annual Operating Hours (hrs/yr)</td><td>U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td><td colspan="6">U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.</td></tr>
<tr><td>Lamp Price ($)</td><td>Calculated</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>Ballast Price ($)</td><td rowspan="2">N/A</td><td rowspan="2" colspan="6">N/A</td></tr>
<tr><td>Fixture Price ($)*</td></tr>
<tr><td>Lamp Cost ($/klm)</td><td>Navigant Price Analysis</td><td colspan="6">U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)</td></tr>
<tr><td>System (l/b/f) Cost ($/klm)*</td><td>N/A</td><td colspan="6">N/A</td></tr>
<tr><td>Labor Cost ($/hr)</td><td rowspan="3">Assume Same as Analgous Conventional Tech</td><td rowspan="3" colspan="6">Assume Unchanged from 2015</td></tr>
<tr><td>Labor System Installation (hr)*</td></tr>
<tr><td>Labor Lamp Change (hr)</td></tr>
<tr><td>Total Installed Cost ($)</td><td rowspan="4">Calculated</td><td rowspan="4" colspan="6">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($)</td></tr>
<tr><td>Total Installed Cost ($/klm)</td></tr>
<tr><td>Annual Maintenance Cost ($/klm)</td></tr>
</table>

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage												
Lamp Lumens				Calculated			N/A					
Lamp Efficacy (lm/W)												
System Wattage							Calculated					
System Lumens				Retailer Websites			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)				N/A			N/A					
CRI							Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				Retailer Websites								
Average Lifetime (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)				Calculated			Calculated					
Ballast Price ($)												
Fixture Price ($)				N/A			N/A					
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)				Navigant Price analysis							Calculated	
Labor Cost ($/hr)				Assume Same as Analgous Conventional Tech			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor System Installation (hr)											Assume Unchanged	
Labor Lamp Change (hr)				N/A			N/A					
Total Installed Cost ($)												
Annual Maintenance Cost ($)				Calculated			Calculated					
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Mercury Vapor Low-bay

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DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case						Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage												
System Lumens												
System Efficacy (lm/W)	Calculated	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
Ballast Efficiency (BLE)	2008 EIA Reference Case						Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated		Calculated								
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule			GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A	N/A	Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

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DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A		Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

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DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case		Assume Same as Analgous Conventional Tech								Assume Unchanged	
Labor System Installation (hr)												
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Mercury Vapor High-Bay

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A		Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage												
System Lumens												
System Efficacy (lm/W)	Calculated											
Ballast Efficiency (BLE)	2008 EIA Reference Case						Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case	Calculated		Calculated								
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule			GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Metal Halide High-Bay

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A		Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial Sodium Vapor High-Bay

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)	N/A	HID Final Determination TSD (DOE, 2015)	N/A		Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case	Calculated		Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)								
System Lumens												
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	HID Final Determination TSD (DOE, 2015)		HID Final Determination TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)												
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated						Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule	GSFL Rule		GSFL Rule								
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial T5 4xF54 HO High-bay

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)	N/A	GSFL IRL Final Rule TSD (DOE, 2015)		N/A	Calculated					
Lamp Lumens	Calculated						Assume Unchanged from 2015					
Lamp Efficacy (lm/W)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage		Calculated		Calculated								
System Lumens		GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)								
System Efficacy (lm/W)	Calculated	Calculated		Calculated								
Ballast Efficiency (BLE)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			Assume Unchanged from 2015					
CRI												
Correlated Color Temperature (CCT)	DOE Solid-State Lighting Multi-Year Program Plan, 2013											
Average Lamp Life (1000 hrs)	2008 EIA Reference Case						U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	2008 EIA Reference Case	GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)												
Fixture Price ($)		Calculated		Calculated								
Lamp Cost ($/klm)	2008 EIA Reference Case											
System (l/b/f) Cost ($/klm)												
Labor Cost ($/hr)	Calculated	GSFL IRL Preliminary Analysis TSD (DOE, 2013)		GSFL IRL Final Rule TSD (DOE, 2015)			Assume Unchanged from 2015					
Labor System Installation (hr)	GSFL Rule											
Labor Lamp Change (hr)												
Total Installed Cost ($)	2008 EIA Reference Case	Calculated		Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated											
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial LED High-bay Luminaire *

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites							
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case	Assume Same as Analgous Conventional Tech									Assume Unchanged	
Labor System Installation (hr)	Assume Same as Analgous Conventional Tech											
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Refrigeration

Data Sources » Commercial Compressor Rack Systems

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	Copeland, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	ADL, 1996 / NCI Analysis, 2015	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Normalized Annual Efficiency	Calculated											
Average Life (yrs)	Kysor-Warren, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI, 2009 / NCI Analysis, 2012	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost ($1000)	ADL, 1996 / NCI Analysis, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	NCI Analysis, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ADL, 1996 / NCI Analysis, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007	Interviews with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	EIA, 2012										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Supermarket Display Cases

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2007 / NCI Analysis, 2008	Navigant Analysis, 2015										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis										
Case Length	DOE, 2014: CRE TSD											
Energy Use (kWh/yr)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Energy Use (kWh/ft)	Calculated											
Normalized Annual Efficiency	Calculated											
Average Life (yrs)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE TSD										
Retail Equipment Cost	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Total Installed Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cst ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Reach-In Refrigerators

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Engineering Spreadsheet										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Energy Use ($kWh/yr/ft^3$)	NCI Analysis, 2012	Calculated										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Reach-In Freezers

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use (kWh/yr/ft^3)	NCI Analysis, 2012	Calculated										
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	Fricke, et al, 2012, Navigant Analysis, 2015											
Size (ft^2)	Navigant Analysis, 2015											
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use ($kWh/ft^2/yr$)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / FMI, 2005 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Walk-In Freezers

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical		High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	Fricke, et al, 2012, Navigant Analysis, 2015										
Size (ft^2)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^2/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: WICF TSD / Navigant Analysis, 2014											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Output (lbs/day)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Water Use (gal/100 lbs)	ADL, 1996 / Distributor Web Sites	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/100 lbs)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/yr)	ACEEE, 2002 / NCI Analysis, 2012	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Total Installed Cost (with Bin)	NCI Analysis, 2008	DOE, 2014: ACIM TSD / Distributor Websites / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2014: CRE TSD											
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use ($kWh/ft^3/yr$)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2015: CRE TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	DOE, 2014: CRE TSD, Navigant Analysis											
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: CRE TSD, Navigant Analysis, 2015											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Refrigerated Vending Machines

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2008 / NCI Analysis, 2008	DOE, 2015: BVM TSD / Navigant Analysis, 2015										
Can Capacity	CEC, 2005 / NREL, 2003 / FEMP, 2004	DOE, 2015: BVM TSD										
Size (ft^3)	DOE, 2015: BVM TSD / Navigant Analysis, 2015											
Energy Use (kWh/yr)	ADL, 1996 / CEC, 2008 / NREL, 2003	DOE, 2015: BVM TSD										
Energy Use (kWh/ft^3/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	DOE, 2008	DOE, 2015: BVM TSD										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM TSD										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM TSD										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2008	DOE, 2015: BVM TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Commercial Ventilation

Data Sources » Commercial Constant Air Volume Ventilation

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	CBECS 2003 & BED 2007											
System Fan Power (kW)	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Data Sources » Commercial Variable Air Volume Ventilation

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	CBECS 2003 & BED 2007											
System Fan Power (kW)	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Data Sources » Commercial Fan Coil Unit

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	Product Literature											
System Fan Power (kW)	Product Literature	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Appendix B
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And

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APPENDIX D

Final

EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case

Presented to:

U.S. Energy Information Administration

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DISCLAIMER

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Final

The objective of this study is to develop baseline and projected performance/cost characteristics for residential and commercial end-use equipment in an "Advanced Case" that assumes accelerated adoption of energy-saving technologies due to increased R&D funding and market incentives.

- 2003/2012 (commercial) and 2009 (residential) baselines, as well as today's (2015)
  - Review of literature, standards, installed base, contractor, and manufacturer information.
  - Provide a relative comparison and characterization of the cost/efficiency of a generic product.
- Forecast of technology improvements that are projected to be available through 2040
  - Review of trends in standards, product enhancements, and Research and Development (R&D).
  - Projected impact of product improvements and enhancement to technology.

The performance/cost characterization of end-use equipment developed in this study will assist EIA in projecting national primary energy consumption.

Input from industry, including government, R&D organizations, and manufacturers, was used to project product enhancements concerning equipment performance and cost attributes.

- Technology forecasting involves many uncertainties.
- Technology developments impact performance and cost forecasts.
- Varied sources ensure a balanced view of technology progress and the probable timing of commercial availability.

- The following tables represent the current and projected efficiencies for residential and commercial building equipment ranging from the installed base in 2003 and 2012 (for commercial products) and 2009 (for residential) to the highest efficiency equipment that is expected to be commercially available by 2040, assuming incremental adoption. Below are definitions for the terms used in characterizing the status of each technology.
  - Installed Base: the installed and “in use” equipment for that year. Represents the installed stock of equipment, but does NOT represent sales.
  - Current Standard: the minimum efficiency (or maximum energy use) required (allowed) by current DOE standards, when applicable.
  - ENERGY STAR: the minimum efficiency required (or maximum energy use allowed) to meet the ENERGY STAR criteria, when applicable. Presented performance data represents certified products just meeting current ENERGY STAR specifications.
  - Low: The minimum available efficiency product or product mix available on the market. This typically reflects minimal compliance with DOE standards.
  - Typical: the average, or “typical,” product being sold in the particular timeframe.
  - High: the product with the highest efficiency available in the particular timeframe.
  - Lumens: All reported lumens are initial lumens.
  - Correlated Color Temperature (CCT): a specification of the color appearance of the light emitted by a lamp.
  - Color Rendering Index (CRI): a scale from 0 to 100 percent indicating how accurate a "given" light source is at rendering color when compared to a "reference" light source. The higher the CRI, the better the color rendering ability.

- The following metrics are commonly referred to throughout the tables to follow. Below are the calculations for each metric
  - **Lighting**
    - **System Wattage** = (Lamp Wattage * Ballast Factor) / Ballast Efficiency
    - **System Lumens** = Lamp Lumens * Ballast Factor
    - **Lamp Efficacy** = Lamp Lumens / Lamp Wattage
    - **System Efficacy** = System Lumens / System Wattage
    - **Lamp Cost ($/klm)** = Lamp Cost / (Lamp Lumens / 1000)
    - **Total Equipment Cost** = Lamp Cost + Fixture (including ballast) Cost
    - **System Cost ($/klm)** = Total Equipment Cost / (System Lumens / 1000)
    - **Total Installed Cost** = Total Equipment Cost + Labor Installation Cost
    - **BLE** = A/(1+B*Avg Total Lamp Arc Power^(-C))
  - **Commercial Refrigeration**
    - **Nominal Capacity over Average Input (Btu in / Btu out)** = (Cooling or Heat Rejection Capacity)*24*365/(Annual Energy Consumption * 3412)
    - **Total Installed Cost** = Retail Equipment Cost + Labor Installation Cost
    - **Total Installed Cost ($/kBtu/hr)** = Total Installed Cost*1000 / (Cooling or Heat Rejection Capacity)
    - **Annual Maintenance Cost ($/kBtu/hr)** = Annual Maintenance Cost * 1000 / (Cooling or Heat Rejection Capacity)
  - **Ventilation**
    - **CFM out / Btu in / hr** = System Airflow / (System Fan Power * 3412)
    - **Total Installed Cost ($/1000 CFM)** = Total Installed Cost * 1000 / System Airflow
    - **Annual Maintenance Cost ($/1000 CFM)** = Annual Maintenance Cost * 1000 / System Fan Power

The market for the reviewed products has changed since the analysis was performed in 2012. These changes are noted and reflected in the efficiency and cost characteristics.

- DOE issued Federal minimum efficiency standards that have or will soon go into effect for General Service Fluorescent Lamps (effective 2012), Incandescent Reflector Lamps (July 2012), Fluorescent Lamp Ballasts (2014), Refrigerated Beverage Vending Machines (2012), Automatic Commercial Ice Makers (2018), Walk-In Coolers and Freezers (2017) and Commercial Refrigeration Equipment (2017). DOE published a Final Rule updating energy conservation standards for Refrigerated Beverage Vending Machines at the end of 2015, effective in 2018.

Residential Lighting

Note: More aggressive R&D investment and effort in the lighting industry will only change future projections of LED technologies as it is unlikely that additional funding/effort will be applied to traditional technologies that have been exceeded in performance by their LED counterparts. Therefore, the inputs for all non-LED technologies remain unchanged from the Reference Case and are therefore not included in this report.

The residential general service lamps characterized in this report are a 60 watt and a 75 watt medium screw based A-type incandescent lamp and their halogen, CFL, and LED equivalents. A standard 60 watt incandescent lamp produces approximately 800 lumens. A standard 75 watt incandescent lamp produces approximately 1100 lumens (ENERGY STAR Program).

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 652 hours/year for residential general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 60 watt general service lamps effective in 2014 and 75 watt lamps effective in 2013. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. California’s Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent, halogen, and CFL technologies.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts ENERGY STAR performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- Beginning in 2017, California’s Title 24 will require all light sources to be high efficacy. All general service lamps with medium screw bases must meet the following requirements: initial efficacy ≥45 lm/W, power factor ≥0.90, CCT ≤3000K, CRI ≥90, rated life ≥15,000 hours.
- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Residential General Service LED Lamps (60 Watt Equivalent)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	7	4	5	4	4	4
Lamp Lumens	800	850	837	865	800	840	840	840	840	840	840
Lamp Efficacy (lm/W)	44	64	93	104	59	123	197	171	230	219	230
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	652	652	652	652	652	652	652	652	652	652	652
Lamp Price ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$4.07	$4.07	$1.33	$1.33	$1.00	$1.00
Lamp Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$7.53	$4.99	$11.98	$4.07	$4.07	$1.33	$1.33	$1.00	$1.00
Annual Maintenance Cost ($)	$2.22	$0.63	$0.20	$0.13	$0.31	$0.05	$0.05	$0.02	$0.02	$0.01	$0.01
Total Installed Cost ($/klm)	$85.00	$28.22	$9.00	$5.77	$14.98	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Annual Maintenance Cost ($/klm)	$2.77	$0.74	$0.23	$0.15	$0.39	$0.06	$0.06	$0.02	$0.02	$0.02	$0.02

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

The residential reflector lamps characterized in this report are directional lamps that emit between approximately 550-750 lumens. Multiple baseline reflector lamps were analyzed, including: 65W Incandescent BR30, Halogen PAR30, Halogen Infrared Reflector (HIR) PAR30, CFL BR30, LED BR30, LED PAR38.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 642 hours/year for residential reflector lamps(DOE SSL Program, 2012a).

Legislation:

- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA 2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008. The 65W BR30, a large majority of the incandescent reflector lamp market is still exempted. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for omnidirectional lamps with CRI ≥ 90 and 70 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Residential Reflector LED BR30

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	18	11	10	8	12	6	4	5	3	4	3
Lamp Lumens	600	670	794	699	605	700	700	700	700	700	700
Lamp Efficacy (lm/W)	33	59	78	89	50	109	197	153	230	196	230
CRI	80	95	84	82	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	5000	2700	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$3.39	$3.39	$1.11	$1.11	$1.00	$1.00
Lamp Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$4.84	$4.84	$1.58	$1.58	$1.43	$1.43
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$98.40	$12.99	$16.67	$20.97	$74.57	$3.39	$3.39	$1.11	$1.11	$1.00	$1.00
Annual Maintenance Cost ($)	$3.16	$0.33	$0.38	$0.54	$1.91	$0.04	$0.04	$0.01	$0.01	$0.01	$0.01
Total Installed Cost ($/klm)	$164.00	$19.39	$21.00	$30.01	$123.26	$4.84	$4.84	$1.58	$1.58	$1.43	$1.43
Annual Maintenance Cost ($/klm)	$5.26	$0.50	$0.48	$0.77	$3.16	$0.06	$0.06	$0.02	$0.02	$0.02	$0.02

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential Reflector LED PAR38

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	Best	Typical	Best	Typical	Best
Lamp Wattage	28	18	16	17	20	13	7	9	6	7	6
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	109	197	153	230	196	230
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	642	642	642	642	642	642	642	642	642	642	642
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Installation (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Annual Maintenance Cost ($)	$5.26	$0.66	$0.64	$0.94	$0.88	$0.09	$0.09	$0.03	$0.03	$0.02	$0.02
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Annual Maintenance Cost ($/klm)	$5.26	$0.56	$0.48	$0.48	$0.84	$0.06	$0.06	$0.02	$0.02	$0.02	$0.02

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. The LED luminaire is more efficient and cost effective for new installations or fixture retrofits.
- Labor costs for lamp changes are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore annual maintenance costs are the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 684 hours/year for residential linear systems(DOE SSL Program, 2012a).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- Beginning November 14, 2014, DOE standards will require that the characterized residential ballasts have a minimum BLE = 0.993 / (1 + 0.41 * Avg Total Lamp Arc power ^ (- 0.25)). Residential ballasts also must have a minimum power factor of 0.5.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR residential fixtures require ≥ 65 lm/W per lamp-ballast platform before September 1, 2013 and ≥ 70 lm/W per lamp-ballast platform thereafter (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T12	0%	0%	-0.5%	Limited as the technology is mature.
T8	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Residential Linear LED Replacement Lamp 2 Lamp System

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	19	18	18	N/A	14	12	11	10	9	9
Lamp Lumens	1355	1743	2151	2309	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	75	92	116	132	N/A	151	173	199	203	230	230
System Wattage	36	38	37	35	N/A	28	24	21	21	18	18
System Lumens	2304	3103	3829	4110	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	64	82	104	117	N/A	142	162	191	194	221	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	70	80	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	4000	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lamp Life (1000 hrs)	35	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$135.83	$22.19	$34.42	$38.30	N/A	$15.21	$15.21	$4.97	$4.97	$2.10	$2.10
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[3]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	$100.25	$12.73	$16.00	$16.59	N/A	$7.24	$7.24	$2.36	$2.36	$1.00	$1.00
System (l/b/f) Cost ($/klm)[3]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor System Installation (hr)[3]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	0	0	0	0	N/A	0	0	0	0	0	0
Total Installed Cost ($)	$271.67	$44.38	$68.84	$76.60	N/A	$30.43	$30.43	$9.93	$9.93	$4.20	$4.20
Annual Maintenance Cost ($)	$5.31	$0.61	$1.05	$1.05	N/A	$0.42	$0.42	$0.14	$0.14	$0.06	$0.06
Total Installed Cost ($/klm)	$200.49	$25.46	$32.00	$33.17	N/A	$14.49	$14.49	$4.73	$4.73	$2.00	$2.00
Annual Maintenance Cost ($/klm)	$3.92	$0.35	$0.49	$0.45	N/A	$0.20	$0.20	$0.06	$0.06	$0.03	$0.03

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.
4. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.

Performance/Cost Characteristics » Residential Linear LED Luminaire

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low[1]	Typical[2]	Best[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	46	48	57	40	55	30	25	22	22	22	22
System Lumens	3395	4044	5697	4918	4000	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	67	84	100	122	73	164	197	230	230	230	230
Ballast Efficiency (BLE) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	87	83	83	83	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
Average Lamp Life (1000 hrs)	50	60	56	50	36	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	684	684	684	684	684	684	684	684	684	684	684
Lamp Price ($)	$731.04	$439.00	$176.61	$513.45	$139.00	$93.02	$93.02	$45.29	$45.29	$22.06	$22.06
Ballast Price ($) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)[5]	$215.34	$108.56	$31.00	$104.41	$34.75	$18.60	$18.60	$9.06	$9.06	$4.41	$4.41
Labor Cost ($/hr)	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Lamp Change (hr) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$765.14	$473.10	$210.71	$547.55	$173.10	$127.12	$127.12	$79.39	$79.39	$56.16	$56.16
Annual Maintenance Cost ($)	$10.46	$5.39	$2.57	$7.49	$3.29	$0.90	$0.90	$0.54	$0.54	$0.38	$0.38
Total Installed Cost ($/klm)	$225.38	$116.99	$36.99	$111.35	$43.28	$25.42	$25.42	$15.88	$15.88	$11.23	$11.23
Annual Maintenance Cost ($/klm)	$3.08	$1.33	$0.45	$1.52	$0.82	$0.18	$0.18	$0.11	$0.11	$0.08	$0.08

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

- The residential outdoor lamps characterized in this report include reflector and general service lamps used for security and/or porch lighting that can be switched on from inside the home (i.e. parking lot/garage and outdoor common area lighting at multifamily buildings are excluded) with lumen outputs of approximately 1000 lumens. Multiple baseline lamps were analyzed according to estimates of installed base average lumens by lamp type, including:

Security (Reflector Lamps)	Porch (General Service Lamps)
Incandescent BR30	Incandescent A-Type
Halogen PAR38	Halogen A-Type
Halogen Infrared Reflector (HIR) PAR38	CFL Bare Spiral
CFL PAR38	LED A-Type Lamp
LED PAR38	

- In 2010, it was estimated that over 96% of residential outdoor lamps were incandescent, halogen, or CFL technologies. Approximately, 51% of residential outdoor lamps were general service and 24% were reflector lamps. The remaining share was made up of primarily decorative and miscellaneous lamp types (DOE, 2012(3)).

Performance:

- 65W BR30 is the only viable incandescent reflector lamp due to exemption from EISA 2007. The lumen output of this lamp type is well below other reflector lamp technologies characterized for residential outdoor spaces, thus its use is limited for this application.
- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Fixture prices and installation costs are not included for the residential sector. Labor costs are assumed to be negligible as the homeowner likely replaces lamps themselves as they burn out. Therefore total installed cost is the price of a lamp, and annual maintenance costs are the cost of replacing the lamps, which is a function of lamp life, lamp price, and the annual operating hours of 1059 hours/year for residential reflector lamps (DOE SSL Program, 2012b).

Performance/Cost Characteristics » Residential Outdoor Lamps

Legislation:

- For ENERGY STAR qualification, general service, omnidirectional lamps must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014).
- Additionally, the lamps must have a CRI ≥ 80 Energy Star, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent Omnidirectional	0%	+0.5%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Incandescent	+0.2%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	In addition to benefiting from higher efficiency reflector coatings, improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Residential Outdoor Lamps (Security: LED Reflector)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	28	18	16	17	20	13	7	9	6	7	6
Lamp Lumens	1000	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	36	64	83	116	53	109	197	153	230	196	230
CRI	80	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	20	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Lamp Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$164.00	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.67	$1.67
Annual Maintenance Cost ($)	$8.68	$1.09	$1.05	$1.55	$1.46	$0.15	$0.15	$0.05	$0.05	$0.04	$0.04
Total Installed Cost ($/klm)	$164.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.19	$1.19
Annual Maintenance Cost ($/klm)	$8.68	$0.93	$0.79	$0.79	$1.39	$0.10	$0.10	$0.03	$0.03	$0.03	$0.03

Data based on an indoor 100W Equivalent LED A-type lamp, scaled to lumen output reported for the building exterior low-output technologies in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)

Performance/Cost Characteristics » Residential Outdoor Lamps (Porch: LED A-Type)

DATA	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	18	13	9	8	14	8	5	6	4	4	4
Lamp Lumens	964	964	964	964	964	964	964	964	964	964	964
Lamp Efficacy (lm/W)	44	64	93	104	71	123	197	171	230	219	230
CRI	80	83	84	81	92	84	84	84	84	84	84
Correlated Color Temperature (CCT)	3000	2700	2700	2700	2700	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	20	25	25	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059	1059
Lamp Price ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$5.02	$5.02	$1.64	$1.64	$1.04	$1.04
Lamp Cost ($/klm)	$85.00	$24.90	$9.00	$5.18	$12.43	$4.84	$4.84	$1.58	$1.58	$1.00	$1.00
Labor Cost ($/hr)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Labor Lamp Change (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Installed Cost ($)	$68.00	$24.00	$8.68	$4.99	$11.98	$5.02	$5.02	$1.64	$1.64	$1.04	$1.04
Annual Maintenance Cost ($)	$3.60	$1.02	$0.37	$0.21	$0.51	$0.11	$0.11	$0.03	$0.03	$0.02	$0.02
Total Installed Cost ($/klm)	$70.54	$24.90	$9.00	$5.18	$12.43	$5.21	$5.21	$1.70	$1.70	$1.08	$1.08
Annual Maintenance Cost ($/klm)	$3.73	$1.05	$0.38	$0.22	$0.53	$0.11	$0.11	$0.04	$0.04	$0.02	$0.02

Data based on an indoor 100W Equivalent LED A-type lamp, scaled to lumen output reported for the building exterior low-output technologies in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)

Commercial Lighting

Note: More aggressive R&D investment and effort in the lighting industry will only change future projections of LED technologies as it is unlikely that additional funding/effort will be applied to traditional technologies that have been exceeded in performance by their LED counterparts. Therefore, the inputs for all non-LED technologies remain unchanged from the Reference Case and are therefore not included in this report.

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Performance/Cost Characteristics » Commercial General Service Lamps in Recessed Can Fixtures

This section characterizes commercial omnidirectional incandescent, halogen, CFL, and LED screw based general service lamps emitting approximately 1600 lumens (equivalent to a 100W incandescent lamp) used in recessed can fixtures. A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, an omnidirectional lamp is not well suited for use in such fixtures, as light that emits upwards and out of the sides must be reflected downwards and out of the fixture and some light is absorbed in the process. A fixture efficiency of 61% is used to characterize these lumen losses for all omnidirectional lamps. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3868 hours/year for commercial general service lamps (DOE SSL Program, 2012a).

Legislation:

- The Energy Independence and Security Act of 2007 (EISA 2007) established standards for 100W lamps effective in 2012. These standards cannot be achieved by incandescent bulbs, but can by halogen, CFL, and LED technologies. As a result, 2015 data is not provided for incandescent general service lamps.
- EISA 2007 also established a requirement that DOE establish standards for general service lamps that are equal to or greater than 45 lm/W by 2020. California's Appliance Efficiency Regulations will require 45 lm/W for general service lamps with certain bases beginning in 2018. These standards can not be achieved by traditional incandescent or halogen technologies currently on the market and given current and projected trends in industry it is not likely they will be met. It is currently assumed that industry will increase their investment in LED technology at the expense of incandescent, halogen, and CFL technologies.
- EPACT 2005 sets performance for medium based compact fluorescent lamps. It adopts ENERGY STAR performance requirements (August 6, 2001 version) for efficacy, lumen maintenance, lamp life, rapid cycle stress test, CRI, etc. The standard is effective for lamps manufactured on or after January 1, 2006. Note that EPACT 2005 standards do not apply to CFL lamps with screw bases other than medium (e.g., pin based). The Secretary may revise these requirements by rule or establish other requirements at a later date. An updated DOE standard is expected in 2017 with a potential effective date of 2020.
- For ENERGY STAR qualification, general service, omnidirectional lamps, must have a minimum lamp efficacy of 55 lm/W and 65 lm/W for lamps with rated wattage of <15W and ≥ 15 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 70 lm/W for omnidirectional lamps with CRI ≥ 90 and 80 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Incandescent	0%	0%	-0.5%	Limited as the technology is mature and the technology cannot meet legislative requirements.
Halogen	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
CFL	+0.5%	+0.5%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	27	17	15	16	23	11	10	8	7	7	7
Lamp Lumens	N/A	1600	1580	1646	1710	1600	1600	1600	1600	1600	1600	1600
Lamp Efficacy (lm/W)	N/A	60	92	108	110	71	150	161	209	220	230	230
System Wattage	N/A	27	17	15	16	23	11	10	8	7	7	7
System Lumens	N/A	976	964	1004	1043	976	976	976	976	976	976	976
System Efficacy (lm/W)	N/A	36.6	56.4	66.2	67.3	43.4	91.6	98.1	127.4	133.9	140.3	140.3
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	80	84	83	81	82	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	3000	3000	2700	2700	3000	2700	2700	2700	2700	2700	2700
Average Lamp Life (1000 hrs)	N/A	22	25	25	25	25	48	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868	3868
Lamp Price ($)	N/A	$40.00	$14.71	$15.30	$15.99	$22.99	$7.74	$7.74	$2.53	$2.53	$1.60	$1.60
Ballast Price ($) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$25.00	$9.31	$9.30	$9.35	$14.37	$4.84	$4.84	$1.58	$1.58	$1.00	$1.00
System (l/b/f) Cost ($/klm) [5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Labor Lamp Change (hr)	N/A	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total Installed Cost ($)	N/A	$117.05	$96.66	$97.25	$97.94	$104.94	$89.69	$89.69	$84.48	$84.48	$83.55	$83.55
Annual Maintenance Cost ($)	N/A	$7.71	$2.91	$3.00	$3.11	$4.19	$0.95	$0.93	$0.51	$0.51	$0.44	$0.44
Total Installed Cost ($/klm)	N/A	$73.16	$61.18	$59.10	$57.27	$65.59	$56.06	$56.06	$52.80	$52.80	$52.22	$52.22
Annual Maintenance Cost ($/klm)	N/A	$4.82	$1.84	$1.82	$1.82	$2.62	$0.60	$0.58	$0.32	$0.32	$0.28	$0.28

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For installations where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

This section characterizes commercial halogen, HIR, and LED screw based reflector lamps emitting approximately 1400 lumens used in recessed can fixtures.

- Halogen infrared reflector (HIR) lamps contain a tungsten halogen capsule with a film coating on the inside of the capsule. The coating reflects infrared radiation back into the lamp filament, which forces the filament to burn at a higher temperature. This increases the efficacy of the lamp, without reducing operating life.
- A recessed can is a directional fixture set into the ceiling, in which all of the light is directed downwards from the opening. Therefore, a reflector lamp, which employs reflective coating to direct light out in only one direction, is well suited for use in such fixtures. However, some light is not able to escape the fixture, and a fixture efficiency of 93% is used to characterize these minimal lumen losses. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 3860 hours/year for commercial reflector lamps (DOE SSL Program, 2012a).

Legislation:

- EPACT92 established minimum performance standards for some reflector lamps and provided exemptions for certain specialty applications (e.g., ER/BR, vibration service, more than 5% neodymium oxide, impact resistant, infrared heat, colored). EPACT92 effectively phased-out R-shaped tungsten filament incandescent reflector lamps at certain wattages and bulb diameters, replacing them with more efficient and cost effective tungsten-halogen parabolic aluminized reflector (PAR) lamps. EISA2007 took away certain exemptions from EPACT 1992, requiring certain previously exempted lamps to meet EPACT92 minimum performance standards by January 1, 2008. In 2015, DOE issued a final rule which determined that amending the standards for incandescent reflector lamps could not be economically justified.
- For ENERGY STAR qualification, directional, reflector lamps must have a minimum lamp efficacy of 40 lm/W and 50 lm/W for lamps with rated wattage of <20W and ≥ 20 W, respectively. Additionally, the lamps must have a CRI ≥ 80, nominal CCT of 2700, 3000, 3500, 4000/4100, 5000, or 6000 K, and rated lifetime ≥ 10,000 hours (ENERGY STAR, 2014). The ENERGY STAR Lamps Version 2.0 specification, currently under revision and will take effect January 2, 2017, will require 61 lm/W for omnidirectional lamps with CRI ≥ 90 and 70 lm/W for omnidirectional lamps with CRI < 90 (ENERGY STAR).
- The ENERGY STAR Luminaires v1.2 specification took effect on December 21, 2012 and requires 42 lm/W for recessed downlights (ENERGY STAR, 2012). The ENERGY STAR Luminaires v2.0 specification will supersede v1.2 effective June 1, 2016 and will require 55 lm/W for recessed downlights (ENERGY STAR).

Performance/Cost Characteristics » Commercial Reflector Lamps in Recessed Can Fixtures

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

	Efficacy	Lifetime	Price	Potential for Improvements
Halogen	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
HIR	+0.5%	+0.5%	-0.5%	Improvements can be made by improved filament design and placement, higher pressure capsules, or higher efficiency reflector coatings.
CFL	+0.5%	+0.5%	-0.5%	Improvements in efficacy can be made by using more rare-earth phosphors in compact fluorescent lamps. Lifetime improvements can be made by improving the compact fluorescent lamp electrodes.

Performance/Cost Characteristics » Commercial LED Reflector Lighting (PAR38)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star[4]	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	17	18	16	17	20	12	11	9	8	7	6
Lamp Lumens	N/A	1045	1172	1328	1958	1050	1400	1400	1400	1400	1400	1400
Lamp Efficacy (lm/W)	N/A	61	64	83	116	53	116	124	162	170	209	216
System Wattage	N/A	17	18	16	17	20	12	11	9	8	7	6
System Lumens*	N/A	972	1090	1235	1821	977	1302	1302	1302	1302	1302	1302
System Efficacy (lm/W)	N/A	57	59	78	108	49	108	115	151	158	194	201
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	83	91	84	81	93	84	84	84	84	84	84
Correlated Color Temperature (CCT)	N/A	3000	2700	3000	4000	3000	3000	3000	3000	3000	3000	3000
Average Lamp Life (1000 hrs)	N/A	22	25	28	25	25	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860	3860
Lamp Price ($)	N/A	$52.25	$25.68	$27.89	$36.59	$34.47	$6.78	$6.78	$2.21	$2.21	$1.40	$1.40
Ballast Price ($)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$50.00	$21.92	$21.00	$18.69	$32.83	$4.84	$4.84	$1.58	$1.58	$1.00	$1.00
System (l/b/f) Cost ($/klm)[5]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$77.05	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95	$81.95
Labor System Installation (hr)[5]	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Labor Lamp Change (hr)	N/A	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total Installed Cost ($)	N/A	$56.99	$30.72	$32.93	$41.63	$39.51	$11.82	$11.82	$7.25	$7.25	$6.44	$6.44
Annual Maintenance Cost ($)	N/A	$10.00	$4.74	$4.54	$6.43	$6.10	$0.93	$0.93	$0.56	$0.56	$0.50	$0.50
Total Installed Cost ($/klm)	N/A	$54.53	$26.22	$24.79	$21.26	$37.63	$8.44	$8.44	$5.18	$5.18	$4.60	$4.60
Annual Maintenance Cost ($/klm)	N/A	$9.57	$4.05	$3.42	$3.28	$5.81	$0.66	$0.66	$0.40	$0.40	$0.36	$0.36

1. Based on lowest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. Represents the lowest efficacy product in the Energy Star Database (as downloaded on 11/4/15) for which all of the information in the table is available.
5. N/A b/c this is an LED Replacement lamp that is for existing fixtures. For installations where a fixture must be purchased, an integrated LED Luminaire would be more efficient and cost effective.

This section characterizes commercial linear fixtures that house 2 4ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4055 hours/year for commercial 4ft linear systems (DOE SSL Program, 2012a).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F32 Commodity	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F32 High Efficiency/High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T5 F28	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	21	19	18	18	N/A	14	12	11	10	9	9
Lamp Lumens	N/A	2091	1743	2151	2303	N/A	2100	2100	2100	2100	2100	2100
Lamp Efficacy (lm/W)	N/A	101	92	116	132	N/A	151	173	199	221	230	230
System Wattage	N/A	42	38	37	35	N/A	28	24	21	19	18	18
System Lumens	N/A	3555	3102	3829	4099	N/A	3948	3948	4032	4032	4032	4032
System Efficacy (lm/W)	N/A	85	82	104	117	N/A	142	162	191	212	221	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	86	80	83	85	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	N/A	4100	4000	4100	5000	N/A	4100	4100	4100	4100	4100	4100
Average Lifetime (1000 hrs)	N/A	50	50	45	50	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp/Luminaire Price ($)	N/A	$234.66	$22.19	$34.42	$38.30	N/A	$15.21	$15.21	$4.97	$4.97	$2.10	$2.10
Ballast Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	$112.20	$12.73	$16.00	$16.63	N/A	$7.24	$7.24	$2.36	$2.36	$1.00	$1.00
System (l/b/f) Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	0.40	0.40	0.40	0.40	N/A	0.40	0.40	0.40	0.40	0.40	0.40
Total Installed Cost ($)	N/A	$495.15	$71.43	$95.90	$103.65	N/A	$42.27	$42.27	$32.02	$32.02	$29.15	$29.15
Annual Maintenance Cost ($)	N/A	$40.16	$5.79	$8.64	$8.41	N/A	$3.50	$3.50	$2.60	$2.60	$2.36	$2.36
Total Installed Cost ($/klm)	N/A	$236.76	$40.98	$44.57	$45.01	N/A	$20.13	$20.13	$15.25	$15.25	$13.88	$13.88
Annual Maintenance Cost ($/klm)	N/A	$19.20	$3.32	$4.02	$3.65	N/A	$1.67	$1.67	$1.24	$1.24	$1.13	$1.13

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

DATA	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low[1]	2015 Typical[2]	2015 High[3]	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36.4	51	48	57	40	N/A	30	25	22	22	22	22
System Lumens	548	4818	4044	5697	4918	N/A	5000	5000	5000	5000	5000	5000
System Efficacy (lm/W)	15	94	84	100	122	N/A	164	197	230	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	84	83	83	83	N/A	83	83	83	83	83	83
Correlated Color Temperature (CCT)	3500	3500	3500	3500	3500	N/A	3500	3500	3500	3500	3500	3500
Average Lifetime (1000 hrs)	50	67	60	56	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4055	4055	4055	4055	4055	N/A	4055	4055	4055	4055	4055	4055
Lamp/Luminaire Price ($)	$215.19	$610.32	$439.00	$176.61	$513.45	N/A	$93.02	$93.02	$45.29	$45.29	$22.06	$22.06
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$108.56	$31.00	$104.41	N/A	$18.60	$18.60	$9.06	$9.06	$4.41	$4.41
Labor Cost ($/hr)	$110.50	$65.10	$68.20	$68.20	$68.20	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	0.5	0.50	0.50	0.50	0.50	N/A	0.50	0.50	0.50	0.50	0.50	0.50
Labor Lamp Change (hr)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$642.87	$473.10	$210.71	$547.55	N/A	$127.12	$127.12	$79.39	$79.39	$56.16	$56.16
Annual Maintenance Cost ($)	$0.07	$38.91	$31.98	$15.26	$44.41	N/A	$5.31	$5.31	$3.22	$3.22	$2.28	$2.28
Total Installed Cost ($/klm)	$493.50	$133.43	$116.99	$36.99	$111.35	N/A	$25.42	$25.42	$15.88	$15.88	$11.23	$11.23
Annual Maintenance Cost ($/klm)	$0.13	$8.08	$7.91	$2.68	$9.03	N/A	$1.06	$1.06	$0.64	$0.64	$0.46	$0.46

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components

Performance/Cost Characteristics » Commercial 8-foot Linear 2-Lamp Lighting Systems

This section characterizes commercial linear fixtures that house 2 8ft long linear lamps and their integrated luminaire equivalents. The technologies available for this system are linear fluorescent and LED.

- Linear fluorescent options are T5, T8, and T12 lamps. T5 lamps are approximately 40% narrower than T8 lamps and almost 60% narrower than T12 lamps. This allows T5 lamps to be coated with higher quality, more efficient phosphor blends than larger diameter lamps, resulting in a more efficacious lamp. The compact size of T5 lamps also permits greater flexibility in lighting design and construction.
- LED options for linear fixtures include replacement lamps that are able to fit directly into an existing fixture and fully integrated luminaire that can be used to replace existing fixtures. LED replacement lamps, also known as T lamps or TLEDs, do not require a ballast but can be installed in existing ballasted configurations with or without the removal of the linear fluorescent ballast. Replacement lamps are only sold to go into existing fixtures, if a new fixture is to be installed, a fully integrated LED luminaire is a more cost effective and efficient option. Because LED luminaires are fully integrated, they do not have lamp/fixture efficiency losses associated with ballasts and fixture optics. For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of 2 lamps, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED replacement lamps which are sold only as a replacement for use in an existing fixture. There are integrated LED luminaires that are more efficient and cost effective for new installations or fixture retrofits. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4147 hours/year for commercial 8ft linear systems (DOE SSL Program, 2012a).

Legislation:

- Beginning July 14, 2012 (or July 14, 2014 for T8 700-series phosphor lamps), DOE fluorescent lamp standards will require a minimum efficacy of 89 lm/W. While the amended performance-based standards do not explicitly prohibit T12 lamps, no T12 lamps met the standard at the time of its announcement. Since then, however, T12 lamps meeting the standard have entered the market.
- California's Title 24 mandates the use of electronic ballasts with high efficacy luminaires (including fluorescent) of 13 W or higher (CEC, 2005).
- ENERGY STAR does not cover commercial linear luminaires (ENERGY STAR, 2012).

Performance/Cost Characteristics » Commercial 8-foot Linear 2-Lamp Lighting Systems

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
T8 F59 Typical Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F59 High Efficiency	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
T8 F96 High Output	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Final

Performance/Cost Characteristics » Commercial 8-ft Linear LED Replacement Lamp for a 2 Lamp System

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical[1]	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	36	N/A	N/A	39	34	30	27	25	25
Lamp Lumens	N/A	N/A	N/A	3975	N/A	N/A	5650	5650	5650	5650	5650	5650
Lamp Efficacy (lm/W)	N/A	N/A	N/A	111	N/A	N/A	144	165	190	211	230	230
System Wattage	N/A	N/A	N/A	71	N/A	N/A	79	69	59	54	49	49
System Lumens	N/A	N/A	N/A	7076	N/A	N/A	10622	10622	10848	10848	10848	10848
System Efficacy (lm/W)	N/A	N/A	N/A	99	N/A	N/A	135	155	182	203	221	221
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	80	N/A	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	N/A	N/A	N/A	5000	N/A	N/A	5000	5000	5000	5000	5000	5000
Average Lifetime (1000 hrs)	N/A	N/A	N/A	50	N/A	N/A	49	49	50	50	50	50
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp/Luminaire Price ($)	N/A	N/A	N/A	$75.53	N/A	N/A	$48.60	$48.60	$15.87	$15.87	$5.65	$5.65
Ballast Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)	N/A	N/A	N/A	$19.00	N/A	N/A	$8.60	$8.60	$2.81	$2.81	$1.00	$1.00
System (l/b/f) Cost ($/klm)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Labor Lamp Change (hr)	N/A	N/A	N/A	0.4	N/A	N/A	0.4	0.4	0.4	0.4	0.4	0.4
Total Installed Cost ($)	N/A	N/A	N/A	$176.63	N/A	N/A	$74.18	$74.18	$41.44	$41.44	$32.70	$32.70
Annual Maintenance Cost ($)	N/A	N/A	N/A	$14.65	N/A	N/A	$6.28	$6.28	$3.44	$3.44	$2.71	$2.71
Total Installed Cost ($/klm)	N/A	N/A	N/A	$44.43	N/A	N/A	$13.13	$13.13	$7.33	$7.33	$5.79	$5.79
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$3.69	N/A	N/A	$1.11	$1.11	$0.61	$0.61	$0.48	$0.48

1. Based on the average of products in the LED Lighting Facts Database (as downloaded on 10/30/15).
2. N/A because Linear LED Replacement Lamps are a retrofit option and sold only to be put in existing fixtures.

Performance/Cost Characteristics » Commercial 8-ft Linear LED Luminaire Replacement for a 2-Lamp System

Final

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical[1]	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	N/A	N/A	N/A	73	N/A	N/A	46	41	35	35	35	35
System Lumens	N/A	N/A	N/A	8000	N/A	N/A	8000	8000	8000	8000	8000	8000
System Efficacy (lm/W)	N/A	N/A	N/A	110	N/A	N/A	173	197	230	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	N/A	N/A	N/A	90	N/A	N/A	90	90	90	90	90	90
Correlated Color Temperature (CCT)	N/A	N/A	N/A	4000	N/A	N/A	4000	4000	4000	4000	4000	4000
Average Lifetime (1000 hrs)	N/A	N/A	N/A	75	N/A	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	N/A	N/A	N/A	4147	N/A	N/A	4147	4147	4147	4147	4147	4147
Lamp/Luminaire Price ($)	N/A	N/A	N/A	$640.00	N/A	N/A	$384.08	$384.08	$187.02	$187.02	$91.07	$91.07
Ballast Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	N/A	N/A	N/A	$80.00	N/A	N/A	$48.01	$48.01	$23.38	$23.38	$11.38	$11.38
Labor Cost ($/hr)	N/A	N/A	N/A	$68.20	N/A	N/A	$68.20	$68.20	$68.20	$68.20	$68.20	$68.20
Labor System Installation (hr)	N/A	N/A	N/A	1.0	N/A	N/A	1.0	1.0	1.0	1.0	1.0	1.0
Labor Lamp Change (hr)[2]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	N/A	N/A	N/A	$708.20	N/A	N/A	$452.28	$452.28	$255.22	$255.22	$159.27	$159.27
Annual Maintenance Cost ($)	N/A	N/A	N/A	$39.16	N/A	N/A	$19.34	$19.34	$10.58	$10.58	$6.60	$6.60
Total Installed Cost ($/klm)	N/A	N/A	N/A	$88.53	N/A	N/A	$56.53	$56.53	$31.90	$31.90	$19.91	$19.91
Annual Maintenance Cost ($/klm)	N/A	N/A	N/A	$4.89	N/A	N/A	$2.42	$2.42	$1.32	$1.32	$0.83	$0.83

1. Based on the CREE CS18-80LHE found on Grainger online of 11/20/15
2. N/A because Linear LED Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Commercial Low-Bay Lighting Systems

The commercial low bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits between 6,000 and 10,000 system lumens. Low bay lighting is defined as "interior lighting where the roof trusses or ceiling height is less than 25ft. above the floor"(IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
T5 4xF54 HO Linear System	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial LED Low-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	68	104	71	46	N/A	47	36	34	30	30	30
System Lumens	548	4877	8410	7042	6294	N/A	7000	7000	7000	7000	7000	7000
System Efficacy (lm/W)	15	72	81	100	136	N/A	150	197	207	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	85	75	81	84	N/A	81	81	81	81	81	81
Correlated Color Temperature (CCT)	4000	4000	5000	4000	4000	N/A	4000	4000	4000	4000	4000	4000
Average Lifetime (1000 hrs)	50	50	100	60	100	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp/Luminaire Price ($)	$215.19	$761.95	$447.31	$267.59	$332.80	N/A	$159.63	$159.63	$77.73	$77.73	$37.85	$37.85
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$156.23	$53.19	$38.00	$52.88	N/A	$22.80	$22.80	$11.10	$11.10	$5.41	$5.41
Labor Cost ($/hr)	$36.83	$68.99	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.20	$68.20
Labor System Installation (hr)	1.5	1.5	1.5	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$865.44	$550.80	$371.08	$436.29	N/A	$263.12	$263.12	$181.22	$181.22	$140.15	$140.15
Annual Maintenance Cost ($)	$0.07	$69.95	$22.26	$25.00	$17.63	N/A	$10.96	$10.96	$7.32	$7.32	$5.66	$5.66
Total Installed Cost ($/klm)	$493.50	$177.44	$65.49	$52.70	$69.32	N/A	$37.59	$37.59	$25.89	$25.89	$20.02	$20.02
Annual Maintenance Cost ($/klm)	$0.13	$14.34	$2.65	$3.55	$2.80	N/A	$1.57	$1.57	$1.05	$1.05	$0.81	$0.81

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18//15).
3. Based on highest efficacy product in the LED Lighting Facts Database (as downloaded on 10/30/15) for which all of the information in the table is available.
4. LED Low-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Performance/Cost Characteristics » Commercial High-Bay Lighting Systems

The commercial high-bay lighting characterized in this report is a one-lamp and one-ballast system in a low/high bay fixture that emits greater than 10,000 system lumens. High-bay lighting is defined as “interior lighting where the roof trusses or ceiling height is greater than 25ft. above the floor” (IESNA, 2000). For all lamp technologies, an annual fixture renovation rate of 10% (i.e., 10-year fixture service life) is used to reflect the proportion of equipment that retires each year.

Performance:

- A majority of residential lamps have a nominal CCT rating of 2700K and give off a warm, yellowish white color, but products with CCTs of 3000K, 3500K, 4100K (neutral white), 5000K (daylight) and 6500K (blueish white) are also available. Traditional incandescent light bulbs have a nominal CCT of about 2700K. When replacing a light bulb, it is advised to chose a product with a similar CCT value in order to achieve the same look.
- Incandescent and halogen lamps have perfect color rendering with a CRI value of 100, but for CFL and LEDs products commonly fall between 70 and 90 CRI, with an average around 80. CRI values of 80 are considered suitable for general illumination, with high CRI products being preferable for retail and display applications where improved color quality is of real value. Higher CRI is not expected to be a focus for future LED products except for these very specific retail and display applications.

Cost:

- The total installed cost is the price of a lamp, ballast (if applicable), and fixture plus the cost for labor associated with the installation, except for in the case of LED luminaires which are sold as one integrated system. Many factors influence the price of LED lamps including CRI, lifetime, dimming capabilities, and efficacy. Therefore typical lamp prices in 2015 reflecting a mix of lamp characteristics and features were used as the basis for projections for both typical and high efficacy products in the future.
- Annual maintenance costs are the cost of labor for replacing the lamps and the cost of the replacement lamp itself. The frequency at which lamps are replaced is a function of lamp life and the annual operating hours of 4042 hours/year for commercial low-bay systems (DOE SSL Program, 2012a).

Legislation:

- ENERGY STAR does not cover low/high bay luminaires (ENERGY STAR, 2012).

Future Performance Improvements:

- Projections were provided for both typical and high performing products for 2020, 2030, and 2040. Assumptions were made that the focus would be on improving efficacy, lifetime and price for products at constant CRI and CCT values.
- *Due to continued R&D investment, competition from LED lighting products, and general market demand for cost-effective lighting, the performance and cost characteristics of conventional lighting technologies are expected to improve over the analysis period. However, the ability of these conventional technologies to react rapidly (in terms of performance improvement) to the emergence of a new light source such as LED lighting is relatively small because these are mature technologies (particularly incandescent and fluorescent) and established market competitors* (Navigant, 2014).
- For LED Technology, efficacy, lifetime, and price improvements were based on the model described in the Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014). For traditional technologies, the following future improvements were assumed to occur year over year through 2040:

Technology	Efficacy	Lifetime	Price	Potential for Improvements
Mercury Vapor	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.
Metal Halide	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
Sodium Vapor	+0.5%	+0.5%	-0.5%	Limited as the technology is mature.
T5 4xF54 HO Linear System	+0.2%	+0.5%	-0.5%	Limited as the technology is mature.

Performance/Cost Characteristics » Commercial LED High-bay Luminaire

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low[1]	Typical[2]	High[3]	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Lumens	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Efficacy (lm/W)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System Wattage	36	212	189	183	101	N/A	100	76	72	65	65	65
System Lumens	548	18915	15070	18722	13640	N/A	15000	15000	15000	15000	15000	15000
System Efficacy (lm/W)	15	89	80	102	135	N/A	150	197	207	230	230	230
Ballast Efficiency (BLE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRI	92	74	73	80	83	N/A	80	80	80	80	80	80
Correlated Color Temperature (CCT)	5000	5000	5000	4000	4100	N/A	4000	4000	4000	4000	4000	4000
Average Lifetime (1000 hrs)	50	70	50	60	50	N/A	97	97	100	100	100	100
Annual Operating Hours (hrs/yr)	4042	4042	4042	4042	4042	N/A	4042	4042	4042	4042	4042	4042
Lamp/Luminaire Price ($)	$215.19	$2,395.94	$398.34	$711.42	$297.76	N/A	$342.07	$342.07	$166.57	$166.57	$81.11	$81.11
Ballast Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fixture Price ($)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lamp Cost ($/klm)[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
System (l/b/f) Cost ($/klm)	$392.68	$126.67	$26.43	$38.00	$21.83	N/A	$22.80	$22.80	$11.10	$11.10	$5.41	$5.41
Labor Cost ($/hr)	$36.83	$72.71	$68.99	$68.99	$68.99	N/A	$68.99	$68.99	$68.99	$68.99	$68.99	$68.99
Labor System Installation (hr)	2	2	2	1.5	1.5	N/A	1.5	1.5	1.5	1.5	1.5	1.5
Labor Lamp Change (hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Installed Cost ($)	$270.44	$2,505.00	$501.83	$814.90	$401.25	N/A	$445.55	$445.55	$270.05	$270.05	$184.59	$184.59
Annual Maintenance Cost ($)	$0.07	$144.63	$40.56	$54.89	$32.43	N/A	$18.56	$18.56	$10.91	$10.91	$7.46	$7.46
Total Installed Cost ($/klm)	$493.50	$132.44	$33.30	$43.53	$29.42	N/A	$29.70	$29.70	$18.00	$18.00	$12.31	$12.31
Annual Maintenance Cost ($/klm)	$0.13	$7.65	$2.69	$2.93	$2.38	N/A	$1.24	$1.24	$0.73	$0.73	$0.50	$0.50

1. Based on lowest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
2. Based on the average of products in the DLC Qualified Product Database (as downloaded on 11/18/15).
3. Based on highest efficacy product in the DLC Qualified Product Database (as downloaded on 11/18/15) for which all of the information in the table is available.
4. LED High-Bay Luminaires are a fully integrated lighting solutions used to replace existing lamp/ballast/fixture systems and therefore does not have lamp, ballast, and fixture components.

Additional Technologies of Interest: Lighting

Final

- Tables were not provided for technologies of interest utilizing occupancy sensors and other controls due to lack of available data and currently small market presence.
  - Lighting controls can save energy by either reducing input wattage or limiting hours of operation.
  - The following table indicates prevalence of various lighting controls in 2010 (DOE SSL Program, 2012a).
  - Leading experts claim that controls penetration remains low, particularly for integrated/advanced controls (DOE Connected Lighting Systems Meeting, November 2015).
  - As a result, there is not enough information to determine the price and performance impacts of controls on current lighting technologies or to project improvements going forward.

Prevalence of Lighting Controls by Sector and Lamp Type

		None	Dimmer	Light Sensor	Motion Detector	Timer	EMS	Total
Residential	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%
Commercial	Incandescent	76%	5%	0%	0%	2%	16%	100%
	Halogen	73%	5%	0%	1%	3%	18%	100%
	CFL	77%	0%	0%	3%	2%	18%	100%
	Linear Fluorescent	68%	3%	1%	7%	4%	17%	100%
	HID	71%	0%	2%	1%	6%	20%	100%
	Other	85%	0%	0%	0%	0%	15%	100%

EMS: Energy Management System
HID: High Intensity Discharge:
CFL: Compact Fluorescent Lamp

Refrigeration
Advanced Case

Commercial Compressor Rack Systems

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,050	1,200	1,200	1,190	930	N/A	830	775	777	679	777	679
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	180	162	162	160	125	N/A	104	102	85	74	74	70
Energy Use (MWh/yr) [2]	1,618	1,497	1,497	1,484	1,160	N/A	1033	914	841	735	841	735
Indexed Annual Efficiency [3]	1.00	1.08	1.08	1.09	1.40	N/A	1.57	1.77	1.92	2.20	1.92	2.20
Average Life (yrs)	15	15	15	15	15	N/A	15	15	15	15	15	15
Total Installed Cost ($1000) [4]	$630	$630	$630	$625	$488	N/A	$452	$422	$408	$356	$408	$356
Total Installed Cost ($/kBtu/hr)	$600	$525	$525	$525	$525	N/A	$545	$545	$524	$524	$524	$524
Annual Maintenance Cost ($1000) [5]	$33	$34	$34	$34	$34	N/A	$34	$34	$34	$34	$34	$34
Annual Maintenance Cost ($/kBtu/hr)	$31.14	$28	$28	$29	$37	N/A	$41	$44	$44	$50	$44	$50

[1] The total capacity represents the nominal compressor capacity required for the entire refrigeration system of a typical supermarket. This usually includes two low temperature racks and two medium temperature racks. For 2012 a 1,200 MBtu/hr total cooling capacity is based on a 100 ton estimate for total capacity – 80 tons for the medium temperature racks and 20 tons for the low temperature racks. Beyond 2012, estimates are based on data provided by a supermarket refrigeration efficiency consultant.

[2] Capacity and Annual energy consumption for 2012 and beyond are based on interviews with supermarket refrigeration consultants

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[4] The total installed cost for 2003 is based on the entire supermarket compressor rack system (two medium temperature racks and two low temperature racks). The equipment purchase price for an entire supermarket compressor rack system is approximately $130,000, the installation cost (including piping, electrical, startup and commissioning) is approximately $400,000, and the rack defrost and lighting controls are approximately $100,000. Therefore the total installed cost for a typical supermarket compressor rack system is approximately $630,000. Total installed cost for 2012 and beyond is based on updated Navigant estimates. Note the decrease in cost over time as required capacity is decreased.

[5] Maintenance cost includes oil changes, bearing lubrication, filter replacement, and system functionality checks.

Commercial Compressor Rack Systems

- Commercial compressor rack systems that serve commercial supermarket display cases and walk-ins consist of a number of parallel-connected compressors located in a separate machine room. By modulating compressor capacity, these integrated systems provide higher efficiency and mechanical longevity.
- Rack integrators generally supply a packaged compressor rack for which much of the necessary piping, insulation, components, and controls are pre-assembled.
- A typical supermarket will have 10 to 20 compressors mounted in racks in the 3-hp to 15-hp size range. Usually there are 3 to 5 compressors per rack serving a series of loads with nearly identical evaporator temperature.
- The duty cycle for compressors is usually in the range 60% to 70%.
- Approximately 34 percent of the total annual electricity consumption for a typical supermarket is attributable to compressors. (NCI, 2009)
- There are an estimated 140,000 compressor rack systems installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- Installed cost, power draw, and capacity are all expected to decrease in the future due to the reduced load of supermarket display cases
- **For this advanced case, a 10% reduction in energy consumption and a 5% reduction in required capacity is assumed to occur over the reference case for 2020 and beyond due to VIP adoption by display cases and a relaxation in charge size limits for more efficient, low GWP, but toxic/flammable refrigerants such as ammonia and propane due to improved safety technology such as leak detection**.

Commercial Condensers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Total Capacity (kBtu/hr) [1]	1,680	1,680	1,680	1,666	1,302	N/A	1,121	1,065	904	833	904	833
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Power Input (kW)	25	25	24	22	18	N/A	14	13	11	9	11	9
Energy Use (MWh/yr)	138	120	115	106	86	N/A	67	64	52	46	52	43
Indexed Annual Efficiency[2]	1.00	1.15	1.20	1.30	1.60	N/A	2.06	2.17	2.64	3.03	2.64	3.18
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Total Installed Cost ($1000)	$47	$54	$54	$53	$51	N/A	$51	$50	$50	$50	$50	$50
Total Installed Cost ($/kBtu/hr)	$27.87	$32	$32	$32	$39	N/A	$45	$47	$55	$60	$55	$60
Annual Maintenance Cost[3]	$817	$954	$954	$954	$954	N/A	$956	$956	$956	$956	$956	$956
Annual Maintenance Cost ($/kBtu/hr)	$0.49	$0.57	$0.57	$0.57	$0.73	N/A	$0.85	$0.90	$1.06	$1.15	$1.06	$1.15

[1] Total capacity is the total heat rejected (THR) of condensers comprised of two low temperature condensers (THRL = 240 MBtu/hr each, suction temperature = -25°F, condensing temperature 110°F) and two medium temperature (THRM = 520 MBtu/hr each, suction temperature = 15°F, condensing temperature = 115°F) condensers; ambient temperature = 95°F. (NCI, 2009). For 2012 and beyond, capacity was estimated based on consultation with a supermarket refrigeration expert.

[2] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).

[3] Maintenance cost includes coil cleaning, leak checking, belt replacement as necessary, and system functionality checks. Note a slight expected increase in maintenance costs due to the expected implementation of hybrid condenser systems.

Commercial Condensers

- Condensers are designed with multiple methods of cooling: air-cooled, water-cooled, and evaporative. These units can be single-circuit or a multiple circuit.
- Commercial condensers are remotely located, typically installed on the roof of a supermarket.
- For use with parallel compressors in supermarkets, air-cooled units are the most commonly used condensers. This analysis is based on multiple air-cooled condensers connected to a supermarket refrigeration system comprised of two low temperature condensers and two medium temperature condensers, using R-404A refrigerant.
- Each compressor rack has a dedicated condenser or a separate circuit of a single common condenser. Condenser temperatures of multiple racks are often different.
- The duty cycle for condensers is usually in the range 50 - 70%.
- Approximately 5 percent of the total annual electricity consumption for a typical supermarket is attributable to condensers. (NCI, 2009)
- There are an estimated 140,000 condensers installed in supermarkets across the U.S. as of 2008. (NCI, 2009)
- Total installed cost is expected to decrease over time due to an expected reduction in required capacity due to more efficient display cases
- **For this advanced case, a 10% reduction in energy consumption and a 5% reduction in required capacity is assumed to occur over the reference case for 2020 and beyond due to VIP adoption by display cases and a relaxation in charge size limits for more efficient, low GWP, but toxic/flammable refrigerants such as ammonia and propane due to improved safety technology such as leak detection**.

Commercial Supermarket Display Cases

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	20,000	17623	17623	17623	17623	N/A	17623	17623	17623	17623	17623	17623
Median Store Size (ft^2)	44,000	46,500	46,500	46,500	46,500	N/A	46,500	46,500	46,500	46,500	46,500	46,500
Case Length (ft)	12	12	10	10	10	N/A	10	10	10	10	10	10
Energy Use (kWh/yr) [1,2]	21,000	13,497	13,497	12,565	11,746	N/A	11,787	10,467	9,420	8,938	7,823	7,667
Energy Use (kWh/ft)	1,750	1,125	1,350	1,257	1,175	N/A	1,179	1,047	942	894	782	767
Indexed Annual Efficiency[3]	1.00	1.56	1.56	1.67	1.79	N/A	1.78	2.01	2.23	2.35	2.68	2.74
Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$4,371	$8,510	$8,510	$8,940	$9,601	N/A	$9,356	$9,454	$9,926	$10,868	$10,096	$10,302
Total Installed Cost	$6,452	$10,811	$10,811	$11,241	$11,902	N/A	$11,657	$11,755	$12,227	$13,169	$12,397	$12,603
Total Installed Cost ($/kBtu/hr)	323	613	613	638	675	N/A	661	667	694	747	703	715
Annual Maintenance Cost[4]	$657	$940	$940	$940	$940	N/A	$940	$940	$940	$940	$940	$940
Annual Maintenance Cost ($/kBtu/hr)	$32.85	$53.34	$53.34	$53.34	$53.34	N/A	$53.34	$53.34	$53.34	$53.34	$53.34	$53.34

[1] DOE's Federal energy conservation standards for Commercial Refrigeration Equipment (CRE) went into effect on January 1, 2012. The 2012 typical and 2015 low efficiency values are based on minimal compliance with this standard. For 2015 and beyond, energy consumption and cost values were estimated using shipments-weighted averages reported in DOE's 2014 CRE Final Rule TSD for equipment commonly used as display cases. DOE's updated conservation standard goes into effect in 2017, so units sold in 2020 are assumed to comply with this standard.

[2] **For consistency with DOE rulemaking practices, Supermarket Display Case Energy Use reported above includes energy use of the compressor racks and condensers. To avoid double counting, do not add Energy Use from the Compressor Rack or Condenser Systems tabs if calculating total energy consumption.**

[3] **Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).**

[4] Maintenance cost includes preventative maintenance costs such as cleaning evaporator coils, drain pans, fans, and intake screens as well as lamp replacements and other lighting maintenance activities. After 2012, these values are based on a reported maintenance and repair cost of $220 per unit for preventative maintenance plus approximately $60 per linear foot for additional repair and maintenance

Commercial Supermarket Display Cases

- DOE set Federal energy efficiency standards for Commercial Refrigeration Equipment (CRE) in 2009. These standards set maximum daily energy consumption levels, in kWh/day, for display cases manufactured and/or sold in the United States on or after January 1, 2012.
- DOE updated its Energy Conservation Standards for Commercial Refrigeration Equipment in 2014, for equipment sold on or after March 27, 2017.
- The table below lists equipment used as supermarket display cases and their corresponding Energy Conservation Standard levels. The maximum allowable daily energy consumption for each equipment class is a linear function of Total Display Area (TDA)

Equipment Description	DOE Designation	Standards Equation (2012)	Standards Equation (2017)
Vertical Open Cooler	VOP.RC.M	0.82xTDA+4.07	0.64xTDA+4.07
Semi vertical Open Cooler	SVO.RC.M	0.83xTDA+3.18	0.66xTDA+3.18
Horizontal Open Cooler	HZO.RC.M	0.35xTDA+2.88	0.35xTDA+2.88
Transparent-Doored Cooler	VCT.RC.M	0.22xTDA+1.95	0.15xTDA+1.95
Deli Display Cooler	SOC.RC.M	0.51xTDA+0.11	0.44xTDA+0.11
Transparent-Doored Freezer	VCT.RC.L	0.56xTDA+2.61	0.49xTDA+2.61
Horizontal Open Freezer	HZO.RC.L	0.57xTDA+6.88	0.55xTDA+6.88

Commercial Supermarket Display Cases

- The Food Marketing Institute reported the median total supermarket size in 2003 was 44,000 sq. ft., and in 2013, the last year reported in the study, it was listed as 46,500 sq. ft.
- Unit energy consumption for 2012 and beyond is estimated using a shipments weighted average by efficiency level and equipment class, using data in DOE's 2014 CRE Final Rule TSD and Engineering Spreadsheet. The equipment classes analyzed are listed in the table on the previous slide.
- Supermarket refrigeration systems consist of refrigerated display cases, condensing units, and centralized compressor racks
- A typical supermarket display case contains lighting, evaporators, evaporator fans, piping, insulation, valves, and controls.
- Approximately 20% of total annual electricity consumption for a typical supermarket is directly attributable to display cases (this does not include the energy consumed by compressors and condensers necessary to cool the display cases). (NCI, 2009)
- The efficiency of supermarket display cases can be increased through the use of improved evaporator coils, larger evaporators, higher efficiency evaporator fan blades, high efficiency doors, LED lighting, and improved insulation.
- Unit energy consumption for supermarket display cases is expected to decrease over time as a result of DOE's updated energy conservation standards
- In addition, a transition from open to transparent-doored display cases is expected to occur as supermarkets increase focus on energy efficiency.
- **For this advanced scenario, the typical display case in 2020 is assumed to minimally comply DOE's updated ECS.**
- **For 2020 and beyond, accelerated adoption of energy savings technologies is assumed to take place over the reference case, including accelerated shipments migration to doored over open units, where applicable, as well as vacuum insulated panels.**
- **The incremental cost of VIPs is assumed to decrease from its present value due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This advanced case assumes a transition from HFC to more efficient propane and ammonia refrigerants by 2040**

Commercial Reach-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	3,000	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929	2,929
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)	3,800	2,340	2,665	2,033	1,394	1,394	1,448	1,303	1,099	1,047	1,047	1,026
Energy Use (kWh/yr/ft^3) [1]	79	48	54	41	28	28	30	27	22	21	21	21
Indexed Annual Efficiency[3]	1.00	1.62	1.43	1.87	2.73	2.73	2.62	2.92	3.46	3.63	3.63	3.70
Average Life (yrs)	10	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,810	$2,624	$2,728	$2,780	$3,021	$3,021	$2,947	$3,242	$3,632	$3,335	$3,115	$3,271
Total Installed Cost[4]	$2,966	$3,454	$3,591	$3,643	$3,884	$3,884	$3,810	$4,105	$4,495	$4,198	$3,978	$4,134
Total Installed Cost ($/kBtu/hr)	$989	$1,227	$1,226	$1,244	$1,326	$1,326	$1,301	$1,402	$1,535	$1,434	$1,358	$1,411
Annual Maintenance Cost[5]	$143	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185	$185
Annual Maintenance Cost ($/kBtu/hr)	$48	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63	$63

[1] EPACT 2005 energy standards went into effect in 2010. 2015 low efficiency cost and energy consumption values are based on minimum compliance with this standard. Unless otherwise noted, all other cases are based on shipments-weighted averages of solid and transparent doored units reported in the 2014 CRE TSD. DOE's updated Energy Conservation standards go into effect in 2017; therefore, compliance with this standard is assumed for 2020 and beyond.

[2] The Energy Star category is based on a shipments weighted average of solid and transparent-doored units that are minimally compliant with Energy Star v3, effective October 1, 2014. Units compliant with Energy Star are found to be the most efficient reach-in refrigeration equipment on the market in 2015

[3] Annual efficiency normalized to the typical efficiency of the 2003 installed base. Normalized Annual Efficiency = (Typical 2003 Energy Use) / (Energy Use)[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based DOE's CRE Final Rule, which assumes a installation cost of $863 for self-contained equipment.

[4] Maintenance costs after 2003 are based on DOE's CRE Final Rule TSD, which reports $35 annual preventative maintenance, per unit, per year, plus approximately $40 per linear foot, per year of additional repair and maintenance costs for the units characterized

Commercial Reach-In Refrigerators

- The Energy Policy Act of 2005 (EPACT 2005) set maximum daily energy consumption levels, in kWh/day, for commercial reach-in refrigerators that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
- In 2014, DOE updated its energy conservation standards for Reach-in refrigerators, effective March 27, 2017. Both standards are reported in the table below.

Equipment Class	EPCA Standard Level (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.M)	0.10xV+2.04	0.05xV + 1.36
Glass Door (VCT.SC.M)	0.12xV+3.34	0.1xV+0.86

- In 2013, EPA updated its Energy Star® for Reach-in refrigerators, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit.

Reach-In Refrigerator Size	0 < V < 15	15 ≤ V < 30	30 ≤ V < 50	50 ≤ V
Solid Door (VCS.SC.M)	0.02xV+1.60	0.09xV+0.55	0.01xV+2.95	0.06xV+0.45
Glass Door (VCT.SC.M)	0.10xV+1.07	0.15xV+0.32	0.06xV+3.02	0.08xV+2.02

Commercial Reach-In Refrigerators

- Unit energy consumption for 2012 and beyond was estimated based on shipment-weighted averages by efficiency level and equipment class for 49 ft^3 VCS.SC.M and VCT.SC.M units reported in DOE's 2014 CRE Final Rule TSD. These units were estimated to comprise approximately 85% and 15% of total reach-in refrigerator shipments, respectively.
- The efficiency of commercial reach-in refrigerators can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- Unit energy consumption is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to compliance with EPA SNAP
- **For this advanced scenario, the typical unit in 2020 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration**
- **A shipments migration from transparent to solid-doored units is assumed for the advanced case**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Reach-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[3]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341	4,341
Size (ft^3)	49	49	49	49	49	49	49	49	49	49	49	49
Energy Use (kWh/yr)[1]	9,392	6,023	7,658	5,592	4,563	4,763	4,453	4,008	3,656	3,473	3,473	3,369
Energy Use (kWh/yr/ft^3)	192	123	156	114	93	97	93	93	93	93	93	93
Indexed Annual Efficiency[4]	1.00	1.56	1.23	1.68	2.06	1.97	2.11	2.34	2.57	2.70	2.70	2.79
Average Life (yrs)	8	10	10	10	10	10	10	10	10	10	10	10
Retail Equipment Cost	$2,498	$2,886	$3,002	$3,033	$3,186	$3,118	$3,395	$3,490	$4,099	$4,304	$3,674	$3,777
Total Installed Cost[5]	$2,654	$3,749	$3,865	$3,896	$4,049	$3,981	$4,258	$4,353	$4,962	$5,167	$4,537	$4,640
Total Installed Cost ($/kBtu/hr)	$611	$864	$890	$897	$933	$917	$981	$1,003	$1,143	$1,190	$1,045	$1,069
Annual Maintenance Cost[6]	$140	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181
Annual Maintenance Cost ($/kBtu/hr)	$32.25	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70	$41.70

1 EPACT 2005 energy standards went into effect in 2010. The 2015 low energy consumption and cost values are based on minimal compliance with this standard.

2 A 49 ft^3 unit was characterized, as this was the representative size selected for DOE’s rulemaking analysis.

3 The Energy Star category was based on a solid doored unit that is minimally compliant with Energy Star v3, effective October 1, 2014

4 **Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use).**

5 Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assumes a cost of $156. Installation cost for 2012 and beyond is based on DOE’s on-going CRE rulemaking which assumes a cost of $863 for self-contained equipment.

6 Maintenance costs are calculated based on a $35 per unit annual preventative maintenance cost, plus an additional $45 per linear foot repair and maintenance cost estimated based on values reported in the in the CRE TSD

Commercial Reach-In Freezers

- EPACT 2005 set maximum daily energy consumption levels, in kWh/day, for commercial reach-in freezers that went into effect on January 1, 2010. The daily energy consumption is based on the volume of the unit (V).
- In December of 2014, DOE updated its energy conservation standards for commercial refrigeration equipment, including reach-in freezers. Both the EPCA and DOE standards are reported in the table below.

Equipment Class	EPCA (2010)	DOE Standard Level (2017)
Solid Door (VCS.SC.L)	0.4xV+1.38	0.22xV+1.38
Transparent Door (VCT.SC.L)	0.75xV+4.10	0.29xV+2.95

- In 2013, EPA updated its Energy Star standards for reach-in freezers, effective October 1, 2014. These standards are also based on the refrigerated volume of the unit

Reach-In Freezer Size	$0 < V < 15$	$15 \leq V < 30$	$30 \leq V < 50$	$50 \leq V$
Solid Door (VCS.SC.L)	0.25xV+1.55	0.20xV+2.30	0.25xV+0.80	0.14xV+6.30
Glass Door (VCT.SC.L)	0.56xV+1.61	0.30xV+5.50	0.55xV+2.00	0.32xV+9.49

Commercial Reach-In Freezers

- The commercial reach-in freezer characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 49 cubic ft. solid two-door unit with a nominal compressor size 4,341 Btu/hr.
- The efficiency of commercial reach-in freezers can be increased through the use of efficient compressors, efficient evaporator fans, efficient condenser fans, electric defrost, and more efficient lighting.
- Unit energy consumption for reach-in freezers is expected to decrease as a result of DOE's updated energy conservation standards, as well as a transition to more efficient propane refrigerant due to EPA SNAP compliance.
- **For this advanced scenario, the typical unit in 2020 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Walk-In Refrigerators

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	37,820	37,820	37,820	37,820	37,820	N/A	37,820	37,820	37,820	37,820	37,820	37,820
Size (ft2)[1]	305	305	305	305	305	N/A	305	305	305	305	305	305
Energy Use (kWh/yr)[2]	53,756	30,689	31,892	30,689	27,571	N/A	16,014	14,413	14,453	14,310	14,019	13,880
Energy Use (kWh/ft2/yr)	176	101	105	101	90	N/A	53	47	47	47	46	46
Indexed Annual Efficiency[3]	1.00	1.38	1.69	1.75	1.95	N/A	3.36	3.73	3.72	3.76	3.83	3.87
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$19,607	$23,598	$23,583	$23,598	$23,644	N/A	$24,290	$25,696	$25,504	$25,696	$25,504	$25,696
Total Installed Cost[4]	$23,846	$27,012	$26,997	$27,012	$27,057	N/A	$27,703	$29,280	$29,088	$29,280	$29,088	$29,280
Total Installed Cost($/kBtu/hr)	$631	$714	$714	$714	$715	N/A	$733	$774	$769	$774	$769	$774
Annual Maintenance Cost[5]	$573	$716	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$15.15	$18.93	$19.59	$19.59	$19.59	N/A	$19.59	$19.59	$19.59	$19.59	$19.59	$19.59

[1] Size is estimated based on analysis from the 2014 WICF TSD, which lists the average size of a walk in cooler as 305 ft^2

[2] EISA 2007 includes prescriptive standards for walk-in refrigerators that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. In 2014, DOE updated energy conservation standards for walk-ins. All units 2015 and beyond use data from this rulemaking, and all units 2020 and beyond are assumed to comply with DOE's updated standards.

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $4,163 and $4,891 respectively. Installation cost for 2012 and beyond is based on DOE's Walk-In TSD

[5] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils.

Commercial Walk-In Refrigerators

- The unit characterized in this report is a walk-in storage cooler with an area of 305 ft^2, the average floor area reported by DOE's 2014 Final Rule TSD for this equipment type.
- A typical walk-in refrigerator includes:
  - insulated floor and wall panels
  - merchandising doors, shelving, and lighting (not included in cost estimate)
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- **This advanced scenario assumes a projected 10% decrease in energy consumption over the reference case due to adoption of more efficient refrigerants.**

Commercial Walk-In Refrigerators

- The Energy Independence and Security Act (EISA) of 2007 included prescriptive standards for walk-in refrigerators (coolers) that went into effect in 2009. These prescriptive standards, which are included in the analysis for all units for 2012 and beyond, state that all walk-in refrigerators manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–25, except for glazed portions of doors and structural members
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in refrigerator is not occupied by people.

Commercial Walk-In Refrigerators

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	$5.93 \cdot 10^{-5} \cdot Q + 2.33$
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	$2.30 \cdot 10^{-4} \cdot Q + 2.73$
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Walk-In Freezers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	22,114	22,114	22,114	22,114	22,114	N/A	22,114	22,114	22,114	22,114	22,114	22,114
Size (ft^2) [1]	172	172	172	172	172	N/A	172	172	172	172	172	172
Energy Use (kWh/yr) [2]	33,540	22,862	23,610	22,862	20,878	N/A	13,421	12,079	12,113	12,006	11,749	11,645
Energy Use (kWh/ft^2/yr)	195	133	137	133	121	N/A	78	70	70	70	68	68
Indexed Annual Efficiency[3]	1.00	1.47	1.42	1.47	1.61	N/A	2.50	2.78	2.77	2.79	2.85	2.88
Insulated Box Average Life (yrs)	12	12	12	12	12	N/A	12	12	12	12	12	12
Compressor Average Life (yrs)	10	10	10	10	10	N/A	10	10	10	10	10	10
Retail Equipment Cost	$16,333	$22,008	$21,993	$22,008	$22,054	N/A	$22,793	$25,856	$25,130	$25,856	$25,130	$25,856
Total Installed Cost[4]	$18,570	$24,058	$24,043	$24,058	$24,103	N/A	$24,843	$28,115	$27,389	$28,115	$27,389	$28,115
Total Installed Cost ($/kBtu/hr)	$840	$1,088	$1,087	$1,088	$1,090	N/A	$1,123	$1,271	$1,239	$1,271	$1,239	$1,271
Annual Maintenance Cost[5]	$573	$741	$741	$741	$741	N/A	$741	$741	$741	$741	$741	$741
Annual Maintenance Cost ($/kBtu/hr)	$25.91	$33.51	$33.51	$33.51	$33.51	N/A	$33.51	$33.51	$33.51	$33.51	$33.51	$33.51

[1] Based on DOE's 2014 WICF Final Rule TSD which states the average floor area for a walk-in storage freezer as 172 ft^2

[2] EISA 2007 includes prescriptive standards for walk-in freezers that went into effect in 2009. All units for 2012 and beyond include these prescriptive standards. Units for 2015 and beyond are characterized using data from DOE's 2014 WICF rulemaking. All units 2020 and beyond are assumed to comply with this standard

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Installation cost for 2003 is based on ADL, 1996 & NCI, 2009 reports which assume a cost of $1,040. Installation cost for 2012 and beyond is based on DOE's WICF TSD.

[5] Maintenance cost includes checking and maintaining refrigerant charge levels, checking settings, and cleaning heat exchanger coils

Commercial Walk-In Freezers

- The commercial walk-in freezer characterized in this report is a walk-in storage freezer with an area of 172 ft^2 , the average size reported by DOE's WICF TSD

- A typical walk-in freezer includes:
  - insulated floor, door, and wall panels
  - semi-hermetic reciprocating compressor
  - refrigerant (R404A)
  - condenser
  - evaporator
- Energy consumption is assumed to scale with AWEF (Annual Walk-in Energy Factor), defined as the ratio of total heat removed from the refrigerated volume per year to the total electrical energy input of refrigeration systems over the same time period.
- The installation cost consists of freight and delivery costs in addition to on-site assembly.
- **This advanced scenario assumes a projected 10% decrease in energy consumption over the reference case due to adoption of more efficient refrigerants.**

Commercial Walk-In Freezers: EISA 2007

- EISA 2007 included prescriptive standards for walk-in freezers that went into effect in 2009. These prescriptive standards, which are included in all units for 2011 and beyond, state that all walk-in freezers manufactured after January 1, 2009 must:
  - have automatic door closers
  - have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open
  - contain wall, ceiling, and door insulation of at least R–32, except for glazed portions of doors and structural members
  - contain floor insulation of at least R–28
  - use electronically commutated motors or 3-phase motors (for evaporator fan motors of under 1 horsepower and less than 460 volts)
  - use electronically commutated motors, permanent split capacitor-type motors, or 3-phase motors (for condenser fan motors of under 1 horsepower)
  - use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in freezer is not occupied by people.

Commercial Walk-In Freezers: DOE 2014 Standards

- In 2014, DOE updated its energy conservation standards for walk-in coolers and freezers. Minimum AWEFs (Annual Walk-in Energy Factor) was set for refrigeration systems, as well as upper limits on energy consumption attributable to passage, freight, and display doors. DOE elected not to set new standards for the R-value of Walk-in Panels.

ENERGY CONSERVATION STANDARDS FOR WALK-IN COOLERS AND WALK-IN FREEZERS

Class descriptor	Class	Standard level
Refrigeration Systems Minimum AWEF (Btu/W-h)		
Dedicated Condensing, Medium Temperature, Indoor System, <9,000 Btu/h Capacity	DC.M.I, <9,000	5.61
Dedicated Condensing, Medium Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.M.I, ≥ 9,000	5.61
Dedicated Condensing, Medium Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.M.O, <9,000	7.60
Dedicated Condensing, Medium Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.M.O,≥9,000	7.60
Dedicated Condensing, Low Temperature, Indoor System, <9,000 Btu/h Capacity	DC.L.I, <9,000	5.93 · 10¥5 · *Q* + 2.33
Dedicated Condensing, Low Temperature, Indoor System, ≥ 9,000 Btu/h Capacity	DC.L.I, ≥9,000	3.10
Dedicated Condensing, Low Temperature, Outdoor System, <9,000 Btu/h Capacity	DC.L.O, <9,000	2.30 · 10¥4 · *Q* + 2.73
Dedicated Condensing, Low Temperature, Outdoor System, ≥ 9,000 Btu/h Capacity	DC.L.O, ≥9,000	4.79
Multiplex Condensing, Medium Temperature	MC.M	10.89
Multiplex Condensing, Low Temperature	MC.L	6.57
Panels Minimum R-value (h-ft2-°F/Btu)		
Structural Panel, Medium Temperature	SP.M	25
Structural Panel, Low Temperature	SP.L	32
Floor Panel, Low Temperature	FP.L	28
Non-Display Doors Maximum energy consumption (kWh/day) **		
Passage Door, Medium Temperature	PD.M	$0.05 \cdot A_{nd} + 1.7$
Passage Door, Low Temperature	PD.L	$0.14 \cdot A_{nd} + 4.8$
Freight Door, Medium Temperature	FD.M	$0.04 \cdot A_{nd} + 1.9$
Freight Door, Low Temperature	FD.L	$0.12 \cdot A_{nd} + 5.6$
Display Doors Maximum Energy Consumption (kWh/day) †		
Display Door, Medium Temperature	DD.M	$0.04 \cdot A_{dd} + 0.41$
Display Door, Low Temperature	DD.L	$0.15 \cdot A_{dd} + 0.29$

Commercial Ice Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[5]	Typical	High	Typical	High	Typical	High
Output (lbs/day)[1]	300	300	300	300	300	300	300	300	300	300	300	300
Cooling Capacity (Btu/hr)[2]	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963
Water Use (gal/100 lbs)	20	20	20	20	20	20	20	20	20	20	20	20
Energy Use (kWh/100 lbs)	8.4	7.7	7.7	6.7	6.1	6.7	6.1	5.4	5.7	5.4	5.4	5.4
Energy Use (kWh/yr)[3]	3,833	3,185	3,185	3,078	3,009	3,078	2901.0	2,611	2,525	2,508	2,399	2,383
Normalized Annual Efficiency[4]	1.00	1.20	1.20	1.25	1.27	1.25	1.32	1.47	1.52	1.53	1.60	1.61
Average Life (yrs)	8.0	8	8	8	8	8	8	8	8	8	8	8
Retail Equipment Cost	$1,374	$2,146	$2,189	$2,284	$2,392	$2,284	$2,392	$2,548	$2,548	$2,925	$2,925	$2,925
Total Installed Cost (with Bin)	$1,499	$2,484	$2,484	$2,579	$2,687	$2,579	$2,699	$2,855	$2,855	$3,232	$3,232	$3,232
Total Installed Cost ($/kBtu/hr)	$763	$1,265	$1,265	$1,314	$1,369	$1,314	$1,375	$1,455	$1,455	$1,647	$1,647	$1,647
Annual Maintenance Cost[6]	$639	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826	$826
Annual Maintenance Cost ($/kBtu/hr)	$326	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421	$421

[1] Based on the Final Rule shipment data from DOE's Automatic Ice Maker rulemaking which states the most common equipment type is a small air cooled unit with an integrated ice making head with a representative capacity of 300 lbs/day.

[2] Defined as the average heat load to remove the latent and sensible heat required to freeze the daily output capacity of ice

[3] EPACT 2005 energy standards went into effect in 2010. The 2015 Low values are based on this standard. In 2014, DOE set new standards for commercial ice machines, with compliance required by 2018. The unit characterized for 2012 and beyond use data from this rulemaking. All units 2020 and beyond are assumed to comply with the updated standard.

[4] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[5] The Energy Star category is based on minimum compliance with the Energy Star v2.0 standard, which went into effect on February 1, 2013. According to this analysis, Energy Star certification is typical for the small air-cooled IMH unit characterized.

[6] Maintenance cost includes cleaning and maintaining refrigerant levels, replacing filters, checking water distribution lines for leaks, cleaning, sanitizing, and descaling the bin and water system. Maintenance cost decreases as the size of the ice machine (i.e. output) decreases.

Commercial Ice Machines

- **For this advanced case, a 10% reduction in energy consumption is projected over the reference case due to the adoption of more efficient refrigerants such as propane, which, while not currently required by EPA SNAP, are a source of possible efficiency improvements**
- The commercial ice machine characterized in this report is an air-cooled, ice maker head unit with an approximate output of 300 lbs/day. Commercial ice machines are typically integrated with an insulated ice storage bin or mounted on top of a separate storage bin. The retail equipment cost includes the ice making head and the integrated storage bin. Commercial ice machine condensers are either air-cooled or water-cooled. Approximately 90% of all units are the air-cooled type.
- Commercial ice machine maintenance includes periodic cleaning (every 2 to 6 weeks) to remove lime and scale, and sanitizing to kill bacteria. Some ice machines are self-cleaning/sanitizing.
- ENERGY STAR® updated its maximum energy consumption levels, in KWh/100 lbs ice, for air cooled ice machines that went into effect on February 1, 2013. These efficiency levels are based on the harvest rate, in lbs/24 hrs. (H). Water cooled ice machines are not eligible for Energy Star certification.

ENERGY STAR Requirements for Air-Cooled Batch-Type Ice Makers

Equipment Type	Applicable Ice Harvest Rate Range (lbs of ice/24 hrs)	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$200 \le H \le 1600$	$\le 37.72 * H^{-0.298}$	≤ 20.0
RCU	$400 \le H \le 1600$	$\le 22.95 * H^{-0.258} + 1.00$	≤ 20.0
	$1600 \le H \le 4000$	$\le -0.00011 * H + 4.60$	≤ 20.0
SCU	$50 \le H \le 450$	$\le 48.66 * H^{-0.326} + 0.08$	≤ 25.0

ENERGY STAR Requirements for Air-Cooled Continuous-Type Ice Makers

Equipment Type	Energy Consumption Rate (kWh/100 lbs ice)	Potable Water Use (gal/100 lbs ice)
IMH	$\le 9.18 * H^{-0.057}$	≤ 15.0
RCU	$\le 6.00 * H^{-0.162} + 3.50$	≤ 15.0
SCU	$\le 59.45 * H^{-0.349} + 0.08$	≤ 15.0

Commercial Ice Machines: EPACT 2005

- EPACT 2005 issued standard levels for commercial ice machines with capacities between 50 and 2500 pounds per 24-hour period that are manufactured and/or sold in the United States on or after January 1, 2010. The energy consumption is based on the harvest rate in pounds per 24 hours (H).

Equipment Type	Type of Cooling	Harvest Rate (lbs ice/24 hrs)	Maximum Energy Use (kWh/100 lbs ice)	Maximum Condenser Water Use (gal/100 lbs ice)
Ice Making Head	Water	<500	7.80-0.0055 H	200-0.022 H
		≥500 and <1436	5.58-0.0011 H	200-0.022 H
		≥1436	4.0	200-0.022 H
	Air	<450	10.26-0.0086 H	Not Applicable
		≥450	6.89-0.0011 H	Not Applicable
Remote Condensing (but not remote compressor)	Air	<1000	8.85-0.0038 H	Not Applicable
		≥1000	5.10	Not Applicable
Remote Condensing and Remote Compressor	Air	<934	8.85-0.0038 H	Not Applicable
		≥934	5.3	Not Applicable
Self Contained	Water	<200	11.40-0.019 H	191-0.0315 H
		≥200	7.60	191-0.0315 H
	Air	<175	18.0-0.0469 H	Not Applicable
		≥175	9.80	Not Applicable

Commercial Ice Machines: 2014 DOE Standards

Energy Conservation Standards for Batch Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<300	6.88 - 0.0055H	200 - 0.022H
		300 and <850	5.80 - 0.00191H	200 - 0.022H
		850 and <1,500	4.42 - 0.00028H	200 - 0.022H
		1500 and <2,500	4.0	200 - 0.022H
		2500 and <4,000	4.0	145
Ice-Making Head	Air	<300	10 - 0.01233H	Not Applicable
		300 and <800	7.05 - 0.0025H	Not Applicable
		800 and <1500	5.55 - 0.00063H	Not Applicable
		1500 and <4,000	4.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	50 and <1,000	7.97 - 0.00342H	Not Applicable
		1,000 and <4,000	4.55	Not Applicable
Remote Condensing and Remote Compressor	Air	<942	7.97 - 0.00342H	Not Applicable
		942 and <4,000	4.75	Not Applicable
Self-Contained	Water	<200	9.5 - 0.019H	191 - 0.0315H
		200 and <2,500	5.7	191 - 0.0315H
		2500 and <4,000	5.7	112
Self-Contained	Air	<110	14.79 - 0.0469H	Not Applicable
		110 and <200	12.42 - 0.02533H	Not Applicable
		200 and <4,000	7.35	Not Applicable

Energy Conservation Standards for Continuous Type Automatic Commercial Ice Makers Effective January 2018

Equipment Type	Type of Cooling	Harvest Rate lb ice/24 hours	Maximum Energy Use kWh/100 lb ice*	Maximum Condenser Water Use gal/100 lb ice**
Ice-Making Head	Water	<801	6.48 - 0.00267H	180 - 0.0198H
		801 and <2,500	4.34	180 - 0.0198H
		2,500 and <4,000	4.34	130.5
Ice-Making Head	Air	<310	9.19 - 0.00629H	Not Applicable
		310 and <820	8.23 - 0.0032H	Not Applicable
		820 and <4,000	5.61	Not Applicable
Remote Condensing (but not remote compressor)	Air	<800	9.7 - 0.0058H	Not Applicable
		800 and <4,000	5.06	Not Applicable
Remote Condensing and Remote Compressor	Air	<800	9.9 - 0.0058H	Not Applicable
		800 and <4,000	5.26	Not Applicable
Self-Contained	Water	<900	7.6 - 0.00302H	153 - 0.0252H
		900 and <2,500	4.88	153 - 0.0252H
		2500 and <4,000	4.88	90
Self-Contained	Air	<200	14.22 - 0.03H	Not Applicable
		200 and <700	9.47 - 0.00624H	Not Applicable
		700 and <4,000	5.1	Not Applicable

Commercial Beverage Merchandisers

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689	4,689
Size (ft^3)	27	27	27	27	27	27	27	27	27	27	27	27
Energy Use (kWh/yr)	3,900	1,829	2,523	1,781	1,694	1,694	1,380	1,242	1,119	1,063	1,063	1,041
Energy Use (kWh/ft^3/yr) [1]	144	68	93	66	63	63	51	46	41	39	39	39
Indexed Annual Efficiency[3]	1.00	2.13	1.55	2.19	2.30	2.30	2.83	3.14	3.49	3.67	3.67	3.75
Average Life (yrs)	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Retail Equipment Cost	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$3,398	$3,432	$3,034	$3,064
Total Installed Cost[4]	$1,457	$2,382	$2,326	$2,602	$2,628	$2,628	$2,811	$2,839	$3,398	$3,432	$3,034	$3,064
Total Installed Cost ($/kBtu/hr)	$311	$508	$496	$555	$560	$560	$599	$605	$725	$732	$647	$654
Annual Maintenance Cost[5]	$84	$108	$108	$98	$95	$95	$95	$95	$95	$95	$95	$95
Annual Maintenance Cost ($/kBtu/hr)	$17.91	$23.03	$23.03	$20.79	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15	$20.15

[1] EPACT 2005 energy conservation standards went into effect in 2010. The 2015 Low values are based on this standard. In 2015, DOE updated its energy conservation standards for commercial refrigeration equipment, including transparent-doored refrigerators with pull-down capability. Compliance with this standard is required by 2017. Units characterized for 2012 and beyond use data reported in this rulemaking's TSD. Units 2020 and beyond are assumed to comply with this updated standard.
[2] The Energy Star category characterizes a unit that is compliant with Energy Star v3, effective October 1, 2014. This standard does not separately define units with pull-down capability
[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)
[4] Beverage merchandisers are shipped ready to be plugged in, so installation costs are assumed to be negligible
[5] Maintenance costs are estimated based on CRE Final Rule TSD data. Note that maintenance costs decrease slightly for more efficient units, which are assumed to include LED lighting with lower associated maintenance costs

Commercial Beverage Merchandisers

- EPACT 2005 sets maximum daily energy consumption levels, in kWh/day, for commercial refrigerators with a self-contained condensing unit designed for pull-down temperature applications and transparent doors (i.e., beverage merchandisers) that went into effect on January 1, 2010.
- In 2014, DOE updated its energy consumption standards for commercial refrigeration equipment, including beverage merchandisers, effective March 27, 2015. Both the DOE and EPCA standards are reported below.

Equipment Type	EPCA (2010)	DOE Standards (2017)
Beverage Merchandisers (PD.SC.M)	0.126xV + 3.51	0.11xV+0.81

- In 2013, EPA updated its Energy Star standards for glass doored commercial refrigerators, which can be used as beverage merchandisers, effective October 1, 2014. These standards are also based on the volume of the unit (V). Note that Energy Star does not have a separate equipment class for units with pull-down capability.

Beverage Merchandiser Size	$0 < V < 15$	$15 \le V < 30$	$30 \le V < 50$	$50 \le V$
Glass Door	0.118*V + 1.382	≤ 0.140*V + 1.050	≤ 0.088*V + 2.625	≤ 0.110*V + 1.500

Commercial Beverage Merchandisers

- The beverage merchandiser characterized in this report, which is the typical unit according to DOE's 2014 CRE rulemaking, is a 27 cubic foot cooler with a single hinged, transparent door, bright lighting, and shelving with a nominal compressor size of 4,689 Btu/hr..
- The efficiency of beverage merchandisers can be increased through the use of more efficient compressors, fluorescent lighting with electronic ballasts, and improved insulation.
- Beverage merchandisers have an estimated installed base of 920,000 units in 2008. Of those beverage merchandisers 460,000 are one-door units, which represents the most common type of beverage merchandiser.
- Unit energy consumption of beverage merchandisers is expected to decrease as a result of DOE's updated Energy Conservation Standards, as well as a transition from R-134a to more efficient propane refrigerant due to EPA SNAP compliance
- **For this advanced scenario, the typical unit in 2020 is assumed to comply with DOE's updated energy conservation standards for commercial refrigeration**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Refrigerated Vending Machines

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star[2]	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810	1,810
Can Capacity	500	470	470	470	470	470	470	470	470	470	470	470
Size (ft^3)	26	26	26	26	26	26	26	26	26	26	26	26
Energy Use (kWh/yr) [1]	3,000	1,632	1,718	1,632	1,504	1,504	1,360	1,224	803	701	701	687
Energy Use (kWh/ft^3/yr)	115	63	66	63	58	58	52	47	31	27	27	26
Indexed Annual Efficiency[3]	1.00	1.84	1.75	1.84	1.99	1.99	2.21	2.45	3.74	4.28	4.28	4.37
Average Life (yrs)	14	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Retail Equipment Cost	$1,769	$3,209	$3,187	$3,209	$3,276	$3,276	$3,551	$3,626	$4,479	$4,612	$4,343	$4,434
Total Installed Cost	$1,844	$3,320	$3,298	$3,320	$3,387	$3,387	$3,662	$3,737	$4,590	$4,723	$4,454	$4,545
Total Installed Cost ($/kBtu/hr)	$1,019	$1,834	$1,822	$1,834	$1,872	$1,872	$2,023	$2,065	$2,536	$2,609	$2,461	$2,511
Annual Maintenance Cost[4]	$209	$270	$270	$270	$250	$250	$250	$250	$250	$250	$250	$250
Annual Maintenance Cost ($/kBtu/hr)	$115	$149.17	$149.17	$149.17	$138.12	$138.12	$138.12	$138.12	$138.12	$138.12	$138.12	$138.12

[1] Energy use for 2012 and beyond is estimated based on DOE's 2015 BVM Final Rule

[2] The Energy Star category assumes units that are compliant with the Energy Star v3 standard, since combination units are currently not separately defined by Energy Star. This standard went into effect on March 1, 2013. Our analysis finds Energy Star certified equipment to be the most efficient currently available on the market

[3] Annual efficiency normalized to the efficiency of the 2003 installed base. Indexed Annual Efficiency = (2003 Energy Use) / (Energy Use)

[4] Maintenance cost includes preventative maintenance costs such as checking and maintaining refrigerant charge levels, cleaning heat exchanger coils and also includes an annualized cost for refurbishments/remanufacturing.

Commercial Refrigerated Vending Machines

- DOE set Federal energy efficiency standards for refrigerated vending machines in 2009. These standards set maximum daily energy consumption levels, in kWh/day, for commercial refrigerated vending machines manufactured and/or sold in the United States on or after August 31, 2012. The daily energy consumption is based on the volume of the unit (V).
  - Refrigerated Vending Machines that are fully-cooled (Type A) ≤ 0.055*V + 2.56
  - Refrigerated Vending Machines that are zone-cooled (Type B) ≤ 0.073*V + 3.16
- Energy Star® updated its maximum daily energy consumption efficiency levels, also in KWh/day, for refrigerated vending machines, which went into effect on March 1, 2013. These efficiency levels are based on refrigerated volume.

Equipment Type	Maximum Daily Energy Consumption	Low Power Mode Requirement
Class A (Transparent-Front)	MDEC= 0.0523 x V + 2.432	Hard-wired controls and/or software capable of placing the machine into a low power mode during periods of extended inactivity while still connected to its power source
Class B (Solid-Front)	MDEC = 0.0657 x V + 2.844	

- **Currently, stakeholders such as Coca Cola have indicated a preference for CO_2 refrigerant, which is less efficient. However, this advanced case scenario assumes a shift to more efficient propane for cost and energy consumption projections due to the superior efficiency of propane refrigerant.**
- **By 2040, the adoption of vacuum insulated panels is assumed to occur, with the aid of decreased incremental costs due to increased R&D funding**
- **Projected installed costs for this advanced scenario are higher than the reference case, even assuming increased R&D funding. Advanced energy-saving technologies are assumed to be made financially viable for operators by increased market incentives such as utility efficiency rebate programs and/or carbon pricing.**
- **This analysis finds that with increased R&D and market incentives for energy efficiency technologies, a limit of possible efficiency improvements for self-contained, vapor compression refrigeration systems will be reached by 2040.**

Commercial Refrigerated Vending Machines

- In December 2015, DOE updated its energy conservation standards for beverage vending machines, and defined two new product classes for combination vending machines Compliance with these standards is required by 2019. For this analysis, compliance with these updated standards is assumed for equipment sold in 2020 and beyond. The updated standards and DOE equipment definitions are listed in the table below.

Equipment Class	Maximum daily energy consumption (kilowatt hours per day)
Class A – a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.052 x V + 2.43
Class B – any refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine	MDEC = 0.052 x V + 2.20
Combination A – a combination vending machine where 25 percent or more of the surface area on the front side of the beverage vending machine is transparent	MDEC = 0.086 x V + 2.66
Combination B – a combination vending machine that is not considered to be Combination A	MDEC = 0.111 x V + 2.04

Commercial Ventilation Advanced Case

Commercial Constant Air Volume

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4,5]	Typical[4,6]	Best[4,7]	Energy Star	Typical[4,7]	Best[4,8]	Typical[4,8,9]	Best[4,8,9]	Typical[4,8,9]	Best[4,8,9]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	11.80	11.56	11.56	11.56	11.56	N/A	11.56	11.56	11.56	11.56	11.56	11.56
Specific Fan Power (W/CFM)	0.787	0.771	0.771	0.771	0.771	N/A	0.771	0.771	0.771	0.771	0.771	0.771
Annual Fan Energy Use (kWh/yr)[1]	44,858	43,924	23,038	20,018	15,226	N/A	15,226	11,155	10,597	9,482	9,482	8,366
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$68,539	$68,539	$68,979	$68,979	$74,178	N/A	$74,178	$74,778	$75,378	$75,978	$75,978	$76,578
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$4,569	$4,569	$4,599	$4,599	$4,945	N/A	$4,945	$4,985	$5,025	$5,065	$5,065	$5,105
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

[1] Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 15,000 CFM CAV AHU and hypothetical supply ductwork layout.

[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

[4] ASHRAE 90.1-2010 & 2013 Section 6.5.3.2 require minimum 2-speed fan control (no longer always constant volume).

[5] Two-speed motor.

[6] Two-speed VFD.

[7] Modulating VFD (66-100%).

[8] Modulating VFD (50-100%).

[9] High aerodynamic efficiency fan.

Commercial Constant Air Volume

- Constant air volume (CAV) ventilation systems are common, inexpensive, air-side HVAC systems that operate in response to a single control zone. Historically, these systems provide a constant flow rate of air (typically a mix of recirculated and outside air) and adjust the supply temperature of that air in order to maintain space temperature setpoint. Recent energy efficiency standard changes (ASHRAE 90.1-2013) now mandate at least two fan speed settings with the requirement of a maximum 40% power at 66% flow. This analysis examines only the fan energy of the CAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for CAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the CAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- The unit characterized in this report is a 15,000 CFM CAV system. The average commercial building is approximately 15,000 square feet (CBECS 2003 and BED 2007). Assuming 1 CFM is needed per square foot of floor area results in a 15,000 CFM air handling unit.
- A 15,000 CFM CAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $60,722 (RS Means 2016). Ductwork would cost approximately $7,817 additional ($68,539 total). A 2-speed motor (estimated $440 incremental cost) and variable frequency drive (estimated $5,639) add cost.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP) for CAV systems. The 2007 version of Standard 90.1 was used to represent the 2012 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, motor efficiency, and speed/flow control.

Commercial Variable Air Volume

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[3]	Low[4]	Typical[5]	Best[6]	Energy Star	Typical[8]	Best[6,7]	Typical[6,7]	Best[6,7]	Typical[6,7]	Best[6,7]
System Airflow (CFM)	15,000	15,000	15,000	15,000	15,000	N/A	15,000	15,000	15,000	15,000	15,000	15,000
System Fan Power (kW)	16.72	15.99	15.99	15.99	15.99	N/A	15.99	15.99	15.99	15.99	15.99	15.99
Specific Fan Power (W/CFM)	1.115	1.066	1.066	1.066	1.066	N/A	1.066	1.066	1.066	1.066	1.066	1.066
Annual Fan Energy Use (kWh/yr)[1]	25,839	24,699	24,699	18,181	16,425	N/A	15,604	15,604	14,783	14,783	13,961	13,140
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$88,207	$88,207	$88,207	$93,846	$94,346	N/A	$94,446	$94,946	$94,446	$94,946	$94,446	$94,946
Annual Maintenance Cost ($)	$900	$900	$900	$900	$900	N/A	$900	$900	$900	$900	$900	$900
Total Installed Cost ($/1000 CFM)	$5,880	$5,880	$5,880	$6,256	$6,290	N/A	$6,296	$6,330	$6,296	$6,330	$6,296	$6,330
Annual Maintenance Cost ($/1000 CFM)	$60	$60	$60	$60	$60	N/A	$60	$60	$60	$60	$60	$60

[1] Based on 3800 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 15,000 CFM VAV AHU, VFD, (10) VAV boxes, and hypothetical supply ductwork layout.

[3] Based on ASHRAE 90.1-2007 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 91% motor efficiency.

[4] ASHRAE 90.1-2010 Section 6.5.3.2 minimum power-flow requirement.

[5] ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 50%-100% flow.

[6] ASHRAE 90.1-2013 fan power limit and typical VAV power-flow relationship for 30%-100% flow.

[7] High aerodynamic efficiency fan.

Commercial Variable Air Volume

- Variable air volume (VAV) ventilation systems are the most common multi-zone system type specified today for conditioning commercial buildings. These systems provide conditioned air to multiple zone terminal units (VAV boxes) that use dampers to modulate the amount of cool air to each zone. An individual zone thermostat controls the VAV box damper to allow more or less cooling. If a zone requires heating then the VAV box provides the minimum flow rate and typically includes a reheat coil to meet space temperature setpoint. As VAV box dampers close in the system, a variable frequency drive reduces fan speed and flow continuously to meet current requirements.
- This analysis examines only the fan energy of the VAV system. VAV systems vary fan speed/flow to meet space conditioning requirements; minimum flow settings apply for DX cooling stages and gas furnace heating stages. Most hours of operation are much lower than full speed, and fan power varies with the cube of fan speed according to fan affinity laws. The 2012 ASHRAE Handbook: HVAC Systems and Equipment (p. 45.11) provided the typical flow profile used for this analysis. The unit characterized in this report is a 15,000 CFM VAV system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for VAV systems. Fan power can be minimized through good design practice (efficient duct layout, low pressure drop ductwork, filters, coils), proper fan selection, and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including packaged systems such as the VAV system type considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- A 15,000 CFM VAV packaged indoor air handling unit with cooling and heating coils can be installed for approximately $69,100 (RS Means 2016). Ductwork and (10) VAV boxes with reheat would cost approximately $19,107 additional ($88,207 total). A 20 hp variable frequency drive (estimated $5,639) is an additional cost.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power for VAV systems (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2012 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type (e.g., centrifugal, axial), fan blade shape (e.g., forward-curved, backward-curved, backward-inclined, airfoil), drive type (belt or direct), configuration (plenum or housed centrifugal), system effects, duct design, filter and coil pressure drops, and motor VFD efficiency.

Commercial Fan Coil Units

Assumes increased rate of technology advancement (lower energy use)

DATA	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average[5]	Low[3]	Typical[6]	Best[6]	Energy Star	Typical[4,7]	Best[4,8]	Typical[4,8]	Best[4,8,9]	Typical[4,8,9]	Best[4,8,9]
System Airflow (CFM)	800	800	800	800	800	N/A	800	800	800	800	800	800
System Fan Power (kW)	0.315	0.241	0.748	0.241	0.148	N/A	0.148	0.148	0.148	0.141	0.141	0.133
Specific Fan Power (W/CFM)	0.394	0.302	0.935	0.301	0.185	N/A	0.185	0.185	0.185	0.176	0.176	0.166
Annual Fan Energy Use (kWh/yr)[1]	709	543	1,683	543	333	N/A	152	94	94	89	89	84
Average Life (yrs)	20	20	20	20	20	N/A	20	20	20	20	20	20
Total Installed Cost ($)[2]	$2,429	$2,429	$2,429	$2,429	$2,753	N/A	$2,753	$2,995	$2,753	$2,995	$2,995	$3,044
Annual Maintenance Cost ($)	$100	$100	$100	$100	$100	N/A	$100	$100	$100	$100	$100	$100
Total Installed Cost ($/1000 CFM)	$3,036	$3,036	$3,036	$3,036	$3,441	N/A	$3,441	$3,744	$3,441	$3,744	$3,744	$3,805
Annual Maintenance Cost ($/1000 CFM)	$125	$125	$125	$125	$125	N/A	$125	$125	$125	$125	$125	$125

[1] Based on 2250 operating hours per year (ADL, 1999) and typical zone air flow requirement profile (ASHRAE S45.11-2012).

[2] Total installed cost of 2-ton horizontal 2-pipe fan coil unit, housing and controls.

[3] Based on ASHRAE 90.1-2010 fan power limit (Table 6.5.3.1.1A) with no pressure drop adjustment. Assumed 80% motor load and 60% motor efficiency.

[4] Based on ASHRAE 90.1-2013 Section 6.5.3.5 requirement of electronically commutated or 70+% efficient fan motor.

[5] Permanent split capacitor fan motor.

[6] Electronically commutated fan motor (single speed).

[7] Electronically commutated fan motor (two-speed).

[8] Electronically commutated fan motor (variable speed).

[9] High aerodynamic efficiency fan.

Commercial Fan Coil Units

- Commercial fan coil units (FCUs) are self-contained, mass-produced assemblies that provide cooling, heating, or cooling and heating, but do not include the source of cooling or heating. The unit characterized in this report is a cooling only (2-pipe), horizontal unit with housing and controls. Fan coil units are typically installed in or adjacent to the space being served and have no (or very limited) ductwork.
- According to manufacturer literature, the cooling capacity for a nominal 800 CFM fan coil unit is about 2 tons. This analysis examines only the fan energy of FCUs.
- Fan coil unit fan motors can be shaded pole, a single phase AC motor with offset start winding and no capacitor; PSC, a single phase AC motor with offset start winding with capacitor; or ECM, an AC electronically commutated permanent magnet DC motor. PSC motors are currently the most common motor type in FCUs, but most manufacturers offer ECM as an option. ASHRAE 90.1-2013 requires an electronically commutated fan motor (or minimum motor efficiency of 70%) for this system.
- There is movement in the industry and in energy codes to reduce fan power. ASHRAE 90.1 includes fan power limits for FCUs. Fan power can be minimized through good design practice and high efficiency type fans. ASHRAE 90.1-2013 now requires a minimum fan efficiency grade (FEG, based on AMCA 205-12: Energy Efficiency Classification for Fans) of 67 and a design operating fan efficiency within 15% of the maximum fan total efficiency. There are exceptions to this requirement, including small systems such as the FCU considered here. Still the fan power limits are expected to become more stringent, and fan efficiency will become more important throughout the industry.
- Fan coil units have higher maintenance costs than central air systems due to the distributed nature of the system. For each unit the filters must be changed and drain systems must be flushed periodically.
- ASHRAE Standard 90.1, which is used as a basis for most state energy codes, limits the fan power (brake HP or nameplate HP). The 2007 version of Standard 90.1 was used to represent the 2012 minimum efficiency level (state energy codes typically refer to older versions of Standard 90.1 due to code revision cycles).
- Fan energy is affected by several factors, including: fan type configuration, filter and coil pressure drops, motor efficiency, and fan speed control.

Appendix A
Data Sources

Navigant Consulting, Inc.
1200 19th Street, NW, Suite 700
Washington, D.C. 20036

And

Leidos
8301 Greensboro Drive
McLean, VA 22102

Residential Lighting

Final

Data Sources » Residential General Service LED Lamps (60 Watt Equivalent)

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2009</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
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<tr><td>Correlated Color Temperature (CCT)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td><td rowspan="2">SSL R&D Plan Table 2.1 (DOE SSL Program, 2015)</td><td>LED Lighting Facts Database (downloaded 10/31/15)</td></tr>
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Data Sources » Residential Reflector LED BR30

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Data Sources » Residential Reflector LED PAR38

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Linear LED Replacement Lamp 2 Lamp System*

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)			N/A	Calculated					
Lamp Lumens						Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)	Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage	Calculated					Calculated					
System Lumens	DOE SSL Program R&D Plan (DOE SSL Program, 2015)					DOE SSL Program R&D Plan (DOE SSL Program, 2015)					
System Efficacy (lm/W)	Calculated					Calculated					
Ballast Efficiency (BLE)	N/A					N/A					
CRI	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List Downloaded 11/17/15	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		Assume Unchanged					
Correlated Color Temperature (CCT)			DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)	DOE SSL Program: LED Application Series, Linear Fluorescent Replacement Lamps (DOE SSL Program, 2011)	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A					N/A					
Fixture Price ($)*											
Lamp Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*	N/A					N/A					
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor System Installation (hr)*											
Labor Lamp Change (hr)											
Total Installed Cost ($)	Calculated					Calculated					
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage											
Lamp Lumens	N/A										
Lamp Efficacy (lm/W)											
System Wattage	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 10/31/15)	DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
System Lumens		Calculated		Calculated		Adjusted for 2015 Typical Lumen Output					
System Efficacy (lm/W)		DLC Qualified Product List (Downloaded 11/18/15)		DLC Qualified Product List (Downloaded 11/18/15)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Efficiency (BLE)	N/A										
CRI	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 10/31/15)	DLC Qualified Product List (Downloaded 11/18/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)											
Average Lifetime (1000 hrs)			DOE SSL Program R&D Plan (DOE SSL Program, 2015)			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp/Luminaire Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites	Retailer Websites	Calculated					
Ballast Price ($)											
Fixture Price ($)	N/A										
Lamp Cost ($/klm)											
System (l/b/f) Cost ($/klm)	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	Assume Same as T5										
Labor System Installation (hr)											
Labor Lamp Change (hr)	N/A										
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Security: LED PAR38)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens	Product Catalogs					Nominal lumen output based on historical values					
Lamp Efficacy (lm/W)	2012 SSL MYPP				Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
CRI	Product Catalogs				Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)		LED Lighting Facts Database (downloaded 10/31/15)	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	LED Lighting Facts Database (downloaded 10/31/15)							
Average Lamp Life (1000 hrs)		Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Lamp Cost ($/klm)	2012 SSL MYPP	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Labor Cost ($/hr)	N/A										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Data Sources » Residential Outdoor Lamps (Porch: LED A-Type*)

DATA SOURCES	2009	2015				2020		2030		2040	
	Installed Stock Average	Low	Typical	High	Energy Star*	Typical	High	Typical	High	Typical	High
Lamp Wattage	Calculated										
Lamp Lumens	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Lamp Efficacy (lm/W)	Scaled based on 60W Residential A-type Lamp										
CRI											
Correlated Color Temperature (CCT)											
Average Lamp Life (1000 hrs)											
Annual Operating Hours (hrs/yr)	DOE SSL Program, Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates (DOE SSL Program, 2012)										
Lamp Price ($)	Calculated										
Lamp Cost ($/klm)	Scaled based on 60W Residential A-type Lamp										
Labor Cost ($/hr)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)										
Labor Lamp Installation (hr)											
Total Installed Cost ($)	Calculated										
Annual Maintenance Cost ($)											
Total Installed Cost ($/klm)											
Annual Maintenance Cost ($/klm)											

Commercial Lighting

Data Sources » Commercial General Service 100W Equivalent LED Replacement Lamp in Recessed Can Fixture

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage							Calculated					
Lamp Lumens		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage												
System Lumens*		Calculated										
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	LED Lighting Facts Database (downloaded 10/31/15)			Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)			Retailer Websites	Assume Same as A19 60W equiv	Retailer Websites							
Average Lamp Life (1000 hrs)		Calculated					U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated	Calculated	Calculated				Calculated	
System (l/b/f) Cost ($/klm)		N/A										
Labor Cost ($/hr)												
Labor System Installation (hr)**		Same as for CFL										
Labor Lamp Change (hr)												
Total Installed Cost ($)												
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)		Calculated										
Annual Maintenance Cost ($/klm)												

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage	N/A	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)				Energy Star Light Bulb product database (downloaded 11/4/15)	Calculated					
Lamp Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Lamp Efficacy (lm/W)						Calculated					Calculated	
System Wattage		Calculated										
System Lumens*												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)		N/A										
CRI		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	Energy Star Light Bulb product database (downloaded 11/4/15)	Assume Unchanged					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)		Calculated	Retailer Websites		Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.										
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated				Calculated	
Ballast Price ($)		N/A										
Fixture Price ($)**												
Lamp Cost ($/klm)		DOE SSL Program, 2013 Multi-Year Program Plan (DOE SSL Program, 2013)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)**		N/A										
Labor Cost ($/hr)		Same as for Halogen										
Labor System Installation (hr)**												
Labor Lamp Change (hr)												
Total Installed Cost ($)		Calculated										
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Replacement Lamp in 2-Lamp System

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage		DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)				Calculated					
Lamp Lumens							Adjusted for 2015 Typical Lumen Output					
Lamp Efficacy (lm/W)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System Wattage		Calculated					Calculated					
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)												
CRI			LED Lighting Facts Database (downloaded 11/17/15)				Assume Unchanged					
Correlated Color Temperature (CCT)												
Average Lamp Life (1000 hrs)		DLC Qualified Product List (Downloaded 11/18/15)	Retailer Websites	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)		Calculated	Retailer Websites	Calculated	Retailer Websites		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)		N/A					N/A					
Fixture Price ($)*	N/A					N/A						
Lamp Cost ($/klm)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
System (l/b/f) Cost ($/klm)*		N/A					N/A					
Labor Cost ($/hr)		Calculated	Assume Same as Analgous Conventional Tech				Assume Unchanged					
Labor System Installation (hr)*		N/A										
Labor Lamp Change (hr)		Calculated										
Total Installed Cost ($)		Calculated					Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 4-ft Linear LED Luminaire to Replace 2-Lamp Systems*

Final

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage												
Lamp Lumens												
Lamp Efficacy (lm/W)	N/A						N/A					
System Wattage							Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)						Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI												
Correlated Color Temperature (CCT)	2008 EIA Reference Case						Assume Unchanged from 2015					
Average Lifetime (1000 hrs)	Calculated	DLC Qualified Product List (Downloaded 11/18/15)		LED Lighting Facts Qualified Product List (Downloaded 11/17/15)	DLC Qualified Product List (Downloaded 11/18/15)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Website	Calculated	Retailer Website		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Ballast Price ($)						N/A						
Fixture Price ($)	N/A						N/A					
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case											
Labor System Installation (hr)	2008 EIA Reference Case	Calculated									Assume Unchanged	
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)												
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)	Calculated						Calculated					
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 High	2015 Energy Star	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Lamp Wattage				LED Lighting Facts Qualified Product List (Downloaded 11/17/15)			Calculated					
Lamp Lumens							Nominal Lumen output based on 2015 values					
Lamp Efficacy (lm/W)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System Wattage				Calculated			Calculated					
System Lumens												
System Efficacy (lm/W)												
Ballast Efficiency (BLE)				N/A			Assume Unchanged from 2015					
CRI				Calculated from LED Lighting Facts Qualified Product List Downloaded 11/17/15								
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lamp Life (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp Price ($)				Calculated			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Ballast Price ($)				N/A			N/A					
Fixture Price ($)*												
Lamp Cost ($/klm)				Navigant Price Analysis			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
System (l/b/f) Cost ($/klm)*				N/A			N/A					
Labor Cost ($/hr)				Assume Same as Analgous Conventional Tech			Assume Unchanged from 2015					
Labor System Installation (hr)*												
Labor Lamp Change (hr)												
Total Installed Cost ($)				Calculated			Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial 8-ft Linear LED Luminaire Replacement for a 2-Lamp System*

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage												
Lamp Lumens				Calculated			N/A					
Lamp Efficacy (lm/W)												
System Wattage				Retailer Websites			Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)				N/A			N/A					
CRI				Retailer Websites			Assume Unchanged from 2015					
Correlated Color Temperature (CCT)												
Average Lifetime (1000 hrs)							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	N/A			U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.	N/A		U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)				Calculated			Calculated					
Ballast Price ($)												
Fixture Price ($)				N/A			N/A					
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)				Navigant Price analysis			U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)				Assume Same as Analgous Conventional Tech							Assume Unchanged	
Labor System Installation (hr)												
Labor Lamp Change (hr)				N/A			N/A					
Total Installed Cost ($)												
Annual Maintenance Cost ($)				Calculated			Calculated					
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A						N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	Calculated	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)								
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	Retailer Websites	N/A	U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case		Assume Same as Analgous Conventional Tech								Assume Unchanged	
Labor System Installation (hr)												
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Data Sources » Commercial LED High-bay Luminaire *

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	High	Energy Star	Typical	High	Typical	High	Typical	High
Lamp Wattage	N/A					N/A	N/A					
Lamp Lumens												
Lamp Efficacy (lm/W)												
System Wattage	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Calculated					
System Lumens							U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Assume Unchanged	
System Efficacy (lm/W)											Calculated	
Ballast Efficiency (BLE)	N/A						N/A					
CRI	2008 EIA Reference Case	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		Assume Unchanged from 2015					
Correlated Color Temperature (CCT)				DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Retailer Websites							
Average Lifetime (1000 hrs)	Calculated			DLC Qualified Product List (Downloaded 11/18/15)	LED Lighting Facts Database (downloaded 11/17/15)		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)					
Annual Operating Hours (hrs/yr)	U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.						U.S. DOE SSL Program, 2010 Lighting Market Characterization, Prepared by Navigant Consulting Inc., January 2012.					
Lamp/Luminaire Price ($)	2008 EIA Reference Case	Calculated	Retailer Websites	Calculated	Retailer Websites		Calculated					
Ballast Price ($)	N/A						N/A					
Fixture Price ($)												
Lamp Cost ($/klm)												
System (l/b/f) Cost ($/klm)	Calculated	Calculated	Calculated	DOE SSL Program R&D Plan (DOE SSL Program, 2015)	Calculated		U.S. DOE SSL Program, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications (Navigant, 2014)				Calculated	
Labor Cost ($/hr)	2008 EIA Reference Case	Assume Same as Analgous Conventional Tech									Assume Unchanged	
Labor System Installation (hr)	Assume Same as Analgous Conventional Tech											
Labor Lamp Change (hr)	N/A						N/A					
Total Installed Cost ($)	Calculated						Calculated					
Annual Maintenance Cost ($)												
Total Installed Cost ($/klm)												
Annual Maintenance Cost ($/klm)												

Refrigeration

Final

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	Copeland, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	ADL, 1996 / NCI Analysis, 2015	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	Kysor-Warren, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI, 2009 / NCI Analysis, 2012	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost ($1000)	ADL, 1996 / NCI Analysis, 2008	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Condensers

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Total Capacity (MBtu/hr)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Median Store Size	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis, 2015										
Power Input (kW)	NCI Analysis, 2008 / Heatcraft, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Energy Use (MWh/yr)	NCI Analysis, 2008 / ADL, 1996	Interview with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Indexed Annual Efficiency	#REF!											
Average Life (yrs)	ADL, 1996 / NCI Analysis, 2008	EIA, 2012										
Total Installed Cost ($1000)	NCI Analysis, 2008 / Heatcraft, 2008 / RS Means, 2007	Interviews with supermarket refrigeration efficiency consultant / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	EIA, 2012										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Supermarket Display Cases

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2007 / NCI Analysis, 2008	Navigant Analysis, 2015										
Median Store Size (ft^2)	Food Marketing Institute (FMI), 2012	Food Marketing Institute, 2015 / Navigant Analysis										
Case Length	DOE, 2014: CRE TSD											
Energy Use (kWh/yr)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Energy Use (kWh/ft)	Calculated											
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE TSD										
Retail Equipment Cost	DOE, 2007 / NCI Analysis, 2008	DOE 2014: CRE Engineering Spreadsheet / Navigant Analysis										
Total Installed Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cst ($/kBtu/hr)	Navigant Analysis, 2015											
Annual Maintenance Cost	DOE, 2007 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Reach-In Refrigerators

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE Engineering Spreadsheet										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Energy Use (kWh/yr/ft^3)	NCI Analysis, 2012	Calculated										
Indexed Annual Efficiency	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Reach-In Freezers

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD										
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use ($kWh/yr/ft^3$)	NCI Analysis, 2012	Calculated										
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2014: CRE TSD										
Retail Equipment Cost	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	NCI Analysis, 2008	DOE, 2014: CRE TSD										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Walk-In Refrigerators

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Size (ft^2)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^2/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / FMI, 2005 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Walk-In Freezers

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Size (ft^2)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: WICF TSD										
Energy Use (kWh/yr)	ADL, 1996 / PG&E, 2004 / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^2/yr)	Calculated											
Indexed Annual Efficiency	Calculated											
Insulated Box Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Compressor Average Life (yrs)	ADL, 1996 / PG&E, 2004	DOE, 2014: WICF TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost	ADL, 1996 / Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: WICF TSD / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: WICF TSD / Navigant Analysis, 2014											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003 Installed Stock Average	2012 Installed Stock Average	2015 Low	2015 Typical	2015 Energy Star	2015 High	2020 Typical	2020 High	2030 Typical	2030 High	2040 Typical	2040 High
Output (lbs/day)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Water Use (gal/100 lbs)	ADL, 1996 / Distributor Web Sites	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/100 lbs)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Energy Use (kWh/yr)	ACEEE, 2002 / NCI Analysis, 2012	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Average Life (yrs)	ADL, 1996/ Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Total Installed Cost (with Bin)	NCI Analysis, 2008	DOE, 2014: ACIM TSD / Distributor Websites / Navigant Analysis, 2015										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: ACIM TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2014: CRE TSD											
Size (ft^3)	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD										
Energy Use (kWh/yr)	ADL, 1996 / NCI Analysis, 2008	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Energy Use (kWh/ft^3/yr)	Calculated											
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ACEEE, 2002	DOE, 2015: CRE TSD										
Retail Equipment Cost	ADL, 1996 / Distributor Web Sites	DOE, 2014: CRE TSD / Navigant Analysis, 2015										
Total Installed Cost	DOE, 2014: CRE TSD, Navigant Analysis											
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2014: CRE TSD, Navigant Analysis, 2015											
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Data Sources » Commercial Refrigerated Vending Machines

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Energy Star	High	Typical	High	Typical	High	Typical	High
Cooling Capacity (Btu/hr)	DOE, 2008 / NCI Analysis, 2008	DOE, 2015: BVM Engineering Spreadsheet										
Can Capacity	CEC, 2005 / NREL, 2003 / FEMP, 2004	DOE, 2015: BVM FR TSD / Navigant Analysis, 2015										
Size (ft^3)	DOE, 2015: BVM Engineering Spreadsheet											
Energy Use (kWh/yr)	ADL, 1996 / CEC, 2008 / NREL, 2003	DOE, 2015: BVM Engineering Spreadsheet										
Energy Use ($kWh/ft^3/yr$)	Calculated											
Normalized Annual Efficiency	Calculated											
Nominal Capacity Over Average Input (Btu out / Btu in)	Calculated											
Average Life (yrs)	ADL,1996	DOE, 2015: BVM FR TSD										
Retail Equipment Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM Engineering Spreadsheet										
Total Installed Cost	Distributor Web Sites / NCI Analysis, 2008 / DOE, 2008	DOE, 2015: BVM FR TSD										
Total Installed Cost ($/kBtu/hr)	Calculated											
Annual Maintenance Cost	DOE, 2008	DOE, 2014: BVM FR TSD / Navigant Analysis, 2015										
Annual Maintenance Cost ($/kBtu/hr)	Calculated											

Commercial Ventilation

Commercial Constant Air Volume

<table>
<tr><th rowspan="2">DATA SOURCES</th><th>2003</th><th>2012</th><th colspan="4">2015</th><th colspan="2">2020</th><th colspan="2">2030</th><th colspan="2">2040</th></tr>
<tr><th>Installed Stock Average</th><th>Installed Stock Average</th><th>Low</th><th>Typical</th><th>Best</th><th>Energy Star</th><th>Typical</th><th>Best</th><th>Typical</th><th>Best</th><th>Typical</th><th>Best</th></tr>
<tr><td>System Airflow (CFM)</td><td colspan="12">CBECS 2003 & BED 2007</td></tr>
<tr><td>System Fan Power (kW)</td><td rowspan="3">ASHRAE 90.1-2004</td><td rowspan="3">ASHRAE 90.1-2007</td><td rowspan="3">ASHRAE 90.1-2010</td><td colspan="9" rowspan="3">Leidos</td></tr>
<tr><td>Specific Fan Power (W/CFM)</td></tr>
<tr><td>Annual Fan Energy Use (kWh/yr)[1]</td></tr>
<tr><td>Average Life (yrs)</td><td colspan="12">ASHRAE A37.3-2015</td></tr>
<tr><td>Total Installed Cost ($)[2]</td><td colspan="12">2016 RS Means Online</td></tr>
<tr><td>Annual Maintenance Cost ($)</td><td colspan="12">2016 RS Means Online</td></tr>
<tr><td>Total Installed Cost ($/1000 CFM)</td><td colspan="12" rowspan="2">Calculated</td></tr>
<tr><td>Annual Maintenance Cost ($/1000 CFM)</td></tr>
</table>

Commercial Variable Air Volume

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	CBECS 2003 & BED 2007											
System Fan Power (kW)	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Commercial Fan Coil Units

DATA SOURCES	2003	2012	2015				2020		2030		2040	
	Installed Stock Average	Installed Stock Average	Low	Typical	Best	Energy Star	Typical	Best	Typical	Best	Typical	Best
System Airflow (CFM)	Product Literature											
System Fan Power (kW)	Product Literature	ASHRAE 90.1-2007	ASHRAE 90.1-2010	Leidos								
Specific Fan Power (W/CFM)												
Annual Fan Energy Use (kWh/yr)[1]												
Average Life (yrs)	ASHRAE A37.3-2015											
Total Installed Cost ($)[2]	2016 RS Means Online											
Annual Maintenance Cost ($)	2016 RS Means Online											
Total Installed Cost ($/1000 CFM)	Calculated											
Annual Maintenance Cost ($/1000 CFM)												

Appendix B
References

Navigant Consulting, Inc.
1200 19th Street, NW, Suite 700
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And

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11951 Freedom Drive
Reston, VA 20190

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