SERVICE & DOMESTIC HOT WATER

SOLAR THERMAL WATER HEATING SYSTEM, RESIDENTIAL

SWWH032-01

CONTENTS

MEASURE NAME

Solar Thermal Water Heating Systems, Residential

STATEWIDE MEASURE ID

SWWH032-01

TECHNOLOGY SUMMARY

Solar thermal water heating system is a solar energy capturing device that reduces heating demand for water heating, and thus reduces energy consumption in a building. The EE Policy Manual allows the solar thermal water heating technology to be an eligible energy efficiency measure[1]:

> "For the purpose of these Rules, solar-powered, non-generating technologies are eligible energy efficiency measures (D.09-12-022, OP 1)."

A typical solar thermal water heating system consists of a storage tank and solar collectors. The main types of solar thermal water heating system are active system and passive system. The key difference between active and passive, is that the active system has circulation pumps and controls.

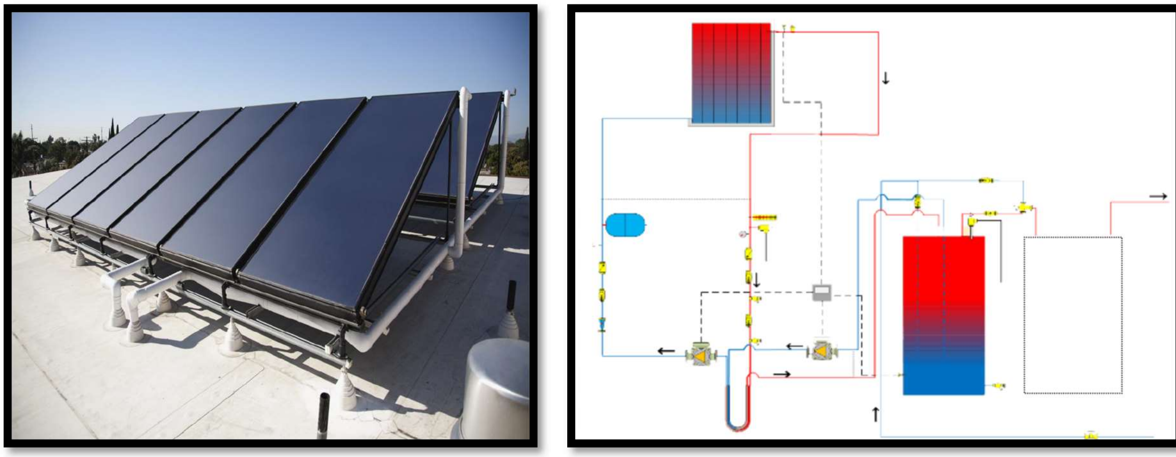
Active solar thermal systems have two types: direct forced circulation and indirect forced circulation. Both systems pump water through the solar collectors into the storage tank and/or backup water heater.

- Direct forced circulation – This system is an open loop system, which uses a pump to circulate potable water from the storage tank to the solar collector to be heated. This system is ideal for mild and moderate climate where freezing is unlikely.
- Indirect forced circulation – This system is a closed loop system with a heat exchanger. The closed loop is heated through the collector, and then passes through the heat exchanger to transfer the solar energy to the domestic hot water. The secondary loop typically has glycol or another additive, so it has good freeze protection and overheat protection making it better for less temperate climates.

Passive solar thermal systems have two types: integral collector storage and thermosyphon. Passive systems are usually not as efficient as active, but they can be more reliable as they do not have motors and other moving parts which could fail.

- Integral collector storage – The collector and storage tanks are combined into a single unit. This works best in warmer climates.
- Thermosyphon – The solar collector(s) are mounted below the storage tank. Heated water flows upward due to natural convection. This is a closed looped system and cannot be used in colder climates.

[1] California Public Utility Commission (CPUC), 2020. *Energy Efficiency Policy Manual Version 6 (page 73)*. April 2020.



Example Picture of a Solar thermal Pumped System and System Schematic

MEASURE CASE DESCRIPTION

The measure case is defined as a solar water heating system that will offset the use of gas-fired domestic water heaters and is based on the ENERGY STAR requirements as seen below. Domestic Hot Water (DHW) is defined as water used, in any type of building, for domestic purposes, principally drinking, food preparation, sanitation and personal hygiene. This does not include space heating, pool heating, or combination systems (domestic hot water & space heating). ENERGY STAR certifies solar water heating systems based on the solar uniform energy factor (SUEF) requirement. The SUEF is a simulated metric and refers to the energy delivered by the total system divided by the electrical or gas energy put into the system.[2]

- Certified ENERGY STAR solar water heaters must have a solar uniform energy factor (SUEF) ≥ 1.8 for gas backup.
- All Solar Water Heating system types are eligible, so long as they are certified by ENERGY STAR.

Measure Case Specification

Statewide Measure Offering ID	Building Type	Measure	Existing Water Heater Type
A	Single family	ENERGY STAR Solar water heating system with storage gas backup water heater	Storage Water Heater
B	Single family	ENERGY STAR Solar water heating system with tankless gas backup water heater	Storage Water Heater
C	Single family	ENERGY STAR Solar water heating system with tankless gas backup water heater	Tankless Water Heater

[2] ENERGY STAR 2021. *ENERGY STAR Program Requirements Product Specification for Residential Water Heaters, Eligibility Criteria Version 4.0*. April 5, 2021

BASE CASE DESCRIPTION

The base case is defined as a gas standard efficiency storage or tankless water heater for single family. The minimum base case efficiencies are consistent with the federal U.S. Department of Energy (DOE) standards (see Code Requirements).

Base Case Specification

Residence Type	Existing Water Heater Type	Efficiency (UEF/TE)	Input Capacity (kBtu/hr)
Single family	Storage Water Heater (50 gal)	0.57 UEF	> 25.0 and ≤ 60.0
	Tankless Water Heater	0.81 UEF	< 200

CODE REQUIREMENTS

Applicable state and federal codes and standards for residential storage water heaters are noted below.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20 (2019)	Section 1605.1(f)(2)	January 1, 2019
CA Building Energy Efficiency Standards – Title 24	Section 110.3	January 1, 2019
Federal Standards	10 CFR 430.32(d)	December 29, 2016

While there are insulation requirements for storage tanks of a solar water heating system, solar water heating systems are not required by code and do not have minimum efficiency criteria above what is required for the backup water heater.

ENERGY STAR updated specifications for Solar Water Heating systems in Version 4.0 Water Heater Specifications announced on April 5, 2021.[3] ENERGY STAR will start certifying systems according to version 4.0 using a new metric called Solar Uniform Energy Factor (SUEF) starting July 26, 2021 with the new specification taking full effect by January 5, 2022.

ENERGY STAR Version 4.0 Solar Water Heating System – Product Type Requirements

Criteria	ENERGY STAR Requirements
Solar Uniform Energy Factor	SUEF ≥ 1.8

NORMALIZING UNIT

Each (Solar Water Heating System)

[3] ENERGY STAR 2021. *ENERGY STAR Version 4.0 Water Heater Final Specification Cover Memo*. April 5, 2021

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations of measure application type, delivery type, and sector that are established for this measure are specified below. Measure application type is a categorization based on the circumstances and timing of the measure installation; each measure application type is distinguished by its baseline determination, cost basis, eligibility, and documentation requirements. Delivery type is the broad categorization of the delivery channel through which the market intervention strategy (financial incentives or other services) is targeted. This table also designates the broad market sector(s) that are applicable for this measure.

Note that some of the implementation combinations below may not be allowed for some measure offerings by all program administrators.

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Normal Replacement	DnDeemed	Res
Normal Replacement	DnDeemDI	Res
Normal Replacement	UpDeemed	Res
New Construction	DnDeemed	Res
New Construction	DnDeemDI	Res
New Construction	UpDeemed	Res

Eligible Products

Eligible products must meet the specifications in the Measure Case Description. Systems must conform to manufacturers' specifications and with all applicable electrical, plumbing and building codes and standards. Permits are required for all SWH system installations. All systems must be installed in compliance with the Solar Rating & Certification Corporation (SRCC)[4] or the International Association of Plumbing & Mechanical Officials (IAPMO)[5] standards and guidelines. Information on standards and guidelines may be found on the SRCC or IAPMO website.

Eligible Building Types and Vintages

This measure is applicable for new and existing single-family homes of any vintage.

Eligible Climate Zones

This measure is applicable in all California climate zones.

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[4] The Solar Rating & Certification Corporation (ICC-SRCC™) www.solar-rating.org

[5] The International Association of Plumbing & Mechanical Officials www.iapmo.org

PROGRAM EXCLUSIONS

Solar water heating systems used for space or pool heating are not eligible.

Participant will not be eligible for high efficiency water heater rebates for the backup water heater.

DATA COLLECTION REQUIREMENTS

The following data will be collected:

- Existing Water heating system type (storage or tankless)
- OG-300 Certification number of installed solar system
- Quantity
- Climate zone
- Backup water heater serial number
- Collector Orientation and Slope (optional)

USE CATEGORY

Service & Domestic Hot Water (SHW)

ELECTRIC SAVINGS (KWH)

The electric energy usage was based on the added electrical load of the controls and recirculating pumps of the solar water heating systems.

Energy savings are based on the Transient System Simulation Tool (TRNSYS)[6] software package that was the basis for the calculated gas savings reported in the CSI Thermal program. The software calculator[7] reflects customer-submitted conditions including tank configuration, heat exchanger type, collector arrangement, auxiliary heater information, estimated hot water demand, and building type.

The TRNSYS model used in the CSI program was modified with assumptions from DEER to better fit the savings for California and align with other water heater workpapers, including ambient air temperature, inlet water temperature, water heater setpoint temperature, and most importantly hot water draw profile from the DEER Water Heater Calculator v4.2.[8] More information on the modeling output and assumptions can be seen in the Performance study conducted by SRCC.[9]

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[6] TRNSYS is produced by Thermal Energy System Specialists, LLC (TESS). This software is used as the simulation for the CSI-Thermal SWH expected savings calculations. http://www.trnsys.com/

[7] Copy of CSI Commercial and Multifamily Residential Incentive Calculator (https://www.csithermal.com/calculator/)

[8] California Public Utilities Commission (CPUC), Energy Division. 2020. *DEER-WaterHeater-Calculator-v4.2.xlsm.* Updated September 16, 2020.

[9] Solar Rating & Certification Corporation (ICC-SRCC), 2021. *Study of Solar Water Heater Energy Savings.* June 28, 2021.

Base Case Inputs and Assumptions

The base case water heater assumptions were derived from the base case water heaters from the DEER Water Heater Calculator v4.2.[8] The technical specifications for the base case water heaters were taken from the base case Tech IDs in the water heater calculator and then applied to the Transient System Simulation Tool (TRNSYS). The models were calibrated so that the outputs for storage and tankless systems matched the water heater calculator in consumption per year for both the storage and tankless water heater baselines.

Measure Case Inputs and Assumptions

The assumptions for solar water heating systems were based on ten different solar collectors which are certified by SRCC as OG-100 collectors and have certified OG-300 systems with both auxiliary tankless water heater and storage water heater. CSI data[10] was examined to determine the most commonly installed systems for single family as part of the program, however some of the most commonly installed units were no longer in production. The list of units was expanded until 10 OG-100 certified collectors were found with certified OG-300 whole systems through SRCC that could be model in TRNSYS

While some systems are passive and do not have pumps, the average electrical consumption over 10 different systems modeled was used to determine the average electric consumption of all systems. Seven forced circulation and three passive systems were modeled which is similar to the ratio of systems installed as part of the CSI Program.

Unit Energy Savings Calculation

The unit energy savings (UES) of the solar water heating system were derived from the energy use simulation models run in TRNSYS with edited inputs as described above. A total of 20 systems were run and the savings were averaged over 10 systems in two measure classifications. The energy savings for the systems are presented as whole system savings and are not normalized on collector storage area like they are In the CSI thermal program. This is a better approximation for single family homes, as building size does not vary as much as in commercial or multifamily, and normalization on collector square footage encourages larger systems rather than higher performing systems.

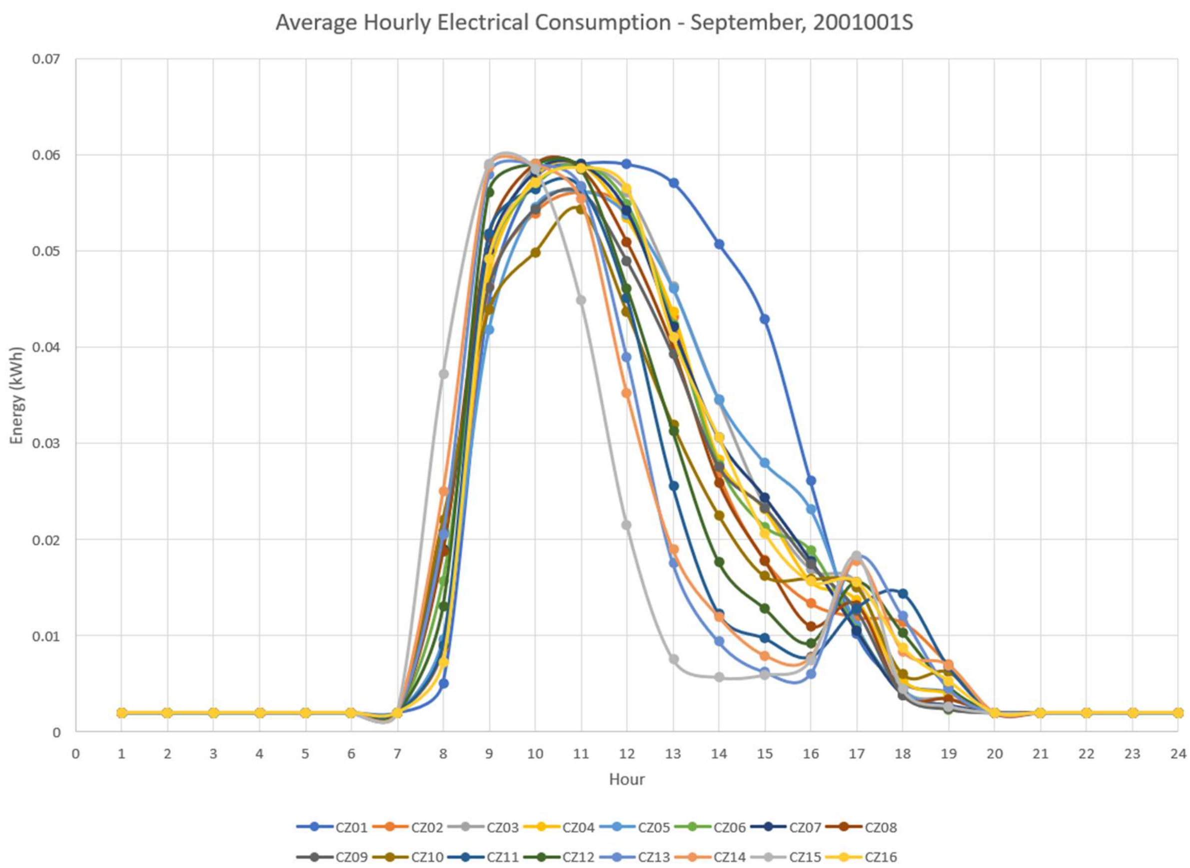
For the purposes of electric savings calculations, the electrical consumption of the base case and backup water heaters were considered to be the same and thus not considered. The added load from the pumps and controls of the solar water heating systems were modeled using TRNSYS and outputs were averaged over the 10 systems for both measure cases.

PEAK ELECTRIC DEMAND REDUCTION (KW)

The electric demand was based on the added electrical load of the controls and recirculating pumps of the solar water heating systems. In general, the pumps only run and draw electrical load during the hours

[10] California Distributed Generation Statistics, https://www.csithermal.com/public_export/ Accessed June 2021

of the day when there is sunlight generating hot water, with most of the electrical usage occurring during the hours of 7:00 am-4:00 pm, as seen in the figure below.



Example of Electrical Usage During the Month of September for one Modeled System

Modeling was done for a system with electrical consumption close to the average electrical consumption of all systems. An average of electric consumption was calculated for each hour of the day and for each month of the year. Using the Peak demand dates from the Climate Zone 2022 data[11], total consumption from the average monthly data over the 5-hour peak demand timeframe of 4-9pm was calculated and then divided by 5 hours to find the average demand during the peak window.

CZ2022 Weather File Peak Demand Days

Climate Zone	Peak Demand Start Date
CZ01	September 16
CZ02	July 8

[11] California Public Utilities Commission (CPUC), Energy Division. 2021. *DEER Draft Resolution E-5152 (Page 42)*. Updated June 8, 2021.

Climate Zone	Peak Demand Start Date
CZ03	July 8
CZ04	September 1
CZ05	September 8
CZ06	September 1
CZ07	September 1
CZ08	September 1
CZ09	September 1
CZ10	September 1
CZ11	July 8
CZ12	July 8
CZ13	July 8
CZ14	August 26
CZ15	August 25
CZ16	July 8

GAS SAVINGS (THERMS)

The gas energy savings were based on the natural gas displaced due to the use of the solar energy. The solar water heating measure is offered only to single family residential buildings.

Energy savings are based on the Transient System Simulation Tool (TRNSYS)[12] software package that was the basis for the calculated gas savings reported in the CSI Thermal program. The software calculator[13] reflects customer-submitted conditions including tank configuration, heat exchanger type, collector arrangement, auxiliary heater information, estimated hot water demand, and building type.

The TRNSYS model used in the CSI program was modified with assumptions from DEER to better fit the savings for California and align with other water heater workpapers, including ambient air temperature, inlet water temperature, water heater setpoint temperature, and most importantly hot water draw profile from the DEER Water Heater Calculator v4.2. [14] More information on the modeling output and assumptions can be seen in the Performance study conducted by SRCC.[15]

Base Case Inputs and Assumptions

The base case water heater assumptions were derived from the base case water heaters from the DEER Water Heater Calculator v4.2. The technical specifications for the base case water heaters were taken

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[12] TRNSYS is produced by Thermal Energy System Specialists, LLC (TESS). This software is used as the simulation for the CSI-Thermal SWH expected savings calculations. (http://www.trnsys.com/)

[13] CSI Commercial and Multifamily Residential Incentive Calculator (https://www.csithermal.com/calculator/)

[14] California Public Utilities Commission (CPUC), Energy Division. 2020. *DEER-WaterHeater-Calculator-v4.2.xlsm*. Updated September 16, 2020.

[15] Solar Rating & Certification Corporation (ICC-SRCC), 2021. *Study of Solar Water Heater Energy Savings.* June 28, 2021.

from the base case Tech IDs from the water heater calculator and then entered into the Transient System Simulation Tool (TRNSYS). The models were run and calibrated until the outputs for storage and tankless systems matched the water heater calculator in consumption per year for both the storage and tankless water heater baselines.

Measure Case Inputs and Assumptions

The assumptions for solar systems were based on 10 different solar collectors which are certified by SRCC as OG-100 collectors and have certified OG-300 systems with both auxiliary tankless water heater and storage water heater. CSI data was used to determine the most commonly installed systems for single family as part of the program, however some of the most commonly installed units were no longer in production. The list of units was expanded until 10 OG-100 certified collectors were found with certified OG-300 whole systems through SRCC that could be model in TRNSYS. The OG-300 certifications through SRCC certify the whole solar system including a specific collector type, piping and tank configurations, and gas water heater type and performance.

Unit Energy Savings Calculation

The unit energy savings (UES) of the solar water heating system were derived from the energy use simulation models run in TRNSYS with edited inputs as described above. A total of 20 systems were run and the savings were averaged over 10 systems in two measure classifications The energy savings for the systems are presented as whole system savings and are not normalized on collector storage area like they are In the CSI thermal program. This is a better approximation for single family homes, as size does not vary as much, and normalization on collector square footage encourages larger systems rather than higher performing systems.

Model Calibration

CSI Impact evaluation Study

An impact evaluation study conducted by Itron for the CSI thermal program was issued on November 21, 2019 provided an M&V study for the three segments of the solar program (Single Family DHW, Commercial/Multifamily DHW, and Pool heating).[16] The report provides a gross realization rates (GRR) for each program including the error bars at 90 percent confidence, as shown in the figure below.

[16] Itron, 2019. *California Solar Initiative (CSI) Thermal Impact Report*. November 21, 2019

FIGURE ES-4: GROSS REALIZATION RATE RANGE AT 90 PERCENT CONFIDENCE

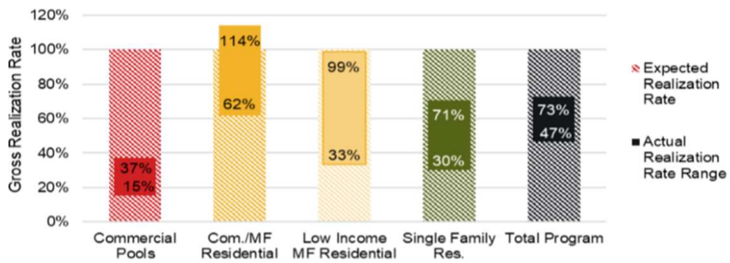

Figure 1: GRR Values from CSI thermal impact evaluation

The savings reported in the CSI program below were compared to the average CSI thermal results below using the GRR from the impact evaluation to confirm the results of the models. The modified TRNSYS models used in the workpaper calculations considered all of the suggestions presented by the impact evaluation, mainly the lower hot water draw profile of California and using ENERGY STAR criteria to eliminate low performing systems. The solar water heating system with storage backup models are all ENERGY STAR certified and should perform higher than the average CSI system. The modified TRNSYS modeling results showed systems on average had about 75% of the savings claimed in the CSI Program. The solar water heating system with tankless backup models are all ENERGY STAR certified and should perform much higher than the average CSI thermal system, as having a tankless water heater eliminates all tank losses from the auxiliary water heater. Tankless systems on average had about 137% of the savings claimed in the CSI Program, when compared to a storage baseline and 65% of the savings claimed when compared to a tankless baseline. These results were deemed to be reasonable.

Table 2: CSI thermal Claimed Average Annual Saving by Climate Zone, Single Family

Climate Zone	Single-Family DHW Savings (Therms)
CZ01	96.08
CZ02	124.55
CZ03	148.02
CZ04	135.28
CZ05	138.17
CZ06	133.87
CZ07	113.37
CZ08	124.30
CZ09	125.11
CZ10	124.96
CZ11	109.19
CZ12	114.66
CZ13	135.66
CZ14	135.25
CZ15	125.59
CZ16	119.84

LIFE CYCLE

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention did not cause the replacement or alteration.

The EUL and RUL specified for this measure are presented below and for any type of buildings (Res or Com) and any California climate zone. The EUL for this measure was adopted from a solar measure cost effectiveness study by Key Span in 2005 for the DEER06/07 update.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs) *WtrHt-SWH*	15.0	California Public Utilities Commission (CPUC). 2014. “DEER2014-EUL-table-update_2014-02-05.xlsx.”
RUL (yrs)	N/A	-

BASE CASE MATERIAL COST ($/UNIT)

The base case is a standard tankless or storage water heater respective to the measure description. To be consistent with approved water heater workpapers, the same cost source was used as the residential storage and tankless water heater workpapers (SWWH012-02 and SWWH013-02 respectively).

For storage water heaters, the material and labor costs were derived from data drawn from the 2010-2012 WO017 Ex Ante Measure Cost Study (“WO017 Study”) Final Report prepared by Itron, Inc.[17] Because this study presents material and labor cost for water heaters units rated with energy factor (EF), the EF values were converted to UEF and a regression analysis was completed to determine the cost for each corresponding UEF rating.

For tankless water heaters, the material and labor costs were derived from the U.S. Department of Energy (DOE) Technical Support Document (TSD): Pool Heaters, Direct Heating Equipment and Water Heaters (EERE-2006-STD-0129).[18] The extracted data includes both labor and material cost. While the DOE data is older than the cost data presented in the WO017 conducted by Itron, Inc., a comparison with online prices for tankless and storage water heaters confirms the DOE and WO017 data is representative of base case material costs.

[17] Itron, Inc. 2014. *2010-2012 WO017 Ex Ante Measure Cost Study Final Report.* Prepared for the California Public Utilities Commission.

[18] U.S. Department of Energy (DOE). 2009. *Technical Support Document: Energy Conservation Program for Consumer Products: Energy Conservation standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters.* Prepared by Navigant Consulting, Inc. and Lawrence Berkeley National Laboratory. Docket ID: EERE-2006-STD-129.

MEASURE CASE MATERIAL COST ($/UNIT)

The measure case labor cost was determined from the CSI Thermal Database of all projects installed under the program. For 20 modeled systems, the costs of matching systems were pulled from the database, including costs for collector, tank, permitting and other. Material costs in the CSI Thermal database include: Solar collector cost, Storage tank cost, and Permitting Costs, and the matching systems are averaged for single-family installations. Below table compares two average costs of the measure case systems to the simple average of nearly 5,800 single family installations in CSI Thermal database.

Table 3: CSI thermal Average Material Cost for Modeled Systems, Single Family

	Single-Family Costs ($)
Solar Water Heating System, Storage Backup	$5,086.06
Solar Water Heating System, Tankless Backup	$6,142.01
Average CSI Thermal Material Cost	$5,189.04

BASE CASE LABOR COST ($/UNIT)

See Base Case Material Costs.

MEASURE CASE LABOR COST ($/UNIT)

The measure case labor cost was determined from the CSI Thermal Database of all projects installed under the program. For 20 modeled systems, the costs of matching systems were pulled from the database, including costs for collector, tank, permitting and other. “Other costs” in the CSI Thermal database are assumed to be the labor cost, and the matching systems are averaged for single-family installations. Below table compares two average costs of the measure case systems to the simple average of nearly 5,800 single family installations in CSI Thermal database.

Table 4: CSI thermal Average Labor Cost for Modeled Systems, Single Family

	Single-Family Costs ($)
Solar Water Heating System, Storage Backup	$3,060.24
Solar Water Heating System, Tankless Backup	$2,666.13
Average CSI Thermal Material Cost	$2,310.27

NET-TO-GROSS (NTG)

The net-to-gross (NTG) ratio represents the portion of gross impacts that are determined to be directly attributed to a specific program intervention. This NTG value is based upon the average of all NTG ratios for all evaluated 2006 – 2008 residential programs, as documented in the 2011 DEER Update Study conducted by Itron, Inc. This sector average NTG (“default NTG”) is applicable to all energy efficiency measures that have been offered through residential programs for more than two years and for which impact evaluation results are not available.

Net-to-Gross Ratios

Parameter	Value	Source
Res-Default>2	0.55	Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.

GROSS SAVINGS INSTALLATION ADJUSTMENT (GSIA)

The gross savings installation adjustment (GSIA) rate represents the ratio of the number of verified installations of the measure to the number of claimed installations reported by the utility. This factor varies by end use, sector, technology, application, and delivery method. This GSIA rate is the current "default" rate specified for measures for which an alternative GSIA has not been estimated and approved.

Gross Savings Installation Adjustment Rates

Parameter	Value	Source
GSIA	1.0	California Public Utilities Commission (CPUC), Energy Division. 2013. *Energy Efficiency Policy Manual Version 5*. Page 31.

NON-ENERGY IMPACTS

Non-energy benefits for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

This section provides a summary of inputs and methods based upon the Database of Energy Efficient Resources (DEER), and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	No
DEER Operating Hours	No
DEER eQUEST Prototypes	No
DEER Version	n/a
Reason for Deviation from DEER	This measure is not in DEER.
DEER Measure IDs Used	n/a
NTG	Source: DEER. The NTG of 0.55 is associated with NTG ID: *Res-Default>2*
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	The value of 15 years is associated with EUL ID: *WtrHt-SWH*. Last updated in 2013.

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision
01	6/30/2021	Anders Danryd, SoCalGas	New workpaper
	7/30/2021	Anders Danryd, SoCalGas	Minor text edits and clarifications due to CPUC comments