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COMPRESSED AIR
VFD RETROFIT FOR AIR COMPRESSOR
SWCA001-02

CONTENTS

MEASURE NAME

VFD Retrofit for Air Compressor

STATEWIDE MEASURE ID

SWCA001-02

TECHNOLOGY SUMMARY

In a system with multiple compressors, a trim compressor is a compressor that is designated for part-load operation, handling the short-term variable trim load of end uses. A compressor with load/unload controls generally operates in conjunction with one or more storage tanks ("receivers"). The purpose of a receiver is to store a volume of compressed air for use when it is needed. The compressor fills the receiver, and the compressed air end users use air from the receiver. The loaded compressor fills the receiver until it reaches a certain pre-set pressure (e.g. 110 psig) and then it unloads.

As the end user uses air from the receiver, the pressure decreases. When the pressure in the receiver reaches a second pre-set pressure (e.g. 100 psig) the unloaded compressor loads again to fill the receiver. Long and/or frequent cycles of unloaded operation reduce the overall efficiency of the compressor by allowing the motor to operate while producing no compressed air. Compressor manufacturers use different strategies for unloading a compressor but, in most cases an unloaded rotary screw compressor will consume 15% to 35% of full-load horsepower while delivering no useful work.[1]

A variable speed drive (VSD) control saves energy by varying the motor speed and compressed air output to match the compressed air demand, greatly reducing or eliminating unloaded operation. A VSD controller is given a single discharge pressure setpoint, and the controls vary the speed of the motor to match this setpoint. Retrofitting a load/unload compressor that operates fully loaded (i.e. no unloading) with a VSD will not generally result in any energy savings. In fact, the VSD controller uses a certain amount of power (generally estimated to be 5% of the full load power of the compressor) to operate, so that retrofitting a fully loaded compressor will actually result in increased in energy use.

MEASURE CASE DESCRIPTION

The measure case is defined as a variable speed drive (VSD) on an existing rotary screw air compressor. Measure offerings (and therefore measure impacts) are defined by horsepower and building type, as specified below.

[1] Lawrence Berkeley National Laboratory (LBNL) and Resource Dynamics Corporation. 2003. *Improving Compressed Air System Performance: A Sourcebook for Industry.* Compressed Air Challenge Publications (U.S. Department of Energy) DOE/GO-102003-1822 (2003): 36.

Table 1. Measure Case Specification

Compressor Horsepower (hp)	Building Type
5 to < 15	Health/Medical - Hospital
	Manufacturing - Bio/Tech
	Manufacturing - Light Industrial
	Office – small
	Retail - Single-Story Large
15 to < 25	Health/Medical - Hospital
	Manufacturing - Bio/Tech
	Manufacturing - Light Industrial
	Office – small
	Retail - Single-Story Large

Due to California Building Energy Efficiency Requirements (Title 24), measure offerings are not specified for compressor air systems ≥ 25 hp.

BASE CASE DESCRIPTION

The base case is an existing rotary screw compressor using load/unload controls, with rated capacity ≥ 5 hp (4 kW) and < 25 hp (18 kW). If the compressed air system includes multiple compressors, the base case compressor operates as a trim compressor and the online capacity of the compressed air system must be less than 25 hp (18 kW) total.

CODE REQUIREMENTS

This measure is not governed by state or federal regulations. Note however that the 2016 California Building Energy Efficiency Standards (Title 24),[2] Section 120.6(e) stipulates VSD requirements for new, additions, and alterations of compressed air systems ≥ 25 hp. Section 120.6(e) is provided below for reference. Since the measure offerings specified for this measure are limited to a horsepower rating ≥ 5 hp and < 25 hp, Title 24 (2019) is not applicable to the measure.

[2] California Energy Commission (CEC). 2015. *2016 Nonresidential Compliance Manual for the 2016 Building Energy Efficiency Standards*. CEC-400-2015-033-CMF.

Table 2. Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None.	n/a
CA Building Energy Efficiency Standards – Title 24 (2019)	Section 120.6(e) Mandatory Requirements for Compressed Air Systems	January 1, 2020
Federal Standards	None.	n/a

Section 120.6(e) Mandatory Requirements for Compressed Air Systems

(e) Mandatory Requirements for Compressed Air Systems. All new compressed air systems, and all additions or alterations of compressed air systems where the total combined online horsepower (hp) of the compressor(s) is 25 horsepower or more shall meet the requirements of Subsections 1 through 3. These requirements apply to the compressors and related controls that provide compressed air and do not apply to any equipment or controls that use or process the compressed air.

EXCEPTION 1 to Section 120.6(e): Alterations of existing compressed air systems that include one or more centrifugal compressors.

EXCEPTION 2 to Section 120.6(e): Compressed Air Systems, including medical gas, serving healthcare facilities.

1. **Trim Compressor and Storage.** The compressed air system shall be equipped with an appropriately sized trim compressor and primary storage to provide acceptable performance across the range of the system and to avoid control gaps. The compressed air system shall comply with Subsection A or B below:

    A. The compressed air system shall include one or more variable speed drive (VSD) compressors. For systems with more than one compressor, the total combined capacity of the VSD compressor(s) acting as trim compressors must be at least 1.25 times the largest net capacity increment between combinations of compressors. The compressed air system shall include primary storage of at least one gallon per actual cubic feet per minute (acfm) of the largest trim compressor; or,

    B. The compressed air system shall include a compressor or set of compressors with total effective trim capacity at least the size of the largest net capacity increment between combinations of compressors, or the size of the smallest compressor, whichever is larger. The total effective trim capacity of single compressor systems shall cover at least the range from 70 percent to 100 percent of rated capacity. The effective trim capacity of a compressor is the size of the continuous operational range where the specific power of the compressor (kW/100 acfm) is within 15 percent of the specific power at its most efficient operating point. The total effective trim capacity of the system is the sum of the effective trim capacity of the trim compressors. The system shall include primary storage of at least 2 gallons per acfm of the largest trim compressor.

EXCEPTION 1 to Section 120.6(e)1: Compressed air systems in existing facilities that are adding or replacing less than 50 percent of the online capacity of the system.

EXCEPTION 2 to Section 120.6(e)1: Compressed air systems that have been approved by the Energy Commission Executive Director as having demonstrated that the system serves loads for which typical air demand fluctuates less than 10 percent.

2. **Controls.** Compressed air systems with more than one compressor online, having a combined horsepower rating of more than 100 hp, must operate with a controller that is able to choose the most energy efficient combination of compressors within the system based on the current air demand as measured by a sensor.

3. **Compressed Air System Acceptance.** Before an occupancy permit is granted for a compressed air system subject to Section 120.6(e), the following equipment and systems shall be certified as meeting the

Acceptance Requirements for Code Compliance, as specified by the Reference Nonresidential Appendix NA7. A Certificate of Acceptance shall be submitted to the enforcement agency that certifies that the equipment and systems meet the acceptance requirements specified in NA 7.13.

NORMALIZING UNIT

Compressor horsepower rating (hp)

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

All combinations all measure application type, delivery type, and sector combinations 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.

Table 3. Implementation Eligibility

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

Eligible Products

The existing compressor shall meet the following eligibility requirements:

- Must be a rotary screw compressor.
- Must have a horsepower rating ≥ 5 hp and < 25 hp (18 kW).

- Must operate in a stand-alone capacity or as a trim compressor, i.e. not base loaded in a multiple compressor system.
- Must be permanently installed.
- Customer production/output must not be modified and customer baselines hours of operation must remain the same.
- Customer must comply with Title 24: Section 120.6(e). Mandatory Requirements for Compressed Air Systems (See Code Requirements)

Eligible Building Types and Vintages

This measure is applicable only for the following building types of any vintage:

- Health/Medical - Hospital
- Manufacturing - Bio/Tech
- Manufacturing - Light Industrial
- Office – Small
- Retail - Single-Story Large

Eligible Climate Zones

This measure is applicable to any California climate zones.

PROGRAM EXCLUSIONS

Air compressor systems (online capacity) rated at 25 hp and greater are not eligible due to Title 24 (2019) code requirements.Portable compressors are not eligible.

Cyclic refrigerated dryers are not eligible.

USE CATEGORY

CompAir

ELECTRIC SAVINGS (KWH)

This measure achieves energy savings by enabling an air compressor to operate more efficiently at part load conditions. The unit energy savings (UES) and demand impacts of this measure were derived as the difference between the base and measure case energy use modeled with AIRMaster+. AIRMaster+ is a software tool created by the U.S. Department of Energy (DOE) to analyze energy use and saving opportunities in compressed air systems and is considered to be the standard analysis tool by the compressed air industry.

Base Case Model Specification

Baseline AIRMaster+ simulations were performed using several sizes of single-stage, lube-injected rotary screw compressors using load/unload controls, ranging from 5 hp to 25 hp, available in the default

AIRMaster+ equipment inventory. Default AIRMaster+ settings were retained for compressor efficiencies, unloaded power, and other controls and performance parameters. The following assumptions were made to define the compressor loading:

- Compressors run at 70% of full load capacity. Quincy Compressor recommends sizing an air compressor to the sum of all cfm required with at least an additional 25% room for growth and error.[3] As a result, a 70% full load operation is considered reasonable practice.
- Compressors are rated at 100 psig. 100 psig was chosen as a conservative assumption. System efficiency increases as operating pressure decreases; however, discharge pressures below 100 psig may cause end users to function improperly.
- System air storage volume is equivalent to two gallons per acfm of compressed air demand. This is based on the minimum storage capacity specified in the Title 24 (2019) compressed air standard.
- Compressors typically operate 24 hours per day, seven days per week for 50 weeks per year (8400 annual operating hours). However, the energy usage (kWh) for this measure analysis was scaled to match the defined operating hours for Manufacturing - Light Industrial buildings existing buildings (Com-ILtg-High Bay, 2790 hours) specified in the California Database of Energy Efficient Resources (DEER) for 2020.[4]

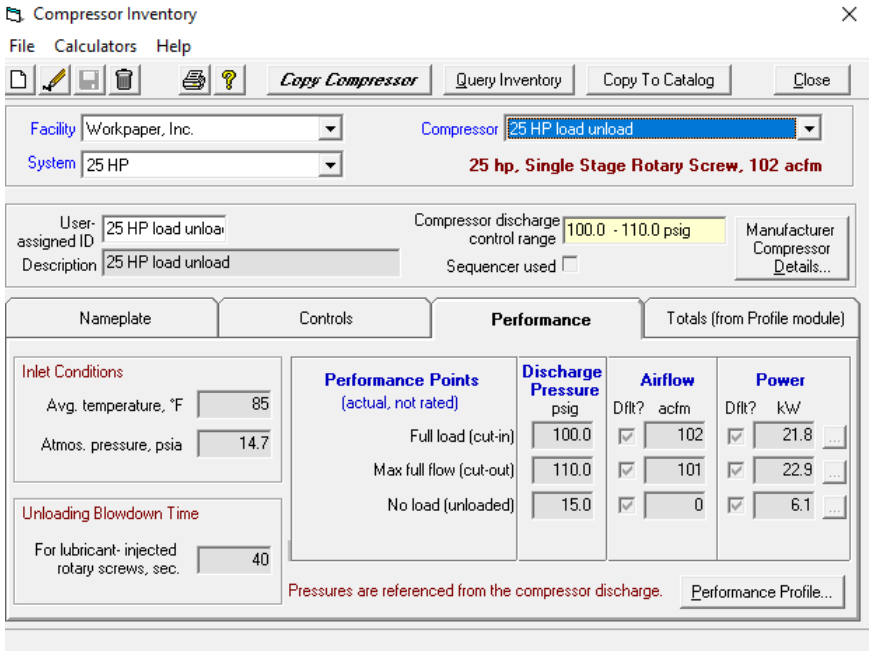

Figure 1 - Sample Baseline Compressor Inputs for AIRMaster+

[3] Quincy Compressor. (n.d.) "Air Compressor Size."

[4] California Public Utility Commission (CPUC). 2018. *Resolution E-4952. DEER 2020 Update (Effective 1/1/2020),* Section 4.

Measure Case Model Specification

AIRMaster+ does not include VSD controlled compressors in its equipment inventory, so it was necessary to construct a measure case VSD compressor in AIRMaster+ to match each base case compressor. The performance profile of each measure case compressor was based on the AIRMaster+ performance of a single-stage, lube-injected rotary screw compressor using inlet modulation with unloading controls, of equivalent size to its respective base case compressor. The default AIRMaster+ performance profile for the compressor was then modified to simulate the performance of a VSD-controlled compressor, using the following steps:

- The measure case VSD compressor was assumed to have equivalent rated air flow at 100 psig to its respective base case (load/unload) compressor.
- To account for the overhead power required to operate the added controls, the full-load power of the VSD compressor was assumed to be 105% of the full-load power of its respective load/unload compressor.
- The no-load power of the VSD compressor was assumed to be 5% of the full-load power of the load/unload compressor.
- The VSD compressor was assumed to unload at the same point (40% of full load capacity) as its respective load/unload compressor.
- The power at the unload point (40% of rated capacity) of the VSD compressor was assumed to be 45% of the full load power of the load/unload compressor.

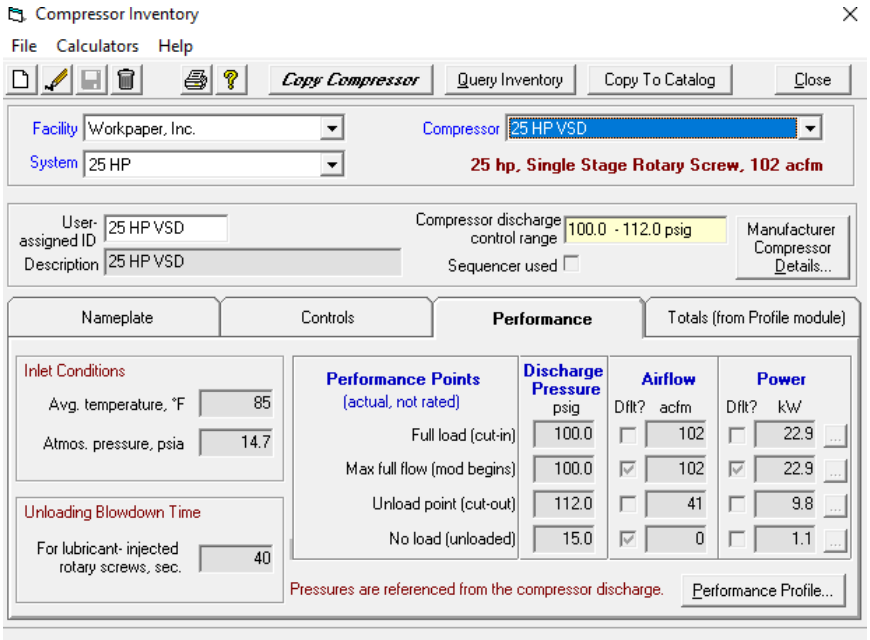

Figure 2 - Sample Measure Compressor Inputs for AIRMaster+

Unit Energy Savings and Demand Reduction

AIRMaster+ simulations yielded annual energy savings (kWh/year) and peak demand (kW), which were divided by hp ratings to calculate impacts by compressor horsepower (kWh/hp/year and kW/hp). These

were then averaged based on hp ranges specified by the two hp ranges of measure offerings. It is assumed that the air compressor system operates at constant load and performance during the 4 p.m. to 9 p.m. peak period, so specific demand reduction is calculated by dividing energy savings by annual operating hours.

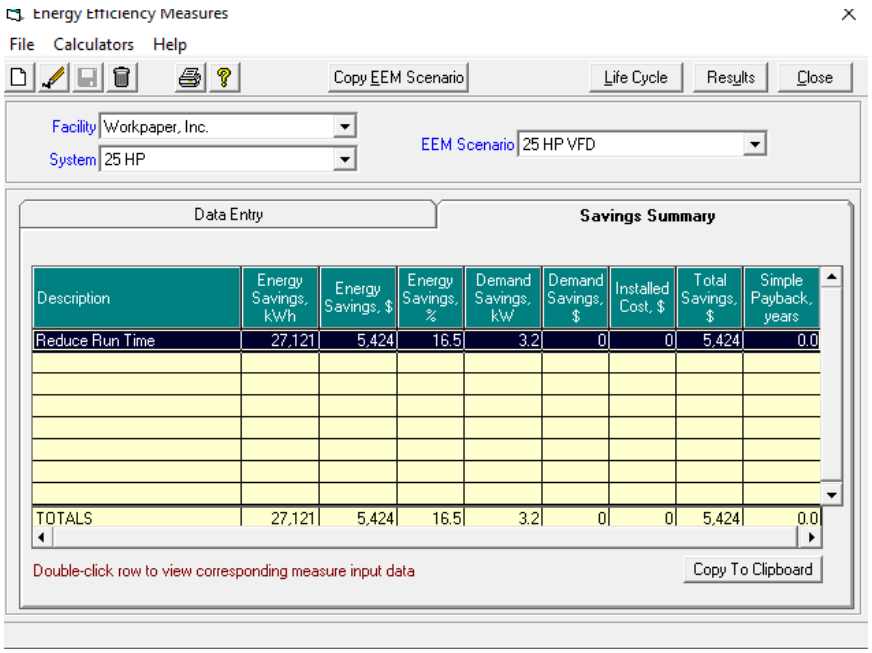

Figure 3 - Sample Savings from AIRMaster+

PEAK ELECTRIC DEMAND REDUCTION (KW)

This measure achieves demand reduction by enabling an air compressor to operate more efficiently at part load conditions. The demand impacts of this measure were derived from base and measure case energy use modeled with AIRMaster+. AIRMaster+ is a software tool created by the U.S. Department of Energy (DOE) to analyze energy use and saving opportunities in compressed air systems and is considered to be the standard analysis tool by the compressed air industry.

See Electric Savings for discussion of the methodology to derive peak demand reduction of this measure.

GAS SAVINGS (THERMS)

Not applicable.

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 not caused the replacement or alteration.

For add-on equipment, the RUL of the pre-existing ("host") equipment cannot exceed the EUL of the add-on equipment. Further, as per Resolution E-4807, the California Public Utilities Commission (CPUC) revised add-on equipment measures so that the EUL of the measure is equal to the lower of the RUL of the modified system or equipment or the EUL of the add-on component."[5]

The EUL and RUL specified for an air compressor VFD retrofit are specified below.[6] Note that RUL is only applicable for add-on equipment and accelerated replacements and is not applicable for this measure.

Table 4. Effective Useful Life and Remaining Useful Life

Parameter	Compressor 5 to < 15 hp	Compressor 15 to < 25 hp	Source
EUL (yrs)	13.0	13.0	Energy & Resource Solutions (ERS). 2005. *Measure Life Study.* Prepared for the Massachusetts Joint Utilities. November 17. Table 1-1.
RUL (yrs)	4.33	4.33	

BASE CASE MATERIAL COST ($/UNIT)

The base case screw type air compressor costs were updated to reflect the most recent costs in 2020 from the online catalogue of the OEM Air Compressor Corporation and Air Compressors Direct, both of which are distributors of air compressors and accessories. The cost data represents 16 compressors (represented by five compressor manufacturers) in the 5 hp to 20 hp range covered by this measure.

A regression analysis on the cost data was conducted to calculate the average base cost for air compressors in the 5 hp to 20 hp range. The final base case material cost was then calculated as the average across cost across all compressors.[7]

MEASURE CASE MATERIAL COST ($/UNIT)

The measure case cost for a screw type air compressor with a VSD were updated to reflect the most recent costs in 2020 from the online catalogue of the OEM Air Compressor Corporation and Air Compressors Direct, both of which are distributors of air compressors and accessories. The cost data represents 12 compressors (represented by five compressor manufacturers) in the 5 hp to 20 hp range covered by this measure.

A regression analysis on the cost data was conducted to calculate the average measure cost for air compressors in the 5 hp to 20 hp range. The final measure case material cost was then calculated as the average across cost across all compressors.

[7] Southern California Edison (SCE). 2020. "SWCA001-02 MeasureDataSpec - Air Compressor VFD 093020."

BASE CASE LABOR COST ($/UNIT)

Labor costs were averaged from the 2020 edition of RSMeans Electrical Cost Data. Labor cost for both the base case and measure are assumed to be equal.

MEASURE CASE LABOR COST ($/UNIT)

Labor costs were averaged from the 2020 edition of RSMeans Electrical Cost Data. Labor cost for both the base case and measure are assumed to be equal.

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. The relevant NTG values for the air compressor VFD retrofit are specified in Table 5. The NTG values are based upon the average of all NTG ratios for all evaluated 2006 – 2008 commercial and industrial programs, as documented in the 2011 DEER Update Study conducted by Itron, Inc. These sector average NTGs ("default NTG") are applicable to all energy efficiency measures that have been offered through commercial and industrial sector programs for more than two years and for which impact evaluation results are not available.

Table 5. Net-to-Gross Ratios

Parameter	Value	Source
NTG – Commercial	0.60	Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.
NTG – Industrial		

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. The GSIA rate specified for an air compressor VFD retrofit is included in Table 6. This GSIA rate is the current "default" rate specified for measures for which an alternative GSIA has not been estimated and approved.

Table 6. 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 DEER-based inputs and methods, and the rationale for inputs and methods that are not DEER-based.

Table 7. 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	DEER does not contain this type of measure.
DEER Measure IDs Used	n/a
NTG	The NTG of 0.60 is associated with NTG ID: *Com-Default>2yrs, Ind-Default>2yrs*
GSIA	The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	The value of 13 years is associated with EUL ID: *CompAir-Screw-VSD*.

REVISION HISTORY

Table 8. Measure Characterization Revision History

Revision Number	Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision Effective Date and Approved By
01	06/30/2018	Jennifer Holmes Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: SCE17PR005 Revision 0 (November 10, 2016) SCE13PR005 Revision 3 (February 1, 2016) WPSDGENRPR0001 Revision 0 (August 20, 2014) Consensus reached among Cal TF members.
	03/07/2019	Jesse Manao (SCE)	Updated text and measure data spec with SCE17PR005 Revision 1 (June 13, 2018) Title 24 (2019) and DEER 2020 Update
02	09/28/2020	Joseph Ling (AESC)	Updated text and measure data spec cost sources for 2020.