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APPLIANCE & PLUG LOADS

CLOTHES DRYER, RESIDENTIAL

SWAP003-03

CONTENTS

MEASURE NAME

Clothes Dryer, Residential

STATEWIDE MEASURE ID

SWAP003-03

TECHNOLOGY SUMMARY

Residential clothes dryers are designed to dry clothes by tumbling the load in a heated drum to remove moisture through evaporation. Because a horizontal axis of rotation is required to create the tumble action, residential clothes dryers are typically front-loading. Front-loading clothes dryers have an opening on the front of the unit, covered by a door, which gives access to an inner cylindrical drum where the load to be dried is placed. The inner drum is perforated and is surrounded by a larger outer housing which collects the moisture-laden air. The clothes dryer uses electricity to power an electric motor that rotates the drum within the housing, which is contained inside a cabinet. Vanes and/or surface textures may be incorporated into the inner surface of the drum to facilitate separation of the clothing to expose surface areas for drying.[1]

Definitions related to clothes dryers include the following:

- *Electric Clothes Dryer:* A cabinet-like appliance designed to dry fabrics in a tumble-type drum with forced air circulation. The heat source is electricity and the drum and blower(s) are driven by an electric motor(s).
- *Gas Clothes Dryer:* A cabinet-like appliance designed to dry fabrics in a tumble-type drum with forced air circulation. The heat source is gas and the drum and blower(s) are driven by an electric motor(s).
- *Heat Pump Clothes Dryer:* A cabinet-like appliance designed to dry fabrics in a tumble-type drum with forced air circulation. The heat source is electricity and the drum and blower(s) are driven by an electric motor(s). Hot air is created by utilizing a heat pump, which reduces drying time and increases energy efficiency. Heat pumps can be used in both vented and ventless dryers.
- *Standard Size Clothes Dryer:* A clothes dryer with a drum capacity of 4.4 cubic feet or greater.
- *Compact Clothes Dryer:* A clothes dryer with drum capacity less than 4.4 cubic feet.
- *Combined Energy Factor (CEF):* The CEF is equal to the clothes dryer test load weight in pounds divided by the sum of the per-cycle standby and off mode energy consumption and either the total per-cycle electric dryer energy consumption or the total per-cycle gas dryer energy consumption expressed in kilowatt hours (kWh).
- *Vented Clothes Dryer:* A clothes dryer that discharges moist, heated air from the cabinet, typically through a duct, to an exterior location. Vented dryers use either an open-loop or a closed-loop system with an internal condenser to remove the evaporated moisture from the heated air.
- *Ventless Clothes Dryer:* A clothes dryer that routes the moist air from the drum through a heat exchanger which condenses the water vapor from the air. The condensed water is either

[1] U.S. Department of Energy (DOE). 2011. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment – Residential Clothes Dryers and Room Air Conditioners*. Page 3-58

collected in a removable container for disposal by the user or it is discharged into a drain line. Open-loop dryers will discharge the relatively dry air into the room, while closed-loop dryers do not. Due to the risks associated with combustion byproducts in gas dryers, ventless dryers are all electrically heated.

Air is drawn through the drum of the clothes dryer by means of an electrically driven blower. This air stream is heated prior to entering the drum to evaporate the moisture in the clothing. Heating may be provided by an electrically energized resistive element. Alternatively, hot air in the drum may be supplied by means of a gas burner system whose combustion products are directed into the drum by the electrically powered blower.

Some high-efficiency clothes dryers can modulate the amount of heat entering the drum, allowing for settings at lower temperatures. This reduces the amount of energy required to heat the drum but increases the dryer run times. The most efficient electric dryers are heat pump dryers. Heat pump dryers function by recirculating the exhaust air back to the dryer after the moisture is removed by a refrigeration-dehumidification system. No heating element is needed. The warm and damp exhaust air of the dryer enters the evaporation coil where it cools down below the dew point, and sensible and latent heat are extracted. The heat is transferred to the condenser coil and reabsorbed by the air in a closed cycle.

MEASURE CASE DESCRIPTION

This measure case is defined as the residential ENERGY STAR certified clothes dryer. The following table provides the classification of high-efficiency clothes dryers that designates two efficiency tiers:

- **Basic Tier** is based upon the ENERGY STAR specification for clothes dryers (V 1.0).
- **Advanced Tier (ENERGY STAR Most Efficient, ESME)** is based upon the ENERGY STAR Most Efficient criteria. For electric heat pump clothes dryers, the CEF is based on lowest efficiency equipment on the 2019 ENERGY STAR Most Efficient list.

Measure Case Specification

Tier	Fuel Type	Size	Voltage	Product Type
Basic Tier ENERGY STAR (ENERGY STAR V1.0)	Electric	Standard	Any Voltage	Vented
				Ventless
		Compact	120VAC	Vented
				Ventless
			240VAC	Vented
				Ventless
	Gas	Any	Any Voltage	Vented
Advanced Tier (ESME) ENERGY STAR Most Efficient	Electric Heat Pump	Standard	Any Voltage	Vented
				Ventless
		Compact	120VAC	Vented
				Ventless
			240VAC	Vented
				Ventless
	Gas	Any	Any Voltage	Vented

BASE CASE DESCRIPTION

There are two base case scenarios for this measure based upon the dryer fuel type:

- A federal code compliant standard-sized gas clothes dryer.
- A federal code compliant standard-sized electric clothes dryer.

See Code Requirements for details.

Note that this workpaper specifically supports measures with same fuel type in both the base case and measure case for both electricity and gas, e.g., fuel substitution measures are not supported.

CODE REQUIREMENTS

Applicable state and federal codes and standards for ENERGY STAR Clothes Dryers are denoted below; note that the California 2019 Appliance Efficiency Regulations (Title 20) and Title 10 of the Code of Federal Regulations for clothes dryers are identical.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20 (2019)	Section 1605.1(q) Clothes Dryers	January 1, 2015
CA Building Energy Efficiency Standards – Title 24	None.	n/a
Federal Standards	10 CFR § 430.23(d) 10 CFR § 430.32(h)	January 1, 2011 January 1, 2015
Federal Standards – ENERGY STAR	ENERGY STAR Program Requirements for Clothes Dryers, Version 1.1	January 1, 2015

Title 10 of the Code of Federal Regulations requires clothes dryers to be tested under either Appendix D1 or Appendix D2 to comply.[2] The federal minimum efficiency requirements effective January 2015 were finalized with the intent that dryers would be tested under the Appendix D1 testing procedure, before Appendix D2 was adopted.

Federal Standard 10 CFR § 430.32(h) Federal Required Minimum CEF Requirements for Clothes Dryers

Product class	Combined energy factor (lbs/kWh)
i. Vented Electric, Standard (4.4 ft³ or greater capacity)	3.73

[2] Code of Federal Regulations at 10 CFR 430. Subpart B. Appendix D1 and D2.

ii. Vented Electric, Compact (120V) (less than 4.4 ft^3 capacity)	3.61
iii. Vented Electric, Compact (240V) (less than 4.4 ft^3 capacity)	3.27
iv. Vented Gas	3.30
v. Ventless Electric, Compact (240V) (less than 4.4 ft^3 capacity)	2.55
vi. Ventless Electric, Combination Washer-Dryer	2.08

Federal Standard 10 CFR § 430.23(d) Test Methodology Requirements for Clothes Dryers

(d) *Clothes dryers.* (1) The estimated annual operating cost for clothes dryers shall be—

(i) For an electric clothes dryer, the product of the following three factors: (A) The representative average-use cycle of 416 cycles per year, (B) the total per-cycle energy consumption in kilowatt-hours per-cycle, determined according to 4.1 of appendix D to this subpart, and (C) the representative average unit cost in dollars per kilowatt-hour as provided by the Secretary, the resulting product then being rounded off to the nearest dollar per year, and

(ii) For a gas clothes dryer, the product of the representative average-use cycle of 416 cycles per year times the sum of (A) the product of the gas dryer electric per-cycle energy consumption in kilowatt-hours per cycle, determined according to 4.2 of appendix D to this subpart, times the representative average unit cost in dollars per kilowatt-hour as provided by the Secretary plus (B) the product of the total gas dryer gas energy consumption per cycle, in Btu's per cycle, determined according to 4.5 of appendix D of this subpart, times the representative average unit cost in dollars per Btu as provided by the Secretary, the resulting product then being rounded off to the nearest dollar per year.

(2) The energy factor, expressed in pounds of clothes per kilowatt-hour, for clothes dryers shall be either the quotient of a 3-pound bone-dry test load for compact dryers, as defined by 2.6.1 of appendix D to this subpart or the quotient of a 7 pound bone-dry test load for standard dryers, as defined by 2.6.2 of appendix D to this subpart, as applicable, divided by the clothes dryer energy consumption per cycle, as determined according to 4.1 for electric clothes dryers and 4.6 for gas clothes dryers of appendix D to this subpart, the resulting quotient then being rounded off to the nearest hundredth (.01).

(3) Other useful measures of energy consumption for clothes dryers shall be those measures of energy consumption for clothes dryers which the Secretary determines are likely to assist consumers in making purchasing decisions and which are derived from the application of appendix D to this subpart.

ENERGY STAR requires all qualifying dryers to be tested using Appendix D2 procedures. Because the federal code requires the Appendix D1 procedure, it was necessary to map the minimum requirements tested under Appendix D1 to the equivalent values as tested under Appendix D2. The Appendix D1-Appendix D2 mapping utilized three datasets comprising of 12 standard size electric dryers and eight gas dryers. The three datasets for this exercise are presented in the following:

- The U.S. Department of Energy (DOE) January 2013 Notice of Proposed Rulemaking,[3]
- The Oak Ridge National Lab (ORNL) study on *Residential Clothes Dryer Performance Under Timed and Automatic Cycle Termination Test Procedures,*[4] and

[3] U.S. Department of Energy (DOE). 2013. *Energy Conservation Program: Test Procedures for Residential Clothes Dryers; Notice of Proposed Rulemaking.*

[4] Gluesenkamp, K. (Oak Ridge National Laboratory). 2014. *Residential Clothes Dryer Performance Under Timed and Automatic Cycle Termination Test Procedures.*

- The Pacific Northwest National Lab (PNNL) *Clothes Dryer Automatic Termination Sensor Evaluation, Volume 1.*[5]

The results of the mapping of the Appendix D1 and Appendix D2 test values are provided below.

Code of Federal Regulations for Clothes Dryers (Title 10) – Mapping of Appendix D1 and Appendix D2 Test Values

Dryer Type	Size	Voltage (V)	Minimum CEF (lbs/kWh) measured using Appendix D1	Minimum CEF (lbs/kWh) measured using Appendix D2
Ventless or Vented Electric	Standard	Any	3.73	3.10
Ventless or Vented Electric	Compact	120	3.61	2.94
Vented Electric	Compact	240	3.27	2.66
Ventless Electric	Compact	240	2.55	2.07
Vented Gas	Any	Any	3.30	2.76

Title 20 1605.1(q) California State Minimum CEF Requirements for Clothes Dryers

Table Q
Standards for Vented Electric Clothes Dryers, Ventless Electric Clothes Dryers, and Vented Gas Clothes Dryers Manufactured On or After January 1, 2015

Appliance	***Minimum Combined Energy Factor (lbs/kWh)***	
	Vented	***Ventless***
Electric, standard clothes dryers	3.73	--
Electric, compact, 120 volt clothes dryers	3.61	--
Electric, compact, 240 volt clothes dryers	3.27	2.55
Electric, combination washer-dryer	--	2.08
Gas clothes dryers	3.30	--

NORMALIZING UNIT

Each.

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

[5] TeGrotenhuis, W. (Pacific Northwest National Laboratory). 2014. *Clothes Dryer Automatic Termination Sensor Evaluation Volume 1: Characterization of Energy Use in Residential Clothes Dryers.*

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	UpDeemed	Res
Normal replacement	DnDeemed	Res
Normal replacement	DnDeemDI	Res
New construction	UpDeemed	Res
New construction	DnDeemed	Res
New construction	DnDeemDI	Res

Eligible Products

Eligible clothes dryers must comply with the ENERGY STAR (Basic Tier) OR ENERGY STAR Most Efficient (Advanced Tier) classification presented in the Measure Case Description. Advanced Tier electric clothes dryers must be heat pump clothes dryers.

Eligible Building Types

Eligible building types include any new or existing residential building, including single family, multifamily units, and double-wide mobile homes.

Eligible Climate Zones

The measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

None.

DATA COLLECTION REQUIREMENTS

Data collection requirements are to be determined.

USE CATEGORY

Appliance and plug loads (AppPlug)

ELECTRIC SAVINGS (kWh)

Unit energy savings (UES) is calculated as the difference between the baseline and measure case unit energy consumption (UEC).

$$UES = UEC_{Base} - UEC_{Measure}$$

Calculation of Unit Energy Consumption

Factors that affect the UEC of a residential clothes dryer include the efficiency of the dryer, represented by combined energy factor (CEF), the number of cycles per year that the dryer operates, the moisture content of the clothing, and the weight of the clothing dried per cycle.

$$\mathrm{UEC} = \left(\frac{(\mathrm{cycles} \times \mathrm{C}\ [\mathrm{lbs}])}{(\mathrm{CEF}\ [\frac{\mathrm{lbs}}{\mathrm{kWh}}])} \times \mathrm{RMC_{red}} \right)$$

CEF = Combined Energy Factor [lbs/kwh]
C = Weighting of clothing per cycle in pounds [lbs]
$\mathrm{RMC_{red}}$ = Ratio of remaining moisture contents

Cycles are expressed per year for either standard or compact dryers. C is the weight of clothing per cycle for the standard or compact dryer. Combined energy factor (CEF) is the weight of clothing per cycle per total energy usage for the standard or compact dryer. Total energy usage is the combination of the active mode energy usage and the standby energy usage.

$$\mathrm{CEF} = \frac{\mathrm{C}\ [\mathrm{lbs}]}{(\mathrm{E_{Active\ Cycle}} + \mathrm{E_{Standby}})}$$

$\mathrm{E_{Active\ Cycle}}$ = Dryer energy during active drying cycle
$\mathrm{E_{Standby}}$ = Standby dryer energy

Remaining moisture content (RMC_{red}) is the result from the remaining moisture content of the clothes prior to drying ($RMC_{w,D2}$), the remaining moisture content of clothes after drying ($RMC_{d,D2}$), and the remaining moisture content of the clothes washed in an ENERGY STAR washer ($RMC_{w,EnergyStar}$).

$$\mathrm{RMC_{red}} = \frac{\mathrm{RMC_{w,EnergyStar}} - \mathrm{RMC_{d,D2}}}{\mathrm{RMC_{w,D2}} - \mathrm{RMC_{d,D2}}}$$

$\mathrm{RMC_{w,D2}}$ = Remaining moisture content after washing machine from DOE Appendix D Test Procedure
$\mathrm{RMC_{d,D2}}$ = Remaining moisture content after dryer from DOE Appendix D Test Procedure
$\mathrm{RMC_{w,Energy\ Star}}$ = Remaining moisture content after washing machine for EnergyStar compliant washers

The inputs to the dryer calculations are specified below.

ENERGY STAR Electric Dryer UEC Inputs

Performance Input	Value	Source
Combined Energy Factor (CEF)	Varies	See tables below.

Performance Input	Value	Source
Number of cycles per year – standard dryer	283	U.S. Department of Energy (DOE). 2011. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment – Residential Clothes Dryers and Room Air Conditioners.* Prepared by Navigant Consulting, Inc. and Lawrence Berkeley National Laboratory.
Number of cycles per year – compact dryer	251	U.S. Department of Energy (DOE). 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers*. Prepared by Navigant Consulting, Inc. and Ernest Orlando Lawrence Berkeley National Laboratory.
Weight of clothing per cycle - standard	8.45	U.S. Department of Energy (DOE). 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers*. Prepared by Navigant Consulting, Inc. and Ernest Orlando Lawrence Berkeley National Laboratory.
Weight of clothing per cycle - compact	3.00	U.S. Department of Energy (DOE). 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers*. Prepared by Navigant Consulting, Inc. and Ernest Orlando Lawrence Berkeley National Laboratory.
Remaining moisture content of clothes *prior* to drying	57.5%	Code of Federal Regulations at 10 CFR 430, Appendix D2
Remaining moisture content of clothes *after* drying	1.75%	Code of Federal Regulations at 10 CFR 430, Appendix D2
Remaining moisture content of clothes washed in an ENERGY STAR dryer	Standard: 35% Compact: 38%	U.S. Department of Energy (DOE). 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers*. Prepared by Navigant Consulting, Inc. and Ernest Orlando Lawrence Berkeley National Laboratory.
Percent of Compact Dryers Paired with Compact or Standard Washers	Standard: 27.6% Compact: 72.4%	Hamilton, M. and A. Salazar (EMI Consulting, Inc.). 2016. "2016 PG&E Retail Products Platform (RPP) – Clothes Dryer Research Results." Memorandum for Pacific Gas & Electric. December 30.

Remaining moisture content (RMC). As per the disposition of the California Public Utilities Commission (CPUC) Energy Division issued on December 15, 2015, pending additional evaluation of the efficiency washers paired with dryers, savings calculations assume that the remaining moisture content prior to drying the load is equal to the remaining moisture content of a load washed in an ENERGY STAR clothes washer that meets the lowest current ENERGY STAR criteria.[6] Subsequently, in December 2016, EMI

[6] California Public Utilities Commission (CPUC), Energy Division. 2015. "Workpaper Disposition for PGECOAPP128 Revision 0 Retail Products Platform." December 15. Page 2.

Consulting, under contract with PG&E, published a memo presenting research on the topic. In particular, a survey of residential customers in the PG&E service territory found that each ENERGY STAR clothes dryer in the study sample was paired with an ENERGY STAR clothes washer.[7] According to the 2012 DOE Technical Support Document for residential clothes washers, the use of a 2016 ENERGY STAR-rated clothes washer results in a remaining moisture content of approximately 35% for standard sized washers and 38% for compact washers.[8] For compact clothes dryers, the RMC_{red} value is weighted between the values for both Standard and Compact Washers to account for the percent of compact dryers paired with each washer type.

Combined energy factor (CEF). The minimum CEF for Basic Tier (ENERGY STAR), Advanced Tier, and base case electric clothes dryers and the corresponding (maximum) UEC for each dryer type are provided in the following tables. (Minimum DEF determined using the Code of Federal Regulations Appendix D2 testing protocol for measuring the energy consumption clothes dryers.)

Electric Clothes Dryer Minimum CEF – Basic Tier ENERGY STAR Models

Dryer Type	Size	Voltage (V)	Minimum CEF [a] (lbs/kWh)	Max. UEC (kWh/yr)	Source
Electric Ventless or Vented	Standard	Any	3.93	363	ENERGY STAR. 2015. "ENERGY STAR Program Requirements Product Specification for Clothes Dryers Partner Commitments." Effective January 1, 2015.
Electric Ventless or Vented	Compact	120	3.80	126	
Electric Vented	Compact	240	3.45	139	
Electric Ventless	Compact	240	2.68	179	

Electric Clothes Dryer Minimum CEF – Advanced Tier ENERGY STAR Models

Dryer Type	Size	Voltage (V)	Minimum CEF (lbs/kWh)	Max. UEC (kWh/yr)	Source
Electric Heat Pump Ventless or Vented	Standard	Any	4.50	317	ENERGY STAR. 2019. ENERGY STAR qualified product list. Effective December 2019.
Electric Heat Pump Ventless or Vented	Compact	120	4.50	106	

Electric Clothes Dryer Minimum CEF – Base-Case Models

Dryer Type	Size	Voltage (V)	Minimum CEF (lbs/kWh)	Source
Electric Ventless or Vented	Standard	Any	3.73	Code of Federal Regulations at 10 CFR 430.32 (h) (3)
Electric Ventless or Vented	Compact	120	3.61	
Electric Vented	Compact	240	3.27	

[7] Hamilton, M. and A. Salazar (EMI Consulting, Inc.). 2016. "2016 PG&E Retail Products Platform (RPP) – Clothes Dryer Research Results." Memorandum for Pacific Gas & Electric. December 30.

[8] U.S. Department of Energy (DOE). 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers.* Prepared by Navigant Consulting, Inc. and Ernest Orlando Lawrence Berkeley National Laboratory. Table 7.2.1.

Dryer Type	Size	Voltage (V)	Minimum CEF (lbs/kWh)	Source
Electric Ventless	Compact	240	2.55	

Note that the federal minimum efficiency requirements are based on the testing method described in the Appendix D1 protocol of the Code of Federal Regulations. Manufacturers are not required to test under the Appendix D2 protocol, but they can if they choose. The ENERGY STAR specification for clothes dryers requires all qualifying dryers to be tested using Appendix D2 procedures. Thus, it was necessary to map the minimum requirements tested under Appendix D1 to their equivalent values as tested under Appendix D2. The Appendix D1-Appendix D2 mapping utilized three datasets comprising of 12 standard size electric dryers and eight gas dryers. The three datasets are presented in the following:

- The U.S. Department of Energy (DOE) January 2013 Notice of Proposed Rulemaking,[9]
- The Oak Ridge National Lab (ORNL) study on *Residential Clothes Dryer Performance Under Timed and Automatic Cycle Termination Test Procedures,*[10] and
- The Pacific Northwest National Lab (PNNL) *Clothes Dryer Automatic Termination Sensor Evaluation, Volume 1.*[11]

A comparison of the results of these tests for electric clothes dryers is provided below.

[9] U.S. Department of Energy (DOE). 2013. *Energy Conservation Program: Test Procedures for Residential Clothes Dryers; Notice of Proposed Rulemaking.*

[10] Gluesenkamp, K. (Oak Ridge National Laboratory). 2014. *Residential Clothes Dryer Performance Under Timed and Automatic Cycle Termination Test Procedures.*

[11] TeGrotenhuis, W. (Pacific Northwest National Laboratory). 2014. *Clothes Dryer Automatic Termination Sensor Evaluation Volume 1: Characterization of Energy Use in Residential Clothes Dryers.*

Comparison of DOE Appendix D1 and D2 Residential Clothes Dryer Test Protocols

Dryer Type	Size	Voltage (V)	Source	Appendix D1 CEF (lbs/kWh)	Appendix D2 CEF (lbs/kWh)
Electric Vented	Standard	Any	DOE	3.58	3.16
			DOE	3.93	2.73
			DOE	3.83	3.49
			DOE	3.71	3.48
			DOE	3.90	3.51
			DOE	3.80	2.71
			DOE	3.84	3.06
			DOE	3.71	3.11
			PNNL	3.99	3.22
			PNNL	4.01	3.41
			ORNL	3.92	3.19
			ORNL	3.78	3.19
			Avg	**3.83**	**3.19**
Electric Vented	Compact	240	DOE	3.53	3.32
			DOE	3.56	2.27
			PNNL	3.69	3.19
			ORNL	3.74	3.51
			ORNL	3.74	3.14
Electric Vented		120	DOE	3.75	2.18
Electric Ventless		240	DOE	2.98	2.73
			Avg	**3.57**	**2.91**

Based on these results, a conversion factor was developed to convert the minimum CEF per federal regulations to an equivalent Appendix D2 CEF value. For example, the conversion factor for electric vented standard dryers is 3.19 (D2) / 3.83 (D1) = 0.83. The converted code baseline can then be directly compared to the minimum ENERGY STAR CEF.

The converted Appendix D2 equivalent federal minimum CEF values with the UEC for each dryer type are shown below.

Converted Electric Clothes Dryer CEF Assumptions – Base Case Models

Dryer Type	Size	Voltage (V)	Appendix D1 Minimum CEF (lbs/kWh)	Appendix D2 Equivalent Minimum CEF (lbs/kWh)	UEC (kWh/yr)
Electric Ventless or Vented	Standard	Any	3.73	3.10	460
Electric Ventless or Vented	Compact	120	3.61	2.94	163
Electric Vented	Compact	240	3.27	2.66	180
Electric Ventless	Compact	240	2.55	2.08	231

Calculation of Unit Energy Savings

Unit energy savings (UES) are calculated as the difference between the baseline and measure case unit energy consumption (UEC).

$$UES = UEC_{Base} - UEC_{Measure}$$

HVAC Interactive effects are applied to energy use that occurs within a conditioned space and are not applied to energy use that occurs in unconditioned spaces. The updated UES values based on HVAC IE are weighted based on the percent of dryers located in conditioned and unconditioned spaces[12]. The UES values were adjusted for interactive effects using the DEER internal gain fractions shown below. Interactive effects apply in full to the UES of ventless dryers and to 20% of the UES of vented electric dryers. The factor of 20% was adopted from the Database of Energy Efficient Resources (DEER) values for the internal gain fractions for residential appliances.

Because interactive effects factors specific to clothes dryers were not available, HVAC interactive effects factors for screw-in lamps were applied to the clothes dryer measure savings. Interactive effects were drawn from DEER2020-Res-InLtg Res-Indoor-Screw interactive effects table for existing vintage, residential building types for all climate zones. As the lighting HVAC IE are based on electrical impact values (kWh), the UES values used to calculate the HVAC interactive effects are calculated using UES in kWh per year. The HVAC IE is then added to the relevant UES for each fuel (kWh and therms).

Application of Interactive Effects

Dryer Location	% of Dryers	Source
Conditioned Space	66.1%	Hamilton, M. and A. Salazar (EMI Consulting, Inc.). 2016. "2016 PG&E Retail Products Platform (RPP) – Clothes Dryer Research Results." Memorandum for Pacific Gas & Electric. December 30.
Unconditioned Space	33.9%	

DEER Internal Gain Fractions of Clothes Dryers[13]

Dryer Fuel Type	Electric Internal Gains		Gas Internal Gains	
	Sensible	Latent	Sensible	Latent
Clothes Dryer – Electric	0.15	0.05	-	-
Clothes Dryer – Gas	1.00	0.00	0.10	0.05

PEAK ELECTRIC DEMAND REDUCTION (kW)

Peak demand impacts are expected from this measure. There is an expected decrease in demand when converting from electric resistance to heat pump technologies. However, no studies could be found with measured peak demand impacts for clothes dryer equipment.

DEER2020 does not include residential load shapes for clothes dryers but does include residential load shapes for clothes and dish washers (Res_ClothesDishWasher). Due to similar operating times, this load shape was selected for clothes dryers. In order to estimate the peak demand, the energy savings (kWh)

[12] Hamilton, M. and A. Salazar (EMI Consulting, Inc.). 2016. "2016 PG&E Retail Products Platform (RPP) – Clothes Dryer Research Results." Memorandum for Pacific Gas & Electric. December 30.

[13] California Public Utilities Commission (CPUC), Energy Division. 2015. "Workpaper Disposition for PGECOAPP128 Revision 0 Retail Products Platform." December 15. Page 5.

for both measures were applied to the load shape. Subsequently, the average of the hourly values for the DEER2020 peak period was calculated for each climate zone. The DEER peak period is calculated for the hours of 4:00 PM to 9:00 PM on three consecutive days specific to each climate zone. The table below shows the DEER Peak Period days for each climate zone.

Climate Zone	Month	Start Day	End Day
CZ01	9	16	18
CZ02	7	8	10
CZ03	7	8	10
CZ04	9	1	3
CZ05	9	8	10
CZ06	9	1	3
CZ07	9	1	3
CZ08	9	1	3
CZ09	9	1	3
CZ10	9	1	3
CZ11	7	8	10
CZ12	7	8	10
CZ13	7	8	10
CZ14	8	26	28
CZ15	8	26	28
CZ16	7	8	10

Peak demand reduction is then calculated by multiplying UES value to corresponding climate zone with average load shape during the peak period at corresponding climate zone.

GAS SAVINGS (THERMS)

Unit energy savings (UES) can be calculated as the difference between the baseline and measure case and unit energy consumption (UEC).

Calculation of Unit Energy Consumption

The factors that affect the UEC of a residential clothes dryer are the efficiency of the dryer (as represented by the combined energy factor, CEF), the number of cycles per year that the dryer operates, and the weight of clothing dried per cycle.

$$UEC = \frac{cycles \times C}{CEF} \times RMC_{red}$$

UEC	=*Unit energy consumption (therms)*
C	=Weighting of clothing per cycle in pounds [lbs]
CEF	= *Combined energy factor (CEF) (lbs/kWh)*
RMC_{red}	= *Remaining moisture content*

$$RMC_{red} = \frac{RMC_{w,ENERGY\ STAR} - RMC_{d,D2}}{RMC_{w,D2} - RMC_{d,D2}}$$

RMC_{red}	= *Remaining moisture content (RMC) of clothes washed in ENERGY STAR clothes washers*
$RMC_{w,D2}$	= *Remaining moisture content of clothes prior to drying*
$RMC_{d,D2}$	= *Remaining moisture content of clothes after drying*
$RMC_{w,ENERGY\ STAR}$	= *Remaining moisture content of clothes washed in an ENERGY STAR dryer*

The inputs to the gas dryer UEC calculations are specified below.

ENERGY STAR Gas Dryer Unit Energy Consumption Calculation Inputs

Performance Input	Value	Source
Combined Energy Factor (CEF) – baseline	3.30	Code of Federal Regulations at 10 CFR 430.32 (h) (3)
Combined Energy Factor (CEF) – Basic Tier ENERGY STAR	3.48	ENERGY STAR. 2015. "ENERGY STAR Program Requirements Product Specification for Clothes Dryers Partner Commitments." Effective January 1, 2015.
Combined Energy Factor (CEF) – Advanced Tier ENERGY STAR	3.80	ENERGY STAR. 2017. "ENERGY STAR Most Efficient Recognition Criteria: Clothes Dryers." Effective January 2017.
Number of cycles per year – standard dryer	274	U.S. Department of Energy (DOE). 2011. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment – Residential Clothes Dryers and Room Air Conditioners*. Prepared by Navigant Consulting, Inc. and Lawrence Berkeley National Laboratory.
Weight of clothing per cycle - standard	8.45	U.S. Department of Energy (DOE). 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers*. Prepared by Navigant Consulting, Inc. and Ernest Orlando Lawrence Berkeley National Laboratory.
Remaining moisture content of clothes *prior* to drying	57.5%	Code of Federal Regulations at 10 CFR 430, Subpart B, Appendix D2
Remaining moisture content of clothes *after* drying	1.75%	Code of Federal Regulations at 10 CFR 430, Subpart B, Appendix D2
Remaining moisture content of clothes washed in an ENERGY STAR dryer	35%	U.S. Department of Energy (DOE). 2012. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers*. Prepared by Navigant Consulting, Inc. and Ernest Orlando Lawrence Berkeley National Laboratory.

Note that the federal minimum efficiency requirements are based on the testing method described in the Appendix D1 protocol of the Code of Federal Regulations. Currently manufacturers are not required to test under the Appendix D2 protocol, but they can if they so choose. Furthermore, as noted above, ENERGY STAR requires testing under the Appendix D2 protocol for their certification process. The Appendix D1 and Appendix D2 test protocols give very different CEF values, which cannot be directly compared. However, the DOE did some tests under both protocols in their 2013 Notice of Proposed Rulemaking on Test Procedures for Residential Clothes Dryers (U.S. Department of Energy, Energy Efficiency & Renewable Energy, 2013). Oak Ridge National Laboratory (ORLN) and Pacific Northwest

National Laboratory (PNNL) also carried out some testing to compare CEF values across the test protocols. The following table provides the results of these tests for gas clothes dryers.

DOE Appendix D1 and D2 Residential Gas Clothes Dryer Test Protocol Comparison

Product Type	Size	Voltage (V)	Source	Appendix D1 CEF (lbs/kWh)	Appendix D2 CEF (lbs/kWh)
Vented Gas	Standard (≥ 4.4 ft^3)	Any	DOE	3.43	2.70
			DOE	3.31	2.87
			DOE	3.49	3.07
			DOE	3.39	2.69
			DOE	3.37	3.25
			DOE	3.37	2.94
			PNNL	3.35	2.54
			ORNL	3.74	2.93
			Avg	**3.43**	**2.87**

Based on these results, a simple conversion factor was used to convert the minimum CEF per federal regulations to an equivalent D2 CEF. The conversion factor for a vented gas standard dryer is: 2.87 (D2)/3.43 (D1) = 0.84. The converted code baseline can then be directly compared to the minimum ENERGY STAR CEF. The converted Appendix D2 equivalent federal minimum CEF is 2.76 lbs/kWh. Using this value for the CEF of a base case gas dryer results in a baseline UEC of 500 kWh/year.

Calculation of Unit Energy Savings

Unit energy savings (UES) can be calculated as the difference between the baseline and measure case and UEC.

$$UES = UEC_{Base} - UEC_{Measure}$$

Unit energy savings of Gas Clothes Dryers are then converted to gas savings by multiplying with the conversion factor of 0.03412 therms/kWh. There is no gas savings for Electric Clothes Dryers.

Interactive Effects. The replacement of a clothes dryer with a more efficient clothes dryer sees a Therms penalty through HVAC Interactive Effects (IE). See the previously discussed Interactive Effects section for Therms calculation due to interactive effects.

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 cause the replacement or alteration.

The EUL specified for a residential clothes dryer is specified below. The RUL is only applicable to the first baseline period for a retrofit measure with an applicable code baseline, and thus is not applicable to this measure.

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs): Appl-EffCD	12.0	Appliance Magazine. 2013. "The U.S. Appliance Industry: Market Value, Life Expectancy & Replacement Picture 2013." January. Page 9.
RUL (yrs)	n/a	-

BASE CASE MATERIAL COST ($/UNIT)

The base case material cost for equipment *delivered via direct install* is equal to $0.

Baseline clothes dryer costs were obtained through online price research from various retailer websites in the last quarter of 2019 and first quarter of 2020. As the baseline represents standard gas and electric clothes dryers with a code compliance CEF, Energy Start model prices were excluded.

Standardized Electric Baseline Cost

Technology	Size	Voltage	Average ECD Cost	Sample Count
Electric Clothes Dryer (ECD)	Standard	Any	$747.23	53
Electric Clothes Dryer (ECD)	Compact	120	$466.93	13
Electric Clothes Dryer (ECD)	Compact	240	$668.94	3
Electric Clothes Dryer (ECD)	Compact	240	$753.54	22
Natural Gas Clothes Dryer (NGCD)	Any	Any	$869.14	97

MEASURE CASE MATERIAL COST ($/UNIT)

Measure case material costs for the Basic Tier clothes dryers for *all delivery types* were estimated from a hedonic price model that utilized web-scraped ("web harvested") data.[14] The time series of data combined with the hedonic price model will support a broader program effort to understand the dynamics between product attributes and price. This approach and the results for residential clothes dryers are documented by Energy Solutions in its 2016 memorandum to Pacific Gas and Electric Company.[15]

The web harvester collects data from retailer websites using one of two methods: 1) through a retailer Application Program Interface (API), which provides all the information presented on the retailer website in table format, or 2) using screen scraping methods, in which an automated script is run to collect product attribute data page-by-page.[16] Through these methods, the web harvester collects product data including retailer, brand, model number, price, and relevant product specification data (both related and unrelated to product energy consumption). The web harvester can collect hundreds or thousands of data points for a specific product at a single point in time to develop a large sample size. Minimal additional effort is needed to replicate the process so that data are collected on an ongoing basis, which can help identify changes in product price over time.

Additionally, the web-harvester collects data for different locations to identify potential differences in price by region. For example, some online retailers, such as Home Depot, display online prices based on the assumed zip code of the user browsing the website. Web harvesters can be programmed to search from any zip code, so it is possible to collect and compare prices from all over the country.

Hedonic price models were created to estimate the incremental measure cost (IMC). Hedonic price modeling is often used to estimate the individual contribution of model characteristics (including energy efficiency) to the product's price. It is most commonly estimated using regression analysis. This is the method utilized in the 2010-2012 Measure Cost Study to identify key drivers of price and determine the fraction of price explained by specific variables (such as energy efficiency). As outlined in Young et al. (2014), the key drivers of cost may be unrelated to energy efficiency, such as brand. In this modeling approach, IMC is defined as the fraction of cost difference between program qualified and non-program qualified that can be attributed to energy efficiency. For example, if the measure is an ENERGY STAR product and the base case is a non-ENERGY STAR product, IMC is defined as the fraction of incremental cost that can be attributed to the ENERGY STAR certification. The IMC can be different for various models, and therefore a weighted average is calculated across multiple model-specific IMC values to establish an overall IMC by product.

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[14] Energy Solutions. 2015. "Analysis of Incremental Measure Costs for the Retail Products Portfolio." Memorandum submitted to Brian Smith, Pacific Gas & Electric Company.

[15] Energy Solutions. 2015. "Analysis of Incremental Measure Costs for the Retail Products Portfolio." Memorandum submitted to Brian Smith, Pacific Gas & Electric Company.

[16] Young, D., M. McGaraghan, N. Dewart, D. Hopper, P. Borocz, F. Kaser, et al. 2014. "Leveraging Big Data to Develop Next Generation Demand Side Management Programs and Energy Regulations." Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings, 11-332. Washington, DC: American Council for an Energy Efficient Economy (ACEEE).

Note that the 2010-2012 Measure Cost Study conducted by Itron does not cover residential clothes dryers.[17] Moreover, while the 2010-2012 Measure Cost Study utilized point-of-sale data to determine IMC, the data is limited to a specific time period. Retail product pricing is dynamic in nature and the pricing of highly efficient or new products may decrease more quickly than the pricing of less efficient products.[18] Due to the lack of product coverage and the need to determine how product retail prices change over time, the applicability of the 2010-2012 Measure Cost Study data is limited to providing a general analytical framework for establishing IMCs for measures delivered through the retail channel.

Electric Clothes Dryers

Measure case and base case material costs were estimated from a hedonic price model that utilized web-scraped data from five online retailers (Best Buy, Home Depot, Lowes, Sears, and WalMart) that yielded 492 initial product models and approximately 130 initial attributes. The estimated incremental measure cost (IMC) for electric clothes dryers is statistically significant at the 0.11 level, but not at the pre-established 0.05 level. This point estimate is the most credible initial IMC value, however.

An ENERGY STAR Most Efficient qualifying dryer (Advanced Tier) commands a high price premium (due to incorporation of heat pump technology for electric dryers). Heat pump clothes dryer material costs are adopted from SWAP014-01 'Gas to Heat Pump Clothes Dryer' workpaper. Heat pump clothes dryers were based on approved equipment in the ENERGY STAR Most Efficient 2019 listings. Clothes dryers that comprise these listings are the best in class for energy savings. Measure case costing for these heat pump clothes dryers was obtained through online price research from various retailer websites in the fourth quarter of 2019. Sample size of the measure case is significantly smaller than the base case due to the lower number of appliances that make the ENERGY STAR Most Efficient listings.

Standardized Measure Cost

Technology	Size	Voltage	Average HPCD Cost	Sample Count
Electric Clothes Dryer (ECD)– ENERGY STAR Basic Tier	Any	Any	$940.00	81
Heat Pump Clothes Dryer (HPCD) – Advanced Tier	Compact	120	$1,399.00	6
Heat Pump Clothes Dryer (HPCD) – Advanced Tier	Compact	240	$1,248.08	28

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

[18] Young, D., M. McGaraghan, N. Dewart, D. Hopper, P. Borocz, F. Kaser, et al. 2014. "Leveraging Big Data to Develop Next Generation Demand Side Management Programs and Energy Regulations." Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings, 11-332. Washington, DC: American Council for an Energy Efficient Economy (ACEEE).

Desroches, L.-B., K. Garbesi, C. Kantner, R. Van Buskirk, H.-C. Yang, and M. Ganeshalingam. 2013. *Trends in the Cost of Efficiency for Appliances and Consumer Electronics.* May 9.

Heat Pump Clothes Dryer (HPCD) – Advanced Tier	Standard	Any	$1,507.63	14

Gas Clothes Dryers

As discussed in Energy Solutions' 2016 memorandum[19] to Pacific Gas and Electric Company the costs for the ENERGY STAR Basic Tier gas dryer is assumed to be the same as the electric dryer. This assumption is used in this workpaper as well, however future revisions of this workpaper will further evaluate this assumption.

At the time of this analysis, there were no gas clothes dryers on the market that meet the Advanced Tier requirement (ENERGY STAR Most Efficient). Nonetheless, an Advanced Tier gas clothes dryer will command a high price premium. Because there are currently no models available on the market, a regression analysis was not feasible for Advanced Tier gas dryers. Until better data becomes available, the cost for Advanced Tier gas dryers is assumed to be the same as the cost for Advanced Tier electric dryers standard size.

BASE CASE LABOR COST ($/UNIT)

For *all delivery types*, a high efficiency model does not require additional installation labor compared to a base case model. Since this measure is applicable for normal replacement and new construction installations, the base case and measure case model installation costs are expected to be the same for the customer and thus not estimated for the incremental cost analysis.

MEASURE CASE LABOR COST ($/UNIT)

For *all delivery types*, a high efficiency model does not require additional installation labor compared to a base case model. Since this measure is applicable for normal replacement and new construction installations, the base case and measure case model installation costs are expected to be the same for the customer and thus not estimated for the incremental cost analysis.

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. According to the disposition issued by the California Public Utilities Commission (CPUC) Energy Division issued on December 15, 2015, these NTG values were derived from a variety of analyses and are intended to represent short-term (one to two years) program

[19] Energy Solutions. 2015. "Analysis of Incremental Measure Costs for the Retail Products Portfolio." Memorandum submitted to Brian Smith, Pacific Gas & Electric Company.

outcomes.[20] Additionally, "default" NTGs are assigned to qualified dryers that are incentivized downstream or Advanced Tier Electric Heat Pump only, Downstream. The residential default values are 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. These sector average NTGs ("default NTGs") are applicable to all energy efficiency measures that have been offered through residential programs based on the years that programs have been running.

Net-to-Gross Ratios

Parameter	NTG ID	Clothes Dryer – Gas	Clothes Dryer – Electric	Source
Midstream or Upstream	*NonRes-sAll-mRfg-DG (placeholder)*	0.30	0.20	California Public Utilities Commission (CPUC), Energy Division. 2015. "Workpaper Disposition for PGECOAPP128 Revision 0 Retail Products Platform." December 15. Page 8.
Downstream	*Res-Default>2*	0.55	0.55	Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Page 15-4 Table 15-3.
Advanced Tier, Electric Heat pump only, Downstream	*All-Default<=2yrs*	N/A	0.70	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 impacts for this measure have not been quantified.

DEER DIFFERENCES ANALYSIS

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

[20] California Public Utilities Commission (CPUC), Energy Division. 2015. "Workpaper Disposition for PGECOAPP128 Revision 0 Retail Products Platform." December 15. Page 7.

DEER Difference Summary

DEER Item	Comment
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	Source: DEER2020. The value of 0.55 is associated with NTG ID: *Res-Default>2* The value of 0.70 is associated with NTG ID: All-Default<=2yrs. This is only applicable to the Advanced Tier Electric heat pump clothes dryer measure (downstream). The value of 0.30 and 0.20 are not associated with *NTG IDs,* thus the ID *NonRes-sAll-mRfg-DG* is used as a proxy.
GSIA	Source: DEER. The value of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	The EUL of 12 years is associated with EUL ID: *Appl-EffCD*

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Complete Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision Effective Date and Approved By
01	10/31/2017	Jennifer Holmes Cal TF Staff	Draft of consolidated text for this statewide measure is based upon: PGECOAPP128, Revision 6 (January 30, 2018) PGECOAPP128, Revision 3 (March 29, 2017) PGECOAPP129, Revision 1 (April 4, 2016) Consensus reached among Cal TF members.
	12/27/2018	Jennifer Holmes Cal TF Staff	Revisions in preparation for submittal of version 01
02	4/6/2020	Lake Casco, PE TRC	Updated Advanced Tier electric measure to require heat pump clothes dryer and efficiencies corresponding to similar Fuel Substitution Measure (SWAP014-01) Updated baseline electric and gas, and electric heat pump measure costs Updated savings calculations with new HPCD CEF Update savings methodology for all measures to include HVAC IE and CDF specific to each CZ Added new NTG for heat pump clothes dryer measure Made New Construction MAT applicable to all delivery types
02	05/06/2020	Andres Fergadiotti / SCE	Removed language on "Gas baseline for new construction" Updated EAD table – Bldg Type field
02	05/28/2021	Andres Fergadiotti / SCE	Workpaper packaged resubmitted to include updated/corrected EAD table per CalTF feedback.
03	12/08/2020	Soe Hla/ PG&E	Revision update due to matching incorrect energy savings between EAD and Data Spec (see below), IE Table is updated from IOUs to Any which in turn causes energy saving changes in CZ13, correcting RMC equation, fixing incorrect UEC values on Advanced Tier Electric Heat Pumps and incorrect Compact 240V Electric Clothes Dryer Baseline Cost, Reformatting NTG table and minor updates The following energy savings for Measure IDs are swapped on Data Spec- Measure Specific Constants Tab and EAD- EnergyImpactExAnte tab. • A to B • B to A • C to D • D to C • H to I • I to H • J to K • K to J
03	06/25/2021	Soe Hla/ PG&E	Addressed CPUC feedback and updated the data collection requirement to limit workpaper updates to ensure stability in offerings.