**Work Paper PGECOPRO101**

**Process Boiler**

**Revision 4**

**Pacific Gas & Electric Company**

**Customer Energy Solutions**

**Process Boiler**

**Measure Codes H11, H15**

# At-A-Glance Summary

|  |  |  |
| --- | --- | --- |
| **Applicable Measure Codes:** | **H11 – Water Process Boiler** | **H15 – Steam Process Boiler** |
| **Measure Description:** | Replacement of process water boiler with new boiler. Must have combustion test to verify combustion efficiency of 85% or better and input rating < 20,000 kBTUh | Replacement of process steam boiler with new boiler. Must have combustion test to verify combustion efficiency of 83% or better and input rating < 20,000 kBTUh |
| **Energy Impact Common Units:** | Per kBTUh of boiler rated input | Per kBTUh of boiler rated input |
| **Base Case Description:** | Process water boiler with **combustion efficiency of 82%.**  Source: 2013 Title 24 | Process steam boiler with **combustion efficiency of 80%.**  Source: 2013 Title 24 and DOE Steam Tip Sheet |
| **Base Case Energy Consumption:** | **36.7 Therms / kBTUh**  Source: Engineering Calculations | **36.7 Therms / kBTUh**  Source: Engineering Calculations |
| **Measure Energy Consumption:** | **33.6 Therms / kBTUh**  Source: Engineering Calculations | **34.8 Therms / kBTUh**  Source: Engineering Calculations |
| **Energy Savings (Base Case – Measure)** | **3.1 Therms / kBTUh**  Source: Engineering Calculations | **1.9 Therms / kBTUh**  Source: Engineering Calculations |
| **Costs Common Units:** | Per kBTUh of boiler rated input | Per kBTUh of boiler rated input |
| **Base Case Equipment Cost ($/unit):** | **$12.22/kBTUh**  Source: SCG WP 2012 Data | **$14.89/kBTUh**  Source: SCG WP 2012 Data |
| **Measure Equipment Cost ($/unit):** | **$15.17/kBTUh**  Source: SCG WP 2012 Data | **$19.24/kBTUh**  Source: SCG WP 2012 Data |
| **Measure Incremental Cost ($/unit):** | **$2.95/kBTUh**  Source: SCG WP 2012 Data | **$4.35/kBTUh**  Source: SCG WP 2012 Data |
| **Effective Useful Life (years):** | EUL: 20yrs  RUL: 6.67yrs  Source: DEER 2016 | EUL: 20yrs  RUL: 6.67yrs  Source: DEER 2016 |
| **Program Type:** | ROB | ROB |
| **Net-to-Gross Ratios:** | 0.60  Source: DEER 2014 NTG Values – Industrial; All other EEMs with no evaluated NTGR; existing EEM programs with same delivery mechanism for more than 2 years | 0.60  Source: DEER 2014 NTG Values – Industrial; All other EEMs with no evaluated NTGR; existing EEM programs with same delivery mechanism for more than 2 years |
| **Important Comments:** |  |  |

# Document Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Revision #** | **Revision Date** | **Section-by-Section Description of Revisions** | **Author (Company)** |
| **Revision 0** | **02/27/08** | **Original workpaper:**  **Process BoilerPGECOPRO101 R0.doc** | **Jim Kelsey and Nicolas Fauchier-Magnan (kW Engineering)** |
| **Revision 1** | **3/23/2010** | **Process BoilerPGECOPRO101 R1.doc update including available 2008 DEER cost data, and update NTGR value to 0.46.** | **Breesa Kassing (PG&E) and Charlie Middleton (PG&E)** |
| **Revision 2** | **5/24/2012** | **Process BoilerPGECOPRO101 R2.doc update including available 2011 DEER data and update NTGR value to 0.60.** | **Justin Westmoreland (PG&E)** |
|  | **8/28/2012** | **Nomenclature Update** | **Justin Westmoreland (PG&E)** |
| **Revision 3** | **04/25/2014** | **Formatted to new template. Updated for Title 24 code impact.** | **Curtis Lee**  **(kW Engineering)**  **Charlie Middleton (PG&E)** |
| **Revision 4** | **3/1/2016** | **Added Title 20 [2015]. Added midstream delivery channel. Updated savings calculations.** | **Linda Wan (PG&E)** |

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# *Section 1. General Measure & Baseline Data*

## 1.1 Product Measure Description & Background

**Catalog Description**

* H11 Water Process Boiler
* H15 Steam Process Boiler

**Program Restrictions and Guidelines**

This work paper documents the rationale for the savings methodologies and assumptions for Process Boilers, as listed in the Boilers and Water Heating Rebate Catalog. The Boilers and Water Heating Rebate Catalog is part of Pacific Gas and Electric Company’s Customer Energy Efficiency Program. PG&E offers incentives to industrial customers for installing qualifying, high-efficiency equipment.

**Terms and Conditions:**

Requirements from Boilers and Water Heating Catalog:

* This rebate is available to industrial end-use customers who manufacture a saleable product typically in NAICS codes 31-33, but other NAICS codes may apply.
* Application must include the manufacturer’s name and model name/number for the equipment.
* Installation address must have a commercial natural gas account with PG&E
* Boilers used primarily for domestic hot water, space conditioning, pools, or spas do not qualify for this rebate.
* A combustion test measured under full-load conditions to document combustion efficiency must be submitted after installation is complete.
* Input rating of the boiler is ≤ 20,000 Mbtuh.

**Market Applicability:**

This measure is applicable to any industrial process boiler and not applicable to boilers used for space heating, domestic hot water, pools, or spas. This measure is applicable to any commercial application through midstream and downstream channels. The midstream rebate requires the distributor to send receipt of the make and model and spec sheet of the process boiler.

## 1.2 Product Technical Description

Process boilers are pressure vessels that transfer heat to water for use primarily in process applications. Energy efficient units often feature high-efficiency and/or low NOx burners, and typically have features such as forced air burners, relatively large heat exchange surfaces, and/or utilize heat recovery from stack gases.

## 1.3 Measure Application Type

The DEER measure application types are defined in the table below:

Table Measures Application Type[[1]](#endnote-1)

|  |  |  |
| --- | --- | --- |
| **Code** | **Description** | **Comment** |
| ER | Early retirement | *measure applied while existing equipment still viable, or retrofit of existing equipment* |
| ROB | Replace on Burnout | *measure applied when existing equipment fails or maintenance requires replacement* |
| NC | New Construction | *measure applied during construction design phase as an alternative to a code-compliant standard design* |

Measures H11 and H15 are applicable to industrial installations. The savings for all measures are calculated assuming that the installation is replace-on-burnout (ROB).

## 1.4 Product Base Case and Measure Case Data

## 1.4.1 DEER Base Case and Measure Case Information

The DEER 2016 database does not contain measures equivalent to either of the PG&E catalog measures H11 or H15. Therefore, custom calculations have been developed to estimate energy savings resulting from H11 and H15. See Section 2 for further detail. The DEER 2016 documentation does contain applicable information for net-to-gross, installation rate, and effective and remaining useful life for measures H11 and H15.

**Net-to-Gross Ratio**

The NTG value was obtained using the DEER READI tool v 2.3.0. The relevant NTG value for the measures in this work paper is in the table below:

Table DEER Net-to-Gross Ratios

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Measure Delivery** | **NTGR** |
| Ind-Default>2yrs | All other EEMs with no evaluated NTGR; existing EEM in programs with same delivery mechanism for more than 2 years | Ind | Any | Any | 0.6 |

The NTG Ratios in Table 2 are appropriate for the measures because:

* Measures are for industrial applications
* No evaluated NTGR available for this measure
* Equipment has the same delivery mechanism for more than two years

**Spillage Rate**

Spillage rates are not tracked in work papers; they are tracked in an external document which will be supplied to the Commission Staff.

**Installation Rate**

The IR value was obtained using the DEER READI tool. The relevant IR value for the measures in this work paper are in the table below:

Table Installation Rate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **GSIA ID** | **Description** | **Sector** | **BldgType** | **ProgDelivID** | **GSIAValue** |
| Def-GSIA | Default GSIA values | Any | Any | Any | 1 |

**Hours of Operation**

The assumed hours of operation are based on continual plant operation. Variation in plant operating hours is accounted for in the capacity factor. While the boiler may be enabled to operate during the entire year, it may not be operating at its full rated load. To account for this, the capacity factor is multiplied by the enabled hours of operation to obtain the effective full load hours (EFLH). See Section 2 for details.

Table Hours of Operation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Building type** | **Building Vintage** | **Climate Zone** | **Hours of Operation hrs/yr** | **Reference** |
| ANY | EX | ANY | 8,760 | N/A |

**Effective and Remaining Useful Life**

The EUL and RUL values were obtained using the DEER READI tool. DEER defines the RUL as 1/3 of the EUL value. The RUL value is only applicable to the first baseline period for an RET measure with an applicable code baseline. The relevant EUL and RUL values for the measures in this work paper are in the table below:

Table Effective and Remaining Useful Life

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| PrcHt-Blr | High Efficiency Boiler | Com | ProcHeat | 20 | 6.67 |
| PrcHt-StmBlr | High Efficiency Boiler | Com | ProcHeat | 20 | 6.67 |

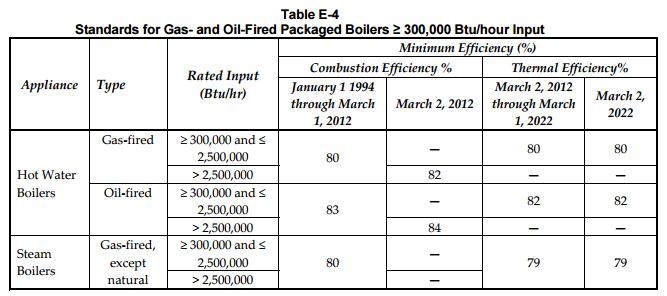
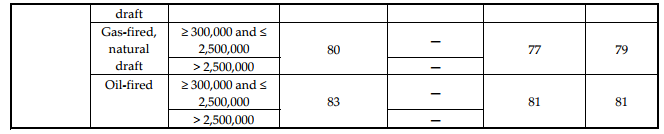
## 1.4.2 Codes & Standards Requirements Base Case and Measure Information

It should be noted that the more stringent code be applied in all applicable situations.

***Title 20:*** These measures do fall under Title 20 [2015] of the California Energy Regulations. Section 1605.3 of Title 20 states:

*The efficiency of boilers, central furnaces, duct furnaces, and unit heaters shall be no less than, and the standby loss shall be not greater than, the applicable values shown in Tables E-7, E-8, and E-9.*

The table below shows the 2015 California Title 20 Appliance Efficiency Regulations, Section 1605.1, Table E-4, Standards for Gas- and Oil-Fired Packaged Boilers ≥ 300,000 Btu/hour Input[[2]](#endnote-2).

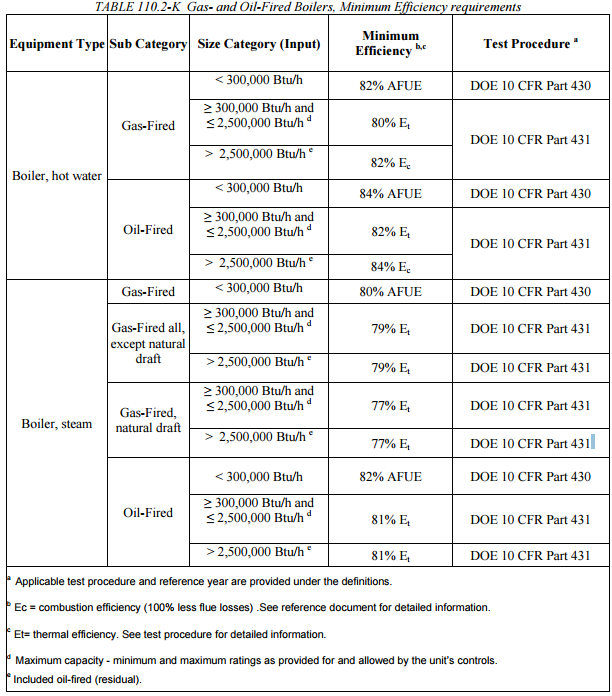
 

***Title 24:*** These measures do fall under Title 24 of the California Energy Regulations. Title 24 states[[3]](#endnote-3):

*Any space-conditioning equipment listed in this section may be installed only if the manufacturer has certified to the Commission that the equipment complies with all the applicable requirements of this section.*

1. ***Efficiency.*** *Equipment shall meet the applicable efficiency requirements in TABLE 110.2-A through TABLE 110.2- K subject to the following:*
   1. *If more than one efficiency standard is listed for any equipment in TABLE 110.2-A through TABLE 110.2-K, the equipment shall meet all the applicable standards that are listed; and*
   2. *If more than one test method is listed in TABLE 110.2-A through TABLE 110.2-K, the equipment shall comply with the applicable efficiency standards when tested with each listed test method; and*
   3. *Where equipment can serve more than one function, such as both heating and cooling, or both space heating and water heating, it shall comply with all the efficiency standards applicable to each function; and*
   4. *Where a requirement is for equipment rated at its "maximum rated capacity" or "minimum rated capacity," the capacity shall be as provided for and allowed by the controls, during steady-state operation.*

The table below lists the 2013 California Title 24 Build Energy Efficiency Standards, Section 110.2, Table 110.2-K, Gas- and Oil-Fired Boilers, Minimum Efficiency requirements.



***Federal Standards:*** These measures do not fall under Federal DOE or EPA Energy Regulations.

## 1.4.3 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information

There are no M&V or other studies which apply to these measures. Information on the base and measure case is found in the sub-sections of 1.4.

## 1.4.4 Assumptions and Calculations from other sources—Base and Measure Cases

The following assumptions from other sources were used to estimate savings.

**Energy Savings Assumption (ΔTherms):**

* New high-efficiency unit has the same input rating (measured in kBTU/h) as the unit being replaced.
* Both units (old and new) deliver the same amount of hot water or steam on an annual basis (i.e., customer demand for hot water or steam does not change).

RUL savings are not applicable to this measure because this measure only covers ROB measure types.

Base case efficiencies are based on 2013 Title 24 minimum efficiencies for boilers. Title 24 requires large water boilers to have a minimum combustion efficiency of 82% and large steam boilers to have a minimum thermal efficiency of 79%.7 While Title 24 is targeted specifically to space conditioning equipment, we have applied the more stringent code regulations to this workpaper.

Since PG&E cannot readily measure thermal efficiency, combustion efficiency will be used to determine the eligibility of the boilers. In addition, because Title 24 evaluates steam boilers in thermal efficiency, we have adjusted the combustion efficiency of a water boiler to estimate the combustion efficiency of a steam boiler. Based on the DOE Steam Tip Sheet #4[[4]](#endnote-4) we have estimated the combustion efficiency for a steam boiler. If we assume a 3% excess oxygen level and assume that steam boilers have flue gas temperatures 100 ⁰F higher than a similarly sized water boiler, we have estimated that steam boilers are 2% less efficient than a comparable water boiler.

Therefore, we have reduced the Title 24 minimum combustion efficiency of a large water boiler by 2% to estimate the Title 24 minimum combustion efficiency for a large steam boiler.

Table Base Case Combustion Efficiencies

|  |  |
| --- | --- |
|  | **Standard/Base Case Title T20/T24**  **Combustion Efficiency** |
| **Hot Water Boiler** | 82% |
| **Steam Boiler** | 80% |

## 1.4.5 Time-of-Use Adjustment Factor

We are required by CPUC decision 06-06-063 dated June 29, 2006 to apply time-of-use (TOU) adjustment factors on residential A/C and commercial A/C (packaged and split-system direct-expansion cooling) measures only. Since this is not an A/C measure, the TOU adjustment factor is 0.

# *Section 2. Calculation Methods*

**H11 – Water Process Boiler**

Qualifying water boilers for this measure must have an input rating of less than 20,000 kBTU/h. The combustion efficiency must be documented achieving a combustion efficiency of 85% or greater under full load conditions.

**H15 – Steam Process Boiler**

Qualifying steam boilers for this measure must have an input rating of less than 20,000 kBTU/h. The combustion efficiency must be documented achieving a combustion efficiency of 83% or greater under full load conditions.

## 2.1 Electric Energy Savings Estimation Methodologies

There are no electric savings (kWh per kBTUh) associated with this measure.

## 2.2. Demand Reduction Estimation Methodologies

There is no Demand Reduction (kW per kBTUh) associated with this measure.

## 2.3. Gas Energy Savings Estimation Methodologies

There are no DEER measures that match catalog measures H11 and H15. Therefore, we calculated energy savings[[5]](#endnote-5) based on average combustion efficiencies from the California Energy Commission (CEC) Appliance Databases[[6]](#endnote-6) and capacity factors taken from the Characterization of the U.S. Industrial/Commercial Boiler Population[[7]](#endnote-7).

**Capacity Factor**

Boilers, like many gas systems, have modulating controls that allow them to operate at a fraction of their nominal capacity. As a result, the number of operating hours of a boiler is not an accurate representation of its energy consumption, and the average capacity factor needs to be taken into account. This capacity factor is the ratio of actual energy consumption during a certain time period and the consumption that would have occurred if the boiler were at full capacity during the same period (see formula below):

Where,

CF = capacity factor, no units

AGC = actual gas consumption during a given time period, kBTUh

MGC = maximum gas consumption during a given time period, kBTUh

Data from the analysis of industrial and commercial boilers was combined with industry-specific Gross Domestic Product (GDP) data to get an accurate estimation of the average process boiler capacity factor in California. The average capacity factor is estimated by the equation below:

Where,

ACF = average capacity factor, no units

WCF = weighted capacity factor, no units

The weighted capacity factor accounts for the number of boilers in each industry. This factor is weighted based on the total number of boilers surveyed in Characterization of the U.S. Industrial/Commercial Boiler Population9multiplied by the size of each industry based on California GDP information from the Bureau of Economic Analysis.[[8]](#endnote-8) The weighted capacity factor is estimated by the equation below:

Where,

NB = number of boilers in industry, no units

PGDP = percent of California GDP versus nationwide GDP, no units

TBCA = total number of boilers in California, no units

Table Average Capacity Factor Across Different Industries



To determine the average boiler efficiency in the measure case, the California Energy Commission (CEC) Appliance Databases and records of boilers that PG&E has rebated under this measure were used. The CEC inventory includes over 3,000 gas boilers for steam and hot water production. To determine efficiencies for the measure case boilers in the database were sorted in order of increasing efficiency and divided into steam and hot water boilers.

The measure efficiencies were calculated as a simple average of the efficiencies of boilers listed in the CEC inventory. Finally, an average efficiency was calculated for all models with combustion efficiency of at least 83% and 85% respectively, the minimum efficiency specified for this measure, including very high efficiency condensing models. The calculated average efficiencies are summarized in the following table:

Table Average Combustion Efficiencies for High Efficiency Boilers from CEC Inventory

|  |  |
| --- | --- |
| Average Combustion Efficiency | |
| (High Efficiency Boilers) | |
| Hot Water | 89.4% |
| Steam | 84.4% |

**∆Therms per kBTUh for H11 and H15:**

The gas savings (therms per kBTUh) for measures H11 and H15 is based on the difference between the annual gas usage of the base case boiler and the measure boiler. The gas savings for these measures is defined as:

Where,

GS = gas savings, therms / kBTUh input rating

BCGU = base case gas usage, therms / kBTUh input rating

MCGU = measure case gas usage, therms / kBTUh input rating

Base case annual gas usage is based the average capacity factor, and operating hours. The base case gas usage is calculated as:

Where,

= 0.419, average capacity factor across all industries, no units

H = 8,760, annual operating hours, hr/yr

C = 0.01, conversion factor, therms / kBTU

Measure case annual gas consumption is based on the ratio of efficiencies between the base case efficiency and the measure case efficiency. The measure case gas usage is calculated as:

Where,

= base case efficiency, no units

= measure case efficiency, no units

**Savings for H11 (∆Therms / kBTUh):**

*therms / kBTUh input rating*

*therms / kBTUh input rating*

*therms / kBTUh input rating*

**Savings for H15 (∆Therms / kBTUh):**

*therms / kBTUh input rating*

*therms / kBTUh input rating*

*therms / kBTUh input rating*

# *Section 3. Load Shapes*

Load Shapes are an important part of the life-cycle cost analysis of any energy efficiency program portfolio. The net benefits associated with a measure are based on the amount of energy saved and the avoided cost per unit of energy saved. For electricity, the avoided cost varies hourly over an entire year. Thus, the net benefits calculation for a measure requires both the total annual energy savings (kWh) of the measure and the distribution of that savings over the year. The distribution of savings over the year is represented by the measure’s load shape. The measure’s load shape indicates what fraction of annual energy savings occurs in each time period of the year. An hourly load shape indicates what fraction of annual savings occurs for each hour of the year. A Time-of-Use (TOU) load shape indicates what fraction occurs within five or six broad time-of-use periods, typically defined by a specific utility rate tariff. Formally, a load shape is a set of fractions summing to unity, one fraction for each hour or for each TOU period. Multiplying the measure load shape with the hourly avoided cost stream determines the average avoided cost per kWh for use in the life cycle cost analysis that determines a measure’s Total Resource Cost (TRC) benefit.

## 3.1 Base Case Load Shapes

Load shapes are not applicable to gas measures, however, because the price of gas is not dependent on time-of-use.

## 3.2 Measure Load Shapes

Load shapes are not applicable to gas measures, however, because the price of gas is not dependent on time-of-use.

# *Section 4. Base Case & Measure Costs*

DEER2016 does not contain base case or measure costs for process boilers. The costs gathered for the base case and measure was from a survey, also reported in Southern California Gas Company’s Workpaper WPSCGNRPH120206A Revision 5 Process Boilers (Including Direct Contact Hot Water Heaters).

## 4.1 Base Case(s) Costs

The table below lists the results of a survey of equipment vendors that sell process hot water and steam process boilers in California. The vendor calls produced data for the categories of boiler type, rated input, and efficiency used in this workpaper. The base case costs shown represent an arithmetic average of the equipment cost per kBtu/h. Please reference the cost spreadsheet for detailed information[[9]](#endnote-9).

Table Base Case Cost

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure ID** | **Measure Description** | **Measure Application Types** | **Base Case Cost ($/MBtuh)** |
| H11 | Water Process Boiler | ROB | $12.22 |
| H15 | Steam Process Boiler | ROB | $14.89 |

## 4.2 Measure Case Costs

The table below lists the results of a survey of equipment vendors that sell hot water and steam process boilers in California. The vendor calls produced data for the categories of boiler type, rated input, and efficiency used in this workpaper. The base case costs shown represent an arithmetic average of the equipment cost per kBtu/h. Please reference the cost spreadsheet for detailed information.

The start-up costs and labor costs are estimated to be the same in the base case and measure case.

Table Measure Cost

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure ID** | **Measure Description** | **Measure Application Types** | **Measure Cost ($/MBtuh)** |
| H11 | Water Process Boiler | ROB | $15.17 |
| H15 | Steam Process Boiler | ROB | $19.24 |

## 4.3 Incremental & Full Measure Costs

Table Full and Incremental Measure Cost Equations

|  |  |  |  |
| --- | --- | --- | --- |
| **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| ROB | (MEC + MLC) – (BEC + BLC) | (MEC + MLC) – (BEC + BLC) | N/A |
| NEW/NC |
| RET/ER | (MEC + MLC) – (BEC + BLC) | MEC + MLC | (MEC + MLC) – (BEC + BLC) |
| REF | (MEC + MLC) – (BEC + BLC) | MEC + MLC | N/A |
| REA | MEC + MLC | MEC + MLC | N/A |

MEC = Measure Equipment Cost; MLC = Measure Labor Cost

BEC = Base Case Equipment Cost; BLC = Base Case Labor Cost

This table below is a summary of the base case cost, measure cost, and incremental measure cost.

Table Incremental Measure Costs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure ID** | **Measure Application Types** | **Base Case Cost (per kBtuh)** | **Measure Case Cost (per kBtuh)** | **Incremental Measure Cost (per kBtuh)** |
| H11 | ROB | $12.22 | $15.17 | $2.95 |
| H15 | ROB | $14.89 | $19.24 | $4.35 |

# References

1. 2014 Database for Energy Efficiency Resources (DEER) Update Study, prepared by Itron Inc., November 2013 ;D13v1.00 [↑](#endnote-ref-1)
2. Singh, Harinder, Ken Rider, and Jared Babula. 2015. 2015 Appliance Efficiency Regulations. California Energy Commission. Publication Number: CEC‐400‐2015‐021. page 146. [↑](#endnote-ref-2)
3. 2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Title 24, Part 6 and Associated Administrative Regulations in Part 1. California Energy Commission. Publication Number: CEC‐400‐2012‐004-CMF-REV2. [↑](#endnote-ref-3)
4. DOE Steam Tip Sheet 4 [↑](#endnote-ref-4)
5. Energy Savings Calculations Excel [↑](#endnote-ref-5)
6. California Energy Commission (CEC) Appliance Databases –Extracted 02/22/2016. <http://www.appliances.energy.ca.gov/AdvancedSearch.aspx> [↑](#endnote-ref-6)
7. Characterization Industrial Commercial Boiler Population [↑](#endnote-ref-7)
8. Bureau of Economic Analysis – Regional Economic Accounts – Gross Domestic Products by State – http://www.bea.gov/regional/gsp/ [↑](#endnote-ref-8)
9. Southern California Gas Company. Workpaper WPSCGNRPH120206A, Revision 5. Process Boiler Cost Data and Calculations Excel [↑](#endnote-ref-9)