WPSCGWP110812A

**Revision 4**

**SoCalGas**

**Pipe Insulation (Non-Space Conditioning)**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Measure Codes** | TBD |
| **Measure Description** | Adding a minimum of one inch of insulation thickness to existing pipe ranging from one-half to five inches in diameter. The pipe must be transporting a hot fluid either in the commercial or industrial setting. |
| **Base Case Description** | Existing, uninsulated commercial or industrial pipe used to transport hot fluids |
| **Units** | -Each (fitting)  -Linear Foot |
| **Energy Savings** | Large Commercial Pipe Insulation Steam, <15 PSIG, <1" Pipe, 1" Insulation Layer, Outdoor (CZ9: 18.91 Therms) |
| **Full Measure Cost ($/unit)** | Large Commercial Pipe Insulation Steam, <15 PSIG, <1" Pipe, 1" Insulation Layer, Outdoor (CZ9: $6.68) |
| **Incremental Measure Cost ($/unit)** | Large Commercial Pipe Insulation Steam, <15 PSIG, <1" Pipe, 1" Insulation Layer, Outdoor (CZ9: $6.68) |
| **Remaining Useful Life** | 6.67 years (WtrHt-PipeIns-Gas-2017) |
| **Measure Installation Type** | Retrofit Add-on (REA) as a prescriptive rebate |
| **Net-to-Gross Ratio** | 0.45 (NonRes-sAll-mPipeIns-deemed) |
| **Important Comments** | This work paper has a complementary Ex Ante Database data set that will be provided in a separate submission to the California Public Utilities Commission (CPUC).  This is an update to an existing workpaper based on the recommendations in the 2014 and 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Reports.  This update also involves changing the formatting of the original workpaper to be concurrent with the State-Wide format for workpapers. |

# Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| Revision No. | Date | **Description** | **Author** |
| --- | Jan. 31, 2006 | Original release | EEA (S. Knoke) |
| A | May 9, 2006 | 1. Added medium-pressure steam pipes 2. Other minor changes | EEA (S. Knoke) |
| B | July 6, 2006 | 1. Added Review and Acceptance page 2. Added Revision History page 3. Added Disclaimer page 4. Added discussion addressing reluctance to adopt technology in Executive Summary 5. Added line for steam pressure range to table in Executive Summary 6. Corrected minor error in the annual energy savings calculations 7. Added 3 and 4-inch pipe to Table 4 8. Added annual energy savings chart (Figure 1) in Section 3 and attachment showing calculations 9. Added discussion addressing reluctance to adopt technology in Incentive and Payback chapter 10. Renumbered attachments | EEA (S. Knoke) |
| C | Jan. 26, 2007 | 1. Added smaller pipe sizes 2. Added second category for annual operating hours 3. Reduced incentives to two categories 4. Increased annual energy savings to 6 categories 5. Added cost to SCG | EEA (S. Knoke) |
| D | Mar. 23, 2007 | 1. Removed CPUC attachment | EEA (S. Knoke) |
| E | Sept 5, 2008 | 1. Added large pipes at small commercial 2. Added insulation on pipe fittings | EEA (S. Knoke) |
| 1[[1]](#endnote-1)[[2]](#endnote-2) | Mar. 26,2009 | \*Updated DEER values (NTG, EUL, Cost ) | Lucie Sidibe (SDGE) |
| 2 | Aug. 12, 2009 | Inclusion of CPUC’s comments[[3]](#endnote-3) | Stu Knoke  Chan Paek |
| 3 | May 12, 2014 | 1. New WP template “SCG WP Template\_Rev3”  2. Changed program type to REA  3. Include savings specific to each CA climate zone  3. Savings distinguished between indoor and outdoor pipes  5. Updated NTG  6. Updated CEC Boiler Data | Michael Crayne (PECI) |
| 4 | 09/22/2017 | * Update per [*“2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report”*](#Attachments) *and “*[*2015 Nonresidential Downstream ESPI DEEMED Pipe Insulation Impact Evaluation*](#Attachments)*”*   + Format updated to State Wide template * Savings per new relevant parameters (combined both 2014 and 2015 impact evaluations studies)   -Operating Hours  -Boiler Efficiency  -Inside Air Temperature  -Pipe Surface Temperature   * DEER values: NTG, IR, EUL, Load Shapes * Added new pipe size (4 inch NPS) * Updated Pipe Insulation Cost | Carlos Pineda (SCG) |

Table of Contents

[At-a-Glance Summary 2](#_Toc502047542)

[Revision History 3](#_Toc502047543)

[Section 1. General Measure & Baseline Data 6](#_Toc502047544)

[1.1 Measure Description & Background 6](#_Toc502047545)

[1.2 Technical Description 7](#_Toc502047546)

[1.3 Installation Types and Delivery Mechanisms 7](#_Toc502047547)

[1.4 Measure Parameters 8](#_Toc502047548)

[1.4.1 DEER Data 8](#_Toc502047549)

[1.4.2 Codes and Standards Analysis 9](#_Toc502047550)

[1.5 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information 12](#_Toc502047551)

[1.5.1 Itron: 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report 12](#_Toc502047552)

[1.5.2 Itron: 2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report 12](#_Toc502047553)

[1.5.3 Steam Trap Survey and Billing Analysis Report 2006 12](#_Toc502047554)

[1.5.4 Enbridge Steam Trap Survey 13](#_Toc502047555)

[1.6 Data Quality and Future Data Needs 13](#_Toc502047556)

[Section 2. Calculation Methodology 14](#_Toc502047557)

[2.1 Methodology 14](#_Toc502047558)

[2.2 Calculations 15](#_Toc502047559)

[2.2.1 Bare pipe Analysis 16](#_Toc502047560)

[2.2.2 Insulated pipe Analysis 19](#_Toc502047561)

[Section 3. Load Shapes 20](#_Toc502047562)

[Section 4. Costs 20](#_Toc502047563)

[4.1 Base Case Cost 20](#_Toc502047564)

[4.2 Measure Case Cost 20](#_Toc502047565)

[4.3 Full and Incremental Measure Cost 22](#_Toc502047566)

[Referenced Attachments 23](#_Toc502047567)

[References 24](#_Toc502047568)

**List of Tables**

[Table I: Base, Standard, and Measure Cases 6](#_Toc502047569)

[Table II: Measures and Codes 6](#_Toc502047570)

[Table III: Installation Type Descriptions 7](#_Toc502047571)

[Table IV: Delivery Method Descriptions 7](#_Toc502047572)

[Table V: Incentive Method Descriptions 7](#_Toc502047573)

[Table VI: DEER Difference Summary 8](#_Toc502047574)

[Table VII: NTGR ID 8](#_Toc502047575)

[Table VIII: GSIA ID 8](#_Toc502047576)

[Table IX: GRR 9](#_Toc502047577)

[Table X: GRR 9](#_Toc502047578)

[Table XI: EUL ID 9](#_Toc502047579)

[Table XII: Code Summary 10](#_Toc502047580)

[Table XIII: Building Types and Load Shapes 20](#_Toc502047581)

[Table XIV: Pipe Insulation Cost 21](#_Toc502047582)

[Table XV: Pipe Insulation Costs (Material & Installation) Provided by Vendor 21](#_Toc502047583)

[Table XVI: Full and Incremental Measure Cost Equations 22](#_Toc502047584)

[Table XVII: Full and Incremental Costs (Pipe Insulation: Indoor, Outdoor) 22](#_Toc502047585)

[Table XVIII: Full and Incremental Costs (Pipe Fitting: Indoor, Outdoor) 22](#_Toc502047586)

**List of Figures**

[Figure 1: Tittle 24, 1/2 10](#_Toc502047587)

[Figure 2: Tittle 24, 2/2 11](#_Toc502047588)

[Figure 3: Occupational Safety and Health Administration(OSHA) 11](#_Toc502047589)

[Figure 4: Insulated Pipe Heat Flux Diagram 16](#_Toc502047590)

# Section 1. General Measure & Baseline Data

## 1.1 Measure Description & Background

This Workpaper outlines the Retrofit Add-On of insulation to bare pipe and pipe fittings to reduce the heat loss and offset the water heater or steam boiler energy load. Many commercial and industrial customers particularly smaller, hard to reach businesses configure pipe systems with sub-optimal amounts of insulation. This measure addresses cost-effective energy efficiency opportunities in the pipe insulation area, and encompasses both fiberglass and heavier duty insulation systems such as Perlite and rigid Phenolic insulation. Pipe insulation applications in the industrial and commercial sector include steam, and hot water.

Table I: Base, Standard, and Measure Cases

|  |  |
| --- | --- |
| **Case** | **Description of Typical Scenario** |
| Measure | Adding a minimum of one inch of insulation to existing bare pipe used to transport a hot fluid ranging from half-inch to four inches in diameter either in the commercial or industrial sector. |
| Existing Condition | Uninsulated commercial or industrial pipe used to transport hot fluids |
| Code/Standard | -Title 24: Section 120.3  -Occupational Safety and Health Administration (OSHA) applicable requirements. |
| Industry Standard Practice | Minimally insulating to comply with applicable code. |

Table II: Measures and Codes

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Codes** | | | | **Measure Name** |
| SCG | SDG&E | SCE | PG&E |
| TBD |  |  |  | Industrial Fitting Insulation |
| TBD |  |  |  | Small Commercial Fitting Insulation |
| TBD |  |  |  | Large Commercial Fitting Insulation |
| TBD |  |  |  | Industrial Pipe Insulation 1” Insulation Layer |
| TBD |  |  |  | Small Commercial Pipe Insulation 1” Insulation Layer |
| TBD |  |  |  | Large Commercial Pipe Insulation 1” Insulation Layer |

**A. Eligibility Requirements:** This measure is applicable to small, large commercial and industrial buildings with existing uninsulated pipe systems. These buildings must be within the IOU territory and shall use natural gas provided by an IOU.

**B. Implementation Requirements:**

* These measures are applicable to any small, large commercial and industrial pipe insulation retrofit (i.e., non-new construction) application. They cannot be used for residential purposes.
* Insulation required by California Building Code (Title 24) or employee safety laws (Occupational Safety and Health Administration: OSHA) is not eligible for a rebate.
* The pipes must transfer hot water, low-pressure steam, or medium-pressure steam directly from gas-fired equipment. The fluid type must be indicated. If the fluid is steam, the pressure of the steam must also be indicated.
* Maximum qualifying pipe diameter is four inches, and minimum qualifying pipe diameter is half-inch.
* The length of insulation to be installed at each pipe size must be indicated.
* A minimum of one inch of pipe insulation must be added to existing bare commercial or industrial steel or copper pipe.
* The hours of operation must be indicated on the top of the application.
* Acceptable types of insulation for hot water pipes include: elastomeric foam rubber, polyethylene foam, UV-resistant polyethylene foam and rigid polyurethane foam.
* Acceptable types of insulation for steam pipes include silicone foam rubber, melamine foam, rigid urethane-based foam, cellular glass, rigid fiberglass and rigid mineral wool.
* Replacement of damaged (existing) insulation is not eligible for a rebate.
* The manufacturer’s specification sheet must be submitted with the application.

## 1.2 Technical Description

The measure presented in this Workpaper adds a layer of insulation to existing pipe systems to reduce the amount of heat loss throughout the pipe length. Insulation adds thermal resistance and forces the heat flux to reduce in magnitude. As an effect, the fluid in the pipe system can retain its temperature due to a reduction in the heat loss gradient. This will force the steam or hot water boiler to offset its energy demand and reduce its consumption.

## 1.3 Installation Types and Delivery Mechanisms

The program type/install type for this measure is Retrofit Add-On (REA), which refers to measures that are added onto existing equipment to improve efficiency and performance.

Table III: Installation Type Descriptions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Installation Type** | **Savings** | | **Life** | |
| 1st Baseline (BL) | 2nd BL | 1st BL | 2nd BL |
| Retrofit Add-on (REA) | Above Customer Existing | N/A | RUL | N/A |

A delivery mechanism is a delivery method paired with an incentive method. Delivery mechanisms are used by programs to obtain program participation and energy savings. The delivery mechanism for this measure is Prescriptive Rebate.

Table IV: Delivery Method Descriptions

|  |  |
| --- | --- |
| **Delivery Method** | **Description** |
| Financial Support | The program motivates customers, through financial incentives such as rebates or low interest loans, to implement energy efficient measures or projects. |

Table V: Incentive Method Descriptions

|  |  |
| --- | --- |
| **Incentive Method** | **Description** |
| Down-Stream Incentive | The customer installs qualifying energy efficient equipment and submits an incentive application to the utility program. Upon application approval, the utility program pays an incentive to the customer. Such an incentive may be deemed or customized. |

## 1.4 Measure Parameters

### 1.4.1 DEER Data

Table VI: DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Workpaper?** |
| Modified DEER methodology | Yes |
| Scaled DEER measure | No |
| DEER Base Case | No |
| DEER Measure Case | No |
| DEER Building Types | Yes |
| DEER Operating Hours | No |
| DEER eQUEST Prototypes | No |
| DEER Version | DEER 2017 |
| Reason for Deviation from DEER | DEER does not contain this type of measure |
| DEER Measure IDs Used | N/A |

**Net-to-Gross Ratio**

For all measures in this Workpaper, the NTGR found in the “ESPI Pipe Insulation Reports” was used.

Table VII: NTGR ID

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Measure Delivery** | **NTGR** |
| NonRes-sAll-mPipeIns-deemed | Pipe insulation: non-HVAC or DHW applications; deemed; all delivery mechanisms except upstream | Ind | Any | NonUpStrm | 0.45 |

**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 values were obtained using the [*“Itron: 2014 and 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report”*](#Attachments). The relevant IR values for the measures in this work paper are in the table below.

Table VIII: GSIA ID

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

This measure will use the Gross Realization Rate(GRR) values found in the “ESPI Insulation Reports”, these values are shown in the following table.

Table IX: GRR[[4]](#footnote-1)

|  |  |  |  |
| --- | --- | --- | --- |
| **PA** | **First Year Gross Therm Savings** | | |
| **Ex-Ante Savings** | **Ex Post Savings** | **GRR** |
| PGE | 370,701 | 341,227 | 92% |
| SCG | 905,293 | 709,301 | 78% |
| SDGE | 6,903 | 4,676 | 68% |
| **Statewide** | **1,282,897** | **1,055,204** | **82%** |

Table X: GRR[[5]](#footnote-2)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **PA** | **First Year Gross Therm Savings** | | | |
| **Ex Ante Savings** | **Ex Post Savings** | **GRR** | **RP** |
|
| SCG | 441,396 | 621,752 | 141% | 31% |

The GRR value of 97% will apply to this measure. This value originates from summing the Ex-Ante Savings for both 2014 and 2015 cycles and dividing by the sum of Ex-Post Savings for both years. This is shown in the following expression.

**Effective and Remaining Useful Life**

The life expectancy of pipe exceeds 20 years, however under CPUC guidance the limit of 20 years will apply for the EUL. Various studies and source show that piping life expectancy is of over 20 years.[[6]](#endnote-4) [[7]](#endnote-5) [[8]](#endnote-6) [[9]](#endnote-7)

Table XI: EUL ID

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| WtrHt-PipeIns-Gas-2017 | Pipe Insulation | Com  Ind | SHW | 20 | 6.67 |

### 1.4.2 Codes and Standards Analysis

Application of pipe insulation to hot fluid piping as required by current CA Title 24 and OSHA Standard does not qualify for this measure. While Title 24 (2016) states requirements for pipe insulation, this is a REA measure, therefore remains applicable for installations on existing, uninsulated pipe systems.

Table XII: Code Summary

|  |  |  |
| --- | --- | --- |
| **Code** | **Reference** | **Effective Dates** |
| Title 24 (2016) | Section 120.3 Pages 131-133 | January 1st, 2017 |
| Title 20 (2014) | N/A | N/A |
| DOE | N/A | N/A |
| OSHA | [1910.261(k)(11)](https://www.osha.gov/pls/oshaweb/owalink.query_links?src_doc_type=STANDARDS&src_unique_file=1910_0261&src_anchor_name=1910.261(k)(11)) | August 19, 1998 |

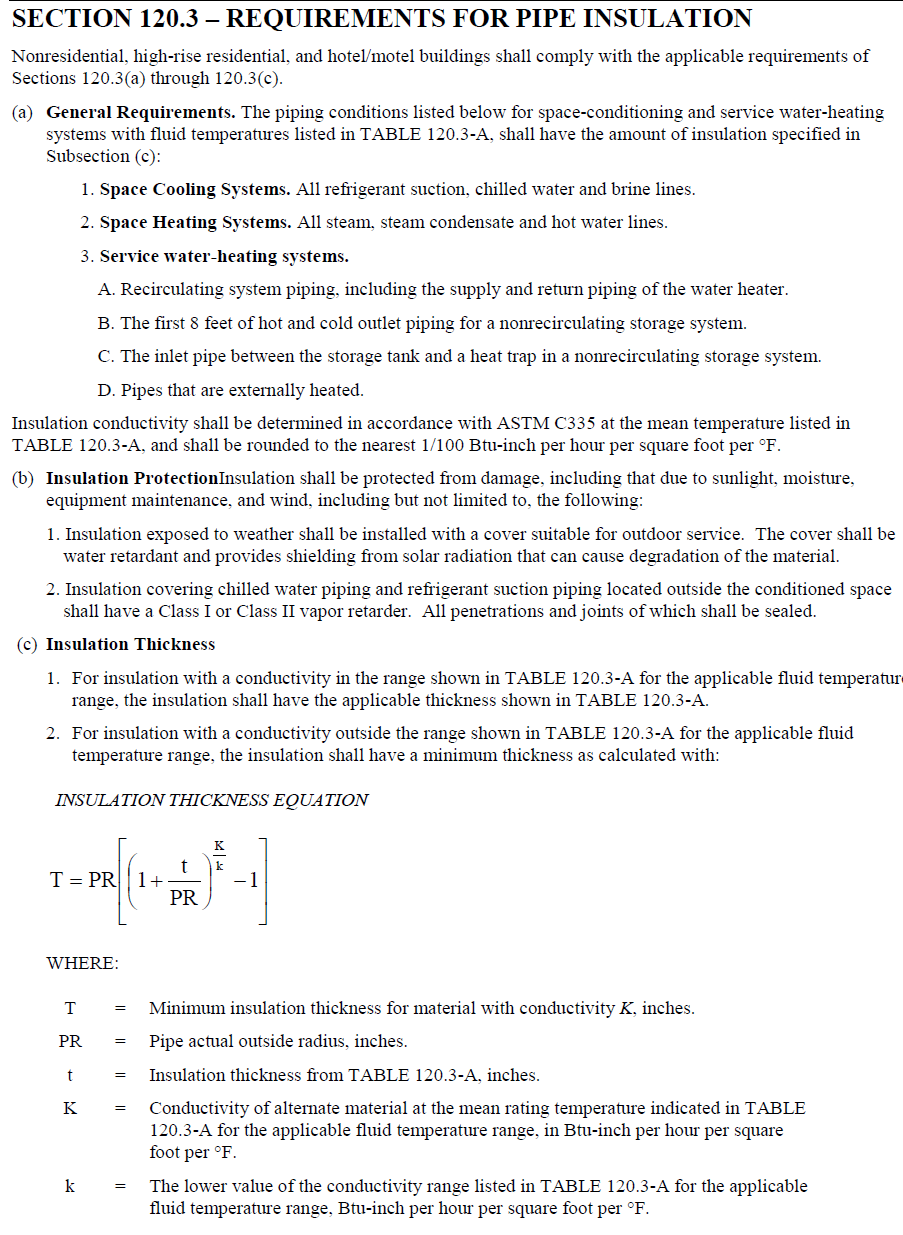


Figure 1: Tittle 24, 1/2

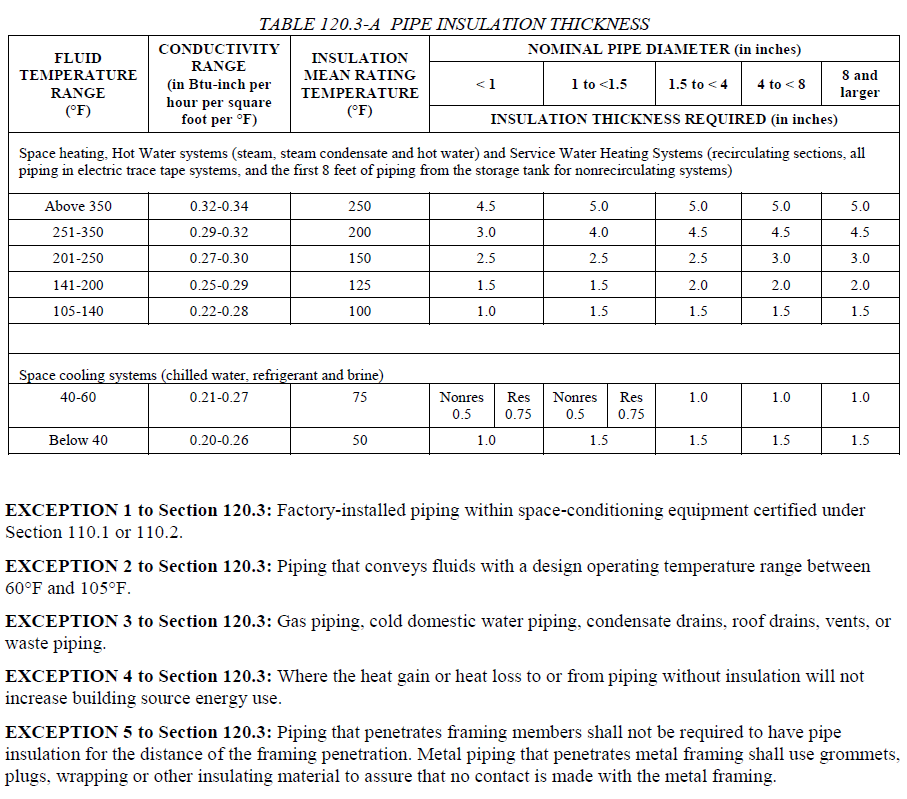


Figure 2: Tittle 24, 2/2

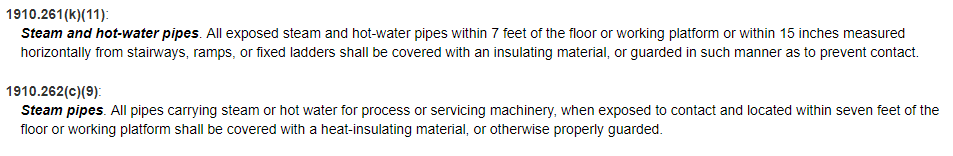


Figure 3: Occupational Safety and Health Administration(OSHA)

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

Surveys were conducted to evaluate the impact of implementing this measure. Two evaluations were conducted, one on 2014 and the second on 2015. Both surveys provided the same parameters and this Workpaper combines both to produce more reliable savings.

### 1.5.1 Itron: 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report

The following parameters were updated and taken from the ESPI study; operating hours, NTG, GRR, pipe surface temperature, ambient air temperature and boiler efficiency. The ESPI study was performed by Itron and prepared for the CPUC to perform an impact evaluation on the deemed savings and measure-parameter associated with pipe insulation measures.

Report:

* Conduct Surveys to evaluate Ex-Ante and post Ex-Ante parameters.
* Confirm installations (verification). This step includes on-site verification of measure

installations that represent a significant percentage of ex ante claimed natural gas savings.

* Estimate baseline (pre-retrofit) and replacement (post-retrofit) pipe heat loss rates and

operating hours to support the estimate of unit energy savings values.

* Estimate participant free-ridership to support the development of NTG ratios

and net savings values.

* Based on the above, estimate first year and lifetime gross and net ex post impacts (Therm)

for pipe insulation measures.

### Itron: 2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report

The following parameters were updated and taken from the ESPI study; operating hours, NTG, GRR, pipe surface temperature, ambient air temperature and boiler efficiency. The ESPI study was performed by Itron and prepared for the CPUC to perform an impact evaluation on the deemed savings and measure-parameter associated with pipe insulation measures.

Report:

* Conducted Surveys to evaluate Ex-Ante and post Ex-Ante parameters.
* Confirm installations (verification). This step includes on-site verification of measure

installations that represent a significant percentage of ex ante claimed natural gas savings.

* Estimate baseline (pre-retrofit) and replacement (post-retrofit) pipe heat loss rates and

operating hours to support the estimate of unit energy savings values.

Estimate participant free-ridership to support the development of net-to-gross ratio

and net savings values.

* Based on the above, estimate first year and lifetime gross and net ex post impacts (Therm)

for pipe insulation measures.

### 1.5.3 Steam Trap Survey and Billing Analysis Report 2006

The annual operating hours for Small Commercial hot water and steam systems were taken from a survey performed in Southern California by kW Engineering in November 2006. The intent of this survey was to determine potential savings from steam trap replacements in dry cleaner facilities, but the operating hours of the boiler systems that were surveyed are relevant to the measure in this work paper.

Report:

* Final report completed by kW Engineering December 12th, 2006
* In November of 2006 65 steam traps were tested at 5 southern California dry cleaners
* Physical surveys were conducted of steam traps and boiler systems
* Concerns are outlined in the executive summary of the report itself and have no bearing on the information used out of the report for this Workpaper.

## 1.5.4 Enbridge Steam Trap Survey

The average steam pressures input into the savings calculations were calculated using values from a survey of steam traps performed by Enbridge2. The sites in this survey represented a number of different building types, including pharmaceutical manufacturing, university, and paper mill. The sites were surveyed between 2002 and 2005. The steam pressures of the surveyed facilities were used to determine the average pressure for steam systems less than or equal to 15 PSIG and greater than 15 PSIG.

Report:

* Final excel completed by Enbridge 2002-2005
* From 2002-2005 various industry sites had their steam traps tested and surveyed
* Physical surveys were conducted of steam traps and boiler systems

## 1.6 Data Quality and Future Data Needs

The data found in the relevant studies presented is adequate and provides a reliable source for energy savings calculations. The data was acquired through a diligent effort and the tools used were appropriate for the data that was collected.

A section that could improve is with respect to the following code clause,

Tittle 24 Section 120.3 section b[[10]](#footnote-3), states the following.

*“(b)* ***Insulation Protection****: Insulation shall be protected from damage, including that due to sunlight, moisture, equipment maintenance, and wind, including but not limited to, the following:*

*1. Insulation exposed to weather shall be installed with a cover suitable for outdoor service. The cover shall be water retardant and provides shielding from solar radiation that can cause degradation of the material.”*

Future data needs could evaluate the quality of the installation made, is the insulation well protected as Tittle 24 states? This could be a factor in the lifecycle gross savings due to insulation deterioration affecting the thermal resistance effectiveness.

# Section 2. Calculation Methodology

## 2.1 Methodology

To calculate the energy savings from adding insulation to existing uninsulated pipes, all three modes of heat transfer were considered, convection, conduction and radiation. Convection was considered between the inside film and inside wall, conduction was then analyzed through the wall (pipe) with a constant thermal conductivity. To finalize the heat flux value, radiation and convection were considered for both the bare pipe and insulated pipe heat loss to the environment.

For outside pipe insulation, the weather data file attached, [*“Pipe Insulation Weather”*](#_Attachments) was used for relevant wind speed and ambient temperature at each climate zone. The values used are the average per climate zone from the 2013 weather data.

The following were also considered.

* Savings are based on installing insulation on bare pipes and fittings. The energy savings that will be achieved depend upon pipe parameters, insulation parameters, boiler efficiency, annual operating hours, and other parameters such as fluid properties and ambient temperature. The energy savings results are expressed per linear foot (LF) of straight pipe or per fitting.
* **Pipe Parameters** – Steam and hot water pipe sizes ranging from one-half to four inches are commonly seen in commercial and industrial facilities prior to this revision this workpaper only provided saving for pipes up to three inches in dimeter. However, the 2015 Impact Evaluation study suggested a larger dimeter size should be added to encompass instances of larger than four inch pipes found in the study. Pipe sizes were divided into three ranges: one-inch or less, greater than one-inch and less than or equal to four inches and greater than four inches. The physical dimensions of a Schedule-40 standard pipe size of ¾-inch was selected to represent ½-inch, ¾-inch, four inches and 1-inch pipe sizes. The 2006-2008 program evaluation effort found that the average pipe diameter for pipes whose diameter was greater than 1 inch was 1.7 inches. Therefore, the physical dimensions of 1.5-inch and 2-inch Schedule-40 standard pipe sizes were interpolated to represent pipe sizes larger than 1-inch. The Schedule-40 was also chosen to represent a pipe with an outside diameter of five inches. The thermal conductivity and surface emittance of black steel pipe were applied in all cases. The thermal conductivity of steel (314.4 Btu-in/hr-ft2-F or 26.2 Btu/hr-ft-F) is required to calculate the outside wall temperature of the steel pipe. In addition, the radiation from the bare pipe surface is characterized by an emittance of 0.94.
* **Insulation Parameters** – Acceptable types of pipe insulation for hot water pipes include polyethylene foam (up to 180 °F), UV-resistant polyethylene foam, and elastomer foam rubber. Acceptable types of insulation for steam pipes include silicone foam rubber (to 425 °F), melamine foam (to 400 °F), rigid urethane-based foam (to 300 °F), cellular glass (to 400 °F), fiberglass, and mineral wool. The protection offered by jacketing is also recommended, especially outdoors. Only some jacket materials are suitable for outdoor use, such aluminum, UV-resistant PVC, and paints. The parameters used to describe the insulation (thermal conductivity, surface emittance) are generally based on prefabricated 1-inch thick fiberglass pipe insulation with paper or aluminum wrap (paper for indoor locations and aluminum for outdoor locations). The energy savings analysis is based on adding 1-inch thick insulation around bare Schedule 40 black steel pipe. In addition to insulation thickness, it is necessary to know the thermal conductivity of the insulation and the thermal radiation emittance of the insulation wrap. The thermal conductivity of pipe insulation varies by material and temperature rating, based on two sources (ASHRAE Handbook and McMaster-Carr catalog, a thermal conductivity value of 0.29 Btu-in / hr-ft2-°F (0.024 Btu/hr-ft-°F) was chosen for both hot water and steam pipe. In addition, the insulation surface participates in radiative heat transfer. Pipe insulation used indoors typically has a paper wrap (with an emittance of about 0.9) and pipe insulation used outdoors typically has an aluminum wrap (with an emittance of about 0.1). These emittances are not critical parameters, since the heat loss is not very sensitive to radiative heat loss from the rather cool surface of the insulation; an average value of 0.5 was applied.
* **Boiler Efficiency –** The finding from both 2014 and 2015 Itron: Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Reports were consolidated to yield the efficiencies used in this work paper. The following table shows the efficiency per fluid type. The data can be found in the following attachment[*“WPSCGWP110812A\_Rev4\_\_Itron\_2014\_2015 WP Parameters”*](#_Referenced_Attachments)

|  |  |
| --- | --- |
| **Fluid** | **Efficiency** |
| Hot Water | 83.49% |
| Low Pressure Steam | 80.71% |
| Medium Pressure Steam | 82.55% |

* **Annual Operating Hours –** The annual Operating hours were also consolidated per the impact evaluation reports. The table below shows the hours used per sector.

|  |  |
| --- | --- |
| **Sector** | **Operating Hours** |
| Small Commercial | 7,003 |
| Large Commercial | 6,056 |
| Industrial | 6,333 |

## 2.2 Calculations

The affected parameters in the energy savings calculations due to the, [*“Itron: 2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report”*](#Attachments)and *“*[*2015 Nonresidential Downstream ESPI DEEMED Pipe Insulation Impact Evaluation*](#Attachments)*”*are as followed.

**Inside Calculations:** Operating hours, air temperature, bare pipe temperature, fluid temperature and boiler efficiency.

**Outside Calculation:** Operating hours, bare pipe temperature, fluid temperature and boiler efficiency. Air temperature was not changed due to it been dependent on the climate zone. For indoor applications, the temperature was changed due to the findings of the ESPI impact evaluation surrounding air temperature.

Figure 1, demonstrates the heat rate for an insulated pipe and the losses due to convection and radiation at the pipe insulation surface.

For a bare pipe Figure 1 applies, however, r3 and k2 are omitted, they are insulation properties.

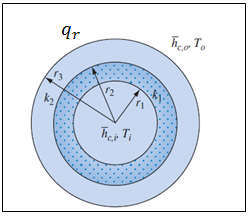


Figure 4: Insulated Pipe Heat Flux Diagram

The calculations for the pipe heat loss with and without insulation follows a process that begins at the hot fluid to either the outer bare pipe surface or the outer insulation surface. The [“Itron: 2014 and 2015 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report”,](#Attachments) provide the bare pipe temperature, with this value known, there is no further need for the analysis of the heat flow from the inside fluid to the outer bare pipe surface. The focus will instead be on the heat flux from the outer insulation surface to the environment.

## 2.2.1 Bare pipe Analysis

To acquire the heat loss from the bare pipe, with the provided bare pipe surface temperature, the convective and radiation heat transfer coefficients must first be estimated.

For the convective heat transfer coefficient, the following formulation was used.

…. (1)

where,

h = Convective Heat Transfer Coefficient (Forced, Free).

d = Characteristic length (diameter).

k = Thermal Conductivity.

The heat transfer coefficient is derived by finding the Nusselts Number twice, once for free convection and the other for forced convection, the two values are then normalized and the resultant is used in equation (1) to solve for the convective heat transfer coefficient.

**Free Convection,**

The Nusselts Number is found by using the following equation (ASHRAE, Heat Transfer, Pg. 3.17, equation T10.10)

Where,

In which,

g = gravity,

β = volumetric thermal expansion coefficient of ambient fluid,

ρ =density of ambient fluid,

Cp = specific heat of ambient fluid,

ΔT = absolute temperature difference between fluid and surface,

D = pipe diameter,

ν = kinematic viscosity,

kf =thermal conductivity of ambient fluid,

**Forced Convection,**

The Nusselts Number is found by using the following equation (ASHRAE, Heat Transfer, Pg. 3.15, equation T9.13)

where,

In which,

V = free stream velocity of ambient fluid,

For the radiation effect, the radiation heat transfer coefficient was found through the following expression (2005 ASHRAE Handbook-Fundamentals, Pg. 26.14, Equation 11).

…. (6)

where,

ε = surface emissivity

σ = Stefan-Boltzmann constant,

Combining the two into a sum will yield the total heat transfer coefficient.

…. (5)

To find the heat flux from the bare pipe into the environment the following expression was used.

.... (7)

Where,

For a sample calculation, consider the heat loss in a bare pipe transporting hot water, the following is known.

-Inside pipe water temperature = 136.65 °F

-Ambient air temperature = 51.50 °F

-Wind Speed = 29783 ft/hr

-Pipe Outer Diameter = 0.0875 ft

From equation 3 and 4 respectively,

Using equation 2,

Using equation 5, the forced convection Nusselts Number is found.

[[11]](#endnote-8)Combining the Nusselts Number and solving for the heat transfer coefficient.

Equation 1 is used to solve for the heat transfer coefficient due to convection.

→

Now, the heat transfer coefficient due to radiation is found through equation 6.

Equation 5 is applied,

To find the heat loss for the bare pipe, equation 7 is applied.

## 2.2.2 Insulated pipe Analysis

The analysis for an insulated pipe follows the same procedure as the bare pipe. However, Iterations had to be made due to the temperature of the outer insulation surface been unknown. The iterative approach will vary the insulation surface temperature until the difference of the conducted heat through the insulation, and the sum of the radiated and convective heats are equal to zero, that is

…. (8)

This expression shows that the heat conducted from the inner-pipe to the outer insulation surface will also be the heat that will be lost to the environment.

To find the conducted heat from the inner surface to the insulation surface the following equation was used.

…. (9)

Where,

For a sample calculation, consider an insulation layer of 1 inch thickness. From equation 7 and using values that apply to the insulation outer surface, the following is observed.

Insulation savings are as followed.

With the added layer (1’’) of insulation, the thermal resistance is increased and the effect is seeing in the outer insulation surface temperature (54.7 °F). The bare pipe surface temperature in this example is (135.3 °F), enabling more heat to be lost without the insulation layer.

For Indoor savings, the forced convection heat transfer coefficient will be (0). This is due to the Nusselts Number for this portion been a function of Reynolds number, which is a function of velocity. For indoor applications, the air velocity is (0).

# Section 3. Load Shapes

Load shapes are used for portfolio lifecycle cost analysis. A load shape indicates the distribution of a measure’s energy savings over one year. A load shape is a set of fractions summing to unity, with one fraction per hour (or other time period). Multiplying a savings value by the load shape value for any hour yields the energy savings for that particular hour.

The ideal load shape for net benefits estimates would represent the difference between the base case and measure case. The closest load shapes that are applicable to the measures in this work paper are listed in the table below.

Table XIII: Building Types and Load Shapes

|  |  |  |
| --- | --- | --- |
| **Building Type** | **Load Shape** | **E3 Alternate Building Type** |
| Commercial | Misc. Commercial | DHW HtPmp |
| Industrial | Industrial | DHW HtPmp |

# Section 4. Costs

## 4.1 Base Case Cost

The base case cost is $0.00, as this will be not doing anything to reduce the heat loss from a pipe.

## 4.2 Measure Case Cost

* **Pipe Insulation:**
* Measure cost for pipe insulation is updated per information gathered from two sources, the first is from projects tracked by SoCalGas that provide a clear separation of material and labor costs. The quotes from those projects were evaluated and the result is used to create a new pipe insulation cost, see *“WPSCGWP110812A\_Rev4\_\_Pipe Cost”* attachment for further reference. In addition, the *“RSMeans 39th Edition, Plumbing Cost Data, 2016[[12]](#footnote-4)”* data was also integrated into the new cost. The data used from this handbook is for the material and labor cost of pipes ranging from one- half to 4 inches in diameter. The cost presented in [*Table VIV*](#_4.2_Measure_Case) is for all pipe insulation applications presented in this workpaper as high temperature (850 ͦ F) fiber glass insulation was used in the quotes tracked, the same insulation can be used for steam.

Table XIV: Pipe Insulation Cost

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Cost Case Description** | **Program Delivery Strategies** | **Material Cost** | **Installation Labor Cost - Retrofit** | **Unit** | **Gross Measure Cost** |
| Pipe Insulation  -Hot Water/Steam | Downstream Prescriptive Rebates/Incentives | $3.49 | $3.18 | Ln. Ft. | $6.68 |

* **Fitting Insulation:**
* Fitting insulation costs (cost of insulation materials plus cost of installation) were determined based on telephone conversations with and written quotes provided by pipe insulation vendors. They provided installed cost for a selection of typical insulation jobs for steam and hot water piping systems. The data was processed to get a breakout of the cost to insulate straight pipe and the pipe fittings, as listed in *“Table XIV: Pipe Insulation Costs (Material & Installation) Provided by Vendor”*. Indoor installations specified an all-service jacket (ASJ), while outdoor installations specified a more durable aluminum wrap. The vendor quoted 1 inch of insulation on hot water pipe and 1.5 inches on steam pipe. The average costs represent an average of typical indoor and outdoor costs. Although the conversations did not lead to separate labor and material cost, the labor cost is estimated by using the percentage of the labor cost of linear insulation to the total cost. The percentage of the fitting total cost to be used as the labor cost will be

(%labor = 3.18/6.68 = 48%).

Table XV: Pipe Insulation Costs (Material & Installation) Provided by Vendor

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Hot Water** | | **Low-pressure Steam (0-15 psig), High Pressure Steam ( > 15 psig)** | |
| Pipe Size  (inch) | 0.75 <= OD <2 | 2 <= OD <= 4 | 0.75 <= OD <2 | 2 < OD <= 4 |
| Insulation Thickness (inch) | 1 | 1 | 1.5 | 1.5 |
| Indoors ($/fitting) | $7.73 | $7.87 | $7.60 | $9.47 |
| Outdoors ($/fitting) | $7.87 | $9.60 | $8.67 | $7.33 |

## 4.3 Full and Incremental Measure Cost

Table XVI: 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

Table XVII: Full and Incremental Costs (Pipe Insulation: Indoor, Outdoor)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Code** | **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
|  | REA | ($3.49 + $3.18) = $6.68 | ($3.49 + $3.18) = $6.68 | N/A |

Table XVIII: Full and Incremental Costs (Pipe Fitting: Indoor, Outdoor)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Measure**  **Code** | **Installation Type** | **Measure** | **Incremental**  **Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
|  | REA | HW, 0.75 <= OD <2  1” Insulation, Indoor | ($4.02 + $3.71) = $7.73 | ($4.02 + $3.71) = $7.73 | N/A |
|  | REA | HW, 0.75 <= OD <2  1” Insulation, Outdoor | ($4.09 + $3.78) = $7.87 | ($4.09 + $3.78) = $7.87 | N/A |
|  | REA | HW, 2 <= OD <= 4  1” Insulation, Indoor | ($4.09 + $3.78) = $7.87 | ($4.09 + $3.78) = $7.87 | N/A |
|  | REA | HW, 2 <= OD <= 4  1” Insulation, Outdoor | ($4.99 + $4.61) = $9.60 | ($4.99 + $4.61) = $9.60 | N/A |
|  | REA | Steam, 0.75 <= OD <2  1.5” Insulation, Indoor | ($3.95 + $3.65) = $7.60 | ($3.95 + $3.65) = $7.60 | N/A |
|  | REA | Steam, 0.75 <= OD <2  1.5” Insulation, Outdoor | ($4.51 + $4.16) = $8.67 | ($4.51 + $4.16) = $8.67 | N/A |
|  | REA | Steam, 2 <= OD <= 4  1” Insulation, Indoor | ($4.92 + $4.55) = $9.47 | ($4.92 + $4.55) = $9.47 | N/A |
|  | REA | Steam, 2 <= OD <= 4  1” Insulation, Outdoor | ($3.81 + $3.52) = $7.33 | ($3.81 + $3.52) = $7.33 | N/A |

# Referenced Attachments

1. WPSCGWP110812A\_Rev4\_Measure Worksheet and Measure Codes

2. WPSCGWP110812A\_Rev4\_Indoor Pipe Insulation Calculations

3. WPSCGWP110812A\_Rev4\_Indoor Pipe Fitting Insulation Calculations

4. WPSCGWP110812A\_Rev4\_Outdoor Pipe Insulation Calculations

5. WPSCGWP110812A\_Rev4\_Outdoor Pipe Fitting Insulation Calculations

6. WPSCGWP110812A\_Rev4\_Steam Trap Survey and Billing Analysis Report

7. WPSCGWP110812A\_Rev4\_Enbridge Steam Trap Survey

8. WPSCGWP110812A\_Rev4\_Itron: 2014 Nonresidential Downstream DEEMED ESPI Pipe Insulation Impact Evaluation Report

9. WPSCGWP110812A\_Rev4\_Weather Data

10.WPSCGWP110812A\_Rev4\_Itron: 2015 Nonresidential Downstream ESPI DEEMED Pipe Insulation Impact Evaluation Report

11.WPSCGWP110812A\_Rev4\_Pipe Cost

12. WPSCGWP110812A\_Rev4\_\_Itron\_2014\_2015 WP Parameters

# References

1. Previous Revision, Pipe Insulation Workpaper

   [↑](#endnote-ref-1)
2. Attachment Files, Zipped, Previous Revision, Pipe Insulation Workpaper

   [↑](#endnote-ref-2)
3. CPUC Decision-138907(ALJ/DMG), July 14, 2011, Attachments A – B, Page A6.

   [↑](#endnote-ref-3)
4. 2014 ESPI Pipe Insulation Report, Table 5-3 [↑](#footnote-ref-1)
5. 2015 ESPI Pipe Insulation Report, Table 6-2 [↑](#footnote-ref-2)
6. AWWA Dec 2011 The Epidemic of Corrosion Part 1 Examining Pipe Life [↑](#endnote-ref-4)
7. <https://www.houselogic.com/organize-maintain/home-maintenance-tips/types-plumbing-pipes-and-their-lifespans/> [↑](#endnote-ref-5)
8. <https://www.nachi.org/life-expectancy.htm> [↑](#endnote-ref-6)
9. <https://essentrapipeprotection.com/what-is-the-life-expectancy-of-your-pipes/> [↑](#endnote-ref-7)
10. http://www.energy.ca.gov/title24/2016standards/index.html [↑](#footnote-ref-3)
11. Combining Nusselt Number:

    <https://books.google.com/books?id=BzJBBAAAQBAJ&pg=PA347&lpg=PA347&dq=combine+free+and+forced+nusselt+number&source=bl&ots=INDkUOpvpO&sig=YlnlIZFvWxvc5rNUNR1tjBP_4sA&hl=en&sa=X&ved=0ahUKEwjPzqPLyorQAhVplFQKHeqsBo44ChDoAQggMAI#v=onepage&q&f=true> [↑](#endnote-ref-8)
12. Mossman, Melville J. *Plumbing cost data*. R S Means, 2016. Page 129 [↑](#footnote-ref-4)