eTRM
best in class

BUILDING ENVELOPE

GREENHOUSE INFRARED FILM

SWBE002-02

CONTENTS

MEASURE NAME

Greenhouse Infrared Film

STATEWIDE MEASURE ID

SWBE002-02

TECHNOLOGY SUMMARY

Polyethylene allows more radiant heat loss than other greenhouse glazing materials. IR films are a common additive to polyethylene plastics that help reduce the heat loss from greenhouses and improve the U-value of double layer polyethylene by nearly 30% (from 0.7 to 0.5).[1]

MEASURE CASE DESCRIPTION

This measure case is defined as a greenhouse roof with infrared (IR) inhibiting film additive on the inflated double polyethylene roof.

Measure Case Specification

Statewide Measure Offering ID	Measure Offering Description
SWBE002A	Greenhouse Infrared Film, installed on double layer polyethylene greenhouse

BASE CASE DESCRIPTION

The base case for this measure is defined as a greenhouse with an inflated double polyethylene roof without an infrared (IR) film additive.

Base Case Specification

Statewide Measure Offering ID	Measure Offering Description
SWBE002A	Hoop house greenhouse with double layer polyethylene covering

CODE REQUIREMENTS

Greenhouses and infrared film are not governed by state or federal codes and standards.

[1] Green Building Studio. 2005. *Greenhouse Baseline Study Final Report.* Prepared for Pacific Gas and Electric Company. Page 29.

Applicable State and Federal Codes and Standards

Code	Applicable Code Reference	Effective Date
CA Appliance Efficiency Regulations – Title 20	None.	n/a
CA Building Energy Efficiency Standards – Title 24	None.	n/a
Federal Standards	None.	n/a

NORMALIZING UNIT

Square feet of installed IR film material (Area-ft2)

PROGRAM REQUIREMENTS

Measure Implementation Eligibility

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

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

Implementation Eligibility

Measure Application Type	Delivery Type	Sector
Add-on equipment	DnDeemed	Ag
Add-on equipment	DnDeemDI	Ag
New Construction	DnDeemed	Ag

Eligible Products

The installation of infrared (IR) film must meet the following requirements:

- The IR film must be installed in a gas-heated greenhouse facility.
- The heating equipment type (building HVAC) must be specified in the implementation of the measure.
- The facility must be a greenhouse with the primary purpose of agricultural use.
- The film must be infrared, anti-condensate, polyethylene plastic with a minimum thickness of six thousandths of an inch.
- The IR film shall not be installed on the walls of the greenhouse.

Eligible Building Types and Vintages

This measure is applicable for agricultural or commercial greenhouse of any vintage for the primary purpose of the production of nursery products, horticultural specialties, or ornamental products.

Eligible Climate Zones

This measure is applicable in all California climate zones.

PROGRAM EXCLUSIONS

None

DATA COLLECTION REQUIREMENTS

Data requirements are to be determined.

USE CATEGORY

Building envelope (BldgEnv)

ELECTRIC SAVINGS (KWH)

Not applicable.

PEAK ELECTRIC DEMAND REDUCTION (kW)

Not applicable.

GAS SAVINGS (THERMS)

The gas unit energy savings (UES) of greenhouse infrared (IR) film were modeled in Virtual Grower Version 3.1. Virtual Grower is a software developed by the USDA to help greenhouse growers simulate and determine heating costs to figure out where greenhouse heat savings can be achieved.[2]

Base Case Inputs and Assumptions

The following base case inputs were used in the Energy Simulation modeling. First the greenhouse size and construction are described, then the heating system type, control, and efficiency are detailed below.

[2] USDA Agricultural Research Service, 2021. Virtual Grower 3 Model : USDA ARS

Base Case Structure Size and Materials

Greenhouse Type	Parameter	Parameter	Source
Hoop House	Number of Spans	1	Engineering Judgement based on: KEMA, Inc. 2010. *PG&E Agricultural and Food Processing Program; Greenhouse Heat Curtain and Infrared Film Measures*. Prepared for the California Public Utility Commission (CPUC) Energy Division. Navigant 2013. *Market Characterization Report For 2010-2012 Statewide Agricultural Energy Efficiency Potential and Market Characterization Study.* Prepared for the California Public Utility Commission (CPUC) Energy Division. Navigant 2015. *Measure, Application, Segment, Industry (MASI): Agriculture.* Prepared for the Southern California Edison (SCE)
	Length	200 ft	
	Width	48 ft	
	Sidewall Height	12 ft	
	Roof Height	17 ft	
	Roof Shape	Arch multi	
	Peaks per span	2	
	Roof Material	Double Polyethylene	
	Roof Material U-Value	0.7	

Heating System/Schedule

Heater Type	Parameter	Parameter	Source
Unit Heater	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. *Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses.* Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65˚F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Forced Air, Above Bench	
Boiler with Radiant Floor Heating	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. *Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses.* Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65˚F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Insulated radiant floor	

Measure Case Inputs and Assumptions

The following measure case inputs were used in the Energy Simulation modeling. The same inputs were used as the base case except for the roof material having Infrared (IR) film and the subsequent U value change from the material. The same heating system and schedule was used in the measure case as in the base case.

Measure Case Structure Size and Materials

Greenhouse Type	Parameter	Parameter	Source
Hoop House	Number of Spans	1	Engineering Judgement based on: KEMA, Inc. 2010. *PG&E Agricultural and Food Processing Program; Greenhouse Heat Curtain and Infrared Film Measures*. Prepared for the California Public Utility Commission (CPUC) Energy Division. Navigant 2013. *Market Characterization Report For 2010-2012 Statewide Agricultural Energy Efficiency Potential and Market Characterization Study.* Prepared for the California Public Utility Commission (CPUC) Energy Division. Navigant 2015. *Measure, Application, Segment, Industry (MASI): Agriculture.* Prepared for the Southern California Edison (SCE)
	Length	200 ft	
	Width	48 ft	
	Sidewall Height	12 ft	
	Roof Height	17 ft	
	Roof Shape	Arch multi	
	Peaks per span	2	
	Roof Material	Double Polyethylene with IR	
	Roof Material U-Value	0.5	

Heating System/Schedule

Heater Type	Parameter	Parameter	Source
Unit Heater	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. *Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses.* Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65˚F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Forced Air	
Boiler with Radiant Floor Heating	Schedule Type	Constant Temperature	Engineering Judgement based on: BASE ENERGY 2021. *Baseline Study of Infrared Films and Heat Curtains for Agriculture Greenhouses.* Prepared for Southern California Gas (SCG) Company.
	Set Temperature	65˚F	
	Heater Efficiency	78 %	
	Heater Age	3-5 years	
	Ventilation	Separated Combustion	
	Delivery Method	Insulated radiant floor	

Unit Energy Savings Calculation

The unit energy savings (UES) of the greenhouse infrared film run in Virtual Grower Version 3.1 with inputs described above. Virtual Grower reports energy outputs as Heating load for a greenhouse building. To determine the heating consumption of a particular HVAC system in a building, the heating load of a greenhouse must be divided by the heating system efficiency of the HVAC system. The heating efficiency of the system is reported by virtual grower, depending on the configuration of the heating system. Once the baseline and measure case consumption is determined, the savings can be determined by taking the difference between the base and measure case consumption.

In order to normalize the savings to infrared film area rather than floor area, a ratio of roof area to floor area was calculated and the savings divided by the ratio. The ratio has units of square foot of infrared film installed per square foot building area.

Heating System Efficiencies

Heater Type	Parameter	Parameter
Unit Heater	HVAC System Efficiency	45 %
Boiler with Radiant Floor Heating	HVAC System Efficiency	73 %

Sample Calculation

A sample calculation for the post processing of the Virtual Grower data follows:

$$UEC_{year} = \frac{Heating_{Load}}{Sys_{Eff} \times RooftoFloor_{Ratio} \times BTU_{Therm}}$$

$UEC_{year} =$ $Annual\ unit\ energy\ consumption\ (therms/sqft/year)$
$Heating\_Load =$ $Heating\ load\ of\ the\ Greenhouse\ (Btu/sqftBA/yr)$
$Sys\_Eff =$ $HVAC\ System\ Efficiency\ (\%)$
$RooftoFloor_{Ratio} =$ $1.107\ Ratio\ of\ Roof\ Area\ to\ Floor\ Area\ (sqft\ IR\ Film/sqft\ BA)$
$BTU_{Therm} =$ $100{,}000\ Btu/Therm$

$$UES_{year} = UEC_{year,baseline} - UEC_{year,measure}$$

$UES_{year} =$ $Annual\ unit\ energy\ savings\ (therms/year)$
$UEC_{year,baseline} =$ $Annual\ unit\ energy\ consumption\ for\ baseline\ case\ (therms/year)$
$UEC_{year,measure} =$ $Annual\ unit\ energy\ consumption\ fore\ measure\ case\ (therms/year)$

LIFE CYCLE

Effective useful life (EUL) is an estimate of the median number of years that a measure installed through a program is still in place and operable. Remaining useful life (RUL) is an estimate of the median number of years that a technology or piece of equipment replaced or altered by an energy efficiency program would have remained in service and operational had the program intervention not caused the replacement or alteration. The RUL is only applicable to the first baseline period for a retrofit measure with an applicable code baseline.

As per Resolution E-4807, the California Public Utilities Commission (CPUC) defined the EUL of a retrofit add-on (REA) measure as the minimum of the EUL of the measure itself and the RUL of the host equipment.[3] The RUL of the host equipment (which is a greenhouse for this particular measure) is calculated as one-third of the EUL of a greenhouse. The EUL of a greenhouse is not available and thus is assigned the maximum allowable EUL of 20 years, as permitted by Version 2 of the Energy Efficiency Policy Manual. The methodology to calculate the RUL of the host equipment conforms with Version 5 of the Energy Efficiency Policy Manual, which recommends "one-third of the effective useful life in DEER as the remaining useful life until further study results are available to establish more accurate values." This

[3] California Public Utilities Commission (CPUC). 2016. *Resolution E-4807*. December 16. Page 13.

approach provides a reasonable RUL estimate without the requiring any a priori knowledge about the age of the equipment being replaced.[4]

The EUL and RUL specified for a greenhouse Infrared Film are specified below.[5]

Effective Useful Life and Remaining Useful Life

Parameter	Value	Source
EUL (yrs) – IR film [a]	5.0	Itron, Inc. 2005. *2004-2005 Database for Energy Efficiency Resources (DEER) Update Study - Final Report.* Prepared for Southern California Edison. Page 4-14. California Public Utilities Commission (CPUC). 2008. "EUL_Summary_10-1-08.xls."
EUL (yrs) – host greenhouse	15.0	California Public Utilities Commission (CPUC), Energy Division. 2003. Energy Efficiency Policy Manual v 2.0. Page 16.
RUL (yrs) – host greenhouse	5.0	

a. The EUL value of five years is adopted for this measure, as it is minimum of the EUL of the measure and the RUL of a greenhouse.

BASE CASE MATERIAL COST ($/UNIT)

Estimates of base case material costs drawn from previous studies are shown below. Because these estimates are not comparable, see Measure Case Material Cost section for derivation of incremental measure cost that is used in the cost effectiveness calculation.

Base Case Cost Estimates for Polyethylene Film with No Infrared Additive

Cost Estimate ($/ft^2)	Original Source
$0.093	Energy and Environmental Analysis, Inc. 2006. *Greenhouse Thermal Curtains and Infrared Films: Workpaper for PY2006-2008.* Prepared for the Southern California Gas Company. B-REP-06-599-17B.
$0.250 Includes installation.	Bartok, J. 2001. *Energy Conservation for Commercial Greenhouses.* Natural Resource, Agriculture, and Engineering Service (NRAES). Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.

Source: Green Building Studio. 2005. *Greenhouse Baseline Study Final Report.* Prepared for Pacific Gas and Electric Company. Page 57.

From *Greenhouse Thermal Curtains and Infrared Films: Workpaper for PY2006-2008,* base cost of $0.093 will be used.

[4] KEMA, Inc. 2008. "Summary of EUL-RUL Analysis for the April 2008 Update to DEER." Memorandum submitted to Itron, Inc.

[5] According to the 2008 EUL update to the Database of Energy Efficient Resources (DEER), the EUL for greenhouse IR film is based upon Pacific Gas and Electric (PG&E) program tracking data and a workpaper developed by Southern California Edison, but these sources are not identified or confirmed.

The 2005-2005 Database for Energy Efficient Resources (DEER) Update Study notes the EUL of this measure depends on the climate "Standard replacement of film is 4 years. In mild climates film may be replaced at 5-year increments or longer."

MEASURE CASE MATERIAL COST ($/UNIT)

Estimates of the measure case material costs drawn from previous studies and manufacturer data are shown below. Because the material cost estimates are not comparable, the estimates of incremental measure cost are adopted for the cost effectiveness analysis.

Energy and Environmental Analysis, Inc. prepared the *Greenhouse Thermal Curtains and Infrared Films: Workpaper for PY2006-2008* for the Southern California Gas Company (SoCalGas),[6] with incremental measure cost of $0.021. Pacific Gas and Electric Company (PG&E) later adopted this cost evaluation in its *PGECOAGR102 Revision 3 Greenhouse IR Film* workpaper of 2012.[7] The *2010-2012 WO017 Ex Ante Measure Cost Study conducted by Itron, Inc reported* similar results

Cost data from the SoCalGas commercial rebate program (2017 to 2020) indicate cost range from $0.05 to $0.15 per square foot of infrared film. These results aligned with the WO017 study results.

Measure and Installation Cost Estimates for Greenhouse Infrared Film [8]

Cost Estimate ($/ft^2)	Incremental Cost of IR Film	Original Source
-	$0.02	Itron, Inc. 2014. *2010-2012 WO017 Ex Ante Measure Cost Study Final Report.* Prepared for the California Public Utilities Commission.
$0.114	$0.021	Energy and Environmental Analysis, Inc. 2006. *Greenhouse Thermal Curtains and Infrared Films: Workpaper for PY2006-2008.* Prepared for the Southern California Gas Company. B-REP-06-599-17B.
$0.210 Includes installation	-	Hoogenbom, J. November 2003. This reference could not be located.
-	$0.010	Bartok, J. 2001. *Energy Conservation for Commercial Greenhouses.* Natural Resource, Agriculture, and Engineering Service (NRAES). Ithaca, NY: Natural Resource, Agriculture, and Engineering Service.
-	$0.030	Itron, Inc. 2005. *2004-2005 Database for Energy Efficiency Resources (DEER) Update Study - Final Report.* Prepared for Southern California Edison.

BASE CASE LABOR COST ($/UNIT)

See Measure Case Labor Cost. Base case labor cost is assumed to be the same as the measure case labor cost.

MEASURE CASE LABOR COST ($/UNIT)

See Measure Case Material Cost section. Due to the inconsistency of cost estimates drawn from previous studies, the installation costs were not developed for this measure, but are assumed to be the same for the base case and measure case.

6

[7] Pacific Gas and Electric Company (PG&E). 2012. "Work Paper PGECOAGR102 Greenhouse IR Film Revision 3." August 28.

[8] Green Building Studio. 2005. *Greenhouse Baseline Study Final Report.* Prepared for Pacific Gas and Electric Company. Page 57.

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. These NTG values are based upon the average of all NTG ratios for all evaluated 2006 – 2008 commercial, industrial, and agriculture 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 commercial, industrial, and agriculture sector programs for more than two years and for which impact evaluation results are not available.

The NTG for greenhouse infrared film is based upon the evaluation of the PG&E Agriculture and Food Processing Program published by KEMA, Inc. in 2010 and is specific to downstream delivery type.

Net-to-Gross Ratios

Delivery Type	NTG ID	NTG Ratio	Source
Downstream	*NonRes-sGHS-mIRF-dn*	0.46	KEMA, Inc. 2010. *2006-2008 Evaluation Report: PG&E Agricultural and Food Processing Program; Greenhouse Heat Curtain and Infrared Film Measures.* CALMAC Study ID: CPU0024.01. Page 60. Itron, Inc. 2011. *DEER Database 2011 Update Documentation.* Prepared for the California Public Utilities Commission. Page 9-4.
Direct Install	*Agric-Default>2yrs*	0.60	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 DEER-based inputs and methods, and the rationale for inputs and methods that are not DEER-based.

DEER Difference Summary

DEER Item	Comment / Used for Workpaper
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	No
DEER Operating Hours	No
DEER eQUEST Prototypes	No
DEER Version	No
Reason for Deviation from DEER	Greenhouse DEER measures are expired
DEER Measure IDs Used	N/a
NTG	The NTG of 0.46 is associated with NTG ID: *NonRes-sGHS-mIRF-dn* The NTG of 0.60 is associated with NTG ID: *Agric-Default>2yrs*
GSIA	Source: DEER. The GSIA of 1.0 is associated with GSIA ID: *Def-GSIA*
EUL/RUL	Source: DEER 2014. The value of 5 years is associated with EUL ID: *Agr-Irfilm* RUL ID: *BldgEnv-CoolRoof*

REVISION HISTORY

Measure Characterization Revision History

Revision Number	Revision Completion Date	Primary Author, Title, Organization	Revision Summary and Rationale for Revision Effective Date and Approved By
01	03/31/2018	Jennifer Holmes, Cal TF Staff	Draft of consolidated text for this statewide measure is based upon Workpaper PGECOAGR102 Revision 3 (August 28, 2012) Consensus reached among Cal TF members.
	06/28/2019	Andres Marquez, SoCalGas Jennifer Holmes, Cal TF Staff	Revisions for submittal of version 01.
02	7/30/2021	Anders Danryd, SoCalGas	Revisions to workpaper due to expiration of DEER measures. Savings modeled using Virtual Grower 3 using results of baseline study, added new Delivery types and NC
	9/24/2021	Anders Danryd, SoCalGas	Text edits and clarifications
	10/20/2021	Anders Danryd, SoCalGas	Added sample calculation section describing the calculations to data needed after Virtual Grower modeling
	11/15/2021	Anders Danryd, SoCalGas	Clarifications to text in sample calculation section