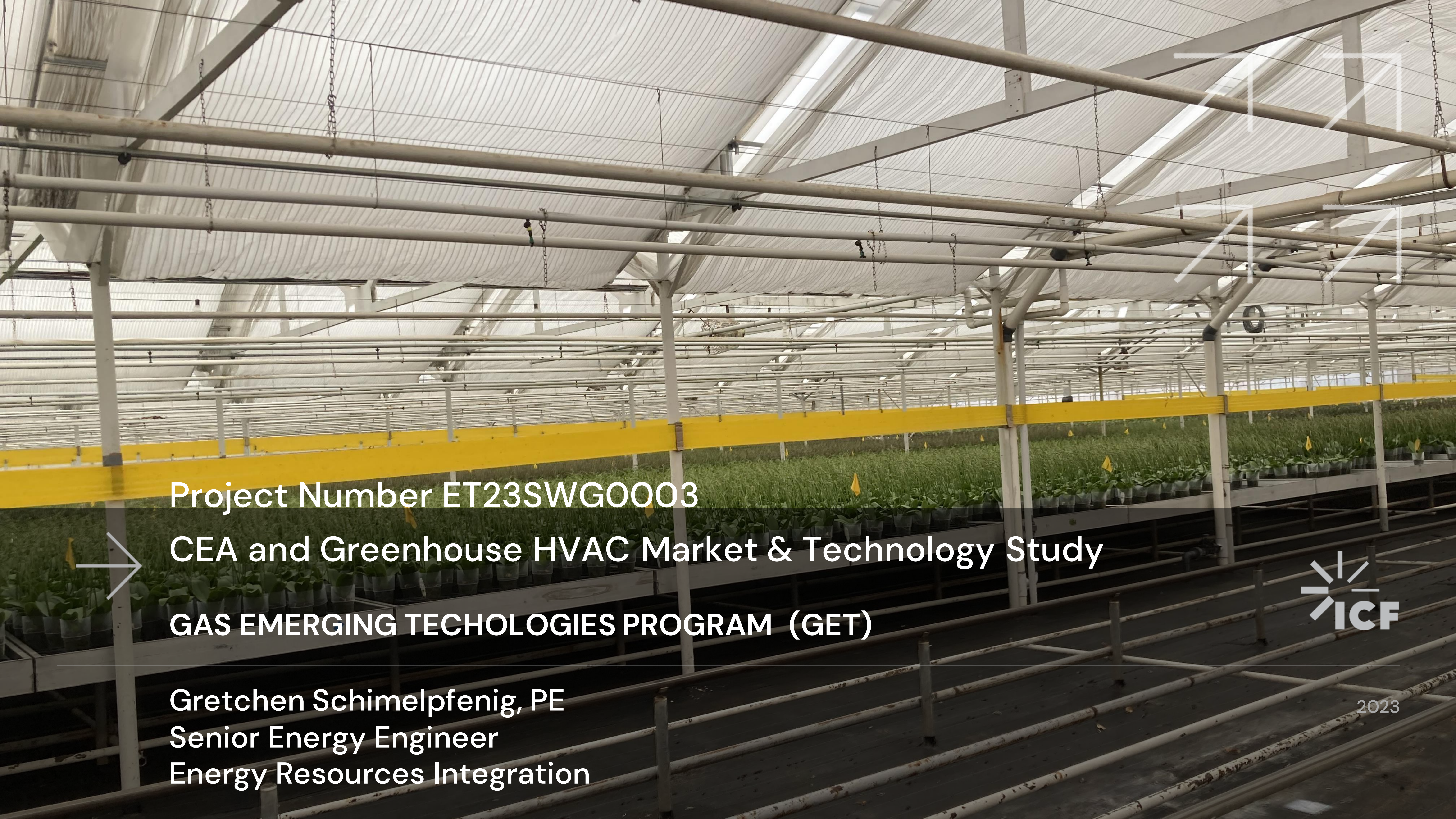

Project Number ET23SWG0003

CEA and Greenhouse HVAC Market & Technology Study

GAS EMERGING TECHOLOGIES PROGRAM (GET)

ICF

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2023

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Presentation Image Sources: Energy Resources Integration (photos taken in California) and Gretchen Schimelpfenig (photos taken outside of California)

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ET03 - CEA HVAC Project Findings

Greenhouses Demand Heating

California greenhouse natural gas energy use intensity ranges from 1.7 therms per square foot per year for greenhouses using double-wall coverings to 3.1 therms per square foot per year for greenhouses using single-wall coverings.

Efficient Heating Saves Energy

A proposed measure table explores five emerging CEA HVAC technologies with estimated energy benefits ranging from 6.7 – 53% annual natural gas savings.

Target Vegetable Greenhouses

Savings opportunity will be the greatest for vegetable greenhouses, a market segment representing 20 million square feet of California farm area and 33 - 62 million annual therms of natural gas usage.

Support Hydronic Systems

Unit heaters are the technology in use in 60% of greenhouses. This presents a significant opportunity for the adoption of more efficient hydronic HVAC systems, finned heat pipes, and root zone heating systems.

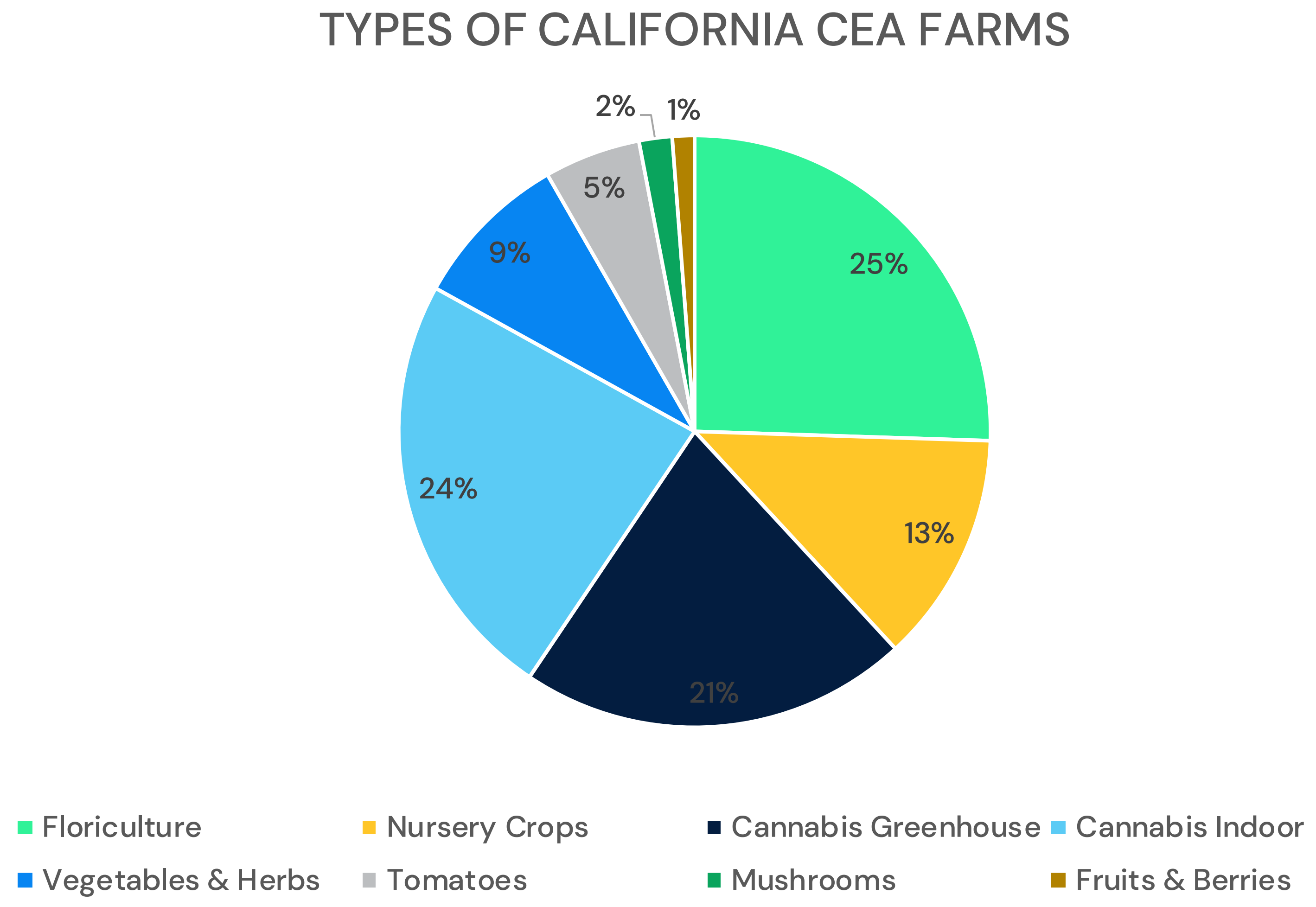
Replace Single-Wall Coverings

The low U-value and high light transmittance of double-wall acrylic coverings will provide the greatest benefits to the 31% of California greenhouses using single-wall coverings and the 46% of greenhouses using polycarbonate coverings.

Introduction to CEA HVAC

ET03 – California CEA Market Overview

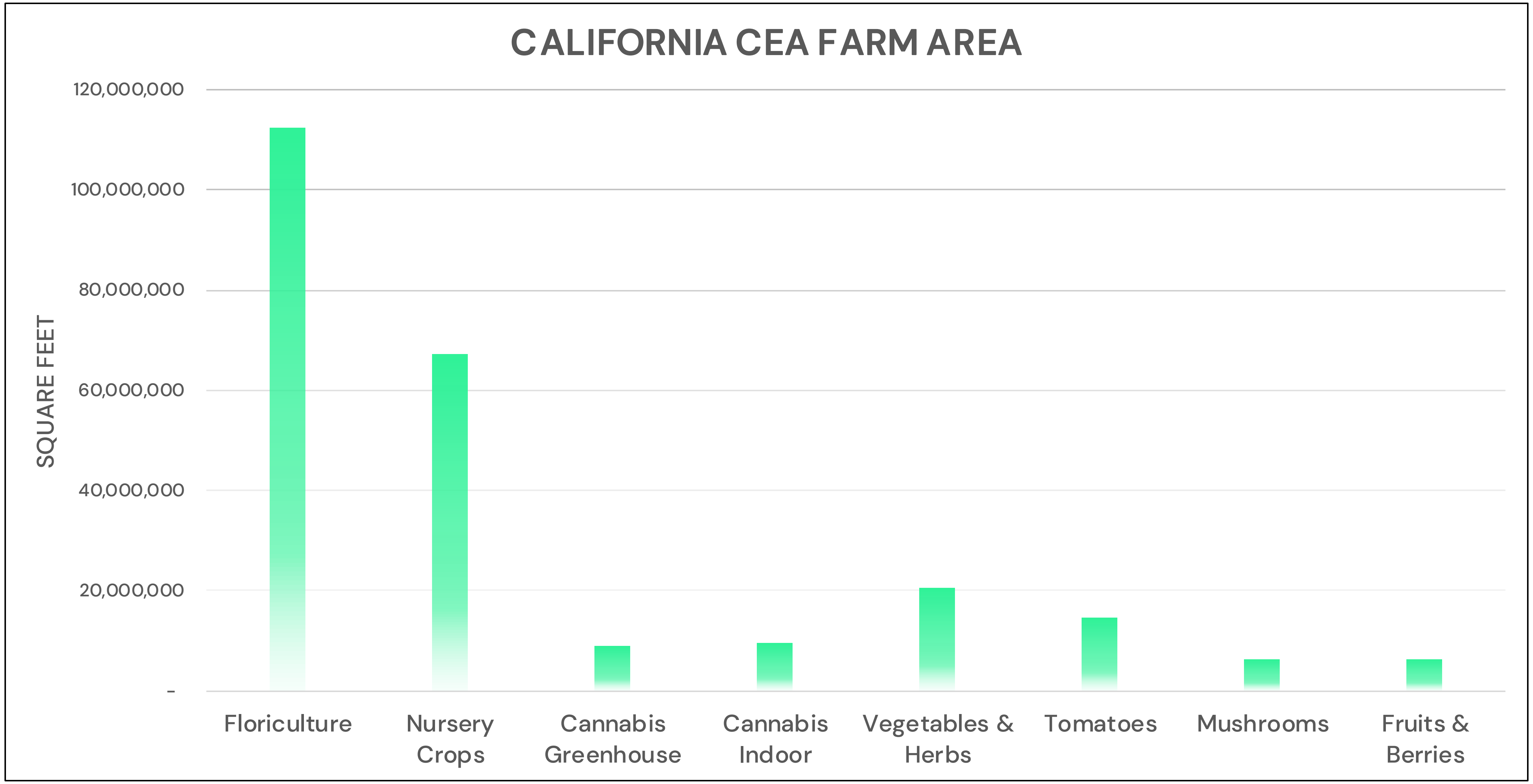
California had 3,800 active CEA operations in 2023.



Sources: USDA (2019), 2017 Census of Agriculture; State of California Department of Cannabis Control (2023), Cannabis Unified License Search.

ET03 – California CEA Farm Area

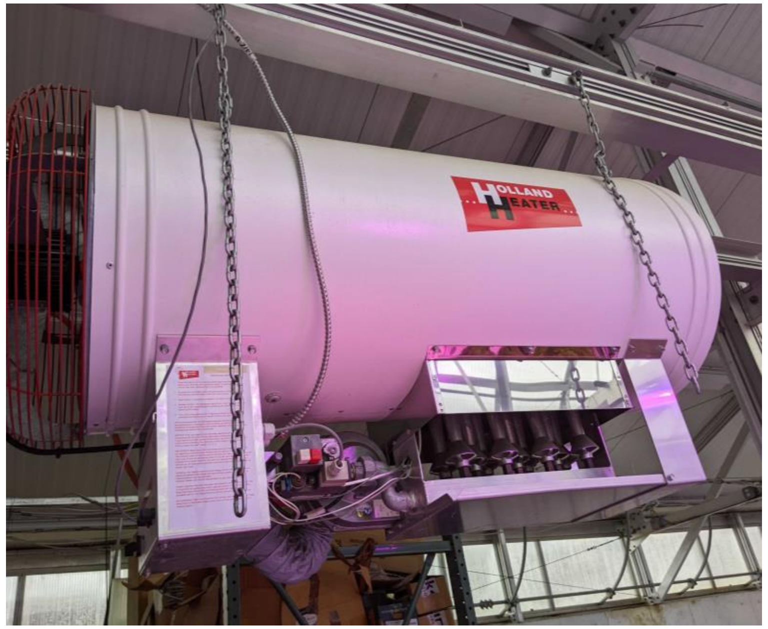
California has 246 million square feet of CEA farms

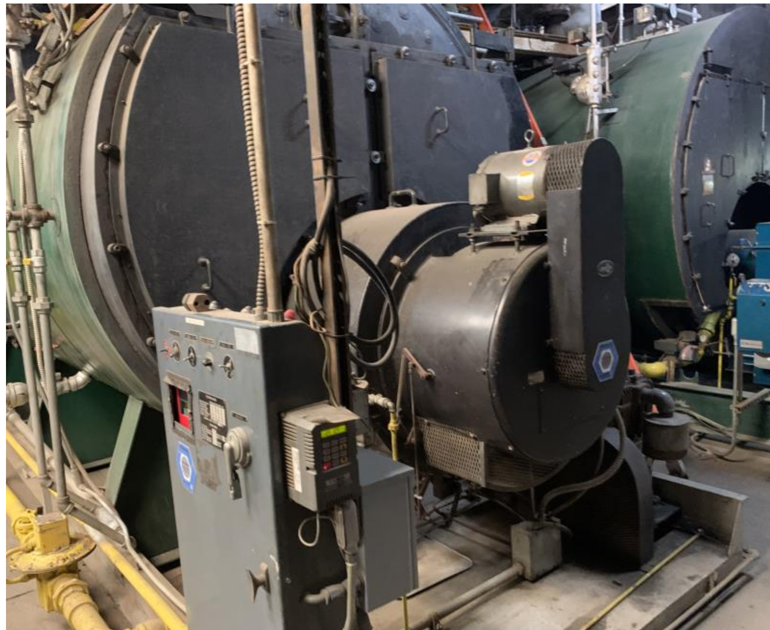


Sources: USDA (2019), 2017 Census of Agriculture; State of California Department of Cannabis Control (2023), Cannabis Unified License Search.

ET03 – Purpose of CEA HVAC Systems

Growers use CEA HVAC systems to maintain vapor pressure deficit (VPD) ranges that support healthy plant growth and do not create an attractive environment for pests and pathogens.





CEA HVAC Energy Consumption

Natural gas for heating end uses can account for 70 – 80% of total annual energy consumption for greenhouses.

Source: Sanford, S. (2011), Reducing greenhouse energy consumption – An overview

ET03 – California CEA HVAC Energy Consumption

- Energy accounts for up to 60% of greenhouse operating costs.
  - Heating can be 2nd or 3rd largest operating cost.

- Facility size may be more impactful than climate zone on natural gas consumption.
  - Future study is needed to explore energy use intensity.
  - Virtual Grower models of a greenhouse in Carpinteria, CA demonstrate 1.7 – 3.1 therms per square foot depending on covering type.

CEA Farm Type	Average Annual Therms for Heating	Facility Count
Vegetable	389,916	2
Cannabis	374,415	8
Orchid	160,247	8
Nursery	83,648	50
Floriculture	73,903	24
CEA WEIGHTED CUSTOMER AVERAGE	**119,709**	**92**

Sources: Southern California Gas (2023), Data Request Emerging Technology Study 06272023; Roehm (2023), ACRYLITE Multi-skin_SoCalGas Case Study_231004

Natural gas consumption for 41 CEA facilities in California Climate Zone 6 for 2022 ranged widely from around 100 therms per year to over 650,000 therms per year.

Source: Southern California Gas (2023), Data Request Emerging Technology Study 06272023

→ Incumbent CEA HVAC Technology

The upfront cost of heating systems is a barrier to energy efficiency for CEA growers.

Capital costs for unit heater systems can be 75 – 88% lower than hydronic systems.

Source: Beytes, C. (2021), Ball RedBook 19th Edition: Volume 1 – Greenhouse Structures, Equipment, and Technology

ET03 – Incumbent CEA HVAC Technologies

1. The size of greenhouse HVAC systems is influenced by covering type and number of 'walls'.
2. Most California greenhouses use unit heaters, a central boiler producing steam or hot water, or a combination of these systems.
3. 51-mm thin-wall steel tubing (called 'heat pipes') with water at temperatures of 180 – 190° F are often used for hydronic greenhouse heat distribution.
4. HVAC systems serving indoor farms may not use natural gas.
5. Larger indoor farms are more likely to use hydronic cooling systems than greenhouses or smaller indoor farms.

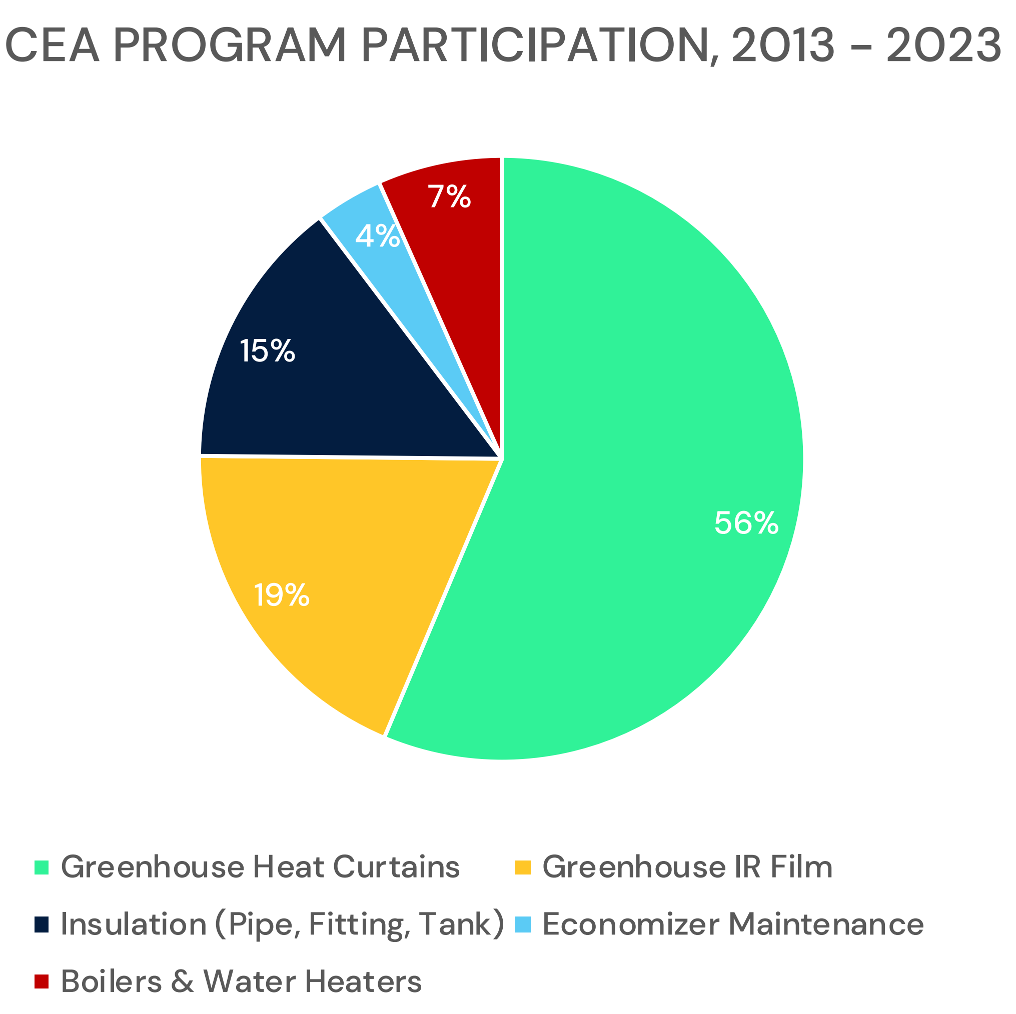
CEA Operation Type	Technology Category	Technology Type
Greenhouse	Covering	Film plastic (polyethylene film) Rigid plastic (single-layer polycarbonate) Glass
	Heating	Unit heaters Infrared heaters Boilers with hydronic distribution
	Heat Distribution	Bare steel heat pipes via top, perimeter, or under-bench (root zone)
	Cooling	Natural ventilation with fans Evaporative 'pad and fan' systems Misting/fogging systems Chillers with hydronic distribution
	Thermal energy storage	Thermal energy storage with water
Indoor	Heating	Electric Direct Expansion (DX) / heat pump Boilers with hydronic distribution
	Cooling	Electric Direct Expansion (DX) / heat pump Chillers with hydronic distribution

ET03 – CEA Customer Historical EE Program Participation

In the past ten years, CEA customers implemented 170 natural gas energy efficiency projects with SoCal Gas.

However, only ten projects addressing process boilers or commercial hot water heating equipment were completed.

This low level of adoption is corroborated by Northern California program implementers.



Source: Southern California Gas (2023), Data Request Emerging Technology Study 06272023

→ Emerging CEA HVAC Technology

In addition to gas-consuming appliances, heat distribution and greenhouse coverings offer significant energy savings potential.

Five technologies explored in this study are recommended for measure development.

ET03 - Emerging CEA Natural Gas Efficiency Technologies

1. Low-mass boilers achieve much better efficiencies compared to legacy greenhouse boilers and unit heaters.
2. Greenhouses using finned heat pipes can increase heat output by 5 – 10 times with 80% less water.
3. Root zone heating systems offer savings for any size of greenhouse.
4. Hybrid-drive high-performance chillers are most feasible for indoor farms and most cost-effective for growers with high electricity rates.
5. Acrylic coverings save energy while also boosting light transmission by 17 – 24% over polycarbonate.

Emerging Technology	Baseline Technology	Natural Gas Savings Potential
Low-mass boilers	Unit heaters	36 – 38%
Finned heat pipes	Bare steel heat pipes	6.7 – 10.5%
Root zone heating with reduced space temperatures	Perimeter or top hydronic heating	19 – 53%
Hybrid gas-electric chillers	Electric chillers	Fuel switch to gas resulting in 30 – 60% lower total energy costs & carbon emissions
Double-wall acrylic greenhouse covering	Single-layer corrugated polycarbonate greenhouse covering	25 – 47%

Root zone heat distribution under benches can satisfy 30 – 40% of greenhouse heating demand and allow for air temperature setpoints to be reduced by 5 °F to 10 °F.

Source: Farm Energy Extension (2019), Root Zone Heating Systems for Greenhouses

Technology Evaluation

ET03 – Assessment Objectives and Results

- Between May and August 2023, the research team exceeded targets for surveys and site visits and did not reach target for stakeholder interviews.
- The research team accessed utility data from SoCal Gas customers for 2022 and part of 2023.

Stakeholder Engagement Instrument	Target	Individuals Contacted	Number of Respondents	Target Achieved	Response Rate
Surveys	100	369	123	Exceeded	33%
Interviews	20	381	17	Not met	4.5%
Site Visits	4	373	5	Exceeded	1.3%
Energy Data Analysis	N/A	N/A	92	N/A	N/A

ET03 – Survey Demographics

The typical respondent to the survey was a greenhouse grower cultivating vegetables.

48%

Grow food (vegetables, tomatoes, herbs, berries, and mushrooms)

46%

Grow ornamentals and nursery crops

6%

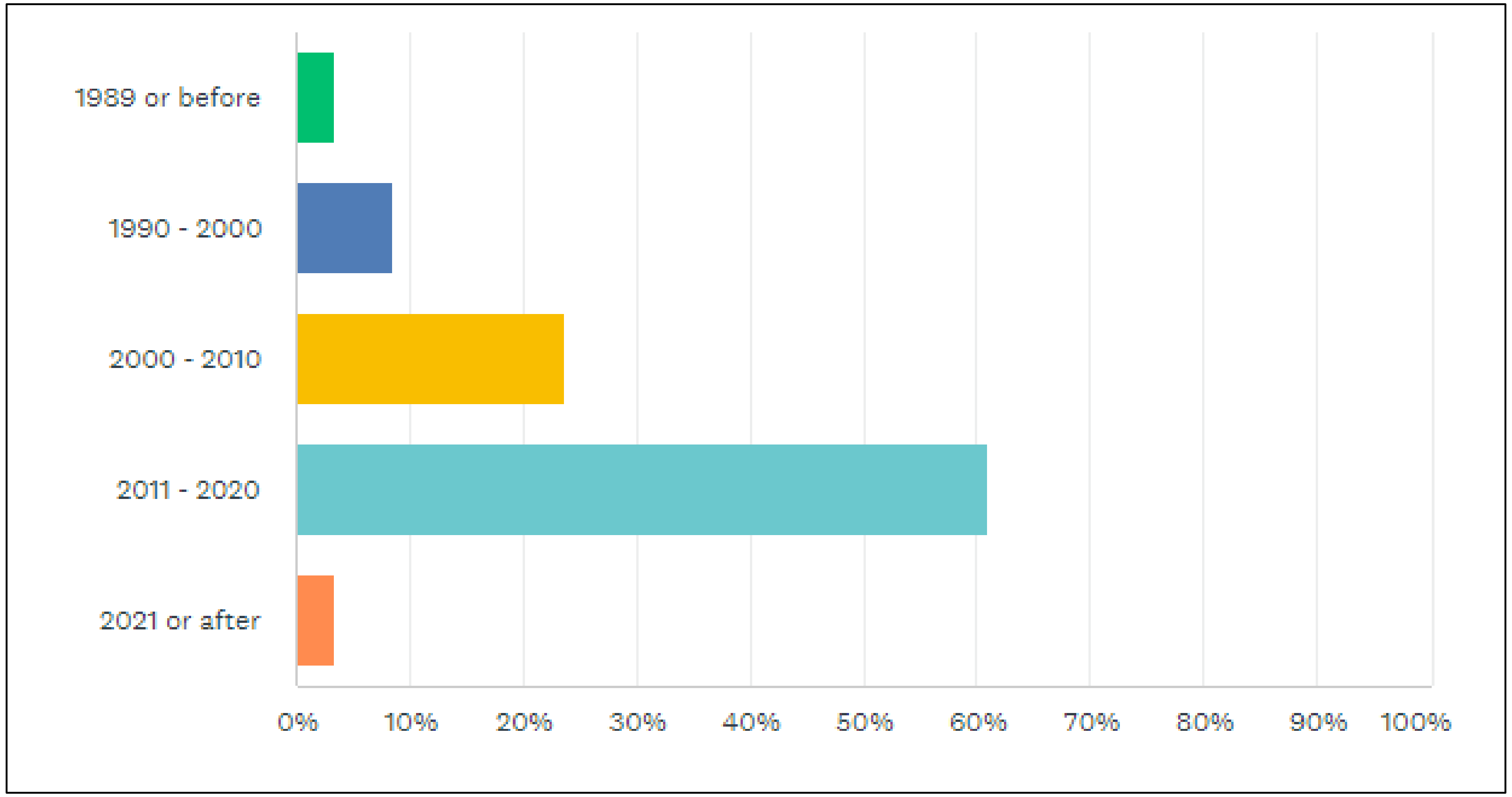
Grow cannabis

75%

Grow in greenhouses

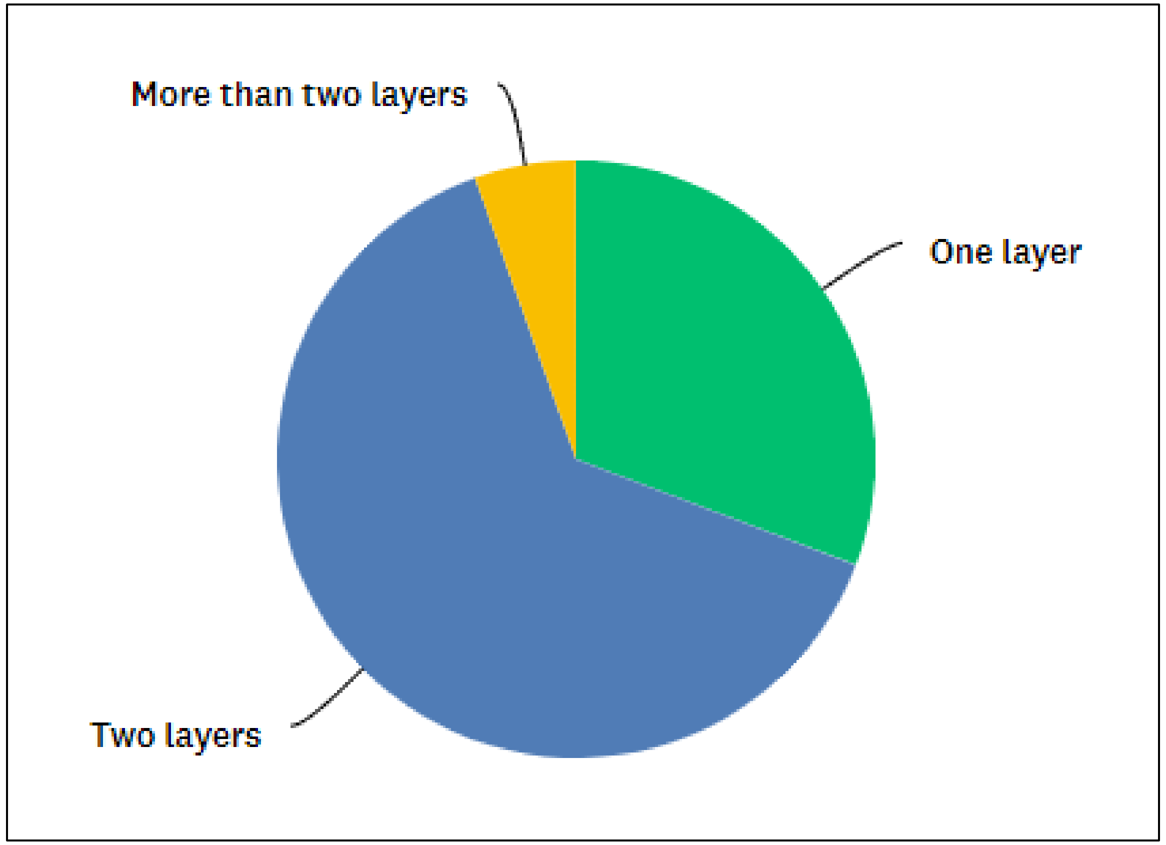
ETO3 – Survey Finding: Greenhouse Boiler Age

- Gas boilers are in use at 45% of responding facilities.
- Greenhouses with older boilers present a large opportunity for boiler upgrades.
- 36% of greenhouses using boilers are served by boilers installed prior to 2010.



ET03 – Survey Finding: Number of Greenhouse Coverings

- Growers often use multiple types of coverings in the same facility.
- 62% of respondents use plastic film coverings like polyethylene.
- 46% use polycarbonate coverings.
- 31% of respondents use single-wall coverings.



ET03 – Stakeholder Interview Demographics

The typical stakeholder interviewed was a manufacturer of emerging CEA HVAC technologies.

8

Manufacturers

3

Consultants

3

Academic researchers and industry associations

3

Energy efficiency program implementers

ET03 – Stakeholder Interview Findings

Boilers

Around 4% of California greenhouses have adopted low-mass boilers due to their significantly higher capital costs than unit heaters. Standalone or small single-span greenhouses are most likely to use unit heaters.

Root Zone Heating

Called the "Cadillac of heating systems", root zone heating (RZH) system costs depend heavily on how much heat load will be covered. Less than 10% of greenhouses have applied RZH across all cultivation spaces.

Greenhouse Coverings

Polycarbonate panels, plastic film, and glass may be found at the same facility. Dutch-style greenhouse construction uses glass due to its high light transmissivity.

Finned Heat Pipes

2 - 3% of California greenhouse growers using hydronic heating systems apply finned pipes for heat distribution. Bare steel heat pipe is standard practice for Dutch-style greenhouse design.

Chillers

20 – 30% of indoor facilities use chilled water systems for cooling. Chillers are most cost-effective for buildings larger than 100,000 square feet growing crops with high profit margins like leafy greens, herbs, or cannabis.

Title 24 Energy Code

Requirements for double-wall coverings only affect conditioned greenhouses or those doing major renovations like additions. Replacements of existing coverings do not trigger California energy code.

ET03 - Site Visit Demographics

The typical CEA site visited was an orchid greenhouse in CZ6.

4

Greenhouses

1

Indoor farm

4

CEA crops

3

California climate zones

ET03 – Site Visit Observations

- Facilities visited grow all the major crop categories represented in the California CEA market.
- The average greenhouse facility visited was 375,000 square feet.
- The indoor facility visited had 31,000 square feet of cultivation space.

CEA Operation	Crop	Location	Greenhouse Covering Type	Heating System	Heat Pipe Type	Cooling System
Greenhouse #1	Floral	CZ3	Single-wall polycarbonate	Steam boiler and hot water boiler	Under-bench bare heat pipe	Natural ventilation & fans
Greenhouse #2	Orchids	CZ6	Single-wall polycarbonate	Hot water boiler	Under-bench and above-canopy bare heat pipe	Pad & fan
Greenhouse #3	Leafy Greens	CZ6	Double-wall polycarbonate with seasonal whitewash	Hot water boiler	Under-bench bare heat pipe	Natural ventilation & fans
Greenhouse #4	Orchids	CZ6	Glass with seasonal whitewash	Hot water boiler	Under-bench and above-canopy bare heat pipe	Natural ventilation & fans
Indoor #1	Cannabis	CZ12	N/A	Hot gas bypass	N/A	Dedicated outdoor air system with energy recovery

Results

ET03 – Measure Table

CEA Operation Type	Technology Category	Brief Description	Detailed Description
Greenhouse	Heating	Low-mass boilers	High-efficiency boilers replacing unit heaters
Greenhouse	Heating	Finned heat pipes	Aluminum radiant heat distribution replacing bare steel heat pipes
Greenhouse	Heating	Root zone heating with reduced air temperatures	Root zone heating replacing top or perimeter heating with reduced space temperature setpoints
Indoor	Cooling	Hybrid gas-electric chillers	Hybrid gas-electric chillers replacing electric chillers
Greenhouse	Covering	Double-wall acrylic panels	Double-wall acrylic panels 8 – 16mm thick with 16 – 64 mm rib spacing replacing single-wall polycarbonate or glass

ET03 – Measure Table

Measure	Low-Mass Boilers	Finned Heat Pipes	RZH with Reduced Space Temperatures	Hybrid gas-electric chillers	Double-Wall Acrylic
Measure Application Type (MAT)	NR/AR	NR/AR	NR/AR	NR/AR	NR/AR
Building Type	Greenhouse	Greenhouse	Greenhouse	Indoor Farm	Greenhouse
Measure Costs ($)	$2-$7/sq ft or $0.02 – $0.03/Btu	$9-10/linear foot	$2-12/sq ft	$3,000/ton	$2 – 3/sq ft (acrylic only) $8/sq ft (including aluminum)
Annual Natural Gas Savings (therms)	55,827	13,336	63,736	N/A	1.4 therms/sq ft
GHG Savings (kg CO_2e)	295,883	70,683	337,800	30 – 60% total emissions from energy use	5.9 kg CO_2e/sq ft
Annual Gas Cost Savings ($)	$67,886	$16,217	$77,503	30 – 60% total energy costs	$2.20/sq ft
Improved Efficiency (%)	36 – 38% gas savings	6.7 – 10.5% increased heat transfer	19 – 53% gas savings	N/A Fuel switch from electric	27% better U-value than code minimum
Simple Payback (years)	6.63	14.65	7.23	Varies	4.66
EUL (years)	20 years	20 years	20 years	20 years	30 years
Proposed Incentive Approach	Deemed	Deemed	Custom	Custom	Deemed

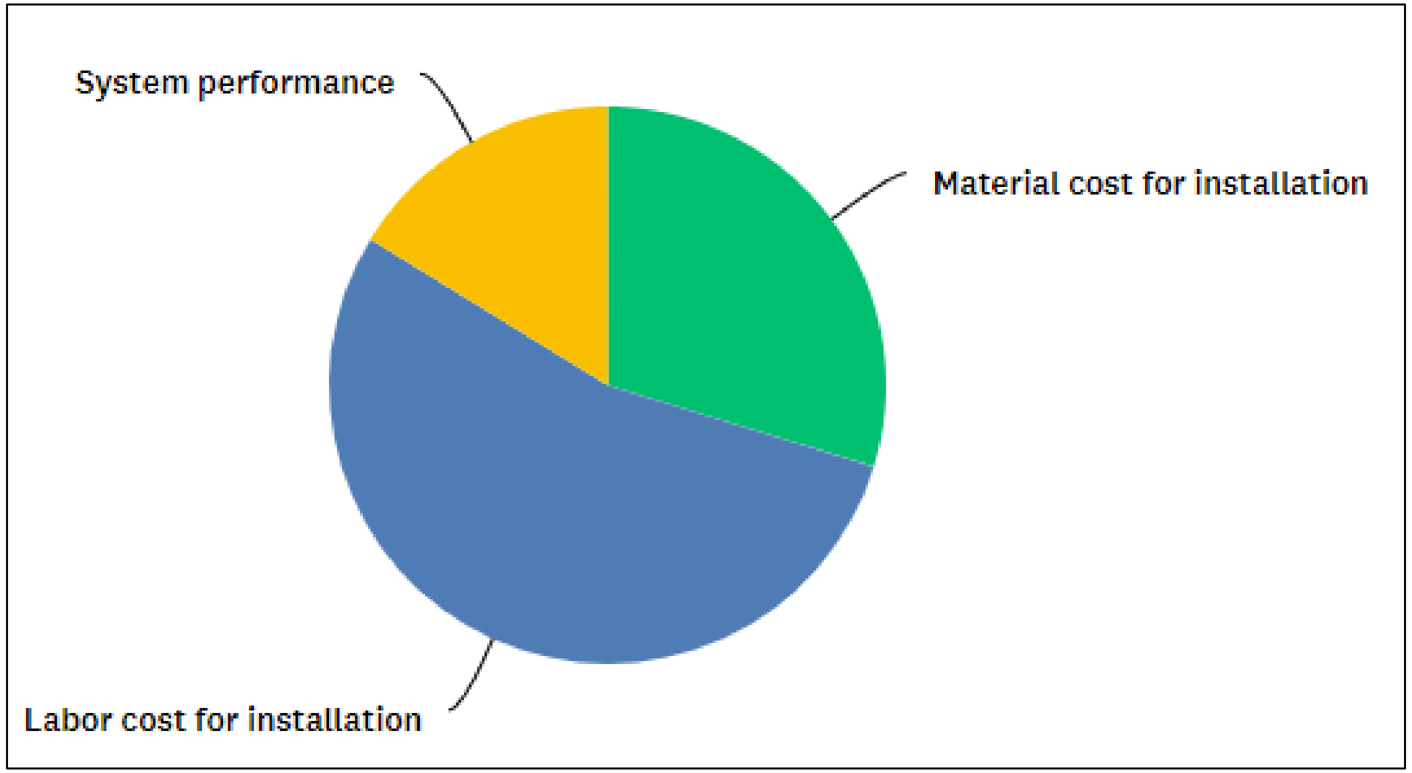
ET03 – Non-Energy Benefits of Emerging Technologies

- Each emerging technology provides a technical improvement over baseline equipment.
- Non-energy benefits for plants and CEA businesses can include impacts on plants.
  - Cycle time
  - Quality characteristics
  - Yields

Brief Description	Quantitative Improvement(s)
Low-mass boilers	Higher combustion efficiency Reduced water use
Finned heat pipes	Higher thermal conductivity Faster heat transfer No painting maintenance
Root zone heating with reduced air temperatures	Better heat delivery to plants Faster production Higher quality crops
Hybrid gas-electric chillers	Lower energy costs Reduced carbon emissions
Double-wall acrylic panels	Reduced heat loss (lower U-value) Higher light transmissivity

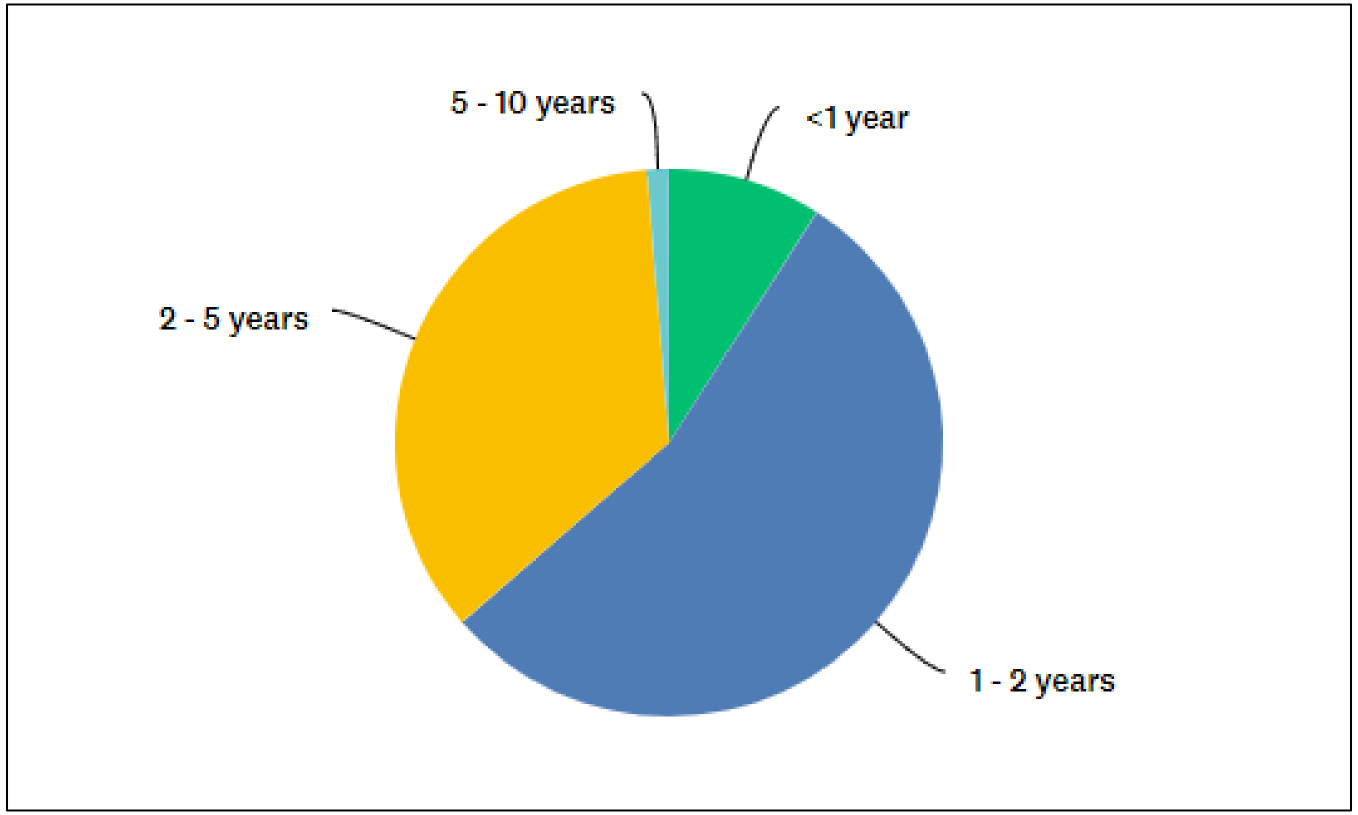
ETO3 – Survey Finding: Barriers to Energy Efficiency

- Capital costs are the biggest barrier to EE project implementation for CEA businesses.
- Labor costs for installation are of greater concern than material costs.
- 12% of surveyed greenhouse growers and indoor farm operators have concerns about system performance of energy efficient products.
  - There is an opportunity to build trust for efficient products to persuade skeptics.



ETO3 – Survey Finding: Payback Periods for Energy Efficiency Projects

- More than half of growers need payback periods to be less than two years.
- A third of CEA operators can implement projects with payback periods of two to five years.
- Smaller CEA operations may be challenged to adopt CEA HVAC measures which can have longer payback periods than the maximum of five years.



ET03 – Suggested Incentive Approach for Recommended Measures

- Four of the recommended measures are novel.
- Two of the new measures can employ a deemed approach if data from field testing and pilot projects can support energy modeling for each California climate zone.
- One measure suggests an improvement to an existing measure and can continue to employ a deemed approach.
- Two of the new measures should employ a custom approach as the inputs for energy modeling vary greatly by facility type and behavior.

Proposed Measure	Proposed Measure Approach	Rationale
Low-mass boilers	Deemed	Update to existing deemed measure
Finned heat pipes	Deemed	Heat transfer improvement is consistent and can be modeled for each California climate zone
Root zone heating with reduced air temperatures	Custom	Proportion of heat load served by RZH is variable, space temperature setpoint adjustment will vary
Hybrid gas-electric chillers	Custom	Dual-fuel equipment, usage of gas and electricity will vary
Double-wall acrylic panels	Deemed	U-value improvement is consistent and can be modeled for each California climate zone

Conclusions and Recommendations

ET03 – Measure Package Development

The GET Program recommends measure package development for the following identified technologies or new products:

1. Low-mass boilers
2. Finned heat pipes
3. Root zone heating with reduced space temperatures
4. Hybrid gas-electric chillers
5. Double-wall acrylic panels

The study will be published at: https://www.etcc-ca.com/reports/cea-and-greenhouse-hvac-market-technology-study

ET03 - Measure Package Development

The following technologies or products are promising and commercially available; and follow-up field or lab testing is recommended:

1. Low-emissivity anti-reflective glass
2. Double-wall insulated glass panels
3. ETFE film
4. Phase change material for thermal energy storage

The study will be published at: https://www.etcc-ca.com/reports/cea-and-greenhouse-hvac-market-technology-study

ET03 – Recommendations for Future Study

Future study is needed to determine the best pathway for high priority technologies, evaluate which should be field tested, assess cost effectiveness and total system benefit for measures, and confirm the deemed or custom structure best suited to the measure.

Further investigations could collect data from on-site pilot installations of high priority measures. Climate control technology could be leveraged for energy monitoring. Future study could investigate gas usage by square footage of greenhouse and indoor facility by California climate zone.

ETO3 – Recommendations for Future Study

A Phase 2 CEA HVAC study is being planned.

The goal of a Phase 2 study is to support utility measure package development and the creation of new natural gas efficiency measures or updated measure packages and identify market barriers and intervention strategies to address these barriers.

The end state of Phase 2 will present a road measure package to integrate cost-effective gas efficiency measures for the CEA sector into program offerings.

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