



# 2026 Process Loads Technology Priority Map

## Final Report

ET26SWE0009



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## Acknowledgements

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## Abbreviations, Acronyms, and Glossary of Terms

| Acronym         | Meaning                                                                    |
|-----------------|----------------------------------------------------------------------------|
| AI              | Artificial intelligence                                                    |
| ASHRAE          | American Society of Heating, Refrigeration, and Air-Conditioning Engineers |
| BRO             | Behavioral, Retro-commissioning, and Operational                           |
| CO <sub>2</sub> | Carbon dioxide                                                             |
| CEH             | Controlled environment horticulture                                        |
| CPUC            | California Public Utilities Commission                                     |
| DAC             | Disadvantaged community                                                    |
| EE              | Energy efficiency                                                          |
| EM&V            | Evaluation, Measurement, and Verification                                  |
| ET              | Emerging technology                                                        |
| eTRM            | Electronic Technical Reference Manual                                      |
| GHG             | Greenhouse gas                                                             |
| GW              | Gigawatts                                                                  |
| GWP             | Global warming potential                                                   |
| HPPH            | Heat pump pool heater                                                      |
| HTR             | Hard-to-reach                                                              |
| HVAC            | Heating, ventilation, air conditioning                                     |
| HVAC/D          | Heating, ventilation, air conditioning, and dehumidification               |
| IOU             | Investor-owned utility                                                     |
| IT              | Information technology                                                     |
| kWh             | Kilowatt-hour                                                              |

| Acronym | Meaning                                       |
|---------|-----------------------------------------------|
| NEMA    | National Electrical Manufacturers Association |
| PEI     | Pump Energy Index                             |
| PG&E    | Pacific Gas and Electric Company              |
| SCE     | Southern California Edison                    |
| SME     | Subject matter expert                         |
| TPM     | Technology Priority Map                       |
| TSB     | Total System Benefit                          |
| VFD     | Variable frequency drive                      |

| Glossary Term            | Meaning                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Technology Category      | One of six broad technology categories (Whole Buildings; HVAC; Water Heating; Lighting, Plug Loads and Appliances; Process Loads; and Portfolio Enhancements).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Technology Family        | Functional grouping that provides description of program role, opportunities, and barriers.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Research Initiatives     | Initiative in place of both subgroups and knowledge indices.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Research Initiatives Key | Visual aid explaining each research initiative's ranking on a low, medium, or high scale.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Rankings                 | <p><b>Future Needs:</b> Covers items that are not yet ready for consideration due to having high needs in validation, market analysis, measure development, or program development. Programs should not be discouraged from submitting proposals for research initiatives with a “Future Needs” classification but instead focus on making a strong argument for how the project outcomes can help fill in the missing gaps for validation or market analysis.</p> <p><b>Low:</b> Covers items that have lower industry interest and/or uncertain impacts for energy efficiency due to having an expansive data set or information readily available or not being pertinent to the research initiative.</p> <p><b>Medium:</b> Covers items that are an evolution of or offer promise to existing and common technologies for energy efficiency. This can be in the form of needs that are currently being addressed with existing projects or needs that may exist but are not critical to the objectives of meeting efficiency metrics.</p> <p><b>High:</b> Covers items that have high industry interest and high impacts for energy efficiency.</p> |
| Definitions              | Narrative to provide additional clarification on the technology family scope.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Opportunities            | Description of potential impacts and potential research areas.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Barriers                 | Description of key barriers and potential barriers research.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| CalNEXT Priority         | Communicates expected level of focus by CalNEXT SMEs.<br><i>Note: Priorities will change as research is completed.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| High                     | <b>High:</b> CalNEXT has highlighted this technology family as having high energy savings with any known barriers surmountable through targeted interventions within the technology category and will prioritize funding projects under this technology family.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Medium                   | <b>Medium:</b> CalNEXT has highlighted this technology family as having moderate to high overall energy savings with known barriers to entry that may be more challenging to address within the technology category and will consider funding projects under this technology family.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

| Glossary Term | Meaning                                                                                                                                                                                                                                                         |
|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Low           | <b>Low:</b> CalNEXT has highlighted this technology family as having moderate to high overall savings but faces difficult or unknown barriers to adoption within the technology category and will not prioritize funding projects under this technology family. |

## Introduction

The Technology Priority Maps (TPMs) provide the CalNEXT program with a framework to externally communicate priorities of the program, clearly define the central focus areas of the program, and assist with project screening. They also document the impact potential, programmatic research needs, and market readiness of all technology families across each of the end-use technology areas and drive product ideation while informing project selection. This Final Report covers the revision process for the 2026 Process Loads TPM.

## 2026 TPM Changes

The CalNEXT team revised the Process Loads category to further clarify and expand the program definitions and priorities for prospective participants. One notable recent driver for these changes includes the passage of the One Big Beautiful Bill Act in 2025,<sup>1</sup> which repealed many tax credits and funding for state-administered incentive programs targeting the market originally signed into law under the Inflation Reduction Act of 2022. In addition, California's investor-owned utility (IOU) Codes and Standards Enhancement team conducted research related to multiple technology families that impacted the program's state of knowledge to varying degrees.

In 2025, by looking at incoming proposals, the team made sensible consolidations, such as changing refrigeration to a single commercial and industrial technology family. The project team also culled TPM areas that did not have much traction and rolled them into adjacent TPMs; for example, we combined water systems with pumping systems, as all water system proposals were related to pumping efficiencies rather than water treatment. Going forward, this will continue to simplify the process through which stakeholders select and propose topics. Furthermore, the cross-partner collaboration on technology families—such as controlled environment horticulture (CEH), where TRC runs the agricultural program for Pacific Gas and Electric Company (PG&E)—was helpful from a stakeholder feedback perspective.

For the 2026 TPM update, the CalNEXT team established a robust process for this initial phase of the TPM development and revisions. Similar to last year, we incorporated a stronger push to gather feedback directly from Process Loads subject matter experts (SMEs) at the beginning of the revision process.

This year, the Process Loads TPM SME team reformed with representatives from each of the program team partners: AESC, Energy Solutions, TRC, UC Davis, and VEIC, along with the Ortiz Group, who provided feedback at the stakeholder outreach stage during the draft report. The Process Loads SME team includes members who support an array of energy efficiency programs using technologies covered by the Process Loads TPM, as well as members who support the California IOUs' Codes and Standards program. These emerging technology products are then contextualized into priority maps through a markets and solutions lens.

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<sup>1</sup> To read the One Big Beautiful Bill Act, see: <https://www.congress.gov/bill/119th-congress/house-bill/1/text>.

In 2026, we revised the research initiatives as needed based on market changes that had occurred since the 2025 Process Loads TPM revision. The research initiatives tables describe the two to five most important technology areas, with the current version providing a simplified ranking view of where the Process Loads portfolio stands for easier use and external understanding. Research initiatives are presented at a higher level than project- or proposal-specific details, with the intent to provide guidance for project submitters rather than specific examples. The end goal of these visual summaries is to have a clear representation of where the technology family stands in the portfolio and what remaining research is needed.

**Table 1: Rankings and their meanings.**

| Icon                                                                                                  | Meaning                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <b>Future Needs</b> | Covers items that are not yet ready for consideration due to having high needs in validation, market analysis, measure development, or program development. Programs should not be discouraged from submitting proposals for research initiatives with a “Future Needs” classification but instead focus on making a strong argument for how the project outcomes can help fill in the missing gaps for validation or market analysis. |
|  <b>Low</b>          | Covers items that have lower industry interest and/or uncertain impacts for energy efficiency due to having an expansive data set or information readily available (or that are not pertinent to the research initiative).                                                                                                                                                                                                             |
|  <b>Medium</b>     | Covers items that are an evolution or offer promise to existing and common technologies for energy efficiency. This can be in the form of needs that are currently being addressed with existing projects or needs that may exist but are not critical to the objectives of meeting efficiency metrics.                                                                                                                                |
|  <b>High</b>       | Covers items that have high industry interest and high impacts for energy efficiency.                                                                                                                                                                                                                                                                                                                                                  |

In 2026, the Process Loads SME team is focused on revising and cleaning up the technology families based on energy efficiency and affordability standards, among annual revisions considering market changes and CalNEXT program priorities.

Overall, the changes made in this 2026 TPM aim to focus on increased technology transfer broadly across the portfolio, allowing the CalNEXT team to define new measures of interest and illustrate its efforts to bring them into the portfolio. These changes should improve shorter-term technology transfer, such as measure packages for expansion of the existing Resource Acquisition programs. Even for longer-term investments, the visual format will provide more tactical guidance to what type of research is needed to better progress different technologies to the goal of portfolio savings.

# Stakeholder Feedback

## Technology Priority Map Advisory Committee Outreach

The TPM Advisory Committee outreach began in August 2026, when the team sent a survey requesting stakeholders' feedback via email, resulting in additions to the research family narratives. The TPM Advisory Committee members we contacted are listed below in [Error! Reference source not found.](#)

Table 2: Technology Priority Map Advisory Committee outreach.

| Organization                                            |
|---------------------------------------------------------|
| California Technical Forum (CaITF)                      |
| California Market Transformation Administrator (CalMTA) |
| California Public Utilities Commission (CPUC)           |
| Pacific Gas & Electric (PG&E)                           |
| Southern California Edison (SCE)                        |
| San Diego Gas & Electric (SDG&E)                        |

This outreach allowed advisory committee members to provide candidly written comments and suggestions, which were reviewed by the TPM coordinator and the 2026 Process Loads TPM SME team and incorporated into the Revised 2026 Process Loads TPM sections below. A detailed table of changes can be found in [Appendix A](#).

## Controlled Environment Horticulture

CalNEXT Priority: High

### Definition

The Controlled Environment Horticulture (CEH) technology family encompasses a combination of lighting and non-lighting equipment used to produce agricultural products in CEH spaces. This includes lighting systems, such as lighting design strategies, lighting control systems, and lighting technologies, as well as non-lighting equipment, such as heating, ventilation, air conditioning, and dehumidification (HVAC/D); precision nutrient monitoring; irrigation systems; pumps; controls systems associated with maintaining environmental conditions for growing; and district strategies for shared utilities, as well as self-generation and energy storage.

### Research Initiatives

Table 3: CEH technology family research initiatives.

| Research Initiatives                                            | Performance Validation Needs                                                        | Market Analysis Needs                                                               | Measure Development Needs                                                             | Program Development Needs                                                             |
|-----------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Advanced environmental controls and equipment for CEH           |   |   |   |   |
| Energy generation & storage                                     |  |  |  |  |
| CEH colocation: Farm Park Model                                 |  |  |  |  |
| Performance optimization and demand flexibility options for CEH |  |  |  |  |
| Performance standards and building codes                        |  |  |  |  |

\*Table above is not exhaustive. More technologies and controls are mentioned below.

**KEY**  High Needs  Medium Needs  Low Needs  Future Needs

### Opportunities

Examples of key opportunities for energy efficiency, decarbonization, and demand flexibility in CEH include:

- **Energy efficiency improvements.** Energy use intensity in CEH ranges from 9.3 kilowatt-hours (kWh) to 27.9 kWh per square foot,<sup>2</sup> particularly in high-tech greenhouses and indoor facilities growing crops like leafy greens and tomatoes, making it a prime sector for efficiency improvements.
- **Efficient equipment and controls.** HVAC/D systems represent 60 percent to 80 percent<sup>3</sup> of energy use in greenhouses and 30 to 50 percent<sup>4</sup> in indoor vertical farms, indicating strong savings potential from more efficient equipment and controls.
- **Deemed measure offerings.** Most efficiency programs focus on deemed lighting or custom HVAC/D measures; there is a clear opportunity to expand deemed measure offerings to include HVAC/D technologies for greater program uptake, which may present differently in cannabis versus non-cannabis production, as well as in indoor versus greenhouse facilities.
- **Water-energy nexus opportunities.** Even as drought conditions vary year to year, efficient fertigation controls and water reuse strategies offer dual benefits for water conservation and reduced embodied energy.
- **Horticultural lighting savings.** Savings from horticultural lighting can go beyond fixture efficiency through improved system design, optimized spectral distributions, and controls such as daylight harvesting and spectral tuning.
- **Energy efficient lighting.** Using thermal curtains can simultaneously reduce light pollution and HVAC loads in greenhouses. Additionally, indoor growing may offer greenhouse gas (GHG) reduction benefits compared to open-field agriculture under certain conditions.
- **Demand management strategies.** Scheduling, thermal storage, or pairing with onsite renewables, particularly agrivoltaics can help reduce peak loads, depending on growers' operational flexibility.
- **Industry-specific standards.** Developing these standards—e.g., through the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) or the American Society of Agricultural and Biological Engineers—would support consistent program implementation. These standards would include sizing guides, test procedures, and commissioning protocols for CEH HVAC/D.
- **Energy grid reductions.** Lowering the kWh draw from the grid by co-locating solar photovoltaics with greenhouses, especially when paired with heat pumps.
- **Co-locating CEH operations with data centers and other industrial users in a Farm Park model.** This strategy could unlock resource-sharing opportunities, such as waste heat reuse, shared infrastructure, and microgrid integration, improving cost competitiveness and supporting rural economic development.

## Barriers

Examples of common barriers to energy efficiency and demand flexibility in CEH include:

- **Rapid industry growth.** This trend has led to many poorly designed systems lacking efficiency considerations, often due to limited technical guidance or program incentives.

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<sup>2</sup> <https://www.energystar.gov/buildings/benchmark/understand-metrics/what-eui>

<sup>3</sup> <https://www.aceee.org/sites/default/files/pdfs/eo-indoor-ag.pdf>

<sup>4</sup> <https://www.sciencedirect.com/science/article/pii/S1359431123021580>

- **Lack of trusted tools and experienced designers to optimize lighting, HVAC/D, and integrated systems**, particularly when balancing energy use and plant productivity.
- **Lack of technical understanding.** Controls like spectral tuning and daily light integral tracking are still novel in this sector and not widely adopted, partly due to limited performance data and grower skepticism.
- **Grower hesitancy.** Many growers are cautious about adopting new technologies due to uncertain return on investment, high first cost, limited in-field evaluations, and a lack of accessible best-practice case studies.
- **Existing HVAC/D equipment lacks horticulture-specific efficiency metrics and test procedures**, which complicates program inclusion and market comparison.
- **The sector lacks a skilled workforce familiar with high-efficiency CEH systems**, emphasizing the need for workforce education and technical training.
- **Limited energy use intensity data specific to California CEH operations**, which hinders the development of performance-based building codes and benchmarking tools.
- **Transition costs.** While new facilities can be designed to meet updated standards, existing CEH operations will need time, resources, and incentives to transition to higher efficiency systems.
- **Operational and behavioral measures face verification and persistence challenges, especially under current Behavioral, Retro-commissioning, and Operational (BRO) measure rules.** Cost-effective measurement and verification strategies are needed to support longer estimated useful life ranges and broader program eligibility.
- **Farm-Park-style colocation faces challenges in aligning heat and resource loads across multiple industries.** Implementation requires coordinated planning, infrastructure investment, and regulatory alignment to fully capture shared efficiency and decarbonization benefits.
- **High real estate and operating costs.** These expenses make it difficult for CEH businesses to compete with other potential land and building uses, raising the bar for profitability and investment in efficiency.
- **Escalating electricity rates strengthen the case for efficiency measures but present a barrier to electrification and decarbonization projects, which may increase operating costs in the near term.** Capacity constraints combined with lengthy, expensive service upgrades are additional related barriers CEH facilities often face when electrifying.

In addition to the barriers listed above, research should focus on activities that help build knowledge among both growers and utilities, including:

- Investigating how changes in lighting, temperature, and humidity affect the overall economics for growers, including growth, energy savings, and production value in various types of facilities—as well as designing effective knowledge transfer approaches to present comprehensive side-by-side results in terms of yield versus the cost of energy in different crops, different light sources, HVAC/D systems, controls strategies, fertigation approaches, and different building types. Work has begun to establish quantitative metrics for CEH that can simultaneously characterize the energy performance and crop yield of a solution to allow growers the ability to make true side-by-side comparisons across different solutions. The next step is for institutions to increase the use of those quantitative metrics.

- Developing guidelines based on studies of difference in yields achieved with high intensity discharge lighting versus light-emitting diode lighting, and how photosynthetic photon efficacy from the different lighting types may affect the overall cost or yield achieved.
- Studying how controlling the light intensity, spectral distribution, and environmental conditions to match a crop growth cycle and shift demand can help growers develop strategies to adjust production, increase energy savings, and manage that demand.
- Studying financial benefits and additional production values regarding the use of energy storage with and without renewable self-generation for HVAC/D and other production equipment needs in sealed greenhouses, particularly to decarbonize and manage demand.
- Conducting market research and a lifecycle study to further inform the determination of industry standard practice and claimable program savings.
- Exploring the technical and economic potential of colocation models—such as Farm Parks—that pair greenhouses with data centers or other industrial users to enable waste heat recovery, shared infrastructure, and microgrid integration, while supporting regional economic development and grid resilience.

Outputs from these research topics would help alleviate growers' hesitancy in trying different technologies or growing practices for fear of lower yields and income.

### **Related CalNEXT Projects**

- ET25SWE0019 – [Agricultural Sector Adoption of PEI Pumps Market Study](#)
- ET24SWE0037 – [Cooling and Dehumidification for Indoor Farming](#)
- ET23SWE0067 – [Smart Controls for Data-Driven Indoor Agriculture Field Evaluation](#)
- ET22SWE0027 – [Greenhouse Lighting Controls](#)
- ET25SWE0032 – [Electrification of Greenhouse Heating Systems](#)
- ET25SWE0034 – [SmartAg Controls: Incentivizing Efficiency & Yields](#)

## Commercial Kitchens

CalNEXT Priority: High

### Definition

The Commercial Kitchens technology family focuses on process load electric equipment and systems typical in commercial kitchens (i.e., at cafes, fast food, and sit-down restaurants) and institutional foodservice facilities (i.e., hospitality and cafeterias).

*Note: Non-process loads commercial kitchen systems are included in other TPMs. Grocery display cases and remote-condensing systems are covered under the Refrigeration, Commercial technology family within this Process Loads TPM. Additionally, related water heating topics are covered under the Water Heating TPM and the Steam and Hot Water Systems technology family within this Process Loads TPM.*

### Research Initiatives

Table 4: Commercial Kitchens technology family research initiatives.

| Research Initiatives                                                                                                                                       | Performance Validation Needs                                                        | Market Analysis Needs                                                               | Measure Development Needs                                                             | Program Development Needs                                                             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| New electric foodservice equipment for gas equipment that historically had no electric alternative (woks, tandoor ovens, rack ovens, electric rotisseries) |  |  |  |  |
| Economics and benefits of electric foodservice cooking equipment                                                                                           |  |  |  |  |
| Hard-to-reach/disadvantaged community engagement on foodservice equipment                                                                                  |  |  |  |  |

**KEY**  High Needs  Medium Needs  Low Needs  Future Needs

### Opportunities

Commercial kitchens are incredibly energy intensive, consuming five to seven times the energy density<sup>5</sup> of other types of buildings, which presents significant energy savings potential. There is also a tremendous opportunity to decarbonize these facilities, as kitchen natural gas consumption makes

<sup>5</sup> <https://www.energystar.gov/buildings/resources-audience/small-biz/restaurants>

up approximately 23 percent of all commercial building gas usage<sup>6</sup> despite being only a small fraction of the square footage. The commercial foodservice industry in California is still dominated by gas-fired cooking equipment, presenting a large opportunity for decarbonization in this technology area.

Opportunities include:

- **New electric commercial foodservice equipment.** While technologies exist to electrify many pieces of commercial cooking equipment, there are several commercial cooking equipment technologies that are still mainly gas fueled, such as woks and tandoor ovens. Microwave technology is another example of an electric foodservice technology that has opportunities for increased market adoption.
- **Economics of electric commercial foodservice equipment.** There are opportunities to quantify and resolve economic barriers associated with electric commercial kitchen equipment, including incremental equipment costs, operating costs, and infrastructure upgrade costs.
- **Commercial foodservice fuel substitution measure package development.** CPUC Decision 23-04-035<sup>7</sup> requires the development of commercially viable electric alternatives for commercial kitchen cooking equipment, shifting CalNEXT's focus in this category toward decarbonization.
- **Identifying and quantifying the non-energy benefits of electric cooking equipment.** Electric foodservice equipment can have other benefits, such as faster cleaning time and improved indoor air quality. Reduced cooling and ventilation needs should continue to be validated, especially within existing facilities. Benefits may be more pronounced in disadvantaged communities (DACs) and hard-to-reach (HTR) communities; additionally, there are opportunities to study the positive impacts of electric cooking equipment specifically on DAC/HTR communities.
- **Measure development and codes readiness.** For maturing technologies, CalNEXT should continue to conduct research that can feed into the development of new deemed measures and standards.
- **Addressing user acceptance barriers to electric commercial foodservice equipment.** Additional research should focus on resolving major industry barriers associated with commercial foodservice electrification, such as end-user reluctance to use electric cooking technology.

## Barriers

Despite the strong opportunities and technical maturity of foodservice equipment, this sector faces significant barriers to the adoption of electric cooking equipment, including:

- **Lack of market awareness of decarbonization opportunities.** Market understanding has improved as programs are now targeting distribution channels and retailers to ensure ENERGY STAR® products are widely available in like-for-like equipment replacements. However, this sector is still in an early stage for decarbonization activities, and historic behavioral practices may influence purchasing practices toward gas-fired foodservice equipment.

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<sup>6</sup> <https://docs.nlr.gov/docs/fy24osti/89130.pdf>

<sup>7</sup> For more information, see: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF>

- **Lack of electric alternatives for foodservice equipment.** Some cooking equipment (such as broilers, woks, and rack ovens) do not have proven electric appliance alternatives yet, requiring industry development of electric cooking equipment to suit the entire foodservice industry's cooking equipment needs.
- **Economics of commercial electric foodservice equipment.** Electrical infrastructure upgrades for all-electric kitchens can present significant costs to business owners and add substantial load to the grid at peak load times. Operating costs using current rate structures can double or triple when comparing gas to electric cooking equipment, as electric foodservice equipment typically operates using resistance or induction technology with smaller comparative efficiency benefits to other electrification technologies, such as heat pumps.
- **Electric rate impacts on commercial electric foodservice equipment.** There are larger structural issues—such as energy rates being misaligned with decarbonization efforts, tenant-owner split incentives, and peak demand charges—impacting electric foodservice economics.
- **DAC/HTR communities and small businesses may have larger barriers to adopting electric cooking equipment** due to potential higher equipment and operating costs compared to gas-fired cooking equipment.

### Related CalNEXT Projects

- ET22SWE0010 – [All-Electric Commercial Kitchen Electrical Requirements Study Evaluation](#)
- ET22SWE0019 – [Market Potential for Heat Pump Assisted Hot Water Systems in Foodservice Facilities](#)
- ET22SWE0048 – [Commercial Kitchen Hot Water System Design Guide](#)
- ET22SWE0054 – [Foodservice Refrigeration: High Efficiency Condenser and Evaporator Units Focused Pilot](#)
- ET23SWE0056 – [High Efficiency Refrigerated Display Case](#)
- ET23SWE0057 – [Overcoming Key Barriers to Electrification of Foodservice Hot Water in California](#)
- ET24SWE0024 – [Commercial Cooktop Fuel Substitution](#)
- ET24SWE0032 – [New CFS Measure Prioritization](#)
- ET24SWE0057 – [High Speed Oven Energy Use Field Monitoring for the Commercial Foodservice Industry](#)
- ET22SWE0046 – [Restaurant Field Monitoring](#)

## Refrigeration, Commercial and Industrial

CalNEXT Priority: High

### Definition

This technology family focuses on commercial and industrial cooling, refrigeration, and freezing systems serving stationary applications in agriculture; food sales; foodservice; commercial kitchens; laboratories; cold storage warehouses; and refrigeration and freezing systems for food, materials, pharmaceuticals, and other manufactured product applications. It also includes refrigerated transportation distribution from manufacturing facilities and packaged refrigeration systems.

### Research Initiatives

Table 5: Refrigeration, Commercial and Industrial technology family research initiatives.

| Research Initiatives                                                                                                                                         | Performance Validation Needs                                                        | Market Analysis Needs                                                               | Measure Development Needs                                                             | Program Development Needs                                                             |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Natural refrigerant and low-global-warming-potential (GWP) refrigeration systems, including designs, systems, and components (new and retrofit applications) |    |    |    |    |
| Thermal energy storage systems and demand shift/management                                                                                                   |  |  |  |  |
| Natural refrigerant and low-GWP refrigeration system modeling tools and analysis methods                                                                     |  |  |  |  |
| Refrigerant management, leak detection, and monitoring                                                                                                       |  |  |  |  |

**KEY**  High Needs  Medium Needs  Low Needs  Future Needs

## Opportunities

Commercial and industrial refrigeration has many opportunities for enhancements and improvements via CalNEXT, as identified:

- **Support the transition to low-global-warming-potential (GWP) and natural refrigerants and systems** through retrofits and new technologies.
- **Accelerate adoption of transcritical carbon dioxide (CO<sub>2</sub>) systems** with integrated energy recovery and efficient components.
- **Retrofit existing systems** with advanced leak detection and refrigerant charge management systems
- **Replace fixed-speed compressors and condensers** with variable-capacity equipment.
- **Deploy thermal energy storage and adaptive controls**, enabling dynamic load shifting and peak demand reduction and alignment with solar generation, grid carbon intensity, and lower-cost periods.
- **Evaluate artificial intelligence (AI)-based refrigeration system optimization platforms** for predictive analytics, refrigerant leaks, energy efficiency, and system maintenance.
- **Support custom projects and site demonstrations with Evaluation, Measurement, and Verification (EM&V)** to validate load-shifting impacts, inform policy evolution, and establish the foundation for future standardized measures that can be scaled broadly.

## Barriers

Commercial and industrial refrigeration also faces several barriers, as identified below:

- New technologies, research and development costs, and system integration complexity all slow market uptake.
- Site-specific customizations make scalability and replicable installations difficult.
- Technical, performance, and long-term reliability data for emerging systems is limited or unvalidated, increasing perceived risk for customers and utility programs.
- Lack of standardized baselines and insufficient industry data impede program design.
- Technician shortages and lack of training on new refrigerants and systems hinder deployment.
- Compliance with refrigerant safety codes adds complexity and cost.
- IOU reliance on custom incentive pathways limits scalability and is more costly to implement.

## Related CalNEXT Projects

- ET25SWE0011 – [Packaged Propane Refrigeration Market Analysis](#)
- ET25SWE0005 – [Comparative Field Assessment of CO<sub>2</sub> System Performance vs. HFC Refrigeration in Supermarkets](#)
- ET24SWE0040 – [CO<sub>2</sub> Chiller for Agricultural Sector](#)
- ET24SWE0054 – [Refrigeration Capacity Load Matching](#)
- ET24SWE0046 – [Modeling CO<sub>2</sub> System Refrigeration Loads](#)
- ET24SWE0034 – [Lab Grade Refrigerators and Freezers Measure Package Development](#)
- ET24SWE0016 – [Large Ultra-Low Temperature Freezer Measure Offering](#)
- ET23SWE0046 – [Field Assessment of Refrigerated Display Cases Air Curtain Guiding Vanes](#)
- ET23SWE0056 – [High Efficiency Refrigerated Display Case](#)

- ET22SWE0054 – [Foodservice Refrigeration: High Efficiency Condenser and Evaporator Units Focused Pilot](#)

### Resources & Links

- [ET21SCE1010](#) – California Air Resources Board, North American Sustainable Refrigeration Council, and SCE M&V Evaluation of Low GWP Supermarket Refrigeration Systems
- [ET21SCE0011](#) – Low-GWP Refrigerant New Construction Energy Impact Case Studies
- [ET21SCE0012](#) – Low-GWP Refrigerant Remodel Energy Impact Case Studies
- EPRI project ID - 1-112820 [ET22SCE0008](#) – Efficient Load Flexibility in Small Food Stores using AI Technology
- [CR24PGE115](#) - Daily Energy Consumption of Self-Contained Commercial Refrigeration Equipment

## Advanced Motors

CalNEXT Priority: High

### Definition

The Advanced Motors technology family focuses on accelerating market adoption and scalability of electric motors and drive systems that exceed the National Electrical Manufacturers Association (NEMA) premium efficiency standards. The technology family places a strong emphasis on increasing market awareness, improving equipment stocking and availability, reducing retrofit complexity by through greater installer familiarity and controls compatibility, and ensuring reliability.

### Research Initiatives

Table 6: Advanced Motors technology family research initiatives.

| Research Initiatives                                                                                                                                     | Performance Validation Needs                                                        | Market Analysis Needs                                                               | Measure Development Needs                                                             | Program Development Needs                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Review of existing variable frequency drive and Motor Technical Reference Manual for readiness and ease of incorporating the new NEMA Power Index rating |   |   |   |   |
| Qualitative evaluation of advanced motor attributes to guide motor selection process                                                                     |  |  |  |  |
| Characterize the load profile of common electric motor loads to aid in the determination of advanced motor savings                                       |  |  |  |  |
| Supply chain readiness, non-original equipment manufacturer                                                                                              |  |  |  |  |

**KEY**  High Needs  Medium Needs  Low Needs  Future Needs

## Opportunities

A recent Lawrence Berkeley National Laboratory motor market assessment estimates an annual US energy savings of 482,000 gigawatt-hours per year.<sup>8</sup> The savings opportunity of adopting advanced motors is not well known in the marketplace, and as such, this technology family has tremendous energy savings opportunities, including:

- **California-specific market research** to identify the potential for increased market share, availability, and applicability of advanced motors.
- **Evaluation of an early replacement program for motors that have been rewound multiple times.** Motors may lose 2 percent to 5 percent efficiency after each rewind.
- **Characterize motor loads to “right-size” motor selection.** This may save up to 115,000 gigawatt-hours per year.<sup>9</sup>
- **Research to better understand key market actors and the customer experience, the contractor experience, and current relevant manufacturer and supplier activities.**
- **Seek out opportunities to educate distributors and train contractors.**
- **Document the full spectrum of benefits associated with advanced motors.**
- **Demystify the variable frequency drive (VFD) product requirements for different advanced motor technologies and the commissioning needs to ensure high performance.**
- **Quantify the technology economics and cost-effectiveness of the various advanced motor designs, based on common end uses for electric motors.**
  - Document the part-load performance characteristics of the motor and drive independently.
  - Quantitative characterization of the load profile for common electric motor end uses to enable robust evaluation of advanced motor benefits.
- **Some motors, such as NEMA Premium 4 (IE4), are offered as drop-in replacements for NEMA premium motors and can operate without a VFD,** significantly reducing the barriers for implementation and lowering the upfront cost.

## Barriers

While advanced motors have secured a foothold in the United States primarily as components within original equipment manufacturer equipment at a 1.5 percent to 2 percent market share, there are significant market barriers preventing widespread adoption, including:

- **Substitution for standard induction motors may require additional controls or engineering support to work properly with a new VFD.**
- **Consumer and practitioner knowledge still lags the technical opportunity, as does program activity within California.** This contributes to a reluctance to use a new product over a familiar technology with a much simpler replacement process.
  - Awareness and understanding of advanced motor benefits is complicated by legacy of older permanent magnetic motors.

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<sup>8</sup> For more information, see: <https://motors.lbl.gov/>

<sup>9</sup> For more information, see: <https://www.osti.gov/biblio/1876861>

- **Unclear retrofits and future product development.** While manufacturers of motor-driven equipment like pumps and fans are incorporating advanced motors and drives into new equipment designs, it is unclear how these motors will be replaced in the future—o how existing equipment packages can be retrofitted with these advanced motors, as the supply channels are not well understood by utilities.

### **Related CalNEXT Projects**

- ET23SWE0065 – [Central HVAC Advanced Electric Motor Lab Evaluation](#)
- ET23SWE0068 – [Advanced Motors Channel Partner Support and Measure Package Development](#)
- ET26SWE0024 – [Measure Development HVAC Pump Motors](#)

## Pumping Systems

CalNEXT Priority: Medium

### Definition

The Pumping Systems technology family focuses on advancing the efficiency and demand flexibility of liquid pumping systems within process-based market segments. This technology family places a strong emphasis on improving pump system efficiencies by advocating for more efficient pump equipment and hydraulic designs, controls improvements, and changes in operational practices that minimize energy use.

*Note: Depending on the project scope, prospective projects related to pumping systems may fit better under the Advanced Motors technology family within the Process Loads TPM.*

### Research Initiatives

Table 7: Pumping Systems technology family research initiatives.

| Research Initiatives                                                                                                                                            | Performance Validation Needs                                                        | Market Analysis Needs                                                               | Measure Development Needs                                                             | Program Development Needs                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Application of pump controls for water distribution systems for commercial, agricultural, and industrial end uses.                                              |   |   |   |   |
| Expand Pump Energy Index (PEI) awareness for pumps for industrial, commercial, and agricultural customers. Help them understand savings potential of PEI pumps. |  |  |  |  |
| Design practices to reduce system resistance within commercial pool circulation systems.                                                                        |  |  |  |  |
| Commercial variable speed pool pumps                                                                                                                            |  |  |  |  |

**KEY**  High Needs  Medium Needs  Low Needs  Future Needs

## Opportunities

Pumping systems are among the largest family of electricity consuming systems in the commercial and industrial sectors and are generally well understood and broadly used across market segments. Transmission, distribution, and pressurization of clean water make up 7 percent<sup>10</sup> of the total net energy use in California, and the following opportunities can help meet CalNEXT's goals of improving the Total System Benefit (TSB):

- Nominal improvements in pump design efficiency and appropriate use of specific pumps based on the needs of the system can produce grid-wide energy savings.
- Advanced pump designs can be paired with advanced motors to achieve greater energy efficiencies in conjunction with advanced pump monitoring and data analytics.
  - These systems can provide optimized operation and control response beyond the standard practice of variable speed, volume, or pressure sensing technology.
- Improving market understanding of the Pump Energy Index (PEI) metric through education and outreach could also help end users select more efficient options.
- Technologies impacting pump demand—including end-use management, dynamic setpoint feedback controls, and other advanced load management controls—will improve overall pump system performance and responsiveness during grid events.
- Tangential technologies that fit into this TPM include energy recovery turbines, revised system designs to reduce pump discharge head pressure requirements, and greenfield systems designed to use static head pressure from gravity in place of pumps.

Pool pumps, a subset of this technology family, move water through the filtering, chlorinating, and heating systems and back into the pool to maintain the cleanliness and safety of the water. California has over one million residential pools and tens of thousands of commercial pools; the following opportunities can help meet CalNEXT's goals of improving their TSB:

- Commercial pool equipment pads often resemble small water treatment facilities, but hydraulic design practices often introduce inefficiencies such as bends before the inlet to pumps. Better training and guidance could improve pool system design at commercial pools.
- Commercial pools often do not provide advanced controls to monitor pressure and flow, and staff may have little or no training to operate the sophisticated system to maintain efficiency. Work could be done to develop a professional class for pool operation of larger pools.
- Commercial variable speed pool pumps are a proven technology, yet their ability to deliver energy savings is hindered by restrictive health codes, lack of standards, best practices, control technology, and training specifically to the public pool operation.

## Barriers

The technical performance of pumps and pumping systems is generally well understood, and since 2020, there have been national energy efficiency (EE) standards covering most pumps. These standards introduced the PEI, a performance metric that has since been adapted for the California

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<sup>10</sup> An Analysis of the Energy Intensity of Water in California: Providing a Basis for Quantification of Energy Savings for Water System Improvements [https://www.aceee.org/files/proceedings/2006/data/papers/SS06\\_Panel12\\_Paper14.pdf](https://www.aceee.org/files/proceedings/2006/data/papers/SS06_Panel12_Paper14.pdf)

Electronic Technical Reference Manual (eTRM).<sup>11</sup> However, there are still certain barriers to efficient pumps, including:

- **Market knowledge contextualizing lifecycle costs to PEI may be less developed.** While there is significant potential for energy savings via advanced pumping solutions, facility operators—and by extension, customers—have shown reluctance in adopting these newer pumps.
- **For critical process or infrastructure systems, such as process pumps in a refinery or a potable water distribution pump, energy efficiency may be a secondary or tertiary consideration, with reliability and performance taking priority.**
  - Risk-averse operators may be more open to switching to more efficient systems when reliability and lower operating costs can be effectively demonstrated.

### Related CalNEXT Projects

- ET22SWE0031 – [Wastewater Treatment SB1383 Compliance Characterization](#)
- ET23SWE0019 – [Onsite Wastewater Treatment and Process Water Recycling Systems for Ag Dairy Farms](#)
- ET23SWE0039 – [Wastewater Pump Measure Development](#)
- ET24SWE0038 – [Water and Wastewater Pump Replacement Industry Standard Practice & Measure Package Update](#)
- ET25SWE0019 – [Agricultural Sector Adoption of PEI Pumps Market Study](#)

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<sup>11</sup> For more information, see: <https://www.caetrm.com/measure/SWWP004/02/>

## Process Heating

CalNEXT Priority: Medium

### Definition

The Process Heating technology family focuses on processes that dry raw materials, preheat process equipment or materials, cure or stabilize produced goods, and heat water for pools, which applies to manufacturing processes for chemicals, plastics, glass, and more. This may include but is not limited to steam and hot water systems, such as electrically heated hot water and steam generation systems; electrification of steam and hot water heating systems traditionally fueled by natural gas; and the ancillary equipment and optimization of downstream end uses, such as steam trap fault detection devices. Heat recovery technologies are also included in the Process Heating technology family.

Municipal and public pools represent a large process heating load in California. While these pools account for less than 2 percent of the number of pools, they are estimated to account for nearly 50 percent of the energy use for pool heating. Non-condensing gas heating is most common, which means there are opportunities to improve TSB by finding opportunities to displace this load with electric heat pump pool heaters, solar thermal pool heaters, or on-site heat recovery technology. Many municipalities have realized the largest point source of GHG emissions within their jurisdiction is the pool heater and have sought opportunities to save energy while reducing operating cost and GHG emissions through these technologies. Within residential pool heating, variable speed heat pump pool heaters (HPPH) offer improved efficiency over single speed equipment. HPPH may also offer significant efficiency gains over resistance heating for portable electric spas (i.e., hot tubs).

*Note: This technology family excludes process heating used in commercial and residential steam and hot water, as well as heating for foodservice equipment, which are covered in other technology family TPMs.*

### Research Initiatives

Table 8: Process Heating technology family research initiatives.

| Research Initiatives                          | Performance Validation Needs                                                        | Market Analysis Needs                                                               | Measure Development Needs                                                             | Program Development Needs                                                             |
|-----------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Industrial heat pump technologies             |  |  |  |  |
| Heat recovery technologies                    |  |  |  |  |
| Advanced controls for energy savings          |  |  |  |  |
| Electrification of high temperature processes |  |  |  |  |

| Research Initiatives                                                 | Performance Validation Needs | Market Analysis Needs | Measure Development Needs | Program Development Needs |
|----------------------------------------------------------------------|------------------------------|-----------------------|---------------------------|---------------------------|
| Replacement of a central heating system with remote local ER systems |                              |                       |                           |                           |
| Electrification of municipal pool heating loads                      |                              |                       |                           |                           |
| Hot tub heat pump pool heaters                                       |                              |                       |                           |                           |
| Residential and commercial variable speed heat pump pool heaters     |                              |                       |                           |                           |

**KEY** High Needs Medium Needs Low Needs Future Needs

## Opportunities

Over the last three decades, many industrial processes switched power sources from electricity to natural gas due to lower energy costs. There are now significant decarbonization opportunities in capturing the GHG reduction benefits of a cleaner grid, including:

- **The industrial sector.** Currently, much of the focus of electrification initiatives does not include the industrial sector, which is a significant consumer of natural gas and energy.
- **Fuel switching.** Applications that use electric resistance or natural gas for drying, preheating, and production could realize EE opportunities to improve performance and decarbonize from natural gas—for example, gas drying could be replaced with industrial microwave dryers or heat pumps.
- **Controls for variable load processes,** including demand flexibility integration.
- **Energy efficiency projects should target scalable and generalizable electric heating improvements that reduce or eliminate unneeded heating.** This includes controls, equipment design, insulation, heat recovery, and combinations of these with operational modifications and production timing.
  - Heat recovery technologies include mechanical vapor recompression, which captures savings in steam generation and gas savings.
- **Many low-temperature hot water end uses could be electrified using commercially available technologies.**

- However, cost effectiveness has not yet been proven in many scenarios within California. Successful demonstrations of cost-competitive industrial heat pumps in California will support the nascent US industrial heat pump market.
- **There are many optimization strategies process heating could benefit from**, including improved pipe insulation, appropriately sized heating coils, leak mitigation strategies such as automated fault detection diagnostics, and incorporating advanced controls.
- **Heat pumps and heat recovery chillers can provide process heating more efficiently than fossil fuel combustion or electric resistance systems and have the potential to recover waste heat from nearby cooling loads.**
- **High-temperature water and steam systems are already being deployed in international markets**, with the International Energy Agency's Annex 58 highlighting promising demonstrations of this technology.<sup>12</sup>
  - The US market remains in an early piloting pre-commercial phase. Increased federal funding from both the Infrastructure Investment and Jobs Act and the Inflation Reduction Act will bolster the commercialization of industrial heat pump technology to help address this market gap. State policies, such as the recent CPUC Decision 23-04-035 to phase out utility gas incentives,<sup>13</sup> further demonstrate broad interest in developing the industrial heat pump market.
- **Considering California's goal of deploying dynamic pricing by 2030, along with continued large-scale renewables build-outs, there will be opportunities for low electric energy costs.**
  - Projects that investigate energy efficiency and fuel switching to electric heating technologies could include consideration of time-of-use rate structures and localized renewable generation resources.
  - Additionally, special utility rate considerations for electrification technologies providing GHG benefits could prove helpful in increasing market adoption.
- **There is an opportunity to address the demand charges and time-of-use costs that severely impact industrial end users** by developing processes and programs that directly help those industries cope with higher and less predictable energy costs while boosting efficiency, demand flexibility, and decarbonization.
- **Field studies for low-cost, deployable technologies should be evaluated for scalable program integration**, including technologies such as waste heat recovery, controls, and automated fault detection and diagnostics.
- **Municipal and public pools require consistent low-temperature heat that aligns with the performance envelope of electric heat pump pool heaters, solar thermal systems, and on-site heat recovery systems.** Pools operate with predictable schedules, so the heating of the water can support load shifting and demand flexibility through thermal storage.
- **Municipal pools are often located within recreation centers. where heating loads may have shared equipment across pool heating, domestic hot water, dehumidification, ventilation, or cooling loads.** Integrated system designs can use heat from one process to reduce gas use on another on-site process.

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<sup>12</sup> <https://heatpumpingtechnologies.org/annex58/>

<sup>13</sup> <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M505/K808/505808197.PDF>

- **Innovative applications of HPPH to provide heating to inground spas.** These projects would demonstrate the utility of hybrid HPPH to provide spontaneous heating.
- **Projects that demonstrate variable speed HPPH in residential and/or commercial pools.**
- **Projects that demonstrate the emergence of new technical innovations,** such as smart controls, variable speed, hybrid units, low-temperature operability, and staggered start-up capability with HPPHs.

## Barriers

Modern electric resistance heating equipment and controls provide accurate temperature control. However, the following barriers to adoption must still be overcome:

- **Energy cost,** which is a key barrier to converting from natural gas to electric heating.
- **Persistent industry perceptions based on old technology control challenges.**
- **Process heating systems are primarily designed for natural-gas-fueled supply equipment, in part due to the higher associated operating temperatures.** As a result, the market understanding of efficient electrified heating is in an early stage, and it is expected that both designers and facility managers will be reluctant to switch to electric equipment without significant incentive support and specialized electric rates.
- **Adoption of heat pumps for applications of greater than 70 °C will require higher temperature delivery than can be provided by typical equipment.**
- **Technology and fuel-switching-related deployment costs are high due to the relatively low industrial process market saturation.**
- **Process heating industries are also generally slower to change due to the high costs of retrofitting the manufacturing process and adopting innovative technologies.**
- **Pool electrification projects can face design barriers because existing systems may serve pool water, domestic hot water, and space conditioning.** The redesign requires a comprehensive assessment of impacts to all systems.
- **Pool electrification projects may be further impacted by limited capital budgets, and yard and roof space.** Retrofit projects may be difficult without incentives and technical assistance.
- **HPPH installation faces opposition where high electric rates discourage the adoption of electric heating.**
- **HPPHs lose heating capacity as temperatures decrease.** While not a concern for spring, summer, and fall heating seasons, many climate zones within California present challenges to economical heating from HPPHs during the winter months, due to an increased heating load and decreased heating capacity.

## Related CalNEXT Projects

- ET23SWE0036 – [Industrial Heat Pump Market Study](#)
- ET23SWE0062 – [Craft Brewery Industrial Heat Pump Screening Tool](#)
- ET23SWE0070 – [Industrial Microwave Technologies Market Study](#)
- ET22SWE0052 – [Swimming Pools as Heat Sinks](#)

## Data Centers and Enterprise Computing

CalNEXT Priority: Low<sup>14</sup>

### Definition

The Data Centers and Enterprise Computing technology family focuses on energy-using equipment related to the functioning of dedicated information technology (IT) facilities. This includes servers, storage, and networking IT equipment; other typical equipment, such as power distribution units and uninterruptable power supply systems; and specialized systems for airflow management and cooling.

Data centers use significant amounts of energy, with demand projected to grow in the United States from 17 gigawatts (GW) in 2022 to 35 GW by 2040 at an annual rate of 10 percent.<sup>15</sup> PG&E forecasts that AI and cloud workloads will consume about 8.7 GW in new demand in California in the coming decade.<sup>16</sup> Additionally, from 2025 to 2033, edge computing data centers are projected to grow at a compound annual growth rate of 26 percent.<sup>17</sup>

### Research Initiatives

Table 9: Data Centers and Enterprise Computing technology family research initiatives.

| Research Initiative              | Performance Validation Needs | Market Analysis Needs | Measure Development Needs | Program Development Needs |
|----------------------------------|------------------------------|-----------------------|---------------------------|---------------------------|
| Energy efficient cooling systems | High Needs                   | Low Needs             | High Needs                | High Needs                |
| Waste heat recovery              | High Needs                   | Low Needs             | High Needs                | High Needs                |
| Efficient modular/edge computing | High Needs                   | Low Needs             | Low Needs                 | High Needs                |

**KEY** High Needs Medium Needs Low Needs Future Needs

### Opportunities

Energy efficiency in data centers can make a significant impact on new generations, carbon emissions, and grid resiliency. There are opportunities for efficiency improvements in the following areas:

<sup>14</sup> This technology family has been deprioritized for the 2026 TPM revision cycle, see further explanation in Appendix A.

<sup>15</sup> [Why invest in the data center economy | McKinsey](#)

<sup>16</sup> [Surging Data Center Growth to Help Lower Energy Costs for PG&E Customers](#)

<sup>17</sup> Grandview Research, Edge Computing Market Size, Share & Trends Analysis Report By Component (Hardware, Software, Services), By Application, By Organization Size, By Industry Vertical, By Region, And Segment Forecasts, 2025 – 2033, GVR-2-68038-106-1, [Edge Computing Market Size, Share | Industry Report, 2033](#)

- **IT equipment itself makes up the bulk of the energy use**, accounting for nearly 60 percent or more in energy consumption, with the remainder due to cooling and electrical losses.
- **Several initiatives are underway to promote efficient cooling and standardization of cooling equipment in data centers.**
- **Demand side management can optimize resource allocation for underutilized servers.**  
Automated software is available to make more effective use of existing servers as opposed to adding new servers.
- **There are opportunities to use waste heat by colocation of data centers with district heating networks or other heating applications**, such as localized space heating, water heating, and controlled environment agriculture.
- **Edge computing data centers will be on the rise due to low latency and increasing AI inferencing tasks.** There is a tremendous opportunity to develop energy efficient, modular, and rapidly deployable data centers to meet this demand.

## Barriers

Data centers are well researched, especially traditional hot-aisle and cold-aisle computer room air conditioning and heating systems. However, there are still significant barriers to consider when designing a program to address this end use, including:

- **Smaller enterprises or edge computing centers need guidelines and strategies for energy efficient retrofits.**
  - Hyperscale data centers have optimized energy efficiency by using optimized air, liquid, or immersion cooling methods. However, smaller edge data centers need guidelines or strategies.
- **Emerging technologies, such as liquid-based cooling, face significant barriers to scale from product availability, downtime concerns, and practitioner familiarity.**
  - It will be beneficial to research and develop code compliance pathways for liquid-based systems, providing a viable pathway toward these scalable impacts.
  - More advanced two-phase liquid cooling technologies must address the impact of per- and polyfluoroalkyl substance fluids.
- **Statewide water supply concerns are driving aversion to evaporative cooling in lieu of less efficient air-cooled systems.** Water use effectiveness metrics need to be incorporated, and a combined energy and water use efficiency metric needs to be defined and adopted.
- **While waste heat recovery is promising, especially with liquid cooling, colocation to use water heating is not always possible.** Edge computing applications may have the potential to address this barrier.
- **Methods of achieving energy efficiency vary greatly depending on the size of the data center, the IT and server configuration, the purpose of the data center (whether it is for AI, high-performance computing, or something else), and the center's cooling method.** This makes drafting a statewide code or standard around data centers challenging.
- **While server utilization monitoring has tremendous savings potential via demand side management, it requires a monthly subscription.** This makes it difficult for standard program delivery models outside of BRO.

- Data center operators and developers prioritize productivity, resiliency, and security over efficiency.

### **Related CalNEXT Projects**

- ET25SWE0046 – [Datacenter Liquid Cooling Case Study](#)
- ET22SWE0051 – [Residential Multi-Function Heat Pumps: Heat Exchanger Improvement](#)
- ET25SWE0051 – [Datacenter Liquid Cooling Lab Evaluation](#)
- ET24SWE0065 – [Datacenter Liquid Cooling Market Characterization](#)

## Process Air Systems

CalNEXT Priority: Low

### Definition

The Process Air Systems technology family focuses on equipment that alters air flow or pressure for the purpose of using air as a working fluid. This includes blowers and fans that may be used to transport heat, fumes, or particulate, and air compressors and vacuum generators used to modify air pressure to perform useful work. This technology family also includes: 1) treatment of air streams using separators, filters, and dryers; 2) air distribution infrastructure such as ducts, pipes, fittings, and storage; and 3) control devices used to manage air pressure or flow.

The boundary between process air systems and HVAC systems is defined by the system's primary purpose. While HVAC systems are primarily intended for occupant comfort, such as space conditioning and ventilation, process air systems support process-specific requirements like production, exhaust, make-up air, compressed air, vacuum generation, and material handling. Where these systems overlap, they should be classified according to their primary purpose and performance requirements.

### Research Initiatives

Table 10: Process Air Systems technology family research initiatives.

| Research Initiatives                           | Performance Validation Needs                                                        | Market Analysis Needs                                                               | Measure Development Needs                                                             | Program Development Needs                                                             |
|------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Compressed air system monitoring and controls  |  |  |  |  |
| Compressed air system modeling and sizing tool |  |  |  |  |
| Vacuum systems                                 |  |  |  |  |
| Demand reduction and end-use optimization      |  |  |  |  |

| Research Initiatives                                                | Performance Validation Needs | Market Analysis Needs | Measure Development Needs | Program Development Needs |
|---------------------------------------------------------------------|------------------------------|-----------------------|---------------------------|---------------------------|
| Continuous commissioning, leak management, and workforce enablement | High Needs                   | High Needs            | Low Needs                 | Low Needs                 |

**KEY** High Needs Medium Needs Low Needs Future Needs

## Opportunities

The CalNEXT team identified the following opportunities for compressed air systems:

- **System configurations should be updated** to use more aerodynamic blade designs, low blade rotational speeds, and larger blade lengths that have a higher fan efficiency and use less energy.
- **Part-load efficiencies can be improved** by using sensors combined with a VFD to control the fan or blower speed instead of throttling devices.
- **Motor loads can be further lowered** by reducing frictional losses in the ductwork and isolating intermittent system users with blast gates or louvers.
- **Tools for right-sizing compressed air plants** that may have been excessively oversized for redundancy and projected future expansion.
- **Reducing energy use** by the use of low pressure drop air treatment equipment, efficient dryers, adequate receiver volume, proper sequencing, engineered nozzles, and leak repairs are well documented.
- **Compressed air distribution systems are often undermaintained and overlooked** when it comes to reducing energy use.
- **There is an energy savings opportunity in improving outreach and education for compressed air system operators and users about the inefficiencies in compressed air systems.**
- **Installing and automating solenoid valves that shut off air when not needed can also dramatically reduce compressed air system energy use, in addition to optimizing end-use demands.**
- **Continuous leak detection systems using wireless ultrasonic sensors and acoustic monitoring networks can identify compressed air leaks continuously rather than relying on periodic audits.** This helps facilities maintain savings over time by detecting leaks early and prioritizing repairs.
- **Advanced heat recovery technologies can capture and reuse waste heat for process heating, water heating, or space heating.** Since most compressor energy is converted to heat, recovery systems can significantly improve overall system efficiency.
- **Internet of Things sensors and advanced analytics can track air consumption at the equipment level, helping facilities identify inefficient uses, excessive demand, and opportunities for substituting compressed air systems.** This shifts optimization efforts from the supply side to the end-use side of the system.

- **Artificial intelligence and machine learning can continuously optimize compressor sequencing, pressure setpoints, and storage utilization in real time.** This reduces energy waste caused by inefficient operation under varying production conditions.

## Barriers

Industrial air systems are well understood from a technical perspective, as the product category has been federally covered since 1992; additionally, the standards were updated following a finalized test procedure in May 2023.<sup>18</sup> However, the team identified several barriers to adoption of efficient process air systems:

- **The new test procedure codifies the Fan Energy Index as a new performance metric that has been adopted in the California Energy Code and the ASHRAE Standard 90.1 but has not yet been adapted for programs.**
- **The primary barriers to upgrading existing systems are the lack of practitioner expertise within industrial facilities and the relatively high capital replacement costs.**
- **To inform industry standard practices, the team recommends investigating programs focused on improving code compliance and supporting the transformation of existing underperforming systems.**
  - California utilities have been active in developing industrial energy codes (i.e., Title 24, Part 6) for compressed air systems, first developing and introducing requirements into the 2013 version, and most recently developing updates for the 2022 version.
- **Facilities would benefit from an expansion of maintenance programs** to identify, locate, and fix leaks within their distribution systems or the deployment of technological solutions to automatically alert facilities staff to leaks or other system performance issues.
- **Industrial facilities are often reluctant to modify compressed air or process air systems because of concerns that changes could affect product quality, process stability, or uptime.** This perceived operational risk can delay or prevent the adoption of efficiency measures.
- **Many facilities have limited maintenance staffing and expertise available to support proactive system optimization.** As a result, activities such as leak management, control tuning, and performance verification are often deferred.
- **Older facilities often have compressed air and process air systems that have evolved incrementally over decades.** Existing piping layouts, equipment configurations, and control systems may limit the feasibility of implementing optimal designs without significant retrofit costs.
- **Developing succinct guidance on the limits imposed by non-energy-related codes and standards as it relates to process air systems would help system operators navigate energy saving system improvements while ensuring they stay within regulatory compliance.**
  - In addition to the California Energy Code Title 24, Part 6, there are other governing bodies and standards for process air systems, including those related to occupant and operator health and safety. For example, fan or blower speeds for a process air system may be restricted by the National Fire Protection Association or Occupational Safety and Health Administration standards, of which customers may not even be aware.

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<sup>18</sup> For more information, see: <https://www.regulations.gov/document/EERE-2021-BT-TP-0021-0046>.

## Related CalNEXT Projects

- ET22SWE0045 – [Compressed Air End-Use Air Management System](#)

## Discussion

Following approval of the 2026 Process Loads TPM, the program team will:

- Update the CalNEXT website with revised 2026 Process Loads TPM and this final report.
- Launch an email announcement through email outreach.
- Develop and submit the distribution report.
- Highlight any technology families to reinvestigate for the 2026 Focused Pilot TPM, which will support the 2027 Focused Pilot projects.

## Appendix A: Process Loads Advisory Committee Feedback & Resolution Matrix

Table 11: Advisory committee feedback and resolution matrix.

| Process Loads<br>TPM Technology<br>Family | Section | Suggestion or Comment                                                                                                                                                                                                                                        | Action Taken and Justification                                                                                                                                                                                          |
|-------------------------------------------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| General Narrative                         | General | Suggest screening each technology family for <b>measure-readiness and market scalability</b> as a practical way to clarify potential next steps: research, pilot, measure development, delivery-channel testing, or market transformation.                   | This is in line with one of our current fast track efforts at classifying the projects into a relevant MRL category; it also touches upon our tech transfer efforts. The changes will be made outside of the TPM scope. |
| General Narrative                         | General | The Process Loads TPM is technically strong. Suggest sharpening the final report into an implementation-readiness and market-scalability map to support pilot prioritization, measure development, market engagement, and repeatable adoption in California. | This comment is relevant to our tech transfer area, and we will emphasize the clarity required around what “comes next” after the final report.                                                                         |
| Controlled Environment Horticulture       | General | Noting the CEC RFI that was sent a few weeks ago related to CEA.                                                                                                                                                                                             | We have previously reviewed the RFI and it aligns with the TPM.                                                                                                                                                         |
| Controlled Environment Horticulture       | Scope   | Consider segmenting by crop, facility type, climate region, and ownership model, and tying technical opportunities to grower concerns such as yield, humidity control, reliability, and controls integration.                                                | We do not think segmenting by these four categories adds value given the complexity it adds or the relative differences between the segments.                                                                           |

| Process Loads<br>TPM Technology<br>Family | Section           | Suggestion or Comment                                                                                                                                                                                                                                                                | Action Taken and Justification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Controlled<br>Environment<br>Horticulture | Opportunity<br>#3 | Agree that there are great opportunities to optimize the HVAC but it can vary with the crop and may not be one size fits all. It remains to be seen if it is more suitable for custom than for deemed. For cannabis grow rooms, conditions changed depending on the stage of growth. | We acknowledge that HVAC optimization is not one-size-fits-all and may vary by crop, growth stage, and facility type, including cannabis vs. non-cannabis and indoor vs. greenhouse applications. However, we did not expand further in this bullet because the goal here is to identify the research opportunity, not resolve measure design questions such as custom vs. deemed treatment. That level of detail is better addressed during later scoping and measure development.                                                                                                                         |
| Controlled<br>Environment<br>Horticulture | Opportunity<br>#6 | Conversely, in some cases outdoor agriculture not requiring lighting can be much less energy intensive.                                                                                                                                                                              | No change made. We agree that outdoor agriculture can be much less energy intensive, especially where no supplemental lighting is needed, but that point does not conflict with the statement as written. The opportunity already frames indoor growing benefits as conditional, not universal, and does not suggest that indoor production is inherently lower energy or lower greenhouse gas (GHG) than outdoor agriculture in all cases. Adding this point would be redundant and could distract from the intended focus on the specific conditions under which indoor growing may provide GHG benefits. |

| Process Loads<br>TPM Technology<br>Family | Section                          | Suggestion or Comment                                                                                                                                                                                                                                | Action Taken and Justification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------------------------------|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Controlled Environment Horticulture       | Barrier #6                       | CEH, from the definition provided, seems lighting-focused. Workforce standards in place are tied to lighting projects that meet a certain set of criteria. Would be helpful if they provided some cited evidence here that the workforce is lacking? | No change made. We disagree that the CEH definition is lighting-focused; it explicitly includes both lighting and non-lighting systems, including HVAC/D, irrigation, pumps, environmental controls, district utility strategies, self-generation, and energy storage. The workforce barrier is not limited to lighting projects. More broadly, existing workforce standards are often adapted from other sectors and are generally not CEH-specific, crop-specific, or tailored to indoor versus greenhouse production. We did not add a citation here because this statement is intended to identify a practical market barrier, not present a literature review, and adding a study reference would not materially improve the point in this context. |
| Controlled Environment Horticulture       | Barrier #9                       | There are default EULs for BRO, but we can look at actual data to modify those.                                                                                                                                                                      | No change made. The comment is consistent with the barrier as written. While default EULs exist for BRO, improving those assumptions requires actual field data, and obtaining that data can be costly and difficult. That challenge is the core of the barrier, so I did not revise the text further.                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Controlled Environment Horticulture       | Additional activities section #3 | Start with a literature review. Spectral lighting is used in cannabis grow rooms.                                                                                                                                                                    | No change made. We did not want to make this activity overly prescriptive by specifying a literature review as the required starting point. The topic of spectral lighting in cannabis grow rooms is already encompassed within the broader research need related to CEH performance optimization and demand flexibility, which could include a literature review as part of future scoping. No further revision was needed.                                                                                                                                                                                                                                                                                                                             |

| Process Loads<br>TPM Technology<br>Family      | Section          | Suggestion or Comment                                                                                                                                                                                                         | Action Taken and Justification                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Commercial Kitchens                            | Scope            | Consider emphasizing operating behavior, replacement timing, ventilation impacts, workflow, small-business barriers, and the best-fit delivery path: direct install, midstream, custom, or pilot.                             | Added detail to the Commercial Kitchens section to call out behavior and small business barriers.                                                                                                                                                                                                                                                                     |
| Commercial Kitchens                            | Opportunity #5   | Yes, good idea. SoCalGas is adding a lot of gas cooking measures. Cost effectiveness may be a problem.                                                                                                                        | Agreed, economics of electric foodservice equipment is a listed barrier.                                                                                                                                                                                                                                                                                              |
| Commercial Kitchens                            | Barriers General | Not as much detailed language as Commercial Kitchens Barriers section? Maintain consistent level of language across all Barriers sections?                                                                                    | This comment will be further addressed in the Final Report.                                                                                                                                                                                                                                                                                                           |
| Commercial Kitchens                            | Barrier #5       | In some past studies microwave ovens were studied to replace gas ovens.                                                                                                                                                       | Added a specific note about microwave technology being an opportunity.                                                                                                                                                                                                                                                                                                |
| Refrigeration,<br>Commercial and<br>Industrial | Scope            | Consider tying refrigeration options to grocery, cold storage, food processing, and agricultural adoption conditions, while distinguishing optimization, refrigerant transition, and system redesign opportunities.           | The different sectors are named in the definition, so that should suffice for the tie to refrigeration systems. The research initiatives distinguish the project types that we are prioritizing, which could apply to any of these sectors.                                                                                                                           |
| Refrigeration,<br>Commercial and<br>Industrial | Opportunity #7   | In some cases it is best to start with custom or pilot programs with Evaluation, Measurement, and Verification (EM&V). There is a need to change policy to allow for load shifting even if there are not site energy savings. | <p>This is a fair comment, especially given the complexity of larger refrigeration systems.</p> <p>Adjusted language of opportunity #7 to be: Support custom projects and site demonstrations with EM&amp;V to validate load-shifting impacts, inform policy evolution, and establish the foundation for future standardized measures that can be scaled broadly.</p> |

| Process Loads<br>TPM Technology<br>Family      | Section       | Suggestion or Comment                                                                                                                                                                                                          | Action Taken and Justification                                                                                                                                                                                                                                                           |
|------------------------------------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Refrigeration,<br>Commercial and<br>Industrial | Barrier #7    | Custom is encouraged by the CPUC but it is more costly to implement.                                                                                                                                                           | Updated the barrier to incorporate this additional nuance.                                                                                                                                                                                                                               |
| Advanced Motors                                | Scope         | Consider framing advanced motors as a deployment ecosystem issue, including stocking, OEM integration, installer familiarity, controls compatibility, retrofit complexity, and reliability.                                    | Modified the technology family definition to place more emphasis on these items.                                                                                                                                                                                                         |
| Pumping Systems                                | Scope         | Consider distinguishing equipment replacement, system optimization, controls, and operating practices across priority segments such as irrigation, municipal water, pools, and process-fluid transfer.                         | Each of the aforementioned improvements (equipment replacement, system optimization, etc.) could apply to each of the mentioned segments; We are happy to update research initiatives and opportunities to reflect this comment, but I think we've captured the spirit of these already. |
| Pumping Systems                                | Opportunities | Goals of improving Total System Benefit (TSB) section.<br><br>Good idea. Due to a higher T-24 baseline the cost effectiveness of residential pool pump measures has gone down, causing a cost effectiveness issue.             | Thank you for the feedback.                                                                                                                                                                                                                                                              |
| Pumping Systems                                | Opportunities | Goals of improving TSB section bullet #3.<br><br>There is still some opportunity by having the chemical feed pumps operate separately from the main recirculation filtering pumps.                                             | This seems like a Research Initiative Idea in scope, but is already covered by the third RI (Design practices to reduce system resistance within commercial pool circulation systems).                                                                                                   |
| Data Centers and<br>Enterprise Computing       | Scope         | Consider segmenting data centers by facility type, ownership, cooling architecture, and flexibility potential, with near-term focus on enterprise retrofits, edge facilities, controls, cooling optimization, and owner tools. | Second paragraph mentions artificial intelligence (AI), cloud and edge types. Barriers mentions challenges with enterprise and edge DC efficiency, and also challenge of standardization because of the different types of DCs.                                                          |

| Process Loads<br>TPM Technology<br>Family | Section                      | Suggestion or Comment                                                                                                                                                                                                                              | Action Taken and Justification                                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Data Centers and<br>Enterprise Computing  | Opportunity<br>#5            | Please explain why is this low priority?                                                                                                                                                                                                           | Changed ratings to “medium” or “low needs,” to reflect the overall “low-priority rating.” This has changed from high-priority last year to low priority due to taking a step back from the research area, with the explanation that high electricity and land costs in California makes data center expansion lower priority compared to other states with lower costs. |
| Data Centers and<br>Enterprise Computing  | Barrier #2,<br>sub bullet #1 | Incorporate existing water efficiency metrics                                                                                                                                                                                                      | Added: “Water use effectiveness metrics need to be incorporated, and a combined energy and water use efficiency metric needs to be defined and adopted.”                                                                                                                                                                                                                |
| Process Air Systems                       | Barrier #1                   | For industrial applications, custom would be a better choice to quantify the savings. The goal should be to make the custom process cost effective.                                                                                                | Removed “in the eTRM.”                                                                                                                                                                                                                                                                                                                                                  |
| Process Air Systems                       | Scope                        | Consider clarifying the boundary between process air and HVAC air systems, especially where ventilation, exhaust, make-up air, filtration, compressed air, and process quality overlap.                                                            | Added to definition.                                                                                                                                                                                                                                                                                                                                                    |
| Process Heating<br>Technology             | Scope                        | Consider segmenting process heating by temperature, duty cycle, production criticality, fuel type, and retrofit complexity, with emphasis on low- and medium-temperature heat recovery, industrial heat pumps, storage, and hybrid configurations. | I believe this is already captured high level in research initiatives and with more specificity within the opportunity bullets.                                                                                                                                                                                                                                         |