2025 Whole Buildings Technology Priority Map

Final Report

ET25SWE0002

Prepared by:

Gabe Duarte, Energy Solutions

Zoe Mies, Energy Solutions

Kitty Wang, Energy Solutions

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CalNEXT Whole Buildings Team members
(SMEs, facilitators, and supporting staff)

Gabe Duarte, Energy Solutions

Zoe Mies, Energy Solutions

Kitty Wang, Energy Solutions

Dara Salour, AESC

David Vernon, UC Davis

Gwelen Paliaga, TRC

Li Ling Young, VEIC

Keith Downes, VEIC

Vanya Krishpinovich, Ortiz Group

Disclaimer

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Abbreviations, Acronyms, and Glossary of Terms

Abbreviation/Acronym	Meaning
BPS	Building Performance Standards
CalMTA	California Market Transformation Administrator
CEC	California Energy Commission
Cx	Building commissioning
CCx	Continuous commissioning
CPUC	California Public Utilities Commission
DAC	Disadvantaged community
DER	Distributed energy resource
DH&C	District heating and cooling
EBCx	Existing building commissioning
GHG	Greenhouse gas
HEMS	Home energy management system
HP	Heat pump
HTR	Hard-to-reach
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
LBNL	Lawrence Berkeley National Laboratory
MBCx	Commissioning based on monitoring
NMEC	Normalized metered energy consumption
REA	Residential energy automation
SCE	Southern California Edison
SME	Subject matter expert
SDG&E	San Diego Gas & Electric
TPM	Technology Priority Map

VCx	Virtual commissioning
VPP	Virtual power plant
WH	Water heating

Glossary	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, barriers.
Research Initiatives	New initiative in place of both subgroups and knowledge indices.
Research Initiatives Key	Visual aid explaining if each research initiative is at a level of high understanding, ranked on a low, medium, or high scale.
Research Initiatives Rankings	**Future Needs**: Covers items that are not yet ready for consideration or that have high needs in validation and market analysis. Programs should not be discouraged from submitting proposals for research initiatives with "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. **Low**: Covers items that have lower industry interest and/or impacts for Total System Benefit due to having an expansive data set or information readily available or not being pertinent to the research initiative. **Medium**: Covers items that are an evolution of or offer potential to existing and common technologies for Total System Benefit. 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 Total System Benefit metrics. **High**: Covers items that have high industry interest and high impacts for Total System Benefit.
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 Role	Describes general level of engagement by CalNEXT SMEs. *Note: Roles will change as research is completed.*
Lead	**Lead:** CalNEXT expects to take on most or all of the work and cost burden.
Collaborate	**Collaborate:** CalNEXT is interested in collaborating and co-funding projects.
Observe	**Observe:** CalNEXT will track progress but encourage external programs to take lead in unlocking these opportunities.

Glossary	Meaning
CalNEXT Priority	Communicates expected level of focus by CalNEXT SMEs. *Note: Priorities will change as research is completed.*
High	**High:** The CalNEXT SME team has highlighted this technology family as having high impacts within the technology category.
Medium	**Medium:** The CalNEXT SME team determined this technology family has moderate overall impacts within the technology category.
Low	**Low:** The CalNEXT SME team has highlighted this technology family as having low relative impacts within the technology category.

Introduction

Technology Priority Maps (TPMs) provide the CalNEXT program a framework to externally communicate priorities of the program, clearly define the central focus areas of the program, and assist with project screening. They document the impact potential, programmatic research needs, and market readiness of all technology families across each of the end-use technology areas. TPMs are used to drive product ideation and inform project selection. This Final Report covers the revision process for the 2025 Whole Buildings TPM.

2025 TPM Key Changes

The Whole Buildings category has seen significant changes over the years, relative to that of other technology areas. Notable drivers for these changes include the passage of the Inflation Reduction Act (IRA) of 2022, which continues to provide additional market support over the next decade in the form of tax credits and state-administered incentive programs targeting the heat pump market. In addition, research conducted by California's investor-owned utility (IOU) Codes and Standards Enhancement (CASE) Team related to multiple technology families has impacted the state of knowledge to varying degrees. Finally, the continued need for programs to transition to the Total System Benefit (TSB) metric has implications for both demand flexibility and low global warming potential (GWP) refrigerants. These changes were reflected in different ways in the 2024 TPM update and before.

As for the 2025 TPM update, the CalNEXT Program Team established a robust process for this initial phase of the TPM development and revisions. This year, the project team incorporated a stronger survey push to ensure feedback directly from Whole Buildings subject-matter experts (SMEs), before beginning the revision process.

The process this year started with the reformation of the Whole Buildings TPM SME Team, with representatives from each of the program team partners: AESC, Energy Solutions, TRC, UC Davis, VEIC, and the Ortiz Group. The Whole Buildings SME Team represents members that collectively support an array of energy efficiency programs, using technologies covered by the Whole Buildings TPM, as well as members who support the California IOUs' Codes and Standards (C&S) program. These emerging technology products are then contextualized into priority maps through a markets and solutions lens.

In 2024, the team implemented visual changes, adding a research initiatives table to each technology family to help submitters and viewers quickly understand what topics are of greatest interest in a technology family and which are most important to progress within the portfolio. The end goal was a simplified view for easier use and better connectedness across domains. In 2025, these research initiatives have been revised as needed based off any market changes that have occurred since the 2024 Whole Buildings TPM revision. Research initiatives should be higher level than project or proposal-specific details, with the intent to provide guidance for project submitters rather than specific examples.

There are now additional rankings — along with the icons — under each of the overhead criteria, which will be shifted slightly with the addition of the high, medium, and low scale. This shift also

means that the overhead criteria will focus more on needs within the technology family. The first two criteria have been updated to Performance Validation Needs and Market Analysis Needs, while the two market-drive criteria have been updated to Measure Development Needs and Program Development Needs. These rankings indicate if the research initiative is at the low, medium, or high stage. The new ranking table design, with its visual elements, is intended to help a potential submitter or viewer quickly understand what topics are of most need within a given technology family and record the current state of progress and understanding. More information about these rankings is available in Table 1 below,

Table 1: Rankings and Their Meanings

Icon	Meaning
Future Needs	Covers items that are not yet ready for consideration or due to having high needs in validation and market analysis. Programs should not be discouraged from submitting proposals for Research Initiatives with "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.
Low	Covers items that have lower industry interest and/or uncertain / impacts for TSB due to having an expansive data set or information readily available or not being pertinent to the RI.
Medium	Covers items that are an evolution or offer promise to existing and common technologies for TSB. 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 TSB metrics.
High	Covers items that have high industry interest and high impacts for TSB.

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. The research initiatives tables describe the three to five most important technology areas, with subsequent versions providing a simplified ranking view of where the Whole Buildings portfolio stands for easier use and external understanding.

During the SME meetings in 2025, the project team received some feedback that the research initiative icons were unintuitive and difficult to parse. The original plan for evolving TPMs was to revert to a text-based ranking, moving away from icons. However, when surveyed, a larger group of respondents preferred the icons and agreed they should remain but be made more intuitive. The project team decided to evolve the icons to a cohesive theme, reword the research initiative columns as a hierarchy of needs, and update the tables accordingly. This shift will be consistent across all TPM end uses.

One additional change to the Whole Buildings TPM in 2024 was the absorption of the Direct Current (DC) Lighting technology family into the Electrical Infrastructure technology family, as well as the sunsetting of the Lighting TPM. The team made these choices to reduce the overall number of

technology families, reorganize and better balance the program's research priorities within each technology family, and clarify how those priorities connect with others throughout the portfolio.

This year, the project team will also incorporate a stronger outreach push for stakeholder feedback by targeting additional deemed measure stakeholders at the California Public Utilities Commission (CPUC), the California Energy Commission (CEC), San Diego Gas & Electric (SDG&E), the California Market Transformation Administrator (CalMTA), CLEAResult, Lawrence Berkeley National Laboratory (LBNL), and the California Technical Forum (CalTF).

Overall, the changes made in this 2025 TPM aim to increase technology transfer across our CalNEXT portfolio, allowing the CalNEXT team to define new measures of interest and illustrate its efforts to bring them to 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 updated visual format and ranking scale of the research initiatives tables will provide more tactical guidance as to what type of research is needed to better encourage the progress of different technologies to utility resource portfolio energy savings.

Stakeholder Feedback

TPM Advisory Committee Outreach

The TPM Advisory Committee outreach began in May 2025. The team requested stakeholder feedback via email, then used that feedback to update the technology family narratives. These stakeholders are listed below in Table 2.

Table 2: TPM Advisory Committee Outreach

Organization
CalMTA
CalTF
CPUC
LBNL
PG&E
SCE
SDG&E

This outreach allowed Advisory Committee members to provide candid feedback, with the opportunity to share written comments and suggestions via a collaborative Word document hosted on Microsoft SharePoint. The TPM coordinator and Whole Buildings SME team reviewed suggestions

and incorporated them into the Revised 2025 Whole Buildings TPM, which are detailed below in **Table 3** in Appendix A.

Integrated Systems

CalNEXT Role: Lead | CalNEXT Priority: High

Definition

This category covers components, systems, or controls with integrated approaches that differentiate them from other TPM technology families. It also includes a single product — or coordination of multiple products — that can serve multiple end-uses, as well as integrated packages of measures, such as electrification packages with envelope improvement measures. Examples include weatherization and air leakage sealing, integrated designs such as thermally activated building systems, or broadly grid-interactive efficient buildings. The measures can be installed as existing building retrofits or in new construction.

Research Initiatives

Research Initiatives	Performance Validation Needs	Market Analysis Needs	Measure Development Needs	Program Development Needs
Multifunction residential and small commercial heat pump technology that reduce barriers to adoption	❗	❗	❗	❕
Equipment or product solutions that reduce barriers to adoption	❗	❗	❗	❕
Controls solutions that reduce barriers to adoption	❗	❗	❗	❕
Equipment and controls that use open frameworks for structuring building operation data to enable interoperability and extensibility	❗	❗	❕	❕
Building design methods and practices to integrate systems	❗	❗	❕	❕

KEY ❗ High Needs ❕ Medium Needs ❕ Low Needs ❕ Future Needs

Opportunities

Opportunities for study for this technology family include, but are not limited, to:

- The development of efficiency measures or strategies that integrate or replace multiple, single-function technologies, resulting in improved performance and reduced deployment costs.
- The study of integrated systems that reduce barriers and costs by providing electrification and large energy savings and improving demand flexibility. Examples of multiple systems include:
    - Integrated lighting and space cooling system that reduce the total number of installed sensors in a building.
    - Residential integration of home area networks with smart appliances and smart panels.
    - Heat pumps that integrate space conditioning and water heating or other loads that are typically separate.
- Low-cost retrofits that modify or add equipment to leverage existing building infrastructure for energy savings. Examples include:
    - Add-on nighttime ventilative cooling.
    - Add-on passive solar shades.

Barriers

Potential studies of barriers may address:

- Integrated systems can be significantly more complex and span multiple building systems, and typically require a greater level of design, assessment, and more complex maintenance.
- There is a lack of support for integrated systems efficiency measures to become deemed measures.
- Barriers to adoption include:
    - Lack of interoperability among software programs in controls systems.
    - Lack of open communication protocols for controls equipment, particularly for small and medium residential and commercial buildings.
    - Lack of field performance data, including system reliability, energy performance, and cost-effectiveness.
    - Lack of maturity of system efficiency testing and ratings, particularly for combination heating, ventilation, and air conditioning (HVAC) and water heating (WH) products.
    - Lack of software tools for designers to quickly model and assess system performance and costs for integrated systems.
    - Lack of standard methodologies for estimating savings of integrated systems.

- Lack of a standard applicable baseline for new systems that integrate new functionality that did not apply to previously existing systems.
- Lack of deployment infrastructure or workforce for integrated systems; need for better understanding of resources available for designers, installers, and maintenance strategies.
- Default settings are often left unmodified, meaning systems never achieve optimal performance, especially as the building's use and characteristics change.

CalNEXT Related Projects

- ET22SWE0044 — Lab Evaluation of Integrated Controls for Commercial Buildings
- ET22SWE0021 — Residential Multi-Function Heat Pumps: Product Search
- ET22SWE0051 — Residential Multi-Function Heat Pumps: Heat Exchanger Improvement
- ET23SWE0047 — Residential Multi-Function Heat Pump Laboratory Testing
- ET23SWE0066 — Multifunction Heat Pump Lab Test – Variable Speed
- ET24SWE0058 — Multi-Function Heat Pump Research Home Test – Variable Speed
- ET25SWE0024 — Residential Multi-function Heat Pump Market Study

Electrical Infrastructure

CalNEXT Role: Lead | CalNEXT Priority: High

Definition

This technology family refers to single- and multi-structure sites that use a common utility connection; it encompasses electrical infrastructure site needs and capabilities to enable energy efficient and low- or carbon-neutral buildings, demand-flexible end uses, distributed energy resources, and grid harmonization.

Research Initiatives

Research Initiatives	Performance Validation Needs	Market Analysis Needs	Measure Development Needs	Program Development Needs
Interoperability of building management system with microgrid controllers	❗	❗	❕	❕
Interoperability of smart panels with distributed energy resource (DER) gateways	❗	❕	❕	❕
Interoperability of home area networks with smart panels	❗	❕	❕	❕
Impact of integrated energy storage systems on residential electrical infrastructure	❗	❗	❕	❕
Electrification enabled by panel or circuit level load management devices	❗	❗	❕	❕

KEY ❗ High Needs ❕ Medium Needs ❕ Low Needs ❕ Future Needs

Opportunities

Opportunities for study within this technology family include, but are not limited to:

- Studies on different panel replacement options, such as upsizing, power-efficient alternatives, and National Electric Code calculation alternates.

- Demand response and flexibility integration in electrical system and building load management.
- Improved resilience and load prioritization through load segregation and panel controls.
- Small-scale and temporary or mobile power storage systems based on 120V power grid.
- Replacement and improvement of ageing transformers to improve efficiency and electrical load capabilities.
- Integration of vehicle-to-everything (V2X) strategies with existing electrification and transportation emerging technology projects on this subject.
- Portable energy storage systems, smart panels, and/or smart circuits to facilitate electrification in disadvantaged community (DAC) and hard-to-reach (HTR) residences as an alternative to traditional electrification retrofits involving panel and service upsizing.[1]

Barriers

Potential studies of barriers may address:

- Research to fully understand how electrical infrastructure acts as a barrier to electrification efforts.
- Lack of experienced electrical practitioners, especially for HTR, DAC, multifamily, and nonresidential buildings.
- Disconnect between the National Electric Code and normal power consumption with electrification and how best to address safety risks for load management approaches. Different stakeholders often have varying perspectives and goals regarding electrification activities.
- Lack of whole-building thinking in electrification programs that promote best practices in design and construction first — such as adequate envelope insulation and rightsizing electric appliances — to reduce demand response requirements.
- Extensive and complex local city and utility codes that can make panel replacements and upsizing a major and expensive project, often requiring permitting or approval processes that can take months to complete.
- High cost of transformer replacements in addition to the limited number of manufacturers, resulting in longer payback periods and lead times for equipment replacement.
- Site-level infrastructure analysis not coordinated with utility-level system planning and the broader evaluation of costs and benefits.

CalNEXT Related Projects

- ET23SWE0061 — Smart Panel Market Characterization Study, AESC, Inc., December 2023
- ET22SWE0057 — Market Study of Household Electric Infrastructure Upgrade Alternatives for Electrification

Operational Performance

CalNEXT Role: Lead | CalNEXT Priority: Medium

Definition

Whole-building operational performance accounts for the dynamic interactions between a building and its environment, energy systems, and occupants. Building commissioning (Cx) is an important strategy for achieving, verifying, and documenting proper operation of new buildings and new systems. Similarly, existing building commissioning (EBCx), also called retro-commissioning, is a process that seeks to improve how building equipment and systems function together. EBCx can also include more sophisticated approaches that ensure operational changes and energy savings persist, such as commissioning based on monitoring (MBCx), continuous commissioning (CCx), and virtual commissioning (VCx).

System modeling and analytics includes the software — algorithms, machine learning and artificial intelligence, digital twins, predictive models, first-principle or physics-based energy models — and data sources — building controls, internet of things (IoT), market and demographic data, external data sources — used to improve operational performance. Building performance standards (BPS) are outcome-based policy and law requiring existing buildings to meet energy or greenhouse gas (GHG) emissions performance targets. Normalized metered energy consumption (NMEC) measures meter data before and after building energy interventions to determine savings. Residential energy automation (REA) systems are a network of devices that automate and control a home's energy systems, such as home energy management systems (HEMS) and distributed energy resource (DER) hardware.

Projects that are primarily HVAC-focused should investigate alignment with the technology families in the HVAC TPM.

Research Initiatives

Research Initiatives	Performance Validation Needs	Market Analysis Needs	Measure Development Needs	Program Development Needs
Site-level normalized meter energy consumption	!	!	!	!
Residential energy automation systems	!	!	!	!
System modeling and analytics	!	!	!	!
Automated building commissioning	!	!	!	!

KEY High Needs | Medium Needs | Low Needs | Future Needs

Opportunities

Opportunities for study for this technology family include, but are not limited to:

- REA systems that provide centralized and integrated control of building loads to optimize energy use and reduce costs for homeowners, which may include electric vehicle charging systems, photovoltaic generation, battery energy storage inverters, and traditional building loads like lighting, HVAC, water heating, and plug loads.
- System modeling and analytics solutions that ingest existing building data, e.g., building automation system trends, IoT, advanced metering infrastructure (AMI), and census data, and output solutions to improve operational performance, such as fault detection, preventive maintenance recommendations, energy improvement measures, energy resiliency planning, or controls optimization.
- Measure development, tools, and program offerings that have a streamlined custom measure verification process to increase program participation.
- Measures and technologies that help buildings achieve BPS targets or improve NMEC incentives.
- Measure development to increase program participation in MBCx, CCx, and VCx. Measure development that aligns with Cal TF custom measure efforts, such as a hybrid or deemed approach for commissioning sub measures with higher effective useful life.
- Technologies that focus on real-time feedback for maintaining operational performance and minimizing costs for customers, utilities, and grid operators — including those that leverage grid-responsive or grid-interactive technologies.
- Reaching underserved or HTR populations with existing operational performance technologies to provide additional energy saving opportunities.

Barriers

Potential studies of barriers may address:

- Lack of understanding of the technical and market barriers to BPS and NMEC, as well as limited tools and technologies for meeting targets or maximizing incentives.
- REA systems face several challenges, including the cost of smart panels, complexity for residential occupants, uncertainty and dynamics of loads and generation, optimal capacity configuration, control strategies, infrastructure limitations, and microgrid challenges.
- Need for validation of automated NMEC software and calculation algorithms, including ways to handle nonroutine events. Lack of understanding of NMEC service providers business models and technology and market barriers.
- Need for a detailed breakdown of benefits by feature combined with comparative analysis among REA products.

- Need for more field validation of physics-based models used for measure identification and program delivery. Lack of understanding of types of service providers, technology applications, and market barriers
- Need to measure the savings and cost-effectiveness of automated commissioning technology. Lack of understanding of technology and vendor landscape of smart building software, interoperability, and open standards.

CalNEXT Related Projects

- ET23SWE0040 — AMI Intelligence Connected Building Energy Modeling
- ET23SWE0049 — Enhanced Normalized Metered Energy Consumption Analysis with Rapid Interventions
- ET22SWE0055 — Performance Evaluation of Advanced HEMS

Envelope

CalNEXT Role: Lead | CalNEXT Priority: Medium

Definition

The envelope category covers products, design, and controls strategies, or installation techniques that reduce building energy demand and improve the moisture and airflow across the building envelope. This includes individual products — such as insulation, windows, air and weather barriers, and insulated cladding — as well as construction techniques — such as quality insulation installation, thermal bridge-free design, and retrofit air seal or vapor control. The envelope category also includes strategies and technologies that reduce the cost of building energy retrofits.

Note: See the design and construction technology family for additional defined project categories, such as innovative building assembly design.

Research Initiatives

Research Initiatives	Performance Validation Needs	Market Analysis Needs	Measure Development Needs	Program Development Needs
Thermal mass additions and improvements				
Window improvements				
Window attachments				
Air sealing retrofits				

KEY  High Needs  Medium Needs  Low Needs  Future Needs

Opportunities

Opportunities for study for this technology family include, but are not limited to:

- In climates with a significant heating load, building envelope upgrades that make heat pump electrification successful by minimizing the use of supplemental heat, improving cost-effectiveness, reducing the heat load, and ensuring comfort.
- In climates with heavy cooling loads, envelope upgrades — including low-cost window attachment products — can significantly reduce HVAC energy use, reduce peak demand, shift peak, and improve thermal comfort and resilience during power outages and demand response events.

- Market research on products, such as improved envelope materials, or on advancing construction practices. Studies are limited to deployable technologies for building sectors or types representing a significant portion of California's building stock.
- Studies that address the high cost of retrofits and techniques that can be deployed with minimal disruption to building occupants or neighboring properties.
- Market research that demonstrates the magnitude of energy savings from envelope improvements to support new programs.
- Studies that examine fire resistance and its effects on building resilience of potential new and retrofit envelope technologies. There is an opportunity to attempt to quantify the resilience benefits along with any energy benefits.

Barriers

Potential studies of barriers may address:

- Lack of information and scalable solutions related to retrofit technologies for existing residential and commercial buildings.
- The high cost of retrofit improvement to the building enclosure.
- Lack of information on impact of lower-performing envelope components.
- Lack of customer awareness of benefits of higher-performing envelope components.
- Overcoming the gap between nominal and effective energy code compliance or assembly performance.
- Lack of trusted tools to facilitate accurate savings estimates in support of programs.

CalNEXT Related Projects

- ET23SWE0018 — Commercial Windows Market Study and Measure Package Development
- ET23SWE0043 — Residential High-Performance Windows Measure Package Development
- ET22SWE0033 — Low-Income Multifamily Housing Characteristics Study
- ET23SWE0017 — Mobile and Manufactured Housing Market Characterization Study

Resources and Links

- US Department of Energy (DOE). Embodied Carbon Reduction in New Construction. https://www.energy.gov/sites/default/files/2024-02/bto-abc-embodied-carbon-022624.pdf
- Pacific Northwest National Laboratory (PNNL) and Guidehouse, Inc. Research Opportunities for Building Decarbonization Through Industrialized Construction. 20240722160808656_c708524e-edb8-4570-9bab-d48af396720a.pdf
- American Council for an Energy-Efficient Economy (ACEEE). Empowering Electrification through Building Envelope Improvements.

https://www.aceee.org/sites/default/files/pdfs/empowering_electrification_through_building_envelope_improvements_-_encrypt.pdf

Design and Construction

CalNEXT Role: Collaborate | CalNEXT Priority: Medium

Definition

This technology family focuses on reducing costs, energy use, and lifecycle emissions in the design and construction of whole buildings. It includes construction practices that reduce waste and improve compliance with high performance standards, as well as the use of off-site construction practices, such as manufactured housing, volumetric modular construction — a construction method where entire rooms or building sections are fully built off-site in a factory — or industrial panelization — a construction method where only flat panels, such as walls and floors, are pre-manufactured in a factory and then transported to site for assembly. Building design includes project delivery practices and building standards that maximize energy efficiency and promote low-lifecycle carbon and cost in the design, construction, and operation of a building.

Lifecycle carbon and lifecycle cost analyses support building design that delivers the same or greater energy savings at lower upfront carbon emissions or lower cost in the near- or long-term.

Research Initiatives

Research Initiatives	Performance Validation Needs	Market Analysis Needs	Measure Development Needs	Program Development Needs
High-performance manufactured housing				
Industrialized construction				
Building lifecycle carbon or cost analysis				
Integrated design and construction project delivery				

KEY High Needs | Medium Needs | Low Needs | Future Needs

Opportunities

Opportunities for study for this technology family include, but are not limited to:

- Studies on how to reduce energy intensity and emissions from the manufacturing of construction materials, e.g., cement, steel, glass, insulation materials, and others.

- Studies to improve on-site construction practices and overall building performance through integrated design and construction project delivery.[2]
- Studies to improve off-site or partial off-site construction, which can reduce construction costs and deployment times while improving energy efficiency, overall performance, and reliability of building systems, as well as facilitate integration of new strategies, such as incorporation of low-embodied carbon materials or all-electric building designs.
- Demonstrations, scaled deployments, improvements to modeling and analysis tools, or other strategies to increase the development and deployment of low-lifecycle carbon buildings or high-performance whole buildings.
- Studies to improve building design practices, which have the potential to reduce lifetime energy and emissions associated with construction by creating systems that exceed California energy and building standards, and favor building materials with lower embodied carbon.
- Market research to expand low-embodied-carbon designs into the private sector, especially in off-site or partial off-site construction.
- Studies of the standardization of carbon impact calculators on building assemblies with layered materials to deepen the impact of low-embodied carbon design.

Barriers

Potential studies of barriers may address:

- Market recognition and understanding of manufactured housing benefits, and verifiable energy benefits compared to associated materials, technology, and implementation costs.
- Barriers to design practices, including practices that facilitate meeting higher energy efficiency standards such as ENERGY STAR®, that result in high efficiency and low carbon buildings by manufacturers, developers, construction managers, and building designers.
- Limited information on efficient building products and end-use systems for designers, engineers, and others to easily assess high-efficiency options across various metrics, including performance, cost, embodied carbon, and others. Data, even when available, is often siloed across many different government and industry-specific product lists — e.g., the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) for HVAC, the Design Lights Consortium (DLC) for lighting, and others.
- Education and training the construction trades in electrified manufactured housing. Measures such as heat pump space conditioning and smart panels require wiring and interconnection by installers on site.
- Programs supporting high-performance electrification of manufactured and modular housing, such as the US Department of Energy (DOE) Zero Energy Ready Home program; the US Department of Housing and Urban Development (HUD) Manufactured Housing program;

[2] AIA California, “Integrated Project Delivery.”

volumetric modular housing, including single-family and multifamily housing; and accessory dwelling units.

- Stacking incentives and tax credits to make high performance industrialized construction cost competitive. Integration of design, construction, and building commissioning in residential and commercial work. Accounting for co-benefits can also move the needle on justifying the costs for higher performance options, e.g., improved building resilience, health, safety, productivity, and more.

CalNEXT Related Projects

- ET23SWE0017 — Mobile and Manufactured Housing Market Characterization Study
- ET23SWE0031 — Manufactured Housing Electrification Measure Development

Resources and Links

- US Department of Housing and Urban Development (HUD). Operation Breakthrough. Office of Policy and Development. https://www.huduser.gov/portal/Operation-Breakthrough.html
- Electric Power Research Institute (EPRI) and Systems Building Research Alliance. Scalable Decarbonization Strategies for Manufactured Homes. The design, advancement, prototyping and field testing of scalable technologies and strategies for manufactured homes to decarbonize.pdf
- American Council for an Energy-Efficient Economy (ACEEE). Ignoring Resilience Benefits Limits Growth of Energy Efficiency Programs. https://www.aceee.org/blog-post/2024/03/ignoring-resilience-benefits-limits-growth-energy-efficiency-programs.

Community Scale Strategies

CalNEXT Role: Observe | CalNEXT Priority: Low

Definition

Community-scale strategies can aggregate, balance, and control the flow of energy — thermal or electric — among multiple buildings and end-uses for improved performance. They include hardware and software technology solutions that orchestrate end-use and building operations across building boundaries. The costs, value streams, and benefits are measured across multiple utility meters and are shared by the community's members, the local grid, and the larger grid system. The benefits include higher system efficiency, energy resilience, load flexibility, and grid harmonization.

Community-scale strategies can contribute toward the CalNEXT program goal of achieving GHG reductions benefits, particularly when community strategies include the use of renewable distributed generation, such as solar energy combined with energy storage. Energy efficiency is a necessary and essential element of maximizing economically feasible community-scale strategies. Energy efficiency reduces the load and therefore, the size and the installed cost of the community-scale solutions. In this respect, energy efficiency becomes an enabling technology for the distributed generation and results in an integrated approach for community-scale strategies.

CalNEXT expects significant research activity will primarily continue in other emerging technology programs with focus areas beyond this program, such as demand response aggregation in the case of virtual power plants and microgrid electric service resiliency. As such, priority designation for this technology family is set to "low" to minimize overlap of research efforts with the other emerging technology programs.

Research Initiatives

Research Initiatives	Performance Validation Needs	Market Analysis Needs	Measure Development Needs	Program Development Needs
Understanding of microgrid controller products				
A market for virtual power plants (VPP) and community microgrid interactions				
Operation of a VPP and community microgrid under a real-time pricing tariff				

Research Initiatives	Performance Validation Needs	Market Analysis Needs	Measure Development Needs	Program Development Needs
Value stacking by community microgrid operators				
Opt-in or opt-out solutions for customers of community microgrids				

KEY  High Needs  Medium Needs  Low Needs  Future Needs

Opportunities

Opportunities for study for this technology family include, but are not limited to:

- Studies that demonstrate performance benefits in terms of magnitude and cost-effectiveness of emissions reductions, e.g., retirement or decommissioning of gas infrastructure in an existing block or avoided cost of installing new gas infrastructure in a new residential development.
- Market research, lab testing, modeling, and field studies that help define benefits and value propositions.
- Microgrid sites should target regions most susceptible to grid outages, such as public safety power shutoff events.
- Virtual power plant (VPP) research — such as energy efficiency, solar and batteries, and flexible loads control and management — that relieve grid constraints or enable greater renewable energy consumption.
- For community microgrids, projects may test or assess the potential and feasibility of receiving benefits from multiple value streams, such as participation in ancillary services markets while operating in parallel with the grid and energy resilience during a grid outage to better understand the economic viability.
- Zonal electrification research. When paired with both VPPs and community microgrids, zonal electrification can have beneficial utility distribution grid level impacts. If sited in areas known to have distribution grid congestion, strategies and plans can be developed and demonstrated by virtual power plant aggregators and community microgrid operators with the local utility distribution services provider to offer grid support.
- For district heating and cooling (DH&C), projects may involve system decarbonization, use of low-global-warming-potential refrigerants, data collection, and evaluation methods of DH&C projects.

Barriers

Potential studies of barriers may address:

- Nascent standards environment for interoperability of grid assets.
- Lack of empirical data and case studies on project costs, operational performance, and benefits.
- Lack of market understanding for microgrid controller products.
- Lower market penetration rates of non-wires alternatives for DAC and HTR communities.
- Limited technology solutions for electrifying DH&C heating systems.
- Lack of demonstrated value stacking by community microgrid operators to show economic viability, such as by including participation in ancillary services markets.
- Lack of demonstrated opt-in and opt-out opportunities[3] for customers of community microgrids.
- Limited types of revenue opportunities in existing markets for technologies used for VPPs and community microgrids to sell into and purchase power from.
- Lack of a real-time pricing tariff to demonstrate economic viability for technologies, such as VPPs and community microgrids, among others.

CalNEXT Related Projects

- There are no CalNEXT projects related to this technology family at this time.

Resources and Links

- Canary Media. Four ways virtual power plants can help the US grid keep up with demand. https://www.canarymedia.com/articles/virtual-power-plants/four-ways-virtual-power-plants-can-help-the-us-grid-keep-up-with-demand

[3] Not all members of a community will want to participate in a community microgrid. Since DERs serving community microgrids are typically in front of the meter assets, community members should be able to opt in or out of participating in the community microgrid. This is especially important when there is an outage so that only those who have subscribed to the service will get the resiliency benefits during that time. This feature is possible through a switch that is part of the utility's smart meter on most people's homes, although it has never been demonstrated to work in this context. Microgrids that are not owned by utilities should avoid depending on the utility smart meter, as doing so adds another layer of complication.

Discussion

Following submittal of the 2025 Whole Buildings TPM, the program team will:

- Update the CalNEXT website with new 2025 Whole Buildings TPM and this final report.
- Launch an email announcement through email outreach.
- Develop and submit the distribution report.

Appendix A: Advisory Committee Feedback and Resolution Matrix

Table 3: Advisory Committee Feedback and Resolution Matrix

Technology Family	Section	Suggestion or Comment	Action Taken and Justification
Integrated Systems	Definition	"This technology family also includes…" This sentence is very long with three embedded examples. Suggest breaking into multiple sentences for clarity.	Definition for Integrated Systems has been simplified and made easier to read.
Integrated Systems	Opportunities	The margins and paragraph spacing for the Opportunities and Barriers sections throughout this document are inconsistent. I recommend adjusting one or the other for alignment.	Corrected.
Integrated Systems	Opportunities	For opportunity two, massive opportunity not just to do more study on technology and technical performance but also study human factors and non-energy benefits of integrated systems that would be opportunities (or pose barriers) for adoption. For example, combination clothes washer with heat pump dryer having extended drying times but also saving users' time by avoiding clothes transfer after wash cycle.	Agreed. Sub-bullet #3 sufficiently covers such opportunities.
Integrated Systems	Barriers	For barrier two, as worded, this doesn't sound like a barrier. Could it be rephrased as "Lack of support for…" or some other way to be more easily understood?	Agreed and reworded to make it clear that this lack of support is a barrier.

Technology Family	Section	Suggestion or Comment	Action Taken and Justification
Integrated Systems	Barriers	For barrier nine, the savings estimation method should be the same as any other energy efficiency measure: base case usage minus measure case usage. Consider rephrasing this to be: "Lack of standard approaches for specifying applicable baselines or base case scenarios. For example, with a combi heating, ventilation, and air conditioning (HVAC)/water heating (WH) product, would the typical base case be replacing both existing HVAC/WH systems or replacing just the one closer to end of life? And what about scenarios where the new system serves multiple end-uses but the existing equipment only provides some of the end uses (e.g., combi heat pumps for water heating and space conditioning in existing homes previously without AC)?"	Added a new bullet under the "…lack of standard methodologies…" barrier bullet to address comment.
Integrated Systems	Barriers	For barrier ten, separate but related additional barrier is likely need for multidisciplinary workforce, including education, training, certification, and outreach — e.g., situation with HPWH today where both plumbers and electricians are often needed when only plumbers were needed for traditional WHs in the past.	Added "workforce" along with deployment infrastructure; education, training, and certification is implied.
Electrical Infrastructure	Opportunities	For opportunity two, include definition or just write-out since the acronym isn't used elsewhere in the document.	Acronym removed, wrote out National Electric Code.

Technology Family	Section	Suggestion or Comment	Action Taken and Justification
Electrical Infrastructure	Opportunities	Significant opportunities to better align building- and site-level electrical infrastructure analysis/studies with broader feeder-level or community scale assessments done for utility distribution planning (e.g., zonal electrification efforts whose benefits could justify the infrastructure costs at individual sites or avoiding site-level panel upgrades that allow zonal electrification funding to benefit more customers in a community).	No action taken. Suggestion does not fit with current research initiatives.
Electrical Infrastructure	Opportunities	For opportunity four, as part of CalMTA's scanning activities, we're looking at residential battery backup systems (e.g., Anker, EcoFlow) that charge on 120v and output both 120v and 240v for multiple electrification uses including potential to overcome panel limitations when replacing gas powered appliances with electric versions. Battery equipped ranges are already in the market, but use of a whole-house battery system applied as a normal means of powering either 120V or especially 240V appliances could also reduce the cost of electrification by enabling use of common, lower-cost electric appliances.	No action taken. Already covered in current opportunities list.

Technology Family	Section	Suggestion or Comment	Action Taken and Justification
Electrical Infrastructure	Barriers	Major barrier is also planning and programmatic siloes that limit alignment of site-level infrastructure analysis with utility-level system planning and more comprehensive assessment of all costs and benefits.	Barrier added per suggestion.
Design and Construction	Definition	I'm not familiar with the definition of this term in the area of building science. I've heard it before within electronics manufacturing, so I think I can infer the meaning here, but I recommend being more specific here for clarity.	Updated definition section to clarify meaning of industrial panelization in this context, and how it differs from volumetric modular construction.
Design and Construction	Barriers	For barrier two, barriers to design also include limited comprehensive information on efficient building products and end-use systems for designers, engineers, and others to easily assess high-efficiency options across various metrics (included performance, cost, embodied carbon, etc.). Data (even when available) is often siloed across many different government and industry-specific product lists (e.g., AHRI for HVAC, DLC for lighting, etc.).	Added additional barrier (barrier #3) that incorporates this suggested edit into the Barriers section.
Design and Construction	Barriers	For barrier five, accounting for co-benefits can also move the needle on justifying the costs for higher performance options (e.g., improved building resilience, health, safety, productivity, etc.).	Added language to barrier #5 (now barrier #6) that incorporates this suggested edit into the Barriers section.

Technology Family	Section	Suggestion or Comment	Action Taken and Justification
Operational Performance	Opportunities	For opportunity six, are there opportunities to leverage these types of technologies with those that are also grid-responsive or grid-interactive? See DOE/LBNL work: Grid-Interactive Efficient Buildings (GEBs) | GEB Overall opportunity/goal would be to maximize benefits and minimize costs for all involved — customers, utilities, grid operators, etc.	Inserted language in Opportunities below.
Envelope	Opportunities	For opportunity five, also opportunity to try quantifying these resilience benefits along with any energy benefits.	Added additional language to this opportunity (now opportunity #6) that incorporates suggested edit into the Opportunities section.
Envelope	Opportunities	Similarly, for opportunity one, in climates with heavy cooling loads, envelope upgrades (including low-cost window attachment products) can significantly reduce HVAC energy use, reduce peak demand, shift peak, and improve thermal comfort and resilience during power outages and DR events.	Added additional opportunity (opportunity #2) that incorporates suggested edit into the Opportunities section.
Community Scale Strategies	Priority	For the priority of the technology family, why did this end up as a low priority for CalNEXT? Might be worth making this a bit more obvious in the definition section below.	Additional clarification added to Definition section.

Technology Family	Section	Suggestion or Comment	Action Taken and Justification
Community Scale Strategies	Opportunities	This section may also be place to mention zonal electrification programs and aligning planning studies from site-level to distribution system level.	Added bullet #6 to the Opportunities section to call out opportunity for further zonal electrification study.

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