Energy Research and Development Division

FINAL PROJECT REPORT

Research Gap Analysis for Zero-Net Energy Buildings

Appendices C-Q

California Energy Commission

Gavin Newsom, Governor

March 2019 | CEC-500-2019-031-AP

APPENDIX C:
Building Envelope

TECH NAME	**Air Sealing**	**TECH ID**	**T001**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Air sealing is used to make the envelope air-tight and reduce air-leakage and heat loss through the envelope. To properly seal the envelope, the infiltration rate must be measured through the envelope.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	**AT MATURITY**	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	5 ACH50 assumed for all new buildings in CA, only credit available for single family bldgs. Measurement of infiltraition is very difficult because it is impossible to isolate individual zones.	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	Need to better align with Passive House, LEED, Energy Star homes to at least better than <3.0 ACH50; and/or incorporate compartmentalization requirements. Current and future performance for commercial buildings is 0.25 cfm/sf façade

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	$0.75/sq ft façade	**O&M COST**	None
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	$0.5/sq ft facade		

TECH NAME	**Air Sealing**	***TECH ID***	**T001**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Demonstration projects, Product certifications/labeling, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Standards development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Public/occupants will like it
TEAM REVIEWER NOTES	Main issue with air sealing is not the technology itself, but rather the method in which it is measured.

→ **RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH**

Technology is already high performing and critical to achieving ZNE. The main issue is that it is difficult and costly to measure envelope infiltration, which is very addressable by research. DOE Building Technologies Office developed research roadmap for air sealing technologies.

→ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1. Real world demonstrations to achieve customer acceptance and understand the actual leakiness of well-sealed buildings and poorly sealed buildings.
2. Development of simplified infiltration measurements protocols. Because guarded blower door testing is so time consuming and difficult, a simpler measurement protocol is necessary. To create such a protocol, guarded blower door testing would need to be conducted on different configurations of rooms in different types of constructions to acquire factors for different configurations.

→ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

→ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Nick Young, Association of Energy Affordability:

"Compartmentalization test in multifamily is easy to do on a sampling basis, but only tells leakage from room to adjacent spaces; doesn't provide information on the leakage outdoors. Therefore, it is challenging to determine the energy impact. The option is to do full building blower door test – possible for new construction, but when occupied it is challenging to do. Can do "guarded blower door test" – do test on a single unit, but also do it on adjacent units; need to do ~8 blower tests on adjacent units – expensive, time consuming."

TECH NAME	**Breathing Wall**	**TECH ID**	**T002**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Pores in building envelope materials so that incoming fresh air can be efficiently tempered with low-grade heat while conduction losses are kept to a minimum.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	NA	**COMMERCIAL BUILDING TYPE**	Small office, Large office, K-12 school, Higher education
APPLICABLE IN CLIMATE TYPES	Cold, Marine, Mild (mixed humid/mixed dry), Hot dry		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	Don't know	**AT MATURITY**	Don't know

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	**IN 5-7 YRS.**	Proof of concept

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	50-70% Heat Recovery	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard.	35% energy savings, system downsizing by 7-10%

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	Don't know	**O&M COST**	Don't know
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	Comparable upfront cost when including equipment downsizing, but requires building envelope redesign		

Tech Name	**Breathing Wall**	***Tech ID***	**T002**
Category	Building envelope		

Other info on the technology

Other Barriers	Product availability, Reliability, condensation and moisture related problems can occur when building materials and envelopes are not sufficiently ventilated
Research Focus Areas Identified by Survey Participants	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects. More research needed for proper weather-proofing, air filtration, vapor transfer and latent heat exchange, transient heat transfer, buoyancy driven ventilation, heat recovery, and low-grade heating and cooling; opportunities for tech integration
Importance to ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Adds value, e.g., improved occupant comfort, control, or amenities
Team Reviewer Notes	Early stage technology, needs a lot of work to reach market maturity

→ Rationale the x-factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

Very early stage technology, but barriers are very addressable by research.

➔ Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE – Use the guidance in the word doc shared with the team to fill this section

1. Prototype development needed to fully understand technology and its potential.
2. Product design evolution/feature enhancement to address areas of improvement (i.e. proper weather-proofing, air filtration, vapor transfer and latent heat exchange, transient heat transfer, buoyancy driven ventilation, heat recovery).
3. Systems integration to connect with low grade heating and cooling systems.

➔ Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLS or report references

Breathing walls: The design of porous materials for heat exchange and decentralized ventilation

➔ Any Subject Matter Expert Names, Affiliation, Comments and Quotes

TECH NAME	**Building Integrated Heat and Moisture Exchange Panels**	***TECH ID***	**T003**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Modular systems installed within the building envelope to precondition ventilation air by transfer of thermal energy from exhaust air, thus decreasing overall energy consumption.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	NA	***COMMERCIAL BUILDING TYPE***	Small office, Large office, K-12 school, Higher education
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	***AT MATURITY***	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	35% energy savings, system downsizing by 7-10%	***PERFORMANCE TARGET FOR 2025*** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	35% energy savings, system downsizing by 7-10%

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	Don't know	***O&M COST***	Don't know
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	Comparable upfront cost when including equipment downsizing, but requires building envelope redesign		

TECH NAME	**Building Integrated Heat and Moisture Exchange Panels**	**TECH ID**	**T003**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Builder/trades acceptance/familiarity, technology requires greater coordination between contractors who work with the building envelope and those who focus on HVAC
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Market awareness campaign, Develop partnerships with leading architectural and engineering firms to demonstrate the BIHME panels on showcase projects
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature
TEAM REVIEWER NOTES	

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Fairly young technology, large potential for energy reduction, not very familiar in the industry, would require extensive coordination between architect and engineers. DOE Office of Energy Efficiency & Renewable Energy developed research roadmap for this technology.

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

Field demonstrations are necessary to determine how BIHME panels compare to traditional DOAS and ERV designs, to understand and validate long-term performance, acquire occupant feedback regarding the BIHME panels, and showcase projects to major market players.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems

→ ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES

TECH NAME	**Dynamic Building Envelopes**	**TECH ID**	**T006**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Building envelopes that are able to change their functions, features or behavior over time in response to changing climatic conditions on daily, seasonally or yearly basis with the aim of improving the overall building performance. Adaptive facades can provide controllable insulation and thermal mass, radiant heat exchange, ventilation, energy harvesting, daylighting, solar shading or humidity control.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	50% or more	**AT MATURITY**	50% or more

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Difficult to implement and integrate with other building systems	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	Ease of implementation/integration with other building systems

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	$50-60/sq ft of glazing	**O&M COST**	None
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	$25/sq ft of glazing		

TECH NAME	**Dynamic Building Envelopes**	***TECH ID***	**T006**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Standards development
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Technology needs standardization and assessment, not high priority

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1. Standards development is necessary for standardized testing procedures, better design support tools so the technology can be evaluated during design, and methods for assessing the operational performance and occupant interactions of buildings with adaptive building envelope components.
2. Systems integration is a big area of research for dynamic building envelopes. Development of shading products that are fully integrated with appropriate controls sequences should be conducted, so these products can be more easily installed and operated.

➔ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

- Adaptive Façades System Assessment: An initial review
- Design for façade adaptability – Towards a unified and systematic characterization

➔ ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES

Michael Martinez, Illumination Associate Principal at Integral Group

TECH NAME	**Phase Change Materials**	***TECH ID***	**T010**
CATEGORY	Building Envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Building material, usually high in thermal mass, that utilizies the principles of latent heat thermal energy storage. These materials have large thermal energy storage capacity in a temprature range near to their switch point.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	Cold, Hot dry, Hot humid		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	***AT MATURITY***	10-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	52 Btu/lb enthalpy	***PERFORMANCE TARGET FOR 2025*** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard.	82-95 Btu/lb enthalpy

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	\$0.65-\$0.91/lb (organic PCM material) \$0.06-\$0.09/lb (inorganic PCM material) \$1.50-\$7.50/lb PCM product	***O&M COST***	None
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	\$2.00/lb organic PCM product \$3.50-\$4.00/lb inorganic PCM product		

TECH NAME	**Phase Change Materials**	***TECH ID***	**T010**
CATEGORY	Building Envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Health and safety
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Market awareness campaign, Establishing distribution network/infrastructure, Product support materials development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Already has market penetration, large opportunity for energy savings, a number of different applications, very addressable barriers. DOE Office of Energy Efficiency & Renewable Energy did research om cost analysis of PCM enhanced envelopes.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1. Performance testing is suggested to understand how the placement of PCM impacts ROI. More full building data is needed from real buildings in different climate zones indicating when HVAC actually turns on, outdoor/indoor temperature differentials, and how well PCM controls humidity. In addition, performance validation is recommended for all existing PCM products in the market to ensure correct phase change properties are being achieved.
2. Product enhancement is recommended to improve the durability, fire resistance and long term thermal behavior of PCM enhanced wallboards and concrete.
3. Systems integration is an area of research that should be explored, with both passive cooling techniques, like natural ventilation, and conventional cooling systems, to increase efficiency and explore different applications.
4. Real world demonstrations are recommended to attract market players.
5. Standards development is necessary because there is currently a lack of clear indicators to effectively assess PCM technologies.
6. To improve cost of PCM products, it is necessary to move from organic materials to inorganic materials, such as salt hydrates. To make this change, the sub-cooling effect and the difficulty in microencapsulating salt hydrates need to be addressed. Salt hydrate PCM products must become easy-to-manufacture, and chemically, physically, and thermally stable.

➔ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Phase change materials (PCM) for cooling applications in buildings: A review
A review on phase change material (PCM) for sustainable passive cooling in building envelopes
A review on phase change material (PCM) for sustainable passive cooling in building envelopes
Phase change materials integrated in building walls: A state of the art review
Cost Analysis of Simple Phase Change Material-Enhanced Building Envelopes in Southern U.S. Climates

➔ ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES

Bruce Severance: *"PCM is being placed in the wrong places, projected ROIs not good; PCM should be placed right on the interior of gypsum; numbers of test case house in Grover beach, CA are very good, pretty much eliminates need for gas furnace, saving neighborhood of $40,000 over first 25 years (favorable ROI scenario)"*

TECH NAME	**Vacuum Insulated Panels**	**TECH ID**	**T016**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

A VIP consists of a porous core enveloped by an air and vapour tight barrier, which is heat sealed. The core is of an open pore structure to allow all the air to evacuate, and create a vacuum.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	Cold		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	Don't know	**AT MATURITY**	Don't know

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	.003 - .011 W/mK; unpredicable lifespan; vulnerable to performation	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	.003 - .011 W/mK; predictable product lifespan; not vulnerable to perforation

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	$0.50/sq ft	**O&M COST**	None
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	$0.25/sq ft		

TECH NAME	**Vacuum Insulated Panels**	**TECH ID**	**T016**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Reliability, Difficulty in predicting product lifetime; if the panel gets perforated or broken, leads to loss of vacuum, increase in thermal conductivity; cutting/adapting panel on-site is not possible; acoustical properties are most
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Improved production equipment or tools, Standards development, Understand product lifetime;make panel less vulnerable towards perforation; develop standard on how to handle VIPs
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), Extremely low conductivity; much thinner than conventional insulation (increased usable space)
TEAM REVIEWER NOTES	

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Already being researched and has some market penetration, already very high performance, large potential for energy reduction in cold climates, more research needed on product lifespand and product vulnerability to perforation. DOE Building Technologies Office developed research roadmap for high performance insulation materials.

→ *RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION*

1. Performance testing and validation is needed to better predict product lifetime and acoustical properties.
2. Performance improvement and product enhancement is suggested to better maintain product vacuum, make the panel less vulnerable towards perforation, utilize new adhesive materials and sealants, and better develop barrier material that will yield a long useful life time and reduce the thermal bridging effect.
3. Cost reduction is needed due to the high production cost of nano-porous materials, lack of commercialization of materials, and production scale that is not comparable to conventional insulation.
4. Standards development is recommended as there is no standard on how to handle VIPs during construction. In addition, modeling capability is needed for complex heat and mass exchange phenomena that occur in VIP systems
5. Demonstration projects would be useful to employ the knowledge generated in the laboratories to manufacture example VIPs with experimentally validated test results under realistic climatic conditions to earn the confidence of the builders, architects and building managers and owners.

→ *KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES*

Vacuum insulation panel products: A state-of-the-art review and future research pathways

Toward aerogel based thermal superinsulation in buildings A comprehensive review

Vacuum insulated panels for sustainable buildings: a review of research and applications

Vacuum Insulation Panels (VIPs) for building construction industry - A review of the contemporary developments and future directions

→ *ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES*

TECH NAME	**Building Integrated PV (BIPV)**	***TECH ID***	**T004**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Building skin as energy generator

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	***AT MATURITY***	10-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	***IN 5-7 YRS.***	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Demonstration	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Proof of concept; change in thinking about building envelope

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	No	***O&M COST***	No
COST BARRIERS	Early market phase (not yet mature), Perception/misleading information that BIPV is too expensive as first cost. Discussion doesn't go beyond there.		

TECH NAME	**Building Integrated PV (BIPV)**	***TECH ID***	**T004**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Facility operator acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Most products are very low efficiency, new materials and product integrations must be investigated, fairly low priority

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1. Prototype development is recommended for new materials such as organic based modules, solar concentrators, solar trapping systems embedded in solar cell surface and material, flexible lightweight inorganic thin film solar cells.
2. Performance improvement is necessary for natural degradation rate and moisture sensitivity.
3. Performance testing and validation of cell efficiency in real buildings will be crucial for the market to be comfortable with the technology.
4. System integration will probably be one of the most significant areas of future research, including integration with prefabricated concrete plates and smart to provide shading. In addition, alternative applications of BIPV, such as thin laminates or paint layer solar cell materials, should be investigated.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Building Integrated Photovoltaic Products: A State-of-the-Art Review and Future Research Opportunities

Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths

→ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

TECH NAME	**Double Skin Facades**	***TECH ID***	**T005**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

A façade with multiple layers of glazing and an air cavity situation between the layers of glazing. The air cavity can be ventilated mechanically or naturally. The strategy is used to improve building insulation.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	NA	***COMMERCIAL BUILDING TYPE***	Small office, Large office, Higher education
APPLICABLE IN CLIMATE TYPES	Cold, Marine, Mild (mixed humid/mixed dry), Hot dry		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	Don't know	***AT MATURITY***	Don't know

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	***IN 5-7 YRS.***	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY		***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	***O&M COST***	50% or greater
COST BARRIERS	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Other, -Reduction of rentable office space -Additional maintenance and operational costs (cleaning, operating, inspection, servicing, and maintenance) -Increased weight of the structure		

TECH NAME	**Double Skin Facades**	***TECH ID***	**T005**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Reliability, Architect acceptance/familiarity, Occupant acceptance/familiarity, Operational cost, -Potential daylight problem: the reduction of the quantity of light entering the rooms as a result of the additional external skin and the compensatory effec
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Development of CFD techniques and simple approaches for modeling
IMPORTANCE TO ZNE	High energy savings potential, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Energy results from existing studies have large variance, more research needed to predict performance, develop CFD techniques, and get data from real buildings

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1. Performance testing and validation. There is a lack of conclusive results in available literature about performance. More data is needed from real buildings to better understand the performance and drawbacks of the strategy.
2. Standards Development. Development of CFD techniques and simple approaches for predicting the physical properties of the cavity are necessary to accurately predict the performance of the strategy.

➔ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

A critical review of the energy savings and cost payback issues of double facades

Double Skin Façades: A Literature Review

Energy Performances of Double-Skin Façades in Temperate Climates

➔ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

TECH NAME	**Night sky radiant cooling (NSRC)**	**TECH ID**	**T009**
CATEGORY	Building Envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Passive, non-evaporative method of cooling below ambient air temperature. This technology requires a surface facing the sky that, due to its thermal and optical properties, sends more heat out to the sky than it receives from the air, without any electrical input.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	Marine, Mild (mixed humid/mixed dry), Hot dry		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	Don't know	**AT MATURITY**	Don't know

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Achieves temp below ambient air temp with solar exposure	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	Don't know	**O&M COST**	Don't know
COST BARRIERS	Don't know		

TECH NAME	**Night sky radiant cooling (NSRC)**	***TECH ID***	**T009**
CATEGORY	Building Envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Industry is unsure of how to use it/what the technology is capable of, engineering materials challenge, currently difficult to integrate with other technologies
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Standards development, demonstration project, technology improvement, systems integration
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.)
TEAM REVIEWER NOTES	Early stage tech, needs much more research to full understand tech and its capability.

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Early stage technology, large potential for different applications

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1. Performance testing and performance improvement of different materials is recommended to optimize the thermal and optical properties that allow for high reflectivity of sunlight but continues to be selectively emissive.
2. Systems integration is another recommended area of research to better understand the different applications of the technology, how it works with solar PV systems, and how to optimize with other building technologies, including HVAC systems
3. Demonstration projects are suggested so the industry gets a better sense of the capabilities of the technology and how it performs
4. Modeling capabilities need to be improved to better predict how the technology performs in different conditions.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Passive radiative cooling below ambient air temperature under direct sunlight

→ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

Aaswath Raman

TECH NAME	**Silica Aerogel Insulation**	***TECH ID***	**T011**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Insulation made with aerogels, a synthetic porous material in which the liquid component of the gel is replaced with gas.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	Cold		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	Don't know	***AT MATURITY***	Don't know

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	0.012 - 0.020 W/mK	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Reduce exposure to dust particles

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	***O&M COST***	50% or greater
COST BARRIERS	Product issues (e.g., manufacturing/raw material costs), More expensive than conventional insulation; High production cost of aerogels		

TECH NAME	**Silica Aerogel Insulation**	**TECH ID**	**T011**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Health and safety, Exposure to dust particles can be a huge health hazard; this has prevented widespread use
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.)
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), Extremely low conductivity; much thinner than conventional insulation (increased usable space); can be used for multiple applications
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Already being researched and has some market penetration, already very high performance, medium potential for energy reduction in cold climates, poses large health risk, cost needs to drastically come down

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

The main area of research is cost improvement, specifically for production and manufacturing the technology. In addition, more research is needed in product design to reduce the exposure to dust particles, which are a huge health hazard.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Aerogel insulation for building applications: A state-of-the-art review;

Toward aerogel based thermal superinsulation in buildings A comprehensive review

→ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

TECH NAME	**SIPs**	TECH ID	**T012**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

SIPs, or structural insulated panels, are prefabricated sandwich panels with an insulating foam core sandwiched between two structural facings, usuallu oriented strand board.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	COMMERCIAL BUILDING TYPE	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	AT MATURITY	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	IN 5-7 YRS.	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Performs at all r-value levels depending in panel thickness. About r-value of 4 per inch.	IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION	Ready today. Mainly installation training and willingness to build differently.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	No	O&M COST	No
COST BARRIERS	SIPs don't cost more when you figure in time and material and labor savings. They save even more over use phase. They also allow for reduced HVAC sizes to save money. They are stronger envelopes and leak less. No thermal bridging.		

TECH NAME	**SIPs**	***TECH ID***	**T012**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, Policy, Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Market awareness campaign
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	shorter construction time and less jobsite waste

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Already established in the market, mostly needs more research in standards development and performance validation

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1. Performance improvement, testing and validation is required, specifically with regard to the engineering mechanics of panels specific to seismic events and fire resistance. In addition, a database of non-proprietary seismic test data applicable to all SIPs is needed. Knowledge of adhesives and long-term durability must be evaluated against the durability of the subsequent constituent materials.

2. Testing standards for SIPs need to be updated to address items like resistance to tensile forces and penetrations in the wall. In addition, an industry specific definition of SIPs must be established to stipulate composites that fall within the definition and address limitations and reinforcements.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Analysis of the Seismic Performance of SIPs

→ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

TECH NAME	**Straw bale wall insulation/construction**	***TECH ID***	**T013**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Straw bale insulation is insulation that consists of straw bale, a byproduct of cereal cultivation that is available in large quantities and at low cost in a great number of countries.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	Single family residential, Low-rise multifamily residential	***COMMERCIAL BUILDING TYPE***	10 out of 13
APPLICABLE IN CLIMATE TYPES	Cold, Mild (mixed humid/mixed dry), Hot dry		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	***AT MATURITY***	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Market maturity	***IN 5-7 YRS.***	Market maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	R-30, 2-hour fire rating, site build or pre-fab	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	greater awareness of carbon benefits

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	No	***O&M COST***	No
COST BARRIERS	Thicker walls can limit applicability, increase overall building size / cost		

TECH NAME	**Straw bale wall insulation/construction**	***TECH ID***	**T013**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Demonstration projects, Systems integration with other products, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Improved production equipment or tools, Product support materials development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Performance testing and validation is essential, pretty low priority tech

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1. Demonstration projects are suggested to get more exposure by the major market players.
2. Performance improvement of straw bale construction standard mix designs is necessary to optimize alternative stabilizing agents and reinforcing options.
3. Performance testing and validation is recommended to evaluate mechanical properties, structural performance, fire classification, resistance to water vapor diffusion, and long-term durability.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Sustainable Earthen and Straw Bale Construction in North American Buildings: Codes and Practice

A review of unconventional sustainable building insulation materials

→ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

TECH NAME	**Trombe Wall**	***TECH ID***	**T015**
CATEGORY	Building envelope		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Thermal mass walls that absorb solar heat, stores energy during peak-use periods, and supplies energy when a building's occupants require it.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	***AT MATURITY***	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Satisfies 20% heating demand	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Optimize thickness, material, color, coating, vent size, and integration with window systems

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10% or less	***O&M COST***	10% or less
COST BARRIERS	Other, Mass walls can be expensive first cost		

TECH NAME	**Trombe Wall**	**TECH ID**	**T015**
CATEGORY	Building envelope		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Reliability, Architect acceptance/familiarity, Facility operator acceptance/familiarity, Designers very unsure how to design trombe wall system (do not know appropriate materials, dimensions, etc.)
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Training materials development (curricula, manuals, videos, etc.), Better understand relationship between trombe wall performance and thickness, material, coatings, color, glazing, and vent size
IMPORTANCE TO ZNE	High energy savings potential, Very cost-competitive when mature
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Early stage, probably not huge impact on energy, low priority, research needed for fundamental performance evaluation

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

Prototype development and performance testing are necessary to understand the relationship between different design parameters (material, thickness, glazing arrangement, distance between wall and glazing, glazing thickness, color, glazing color, absorptive coating, vent size, vent geometry, fan blowing angle) and technology performance.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Trombe walls: A review of opportunities and challenges in research and development

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

APPENDIX D:
Fenestration

TECH NAME	**Electrochromic Fenestration**	***TECH ID***	**T040**
CATEGORY	Fenestration		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Any fenestration product that has the fully reversible ability to change its performance properties, including U-factor, solar heat gain coefficient (SHGC), or visible transmittance (VT). Electrochromic glazing/films actively change the transmission of light when energized by an electrical current.

Typically, an electrochromic layer such as tungsten oxide is sandwiched between layers of glass with electrolyte and ion conductor/storage layers and combined into a window unit such that when current is applied to an anode and cathode, the window darkens. Technologies with similar properties but less versatility include suspended particle devices and polymer dispersed liquid crystal devices.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	Limited	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	***AT MATURITY***	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	controls solar gain and occupant comfort based on user needs or climatic conditions	***PERFORMANCE TARGET FOR 2025***	ΔSHGC ~ 0.4 ($SHGC_{bleached}$ = 0.46 to 0.47 and $SHGC_{tinted}$ = 0.09) plus V_T in the bleached state > 0.6 for the residential sector and > 0.4 for the commercial sector.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25%	***O&M COST***	25%
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	Current cost premium for electrochromic windows, including cost for sensors, controls, and installation is \$22/ft^2. U.S. DOE Building Technologies Office (BTO) projects that installed cost premiums must drop to \$8/ft^2 or less for the technology to be cost competitive in the market and result in paybacks of ≤ 10 years for residential applications and ≤ 22 years for commercial buildings.		

TECH NAME	**Electrochromic Fenestration**	**TECH ID**	**T040**
CATEGORY	Fenestration		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Cost reduction. Product issues (e.g., manufacturing/raw material costs), early market phase (not yet mature), newer manufacturing and technology approaches are needed for major cost improvements Improvements in long term reliability and product uniformity. Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Engineer knowledge of impact of performance values on HVAC sizing, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Market awareness campaign
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, High energy savings potential, R5 + Electrochromatic seems within reach
TEAM REVIEWER NOTES	Savings are very climate, building, and orientation dependent. Recent developments of flexible plastics with EC coatings have cost reduction potential.

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Technology-specific research is needed to reduce costs by refining emerging thin-film EC materials, and pilot studies to develop high volume manufacturing processes.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

Performance Improvements:

Research is needed for the following areas:

- Improved and simplified switching controls. Controls infrastructure needs to be improved
- Faster switching speeds from bleached to tinted phase. Current switching speeds are still slow resulting in noticeable comfort issues.
- Products that can independently switch near-IR and visible light ranges. Current products in tinted mode result in a glass that has reduced visible transmittance. There is a manufacturer that has developed electrochromic glass that can independently switch in both the near-IR range for solar heat gain control, and visible range for glare control and maintain visible light transmittance but technology still expensive and not available on the market.
- Controls reliability and maintenance.

Performance Testing and Validation:

Research should focus on opportunities for reducing cooling capacity in commercial buildings, thereby offsetting costs by reducing HVAC system size and cost. Modeling and demonstrations are needed to assess HVAC and lighting energy use impacts. Productivity impacts could also be evaluated. Design tools are needed that can determine cooling load reduction and equipment savings.

TECH NAME	**Electrochromic Fenestration**	**TECH ID**	**T040**
CATEGORY	Fenestration		

Cost Improvements:

Current cost premium for electrochromic windows, including cost for sensors, controls, and installation is $22/ft^2. U.S. DOE Building Technologies Office (BTO) projects that installed cost premiums must drop to $8/ft^2 or less for the technology to be cost competitive in the market and result in paybacks of ≤ 10 years for residential applications and ≤ 22 years for commercial buildings. Electrochromic glass continues to be a small market because an electrochromic window still costs about twice as much as a traditional double-paned window

Knowledge and Experience:

83% of commercial buildings have no automated controls beyond occupancy sensors. Integrating controls of electrochromic windows with indoor lighting controls is critical to maintaining consistent indoor lighting levels and is not well understood. Currently only approximately 500 commercial buildings with electrochromic windows in the U.S.

In addition to overcoming technology barriers such as the high cost of production and product uniformity and durability, EC window systems can be integrated with lighting controls, and availability of controls and control algorithms to accomplish this would also improve the market potential. By reducing the heat and glare that's allowed into a building, company claims say it can cut HVAC and lighting consumption by up to 20 percent and HVAC peak load by 25 percent.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

(DOE, 2014). https://www.energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf

http://www.helwan.edu.eg/chinese/wp-content/uploads/2013/08/1-4-8.pdf

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R. Narayanamurthy. 2017. Advancing High Performance Windows: Electrochromic Windows. EPRI 3002001226.

https://www.energy.gov/eere/buildings/downloads/low-cost-highly-transparent-flexible-low-emission-coating-film-enable

https://www.greentechmedia.com/articles/read/view-has-raised-more-than-500-million-for-smart-adaptive-windows#gs.JVfLE4I

➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Ram Narayanamurthy:

> *"Utility companies in the US claim that current market technology lacks customer appeal and have limited financial payoffs, which has led to under sized window efficiency rebate programs and many qualifying requirements. On the other hand, as better electrochromic window technologies and methodologies emerge, this can be viewed as an untapped opportunity to provide increased incentives for additional energy savings."*

Brandon Tinianov, View:

> *"Standard curtain wall costs roughly $100 per square foot, while curtain wall that includes electrochromic glass can cost up to $140 per square foot. But the payback math requires a more holistic approach, "not just a bunch of 5 percent solutions." Projects have to make financial sense and take into account HVAC, blinds and O&M."*

TECH NAME	**Highly Insulating Windows**	**TECH ID**	**T043**
CATEGORY	Fenestration		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Typical fenestration products have R-values of R-2.5 to R-3. Highly insulated windows and glazing assemblies with R-values of R-7 to R-10 have the potential for substantial energy savings. These products require next generation Low-E coatings, multi-pane glazing assemblies and highly insulated, well-sealed assemblies, as well as low-conductivity frames.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	50% or more	**AT MATURITY**	50% or more

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Current triple-pane windows are R-5 to R-7. Includes low-conductivity frames, argon or krypton fill, and low-e coatings.	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	R-7 to R-10. May require quadruple panes or other advanced technology to get to R-10.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	**O&M COST**	10-20%
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	Cost premium should be $5/ft2 for premium market, $3/ft2 for broader production market to be competitive.		

TECH NAME	Highly Insulating Windows	TECH ID	T043
CATEGORY	Fenestration		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	Products under this category already exist but triple-pane windows still have have high first cost, low market penetration and early market adoption. Energy savings potential is climate dependent with lower impact in mild climates.

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Thin triple-pane windows with thin inner glass have potential for lower entry cost than traditional triple-pane windows and are same width as double-pane. Reduced cost of materials. DOE funding of research but CEC funding could support field tests and pilot programs. Research needs would probably be too costly for CEC (~$5 million to have an impact). CEC support of code revisions to facilitate additional credit for window improvements would be helpful.

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE

Triple-pane windows are currently only 2% of the U.S. window market. Current cost premium for triple-pane windows w/ krypton fill is $14.50/ft^2 (U-factor=0.18). Target costs are $5-6/ft^2 for extreme climates and $3-4/ft^2 for moderate climates. Baseline cost for code minimum residential windows $25/ft^2. Critical gaps for highly insulating windows include:

Prototype Development:
Development of windows with assembly thicknesses that are comparable to existing windows for retrofit applications. Thinner interior glass and krypton fill are options, but remain costly. Technology for thin triple-glass with thin inner glass have potential for: lower entry cost, minimal additional weight and same width as 2-pane window with single spacer. Goal is for mainstream availability for cold climates by 2020, but technology development still needed. [LBNL, 2017]

Product Design Evolution or Feature Enhancement:
Improved spacers have a meaningful impact on U-factor (~0.01), and do not receive sufficient attention from the research community.

Improved frame assemblies that maintain long-term air infiltration and structural requirements Overcoming the cost, installation, and builder acceptance barriers for wider assemblies, which will likely be necessary for exceeding R-7.

TECH NAME	**Highly Insulating Windows**	***TECH ID***	**T043**
CATEGORY	Fenestration		

Systems Integration:
Simplified window installations, especially for retrofit applications. New replacement window designs that allow for easier installation, such as a sash-only retrofit without replacing frames.

Performance Testing and Validation:
Durability improvements to vacuum edge glazing seals and soft low-E coatings. Listed as a technology gap in the Windows and Building Envelope Research and Development Roadmap from the DOE Building Technologies Office [DOE Roadmap (DOE, 2014)]. Subject matter expert, Ken Nittler does not does not view vacuum insulated glazing as a priority, and does not feel that the durability of soft low-E coatings is a research gap.

Cost Improvements:
Low-cost inert gases for multilayer insulated glazing. Krypton is too expensive for mass adoption.

Window construction cost reductions for triple-glazed assemblies, especially those with thin middle layer, krypton gas fill and multiple low-E coatings. Manufacturers are reluctant to invest in new production lines for triple-panes before significant demand exists, and sufficient demand may not exist until the price comes down.

➔ *KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES*

DOE, 2014. Windows and Building Envelope Research and Development Roadmap, DOE Building Technologies Office, February 2014, https://www.energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf

LBNL, 2017. http://www.cahp-pge.com/CAHP_TRC_HPW_2017-11-17.pdf

➔ *ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES*

Steve Selkowitz on lightweight thin triple-pane windows: *"The goal is to have the units—a 0.028-in. outer pane and a 0.118-in. inner pane with a 0.043-in. pane between them—mainstream and widely available, first for residential buildings in cold climates, by 2020." "The cost to develop a thin-triple technology platform and solve some minor manufacturing issues, such as handling the thin pane, is $3 million to $4 million,"* Selkowitz estimates. To get the product to market, he is planning to create a consortium of stakeholders, including the U.S. Dept. of Energy, owners, builders, designers, and glass suppliers and their trade groups. *"If I can get one or two of the top 10 or 15 window companies, everyone else will follow."*

Ken Nittler: Canada has a 2030 U-value target of 0.14, DOE has 0.10 target for 2030. Would need 4-pane windows or other technologies to get to that goal and might be very difficult to achieve. Does not see that there is a technology gap for soft low-E product. Definitely issues with vacuum sealed glazing. Most issues are market and cost barriers. A $5-10 million CEC investment in technology could have an impact but may not be realistic.

TECH NAME	**Dynamic Glazing – Thermochromic Fenestration**	**TECH ID**	**T039**
CATEGORY	Fenestration		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Dynamic glazing is defined as any fenestration product that has the fully reversible ability to change its performance properties, including U-factor, solar heat gain coefficient (SHGC), or visible transmittance (VT). Dynamic glazing improves window performance by adjusting window conduction and solar heat gain in response to either active or passive means. "Thermochromic" glazing/films passively modifies window U-factor and SHGC based on change in temperature (distinguished from "electrochromic" glazing, which uses an electrical circuit to modify SHGC). Thermochromic glass products use a polyvinyl butyral film with a thermochromic interlayer laminated between layers of outer glazing in a dual pane assembly to achieve an SHGCs as low as 0.09.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	Limited	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	**AT MATURITY**	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	solar gain and comfort control	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	reliability, cost, versatility

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25%	**O&M COST**	10-25%
COST BARRIERS	Thermochromic has potential for lower cost than electrochromic but does not have the versatility and controlability. Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Supply chain issues (e.g., too many distribution layers), Early market phase (not yet mature), Better Tools for design optimization; better tools for optimized real time performance with grid etc		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Durability, Uncertain impacts on HVAC equipment sizing, Architect acceptance/familiarity, Engineer knowledge of impact of performance values on HVAC sizing, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Market awareness campaign
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	Affects both cooling and lighting end uses. Could result in reduced HVAC equipment capacity and related cost savings.

TECH NAME	**Dymamic Glazing – Thermochromic Fenestration**	***TECH ID***	**T039**
CATEGORY	Fenestration		

→ **RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR**

Not as marketable as electrochromic due to lack of controllability. Shift in properties due to temperature of glazing may not align with needs for glare or SHGC reduction in building.

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

Current cost premium for thermochromic windows, is $22/ft^2. Current costs will limit applications to commercial buildings (especially high-rise), and very high-end homes. U.S. DOE Building Technologies Office (BTO) projects that installed cost premiums must drop to $8/ft^2 or less for the technology to be cost competitive in the market and result in paybacks of ≤ 10 years for residential applications and ≤ 22 years for commercial buildings. Research should focus on opportunities for reducing cooling capacity in commercial buildings, thereby offsetting costs by reducing HVAC system size and cost. Modeling and demonstrations are needed to assess HVAC and lighting energy use impacts. Productivity impacts could also be evaluated.

Additional technology gaps are to provide commercially available products that can adjust SHGC from 0.46 to 0.09 while maintaining a minimum visible transmittance (V_T) of 0.6 and 0.4 for residential and commercial products, respectively.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

https://www.energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf

https://www.osti.gov/servlets/purl/894091-FRpWuI/

https://basc.pnnl.gov/code-compliance/dynamic-glazing-code-compliance-brief

https://windows.lbl.gov/electrochromic-and-thermochromic

http://smartfilmsinternational.com/wp-content/uploads/solar/SFI-Thermochromic-brochure.pdf

https://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/BETEC/BETEC3Tinianov.pdf

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

"Glass fabricators will be able to use existing equipment to make the SRT [sunlight responsive thermochromic] window while adding value and flexibility to the basic design. Glazing installers will have the ability to fit the windows with traditional methods without wires, power supplies and controllers. SRT windows can be retrofit into existing buildings." - F.A. Millett, Pleotint Inc.Oh

TECH NAME	**Insulation Glass Coating**	***TECH ID***	**T041**
CATEGORY	Fenestration		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

The two uses of insulating window films are: (1) application of a reflective or low emissivity film directly to the interior side of windows, and (2) application of a heat shrink film to the exterior window frame to create an insulating air gap between the film and the existing window. This topic focuses on low-E films, which are most appropriate for California climate and demographics.

APPLICABILITY

GREATEST OPPORTUNITY	Existing Building Retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	Hot		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	***AT MATURITY***	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	***IN 5-7 YRS.***	Market ready

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	R-2; LSC = 2	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	R-5+; LSC = 2.5

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25%	***O&M COST***	25%
COST BARRIERS	Installation costs. Products are available from a number of manufacturers. At ~$7.50 per square foot, costs are substantially lower than for replacement with double low-E windows, though energy savings are less.		

TECH NAME	**Insulation Glass Coating**	***TECH ID***	**T041**
CATEGORY	Fenestration		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, durability
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance and durability enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Product certifications/labeling, Market awareness campaign, Improved production equipment or tools, Building production facilities, Improving distribution network/infrastructure
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	29% average perimeter savings based on GSA study.

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Products available from multiple manufacturers and through big-box stores. Durability and ease of installation could benefit from research, but no technical, only market and institutional barriers.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

➔ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

https://www.gsa.gov/cdnstatic/GPG_Findings_032-Low-E_Film.pdf

https://northamerica.llumar.com/comparing-standard-and-low-e-window-film-375

➔ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

"Whether you choose to replace your building's windows or install window film on existing windows, any of these options is a smart move toward an energy- and cost-efficient facility. After evaluating the differences in insulating performance, ROI and initial costs, installation processes, warranties, and the effect on occupants, you should be able to make an educated decision about which option is right for your building environment. Any improvement you make to the insulating performance of your windows is a step in the right direction." -Steve DeBusk, Eastman Performance Films LLC.

APPENDIX E:
Heating Ventilation Air Conditioning

TECH NAME	**Heat Recovery - Ventilation**	**TECH ID**	**T124**
CATEGORY	Ventilation and indoor air quality		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Heat recovery ventilation heats the incoming air via recovered waste heat from the exhaust stream. This strategy is used in heat recovery ventilators and heat recovery units in air handlers.

APPLICABILITY			
GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	Single family residential, Low-rise multifamily residential, High-rise multifamily residential	**COMMERCIAL BUILDING TYPE**	9 out of 13
APPLICABLE IN CLIMATE TYPES	All		
ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?			
TODAY	25-50%	**AT MATURITY**	25-50%
TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.			
TODAY	Early market adoption	**IN 5-7 YRS.**	Early market adoption
PERFORMANCE			
CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	fans sized for ventilation only (smaller); elimination of reheat; improved comfort; potential for medium temp chilled water and low temp heating hot water	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	ready for mainstream adoption now but need designers/contractors to familiarize themselves with the concept so that it gets on more jobs
COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?			
FIRST COST	10-25%	**O&M COST**	10-25%
COST BARRIERS	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Market size		

OTHER INFO ON THE TECHNOLOGY	
OTHER BARRIERS	Policy, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Standards development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Technology is readily accessible in the market and provides huge energy savings, heat recovery is applicable to all climates and building types, primary research focus is performance testing and validation

TECH NAME	**Heat Recovery - Ventilation**	***TECH ID***	**T124**
CATEGORY	Ventilation and indoor air quality		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1. The most important area of research is performance testing and validation. Many current projects do not perform as well as products claim and therefore there is a need for more field data to prove the performance of heat recovery units. In addition, standard energy model inputs tend to overestimate internal loads and therefore underestimate heating loads, which can make heat recovery cost/benefit savings inaccurate. There is a need for more field data on internal loads and load profiles.
2. Real world demonstrations would be useful to address designer unfamiliarity with the technology.
3. Product enhancement and system integration are recommended to understand how heat recovery systems can be integrated with passive ventilation strategies. To optimize integration with passive ventilation, certain product parameters should be improved such matrix structure, optimal length of the wheel and the rotation speed, optimum shape and arrangement of heat pipes, heat transfer materials, structures and more efficient fans.
4. Standards development goes hand in hand with performance validation. Once sufficient data is obtained on heat recovery performance, this data will need to be documented for standard modeling practices. In addition, there are currently no widely accepted testing procedure for heat recovery units.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

A Review of Heat Recovery Technology for Passive Ventilation Applications

A comprehensive review of heat recovery systems for building applications

Review on physical and performance parameters of heat recovery systems for building applications

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

Hillary Weitze:

"There is an issue of proving its cost effectiveness. We underestimate heating loads with modeling software because our assumptions from plug loads and lighting are too high, which is giving free heating. So it's not showing as much benefit/cost savings because of the lower heating load."

Hillary Weitze:

"From talking with DOAS manufacturers, there is no widely accepted testing procedure for HRVs. Some people think they fall under one but there is industry confusion."

APPENDIX F:
Indoor Air Quality

Tech Name	**Heat Recovery - Ventilation**	**Tech ID**	**T124**
Category	Ventilation and indoor air quality		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

Heat recovery ventilation heats the incoming air via recovered waste heat from the exhaust stream. This strategy is used in heat recovery ventilators and heat recovery units in air handlers.

Applicability

Greatest Opportunity	New construction		
Residential Type	Single family residential, Low-rise multifamily residential, High-rise multifamily residential	**Commercial Building Type**	9 out of 13
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	25-50%	**At Maturity**	25-50%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Early market adoption	**In 5-7 yrs.**	Early market adoption

Performance

Current Performance, Features, Functionality	fans sized for ventilation only (smaller); elimination of reheat; improved comfort; potential for medium temp chilled water and low temp heating hot water	**Improvements Needed to be Ready for Mainstream Adoption**	ready for mainstream adoption now but need designers/contractors to familiarize themselves with the concept so that it gets on more jobs

Cost decrease required to be competitive relative to currently available technology?

First Cost	10-25%	**O&M Cost**	10-25%
Cost Barriers	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Market size		

Other info on the technology

Other Barriers	Policy, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity
Research Focus Areas Identified by Survey Participants	Performance validation/product testing/simulation, Demonstration projects, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Standards development
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Adds value, e.g., improved occupant comfort, control, or amenities
Team Reviewer Notes	

→ Rationale for scores, especially the X-Factor

Technology is readily accessible in the market and provides huge energy savings, heat recovery is applicable to all climates and building types, primary research focus is performance testing and validation

TECH NAME	**Heat Recovery - Ventilation**	***TECH ID***	**T124**
CATEGORY	Ventilation and indoor air quality		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1. The most important area of research is performance testing and validation. Many current projects do not perform as well as products claim and therefore there is a need for more field data to prove the performance of heat recovery units. In addition, standard energy model inputs tend to overestimate internal loads and therefore underestimate heating loads, which can make heat recovery cost/benefit savings inaccurate. There is a need for more field data on internal loads and load profiles.
2. Real world demonstrations would be useful to address designer unfamiliarity with the technology.
3. Product enhancement and system integration are recommended to understand how heat recovery systems can be integrated with passive ventilation strategies. To optimize integration with passive ventilation, certain product parameters should be improved such matrix structure, optimal length of the wheel and the rotation speed, optimum shape and arrangement of heat pipes, heat transfer materials, structures and more efficient fans.
4. Standards development goes hand in hand with performance validation. Once sufficient data is obtained on heat recovery performance, this data will need to be documented for standard modeling practices. In addition, there are currently no widely accepted testing procedure for heat recovery units.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

A Review of Heat Recovery Technology for Passive Ventilation Applications

A comprehensive review of heat recovery systems for building applications

Review on physical and performance parameters of heat recovery systems for building applications

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

Hillary Weitze:

"There is an issue of proving its cost effectiveness. We underestimate heating loads with modeling software because our assumptions from plug loads and lighting are too high, which is giving free heating. So it's not showing as much benefit/cost savings because of the lower heating load."

Hillary Weitze:

"From talking with DOAS manufacturers, there is no widely accepted testing procedure for HRVs. Some people think they fall under one but there is industry confusion."

APPENDIX G:
Lighting

TECH NAME	**Advanced Lighting Controls Systems (ALCS)**	**TECH ID**	**T085**
CATEGORY	Lighting		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Advanced lighting controls systems (ALCS) use sensors and controls to optimize the balance between natural daylighting and electric lighting to minimize energy use and react to demand response signals while maintaining high lighting quality in occupied spaces. The technology is sometimes used in conjunction with dynamic window coatings, electronically controlled shading, dimmable light fixtures, vacancy sensors, and other advanced lighting technologies. An ALCS often tracks lighting performance and the control strategy can be adjusted based on performance or changing conditions.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	N/A	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50% of connected lighting	**AT MATURITY**	50-75% of connected lighting

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot	**IN 5-7 YRS.**	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Dimming, occupancy responsive, daylight responsive	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	50-75% reduction in lighting energy use

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25% or greater	**O&M COST**	25% or greater
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	The technology is cost-effective in many applications, but the payback period is often over 10 years, and the uncertainty in energy savings makes the cost seem prohibitive. Reduction in first cost, or financial incentives, could help stimulate demand and reduce uncertainty by increasing the number of applications.		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, Policy, Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Systems integration with other products, Standards development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	-

TECH NAME	**Advanced Lighting Controls Systems (ALCS)**	***TECH ID***	**T085**
CATEGORY	Lighting		

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Significant opportunity to leverage LED lighting and new daylighting and control technologies. Several technologies are mature, but are hampered by commercialization barriers that could be addressed by CEC. Investment is needed in real-world demonstrations, best practice guidance, and education throughout the value chain.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

Knowledge and Experience: 83% of commercial buildings have no automated controls beyond occupancy sensors. Only 2% of commercial buildings use daylight harvesting. As a result, there is very limited experience with advanced controls in the existing building stock. Increased training is needed to educate the labor force about how to install, program, and interact with the technology. Investment is needed to scale the delivery of training for this technology, especially for designers/specifiers and contractors/installers. The curricula exist, it's a matter of developing delivery methods and incentivizing the participation.

Complexity: For the more advanced ALCS systems, the range of lighting system designs and control types can make it difficult to develop optimal control algorithms appropriate for multiple applications. Specialized expertise may be required to interact with the system and make adjustments. However, there are many simpler networked systems on the market that achieve most of the savings with a much simpler interface and basic feature set. An additional challenge is architectural lighting, which may require a different approach to optimal control logic because of safety and aesthetic requirements.

Lack of Standardization: Communication among sensors and controllers from different manufacturers is challenging without further standardization of communication protocols that will allow an integrated lighting system control strategy. There is a danger that building owners will be locked into obsolete fixtures that can't communicate with newer equipment that complies with standard communication protocols developed in the future. Standardized data collection guidelines and consistent methodologies for predicting energy savings are also needed.

High Costs: The cost of ALCS remains high due to lack of volume production of standard products, along with design complexity, communication challenges, and high installation costs driven by lack of familiarity and standardization. Hardware costs are higher because the technology is manufactured in low volume; installation costs are higher because contractors do few projects with them and are unfamiliar with the systems. Costs should come down over time with sufficient adoption in the market. The current cost-effectiveness of the technology is not where it needs to be to support mass adoption. Most projects with advanced controls provide a payback in the 7-15 yr range whereas LEDs by themselves provide a payback of 2-5 yrs. As a result, most customers install LEDs without advanced controls to achieve a shorter payback. This creates a lost opportunity for savings that will not be available again until the lighting is replaced in the future, often in 10-15 years. It is crucial to get the advanced controls installed at the time of the LED retrofit.

Value Proposition: Cost effectiveness has not been demonstrated in a sufficient number of buildings. It is especially difficult to identify the characteristics of commercial buildings that will achieve the greatest savings, or best practices for ALCS design and control logic, because calculation methods have not been standardized, ALCS designs have a broad range of control capabilities, and building features and occupant behavior are very diverse. Much larger validation studies (1000s of applications) are necessary to address these questions.

EE Program Designs: ALCS is generally not adequately promoted, targeted, or properly credited by energy efficiency programs due to uncertainty in savings estimates and the use of baselines that assume controls are installed. Utility incentives are very effective at overcoming cost barriers, however California IOU program offerings and incentives for this technology are currently very limited. This is probably due in part to limitations placed on the IOUs by regulators that require them to use a Title 24 baseline for all projects, which in turn has limited the energy savings IOUs can claim for projects using advanced controls, and thereby limited the programs and incentives they can offer for the technology. Another concern is that some programs properly credit ALCS, but are overly complex and cumbersome, discouraging broad participation. Other ALCS technologies in the pipeline will run into the same commercialization barriers faced by market-ready ALCS products now, which makes those barriers the highest priority.

TECH NAME	Advanced Lighting Controls Systems (ALCS)	TECH ID	T085
CATEGORY	Lighting		

➔ **KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES**

Commercial Advanced Lighting Control Demonstration and Deployment. 2016 Building Technologies Office Peer Review. https://energy.gov/sites/prod/files/2016/04/f30/22299_Arnold_040616-1605.pdf

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DesignLights Consortium. 2017. Energy Savings from Networked Lighting Control (NLC) Systems. https://www.designlights.org/lighting-controls/reports-tools-resources/nlc-energy-savings-report/

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➔ **ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES**

Teddy Kisch, Senior Project Manager, Energy Solutions:

"The biggest opportunities California has to support installation are:

- *Improved research on energy savings from ALCS on a large-scale (similar to the DLC's "Energy Savings from NLCs" report), which can provide more certainty to end-use customers.*
- *Standardization of how ALCS claim savings (relative to code baselines) and developing a policy that gives some degree of preferential treatment to controls + LED rather than standard LED retrofits…*
- *Continued development and training for contractors (similar to CALCTP)"*

Gabe Arnold, PE, LC, Technical Director, DesignLights Consortium:

"There are 3 high impact areas where CEC could invest in this technology to accelerate its adoption in California: (1) education, (2) utility incentives and EE program designs, and (3) more data/larger validation studies."

Tech Name	**Advanced Solid State Lighting**	**Tech ID**	**T086**
Category	Lighting		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

Organic Light Emitting Diode (OLED) technology is a form of solid state lighting that has comparable efficiency to LEDs but produce diffuse light over a broader spectrum, and is manufactured in flat, flexible sheets. The result is better quality ambient light with with less glare and greater application flexibility than standard LEDs.

Applicability

Greatest Opportunity	Equal for both new construction and retrofit		
Residential Type	NA	**Commercial Building Type**	Small office, Large office, Healthcare/medical, Restaurant, K-12 school, Higher education
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	10%-30% compared to fluorescent	**At Maturity**	30-50% for retrofits of fluorescent, same energy use as LEDs for new construction

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Proof of concept	**In 5-7 yrs.**	Proof of concept

Performance

Current Performance, Features, Functionality	60-90 lm/W	**Performance Target for 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	150 lm/W

Cost decrease required to be competitive relative to currently available technology?

First Cost	50% or greater	**O&M Cost**	50% or greater
Cost Target for 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	$100/m2 for panels. The current price is about $1000/m2. Cost for luminaires using OLEDs is more difficult to quantify because it is application dependent.		

Other info on the technology

Other Barriers	Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Occupant acceptance/familiarity, Low brightness means larger areas are needed to maintain typical
Research Focus Areas Identified by Survey Participants	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Improved production equipment or tools
Importance to ZNE	Greenhouse gas reduction potential, High energy savings potential, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
Team Reviewer Notes	-

TECH NAME	Advanced Solid State Lighting	TECH ID	T086
CATEGORY	Lighting		

→ **RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH**

U.S. DOE is much more focused on LED than OLED research, and it would probably take deep pockets to address the technical barriers. Some manufacturers of substrates and other components are making investments, as well as display manufacturers. CEC investment in OLED lighting technology may not make sense, because there are no local panel manufacturers and the cost would be high. Technology demonstrations and occupant response studies might be a better fit for CEC funding.

→ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

Cost: OLED technology is still in its early stages, and manufacturing cost is high. The 2025 target is $100/m2, but the current cost is about $1000/m2. There is some hope that Korean investment in OLED displays will have a trickle-down effect on OLED lighting costs. The largest specific cost-related challenges are improving yield, reducing costs for materials (substrates, electrodes, encapsulants), and reducing fabrication costs (patterning, printing). Higher efficacy would also have a beneficial effect on cost by reducing the number of panels necessary for the same light output.

Efficacy: The efficacy of OLEDs is currently about 60 lm/W for commercially available products, and 80 lm/W for some high-end products. Efficacy must be increased to about 100 lm/W to be viable in niche applications. 150 lm/W would be needed for broad usage in buildings. The greatest challenge for efficacy is not converting electricity to light, which is nearly at 100% efficiency for OLEDs, but extracting the light from the OLED. Light extraction is currently at about 40-50%, and must be increased to about 70%.

Limited availability: There appears to be only one U.S. manufacturer of OLED panels at this time. Greater investment has been occurring in Korea, focused on OLED displays, and there is some European manufacturing activity. There are several U.S. luminaire manufacturers interested in using OLEDs if there is demand, but currently there are very few lighting products available. Investment is needed for development and testing of prototype OLED applications to help stimulate markets. Support is also needed for companies that want to be OLED luminaire suppliers.

Product reliability: Performance consistency and degradation in the field is a challenge that must be overcome through better manufacturing techniques, quality control, and designs that better protect OLEDs from environmental pollutants. At times, stability must be traded off against efficacy, such as for blue emitters, which operate at higher energy levels. The power draw of OLEDs typically increases by about 25% over the life of the product, but recent advancements are moving this closer to 10-15%. Lifetime (calculated based on lumen output) is currently about 10,000 hrs, and must be increased to about 50,000 hrs.

Low brightness: Lighting intensity is lower than LEDs and other lighting technologies, so a higher surface area must be used for OLED lighting. Because this is an inherent characteristic of OLED, offering certain aesthetic and visual benefits, it is not viewed as a weakness that should be addressed through research. However, it does limit the number of viable market applications, especially for retrofits, where existing fixtures would have to be replaced. It is expected that market penetration may be capped at 10-20% of the overall lighting market due to this limitation.

Customer awareness: OLEDs are an unfamiliar technology that may require greater education and early adopters to spur market acceptance. Finding an ideal near-term application is key to getting a foothold in the market, reducing cost and generating interest, which will lead to further R&D investment. Customer responsiveness to OLED lighting is not well understood, and studies of occupant reactions to OLEDs would be valuable.

TECH NAME	**Advanced Solid State Lighting**	TECH ID	**T086**
CATEGORY	Lighting		

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Brodrick, James. 2011. LED and OLED Solid State Lighting: A Look Ahead. Washington Report. https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/ledoled_wasreport_march2011.pdf

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➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Naomi J Miller, FIES, FIALD, LC, Designer/Senior Scientist, Pacific Northwest National Laboratory:

> *"The biggest roadblocks are getting efficacy higher, getting panel life extended to 50,000 hrs from 10,000 hours, and finding the killer app."*

Lisa Pattison, Ph.D., Technical Advisor to the DOE Solid State Lighting Program, Solid State Lighting Services

TECH NAME	**Direct DC Lighting**	***TECH ID***	**T087**
CATEGORY	Lighting		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

DC powered lighting can use DC power from PV panels and batteries directly, minimizing the need to convert AC power from the grid to DC power for LED lighting systems. As a result, most of the AC to DC inverter efficiency losses associated with LED lighting can be avoided. Most fluorescent lighting will not benefit from the technology because they are designed for AC power.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	Single family residential, Low-rise multifamily residential, High-rise multifamily residential, Small office	***COMMERCIAL BUILDING TYPE***	Small office
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	***AT MATURITY***	10-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	***IN 5-7 YRS.***	Proof of concept

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	AC to DC inverter losses will be reduced significantly for LED lighting. Fluorescent and most other lighting will benefit less from DC, but the trend is away from those lighting technologies.	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Better DC standards for voltage, safety, etc. LED lighting is already DC.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25-50%	***O&M COST***	25-50%
COST BARRIERS	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Supply chain issues (e.g., too many distribution layers), Market size, Early market phase (not yet mature)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, Policy, Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Health and safety
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Systems integration with other products, Product certifications/labeling, Establishing distribution network/infrastructure, Standards development, Product support materials development, Most effort should be focused on DC distribution in homes and making all equipment types available in DC. I believe DC lighting is ready for broader use, but it would be best if whole buildings went DC, and other products present larger challenges.
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

TECH NAME	**Direct DC Lighting**	***TECH ID***	**T087**
CATEGORY	Lighting		

→ **RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR**

Market and institutional barriers seem to dominate technical barriers. It might be difficult to overcome them with research.

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

Timing of power needs: Unless battery storage is available, conversion of AC power to DC must still be performed to power LED lighting when sunlight is unavailable.

AC Products: Currently, the vast majority of equipment in buildings relies on AC power. It is an expensive proposition to replace all AC devices with DC, but for optimal efficiency it would be important to use a DC power grid and avoid the AC to DC conversion needed for many products, including LED lighting.

Variation in DC power requirements: Different DC applications in buildings have different power requirements, so additional power conversion devices may be necessary until there is further standardization.

Standardized voltage: While higher voltage systems are more energy efficient and can use smaller wiring, they are less safe than low voltage DC systems. There are existing standards for different voltages, but there does not appear to be a consensus on what should be used in residential and commercial buildings.

Availability of DC fixtures and lamps: For situations where fluorescent lamps using AC are required, it may be difficult to find fixtures that accept DC power. For halogen, compact fluorescent, and incandescent lighting, DC lamps can be used with no change to the fixture.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Maury Wright. 2014. *Lighting systems leverage DC distribution for maximum efficiency*. Illumination in Focus. http://www.ledsmagazine.com/articles/iif/print/volume-3/issue-1/features/dc-grids/lighting-systems-leverage-dc-distribution-for-maximum-efficiency.html

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➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

Tech Name	**Enhanced Daylighting**	***Tech ID***	**T088**
Category	Lighting		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

Methods to increase the amount of daylight available to offset electric lighting in commercial buildings. This may include low tech measures such as optimal window placement, light shelves, clear or shorter partitions, and high reflectivity paint, or more advanced measures such as daylight sensors, automatic dimmers, zoned lighting circuits, dynamic windows, tubular skylights, or fiberoptic daylighting.

Applicability

Greatest Opportunity	New construction		
Residential Type	NA	***Commercial Building Type***	Small office, Large office, Retail, Grocery, Restaurant, K-12 school
Applicable in Climate Types	Mild (mixed humid/mixed dry), Hot dry, Hot humid		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	10-25%	***At Maturity***	10-25%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Market maturity	***In 5-7 yrs.***	Market maturity

Performance

Current Performance, Features, Functionality	Electric lighting energy can be reduced by 20% or more with optimal dayliging design and controls.	***Improvements Needed to be Ready for Mainstream Adoption***	New dynamic window treatments, sensors and control technologies can increase lighting and cooling savings by another 10% or more.

Cost decrease required to be competitive relative to currently available technology?

First Cost	No	***O&M Cost***	No
Cost Barriers	There is not a major cost issue, except if very complex controls or tubular skylights are used.		

TECH NAME	**Enhanced Daylighting**	***TECH ID***	**T088**
CATEGORY	Lighting		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Barriers are mostly related to optimal design strategies.
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Demonstration projects, Systems integration with other products, Training materials development (curricula, manuals, videos, etc.)
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Relatively mature technology, applications mostly limited to new and some existing commercial

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

Existing buildings: It is difficult to significantly increase daylighting in existing buildings. The glazing area cannot be easily changed, and often there are physical obstructions that prevent penetration of daylight deep into buildings.

Residential buildings: Electric lighting is a relatively small fraction of residential energy use, and the timing does not coincide with the presence of daylight.

Overheating/glare: Too much daylighting can cause comfort problems related to hot spots where solar gains are excessive, and glare from direct or reflected sunlight.

Control of electric lighting: To save energy, the electric lighting levels must be lowered when daylighting is present. In some buildings dimming is unavailable, or lighting is not zoned in a way that allows electric lighting to be turned off in daylit spaces while staying on in darker areas. Even when dimming switches are available to occupants, manual lighting controls may not be used optimally.

➔ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Gregg D. Ander. 2016. Whole Building Design Guide: Daylighting. Southern California Edison. https://www.wbdg.org/resources/daylighting

Rahul Athalye. Daylighting Controls for Commercial Buildings. PNNL-SA-108996. Pacific Northwest National Laboratory. https://www.energycodes.gov/sites/default/files/documents/ECodes2015_12_01_Athalye.pdf

FacilitiesNet. 2009.

➔ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

TECH NAME	**Fiber-optic Daylighting**	***TECH ID***	**T089**
CATEGORY	Lighting		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Light is transmitted through a fiber optic cable from a roof-mounted collector to a special fixture that may also include fluorescent lights. The fiber optic distribution system allows light to be delivered through a complex path to interior spaces in commercial or residential buildings.

APPLICABILITY

GREATEST OPPORTUNITY	Retrofits or new construction		
RESIDENTIAL TYPE	NA	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	20% reduction in electric lighting	***AT MATURITY***	30% reduction in electric lighting

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	One collector can serve four light fixtures.	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	***O&M COST***	50% or greater
COST BARRIERS	Early market phase (not yet mature)		

TECH NAME	**Fiber-optic daylighting**	***TECH ID***	**T089**
CATEGORY	Lighting		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Demonstration projects, Systems integration with other products
IMPORTANCE TO ZNE	High energy savings potential, eliminate need for electric lighting in some locations
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

In theory this technology can help overcome the need for electric lighting in windowless spaces, and lower costs could make a big difference

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

Cost: Least expensive system is about $10,000 for one collector, four fiber optic cables, and four fixtures. Installation can be complex.

Availability: There appears to be no U.S. manufacturers at the present time, and only 2-3 foreign manufacturers.

Color rendering: The daylight color tends to change over the course of the day.

Efficiency: Approximately 1% of light is lost per foot of fiber optic cable, which limits the distance the fixture can be placed relative to the collector.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Alex Wilson. 2010. *Fiber Optics for Daylighting*. Blog post. BuildingGreen. https://www.buildinggreen.com/blog/fiber-optics-daylighting

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→ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

TECH NAME	**LED Lighting**	**TECH ID**	**T090**
CATEGORY	Lighting		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

LED lighting is the predominant form of solid state semiconductor-based lighting, and is rapidly becoming commonplace in most lighting applications as new fixtures have been developed and the price has decreased. LEDs are very energy efficient, use DC power, and are dimmable.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10% or less	**AT MATURITY**	10% or less

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Market maturity	**IN 5-7 YRS.**	Market maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	good efficacy, good color profiles, good selection	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	None, it is ready

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10% or less	**O&M COST**	10% or less
COST BARRIERS	Early market phase (not yet mature)		

TECH NAME	**LED Lighting**	**TECH ID**	**T090**
CATEGORY	Lighting		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

Cost: The cost of LEDs has decreased significantly in recent years, but is still much more expensive than other lighting options based on first cost.

Directionality: Diffusers are required to create a uniform spread of light due to the directionality of LEDs, which are point-source in nature.

Color rendering: Efficacy and color rendering suffer at lower correlated color temperatures.

Performance variation: Some LED products using older technologies do not perform as well as others. Issues can include flicker, color consistency, and power factor.

Heat management: It is important that sufficient heat sinking is provided to prevent overheating, which significantly degrades efficacy.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

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➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

APPENDIX H:
Demand Response

Tech Name	**Dispatchable Storage for Peak Load Management**	***Tech ID***	**T160**
Category	Demand Response		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

Controllable, fast acting, distributed storage systems at the commercial level or aggregated at the residential level to provide grid and customer services including backup power, peak load reduction, and other ancillary services, while also deferring system upgrades. This requires established communication between the utility and the distributed battery systems for direct control.

Applicability

Greatest Opportunity	Equal for both new construction and retrofit		
Residential Type	All	***Commercial Building Type***	All
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	10-25%	***At Maturity***	10-25%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Demonstration/pilot phase	***In 5-7 yrs.***	Early market adoption

Performance

Current Performance, Features, Functionality	Main residential application: backup power Commercial applications include backup and peak load shifting to avoid demand charges Typical battery round trip efficiency: ~90%	***Performance Target for 2025*** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard.	Ability to reduce peak demand, provide voltage support and frequency regulation, participate in demand response, etc. Need to target a battery lifetime of 15-20 years for competitive levelized cost of energy.

Cost decrease required to be competitive relative to currently available technology?

First Cost	25-50%	***O&M Cost***	10-25%
Cost Target for 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	While not necessarily a 2025 target, battery storage needs to hit \$125-\$165/kWh (a significant reduction from the current ~\$500/kWh price point) for increased market penetration.		

Other info on the technology

Other Barriers	Policy, Product availability, Reliability, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity
Research Focus Areas Identified by Survey Participants	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
Team Reviewer Notes	

TECH NAME	**Dispatchable Storage for Peak Load Management**	***TECH ID***	**T160**
CATEGORY	Demand Response		

→ **RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH**

Dispatchable storage for peak load management is given an x-factor of one due to the high value from both a utility and customer perspective. Communication and control of individual or aggregated loads is a high research priority.

Ongoing research: EPRI's Demand Side Resource Integration Platform funded by the CEC (EPC-15-075)

→ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

In order to improve the value proposition of storage technology (both battery as well as thermal storage), utility controls need to be created and adopted to shift load to off-peak times and increase load during periods of excess generation. With adequate control strategies and technology, rapid response could allow for frequency regulation as well, adding to the value of fast-acting dispatchable storage. Prior to implementation, the following challenges and gaps need to be addressed:

1) DER communication: There is currently a lack of standard communication protocols that would enable products to easily communicate to other products and utilities. This limits projects to pilot programs since there is little to no ability to scale.
2) How do we engineer the architecture and interfaces for communication, especially at a retrofit level? The software architecture must be able to support and interface with existing systems.
3) Determination of and creation of algorithms that should be on the system including: self-supply, TOU, and utility setpoint command control.
4) There is a need for consistent, guaranteed response times for utility needs. For customer convenience and comfort, fast, consistent response time is not necessary. From a utility perspective, response times need to be quick and guaranteed.

High upfront cost remains a barrier to distributed storage, but as more value streams surface, distributed battery storage nears economic viability.

→ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

https://www.greentechmedia.com/articles/read/were-still-underestimating-cost-improvements-for-batteries#gs.yTc8VRs

https://www.ifc.org/wps/wcm/connect/ed6f9f7f-f197-4915-8ab6-56b92d50865d/7151-IFC-EnergyStorage-report.pdf?MOD=AJPERES

https://www.energy.gov/sites/prod/files/2013/05/f0/GTT12_Dist-ActionPlan.pdf

→ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Chris DeBone, E-Gear – Gap #: 1, 3

Teja Kuruganti, ORNL – Gap #: 1, 2, 4

TECH NAME	**Automated Demand Response**	***TECH ID***	**T151**
CATEGORY	Demand Response		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Automated, control of individual or aggregated loads in response to utility pricing signals or demand response events. Controls include: lighting reduction, HVAC setpoint control, electric water heater setpoint control, on/off control, and thermal storage. Auto demand response strategies are typically pre-programmed responses to utility signals. Current standards have helped to define hardware and communication requirements to enable off the shelf, DR ready products.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	***AT MATURITY***	10-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	- kW reduction during peak load - Response times of 4 seconds for automated DR - Manual demand response is most common, requiring human intervention (i.e. flipping switches) on the load end to reduce consumption.	***PERFORMANCE TARGET FOR 2025*** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard.	Reliable control over loads at a commercial, residential and industrial level with response times of less than 4 seconds. A kWh reduction number or percentage is difficult to determine due the variability and uniqueness of every application and the feasibility for only a certain amount of reduction at different sites.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10-25%	***O&M COST***	10% or less
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	Costs of auto demand response implementation is cost competitive, especially with incentives from utility partners. Current addition of connected devices (for residential/small commercial) come at a ~$100-$200 premium per device, plus, typically, the addition of a ~$50-$100 hub. As standardization improves, those costs will be reduced and payback periods should expect to be 5-10 years.		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Market size, Early market phase (not yet mature), Product availability, Facility operator acceptance/familiarity, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Market awareness campaign, Standards development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

Tech Name	**Automated Demand Response**	***Tech ID***	**T151**
Category	Demand Response		

→ Rationale the X-Factor – Primarily listing any existing/ongoing research on this technology and by whom. For EXAMPLE, if DOE or DOD or any others have initiatives to support or fund research for this tech

There is current research at EPRI that uses off the shelf technology to aggregate end use loads in homes to respond to utility demand response calls. There is a need for more research to further develop standards from both a technology (end use and aggregation tech) and implementation (utility rate structure and DR signals) standpoint.

➔ Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE – Use the guidance in the word doc shared with the team to fill this section

1) **Reliability:** Need for increased reliability of system response, especially due to possible customer wifi connectivity issues. Currently, upkeep of aggregation software platforms or hubs is necessary to ensure that each energy management system remains connected and functional. Off the shelf products still experience connectivity or data issues due to outdated software, poor site maintenance, and wifi issues.
2) **Data Security:** As more customer end use data becomes available, extra care must be taken to securely transmit and store the PII.
3) **Site Demonstrations:** There is a need for expanded demonstrations to include data centers, different types of residential sites and smaller commercial buildings to better understand the impact potential as well as the most fluid path to integrating auto DR into these buildings.
4) **Performance testing of off the shelf products:** There is a need for further research to understand the capabilities and functionality of off the shelf demand response enabling technology (DER aggregation hubs,
5) **Demonstrations of auto DR value:** Need demonstration projects to quantify impact and to determine if there are other value streams in which demand response can be valuable (i.e. ancillary services)

➔ Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references

Automated Demand Response Today. EPRI, Palo Alto, CA: 2012. 1025008.

https://www.enernoc.com/sites/default/files/media/pdf/FAQs/P14112_faq_california-autoDR.pdf

https://www.osti.gov/servlets/purl/1212423

➔ Any Subject Matter Expert Names, Affiliation, Comments and Quotes

APPENDIX I:
Other Building Level Controls

TECH NAME	**Predictive (data analytics based) Controls**	**TECH ID**	**T167**
CATEGORY	Other Building Level Controls		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

The control systems in residential and small commercial buildings are categorized in two groups for this group:

- Networked Controls: Traditional building energy management systems which operate with a central controller or a hub, usually connected to the internet. These systems control multiple loads including HVAC, lighting, plug loads, and safety systems.
- Distributed Intelligence: These systems usually control one end use load such as HVAC or lighting, with built in performance optimization for that particular end use system. These units have individual connection to the internet (cloud connected), but can also be locally networked in some cases with the right hardware combination.

Both systems are suitable for retrofit of existing buildings or new constructions. Controls of the systems are to meet four objectives: comfort, convenience, security and savings.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	**AT MATURITY**	10-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Understanding actual operational profiles and needs within buildings, being used at the moment to highlight thermal comfort and similar issues in buildings. Controls are limited to single devices and not aggregated at a premise level.	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard.	Whole home controllability and energy optimization based on data monitoring. Further integration of AI to predict and respond to consumer behavior.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10% or less	**O&M COST**	10% or less
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	No specific cost target due to the low cost of implementing a control system and the variability with which one can be installed and implemented. Currently not enough financial data to understand the metric by which to compare. Target payback period of 2 to 5 years.		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Builder/trades acceptance/familiarity, Facility operator acceptance/familiarity, Operational cost
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Demonstration projects, Systems integration with other products, Market awareness campaign
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities, Asset management and life cycle management
TEAM REVIEWER NOTES	

TECH NAME	Predictive (data analytics based) controls	TECH ID	T167
CATEGORY	Other Building Level Controls		

→ **RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH**

The x-factor is ranked high because data analytics based controls is applicable to both new construction and existing building retrofits. The cheap cost and ease of installation allows building owners/renters to put together a ~$1000 package including smart thermostats, lighting controls, plug load controls and a package of sensors to start controlling, monitoring and optimizing the building performance, while also improving the level of security and comfort immediately.

EPRI has investigated and demonstrated many technology packages in the laboratory environment and in the field, for connectivity, Measurement & Verification, comfort improvement, energy efficiency and demand response purposes.

→ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

As data analytics based controls expand their presence in the residential and small commercial markets, ongoing research will be essential in allowing consumers, architects, engineers, contractors and business owners to make informed decisions, and in helping the technology grow and improve on security, convenience, energy efficiency, reliability, connectivity and capability. Some of the research areas already being focused on by EPRI and others, or in need of research attention include:

1) Proprietary controls and the interoperability issue: many products and ecosystems are not developed with open standards but are proprietary. EPRI also found that products purchased from different brands that are supposed to communicate through ZigBee or Z-wave may still not be able to get connected. These issues are expected to be resolved along with the development of IoT and connected devices. EPRI has been testing and demonstrating technologies in the laboratory and in the field. EPRI will continue the demonstrations to identify the viability and performance of these devices.

2) Large volume of data. Smart sensors, circuit level metering and smart devices are gathering data from homes, businesses and leveraging machine learning algorithms to add value and optimize operations. The volume of this data collected is significant and needs urgently to be properly stored and analyzed.

3) Security issue. When data is collected from customer sites, the data includes customer information directly or indirectly. Research is needed to encrypt, store and analyze data to prevent unwanted dissemination of data. Research projects need to develop processes that can de-identifying data from all Personally Identifiable Information (PII) in order to protect the privacy and critical personal information.

4) Measurement & Verification 2.0. SB350 and AB802 establishes the guidelines necessary for evaluation and measured energy performance. Although the basic standards and methods are defined, a lot of work still need to be done to truly leverage the huge amount of data to achieve the expected M&V 2.0 analytics.

→ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Intelligent Buildings: Control Systems for Integration of Commercial Buildings into the Grid. EPRI, Palo Alto, CA: 2015. 3002005698.

Nest Generation Utility Programs: How M&V 2.0 is Enabling a "Negawatt" Market. http://blox.rmi.org/blog_2016_01_29_next_generation_utility_programs. Jan 2016.

https://www.nlc.org/sites/default/files/The-Economics-of-Energy-Upgrades.pdf

→ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Penn Zhao, EPRI

APPENDIX J:
Water Heating and Efficiency

TECH NAME	**Central Heat Pump Water Heater**	***TECH ID***	**T129**
CATEGORY	Water heating and water reuse related energy use		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Large centralized air to water heat pumps delivering hot water to storage tanks for domestic and service water heating end uses. Used for multifamily housing, hospitality, hospitals, and food service, and other commercial / industrial uses for hot water.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	Low-rise multifamily residential, High-rise multifamily residential	***COMMERCIAL BUILDING TYPE***	Healthcare/medical, Lodging, Restaurant
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	***AT MATURITY***	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	***IN 5-7 YRS.***	Market Maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	2.0 - 4.5 COP. Many current products can't operate at low temperatures or can't deliver hot enough water for commercial applications. The industry is still shaking out the underperforming systems and refining performance and controls; Key component of design is optimizing storage and recirc loop design/performance for maximum energy efficiency	***PERFORMANCE TARGET FOR 2025***	3.5 - 4.5 COPs at minimum 160F delivery temp and low ambient tempereatures.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25-40%	***O&M COST***	10-25%
COST TARGET FOR 2025	There is no information on cost reduction targets needed for central HPWHs. Current incremental costs were difficult to obtain without paying an outside source to provide an estimate. Estimates from one current multifamily project were approximately $4,000 - $5,000 incremental per apartment compared to central gas boiler and storage.		

TECH NAME	**Central Heat Pump Water Heater**	***TECH ID***	**T129**
CATEGORY	Water heating and water reuse related energy use		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Policy, Product availability, Reliability, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Lack of trades awareness. Lack of product availability and long term field perform. Policy = lack of Title 24 complance.
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Research through EPRI and Ecotope have focused on evaluation research. No known primary research being done by national labs. Product design evolution (new/improved features, performance enhancements, etc.), Need for integrated off-the-shelf systems with heat pump and storage tank combined that can be plug and play and require less design customization. Performance validation/reliability, Demonstration projects, Standards development, Need to model and take credit in compliance software. Product certifications/labeling, Training materials development (curricula, manuals, videos, etc.), Establishing distribution network/infrastructure.
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Critical need in electrification of water heating, especially in central multifamilly buildings. Water heating is a key end use that is largely handled with natural gas. Finding an efficient, cost-effective WH solution is an important longer term goal for reduced carbon buildings.
TEAM REVIEWER NOTES	Central HPWH for MF, healthcare, hospitality applications not as mature as SF products. Challenges include finding products that can deliver hot water temperatures for applications, and can operate in cold ambient conditions. In addtion to more product options, cost reductions are needed. Also more installation challenges due to lack of installer training, complex controls.

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Funding of ongoing demonstration sites and better understanding of equipment needs to optimize performance could transform marketplace which has demand for this technology. Potential in multifamily, restaurant, hospital, and industrial applications. Load shaping potential if combined with adequate storage and controls to communicate with grid signals during peak demand periods.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE

Central heat pump water heaters have the potential to transform a key building end use that is currently primarily served with natural gas appliances. Finding an efficient, cost-effective water heating solution is an important longer-term goal for reduced carbon emmissions in buildings.

Performance improvement

Need for products that can operate at low ambient conditions and high delivery temperatures needed for central applications with high COPs and without the need for supplemental electric resistance heat. Variable capacity temperature maintenance HPWH needed for handling warmer entering temperatures (hot water recirculation). Central HPWHs can also benefit from primary research in HVAC refrigeration and heat exchanger technologies (i.e. variable speed compressors, magnetocaloric technology).

TECH NAME	Central Heat Pump Water Heater	TECH ID	T129
CATEGORY	Water heating and water reuse related energy use		

Complexity

System equipment and controls are more complex than conventional water heating equipment, leading to installation and commissioning challenges. Site specific engineering design required for application of this technology and lack of experience can easily lead to improper specification and application of central HPWHs, leading to poor performance and reliability.

Product Enhancement / Systems integration

Systems require optimization of heat pump capacity, storage volume, and reliance on electric resistance backup. This results in engineering design challenges. Need for integrated off-the-shelf systems with heat pump and storage tank combined that can be plug and play and require less design customization. Pre-piped, pre-connected packages that can be shipped to site and installed with little commissioning. Opportunities to get benefit of scale and simpler installations. Need for integration of circulation loop with heat pumps. Available products are designed to heat cold water (high temperature lift).and do not perform well when coupled with hot water recirculation systems that return warmer water.

Cost improvement

HPWH technology for commercial applications is still in low-volume, and manufacturing cost is still high. Because of low production volume for the equipment and lack of familiarity, these systems tend to be much more expensive than gas-fired central water heating equipment. These systems also require a design engineer to implement and not available as an off-the-shelf piece of equipment that can be specified and installed, which also affects costs. Cost reductions can occur in the following areas:

- Equipment costs: If more manufacturers provided products for North American market, there would be more competition.
- Supply chain efficiency: Increased demand for technology could lead to improved supply chain efficiency. There is currently very limited distribution for these products.
- Installation costs: need for increased trades training to be more familiar with installation and startup requirements. Most plumbing contractors have limited familiarity with refrigerant-based systems. Trades in general not trained in systems that may have complex control systems.
- Commissioning & startup costs: Trades need more familiarity with products in order to properly commission these systems for use. Manufacturers need to provide better support, along with commissioning and O&M instructions that are easy for installers to follow.

Limited Availability.

There are very few manufacturers of commercial and central HPWH products at this time. Most products available are not manufactured in U.S. It also limits the pool of qualified engineers (system selection, configuration, storage sizing) and contractors (to install and maintain).

Product reliability

Performance consistency and degradation in the field is a challenge that must be overcome through better manufacturing and quality control. Persistence of the savings. Systems require more active maintenance and ongoing inspections than central gas systems.

Real world demonstrations

Limited experience in the application of central HPWHs. Very little field data available. Funding of ongoing demonstration sites and better understanding of equipment needs to optimize performance could transform marketplace which has demand for this technology. Applied research in better understanding best practices in central HPWH applications. Need for better design standards and best practices. More demonstrations needed to be able to develop these.

Test procedures and protocols

Better test procedures and protocols are also needed for this technology. Central HPWHs are not federally regulated and there is not an AHRI test procedure for this technology.

Tech Name	**Central Heat Pump Water Heater**	***Tech ID***	**T129**
Category	Water heating and water reuse related energy use		

➔ ***Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references***

Research & Development Roadmap for Emerging Water Heating Technologies, DOE Building Technologies Office, September 2014. https://www.energy.gov/sites/prod/files/2014/09/f18/WH_Roadmap_Report_Final_2014-09-22.pdf

Hot Water Temperature Maintenance Pilot Study, ACEEE 2017 Hot Water Forum, https://aceee.org/sites/default/files/pdf/conferences/hwf/2017/Oram_Session4A_HWF17_2.28.17.pdf

Heat Pumps Are Not Boilers, ACEEE, 2018 Hot Water Forum, http://aceee.org/sites/default/files/pdf/conferences/hwf/2018/1c-oram.pdf

➔ ***Any Subject Matter Expert Names, Affiliation, Comments and Quotes***

John Bush – Senior Project Engineer, Electric Power Research Institute:

Central HPWHs require *"an optimization between three factors: the capacity of the heat pump itself, the volume of storage you provide, and the degree to which you are willing to provide backup. You can find the balance point but it is an engineering challenge. Biggest limitation is not efficiency but first cost."* In applications where a design solution is repeatable (restaurants, laundromats), could use research by manufacturers to develop standard off-the-shelf products to bring down costs.

Ben Larson - Director, Research & Technology, Ecotope:

> *"The current products on the market have performance limitations due to the refrigerants used. If the equipment itself was able to handle another half a COP, you would have a great story. Instead of being in the low twos (COP), you would be in the high twos. Especially true if trying to compete against gas systems on a CO2 basis."*

Tech Name	**Grid Integrated Heat Pump Water Heating**	**Tech ID**	**T132**
Category	Water heating and water reuse related energy use		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

HPWHs have the potential for providing demand response (DR) to the electric grid, using the thermal storage capabilities of the HPWH to heat and store water during periods of excess electricity on the grid and reduce the need for water heating electricity use during peak demand periods. Smart controls and communication capabilities with utility or grid signals for preheating during off peak periods to shift energy use away from peak energy demand.

Applicability

Greatest Opportunity	Equal for both new construction and existing building retrofit		
Residential Type	All	**Commercial Building Type**	High-rise multifamily, lodging, and other commercial buildings with water heating loads
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	10-25%	**At Maturity**	10-25%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Proof of Concept	**In 5-7 yrs.**	Early market adoption

Performance

Current Performance, Features, Functionality	Peak load reduction, minimize grid impacts due to water heating demands	**Performance Target for 2025**	Provide ability to shift electrical demands from water heating to off-peak periods. No energy savings but peak reduction potential is 4.5 kW per residential HPWH. Predictive controls can use algorithms that hot water usage patterns to avoid the need for electric resistance use, resulting in up to 20% water heating savings. Off-the-shelf water heating products that can communicate with utility signals to preheat stored water during off-peak periods and provide hot water during peak periods without use of electric resistance operation.

Cost decrease required to be competitive relative to currently available technology?

First Cost	50% or greater	**O&M cost**	50% or greater
Cost Target for 2025	Cost to add includes communications control and mixing valve. Incremental cost over base water heater should be less than $50 to be cost competitive.		

Other info on the technology

Other Barriers	Product availability/demand, Market size, Policy, Builder/trades acceptance/familiarity, Supporting utility rate structures, Occupant acceptance/familiarity
Research Focus Areas Identified by Survey Participants	Product design evolution (new/improved features, performance enhancements, etc.), Demonstration projects, Market awareness campaign, training and capacity building in the trades, Standards development
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.). Potential for 0.3-0.6 kWh of energy storage possible per evening from residential storage water heater.
Team Reviewer Notes	Language above revised to better reflect grid integrated HPWH. Much of the original language was focused more on HPWHs in general, not grid-integrated.

TECH NAME	**Grid integrated heat pump water heating**	**TECH ID**	**T132**
CATEGORY	Water heating and water reuse related energy use		

→ **RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH**

Lack of grid integrated controls available for water heating products. There has been some utility research and there is ongoing research into the potential for residential products.

→ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE***

Electric storage tank water heaters have the potential for providing demand response (DR) to the electric grid, using the thermal storage capabilities of the storage tank to heat and store water during periods of excess electricity on the grid for later use. There are currently no off-the-shelf grid-integrated HPWH products on the market. There have been some research studies into the DR and storage potential of HPWHs in the Pacific Northwest, PG&E and other utilities.

Performance testing and validation: Performance testing and field tests of various DR strategies is still needed to understand the DR potential of this technology. Tradeoff between thermal storage and energy efficiency. Heating water to higher temperatures prior to peak periods decreases compressor efficiency and increases thermal storage losses. Need to better understand the potential benefits with grid communicating water heaters and negative impacts with preheating hot water to above setpoint during off peak periods.

Product Enhancement / Systems integration: There is a need for utilities to partner with manufacturers to provide products that can communicate with utility signals. Manufacturers are interested in technology but need to see that there is a market to justify investing in further development. When heating water above setpoint, a mixing valve is necessary to prevent scalding at the fixtures. There is a need for integrated mixing valves in water heaters to keep costs down. Grid-connected HPWHs can also incorporate fault detection capabilities which can provide improved operation and performance of HPWHs.

Cost improvement: Because there are no available products on the market, the incremental costs are unknown, but the additional cost for control of water heating setpoints and adding tempering valves to water heating systems would potentially be relatively small. Cost reductions can occur with the following: Increased product availability and demand, standardized protocols, integrated controls and mixing valves.

Limited Availability: There are no grid-connected HPWHs products on the market at this time. Manufacturers could offer them but there needs to be a market justification for the technology, through utility load flexibility programs, applicable TOU rates or other customer compensation mechanisms, code support and incentive programs to get technology in marketplace.

Real world demonstrations: Need for field demonstrations to understand real world benefits, value of storage and applications. Modeling and laboratory studies have been done to assess the potential, but there is a need for actual field tests to determine if potential can be achieved when applied in the field.

Test procedures and protocols: Need for common communications protocol or flexibility to communicate across multiple platforms in order communicate and respond to utility DR signals. ANSI/CTA-2045 standard defines port interface for appliances that allows them to receive and respond to utility DR signals.

→ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Assessment of Demand Response Potential of Heat Pump Water Heaters, Bonneville Power Administration, Eklund, K., Sept. 2015. https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Documents/Assessment%20of%20Demand%20Response%20Potential.pdf

Heat Pump Water Heaters for Demand Response and Energy Storage, Northwest Energy Efficiency Alliance, Prepared by: ECOFYS, September 2014. https://neea.org/docs/default-source/reports/final-hpwh-dr-report-and-summary.pdf?sfvrsn=6

→ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Ram Narayanamurthy – Principal Technical Leader – EPRI: Standardization of communications is missing the point. As long as it is open source, this is not a big issue. It is much more important to figure out the applications issues first. Need for field demonstrations to understand the real value of storage.

Tech Name	**Air-to-Water Heat Pumps**	***Tech ID***	**T128**
Category	Water heating and water reuse related energy use		

→ Tech Description – Enter text here to briefly describe the technology in 1-2 sentences

Air to water heat pumps produce hot water for domestic, service water heating, and space heating Can also be used to chilled water for space cooling, which is sometimes refered to as three-function heat pumps.

Applicability

Greatest Opportunity	Equal for both new construction and Existing Building Retrofit		
Residential Type	All	***Commercial Building Type***	Restaurant, small office, large office
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	25-50%	***At Maturity***	25-50%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Early market adoption	***In 5-7 yrs.***	Early market adoption

Performance

Current Performance, Features, Functionality	Efficient electric water heating technology compatible with ZNE strategies	***Improvements Needed to be Ready for Mainstream Adoption***	Better controls and reliability, more Split system options needed,

Cost decrease required to be competitive relative to currently available technology?

First Cost	10-25%	***O&M Cost***	10-25%
Cost Barriers	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Market size		

Other info on the technology

Other Barriers	Policy, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity
Research Focus Areas Identified by Survey Participants	Performance validation/product testing/simulation, Demonstration projects, Training materials development (curricula, manuals, videos, etc.), Standards development
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential
Team Reviewer Notes	

→ Rationale for scores, especially the X-Factor

Three function heat pumps can allow for a single device to provide hot and chilled water for multiple end uses (i.e. space conditioning and service or domestic water heating). Load shaping potential if combined with adequate storage and controls to communicate with grid signals during peak demand periods.

TECH NAME	**Air-to-Water Heat Pumps**	***TECH ID***	**T128**
CATEGORY	Water heating and water reuse related energy use		

➔ *RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE*

Air-to-water heat pumps (AWHPs) are more expensive than traditional forced air heating and cooling systems, and not common in the US. Most manufacturers of these systems make products primarily for markets in Europe and Asia. Very few HVAC professionals are familiar with air-to-water heat pumps and distribution of AWHPs is limited.

Performance improvements are still needed. Most of the available products have focused on optimizing heating performance and overall cooling efficiencies can still be improved.

PG&E is currently funding research on AWHPs as part of the Central Valley Research Homes study, but further performance testing and validation is needed for this technology.

AWHPs need better systems integration to be successful in ZNE buildings. This technology has the potential to provide space heating and cooling, and water heating with a single piece of equipment but current products are difficult to integrate into buildings without requiring very experienced contractors and lots of commissioning. Systems need to be easier to install and integrate into buildings. Three-function AWHPs tend to have complex controls, and most contractors do not have the experience needed to install and start up these systems.

Because of small number of available products and manufacturers, these systems tend to be much more expensive than traditional equipment. Three-function capabilities provide an opportunity to have one piece of equipment instead of two. Cost reductions can occur in the following areas:

- Equipment costs: If more manufacturers provided products for North American market, there would be more competition.
- Supply chain efficiency: Increased demand for technology could lead to improved supply chain efficiency. There is currently very limited distribution for these products.
- Installation costs: need for increased trades training to be more familiar with installation and startup requirements. Many HVAC contractors do not work with hydronic equipment and plumbers not familiar with refrigerant-based systems or ductwork. Trades in general not trained in systems that may have complex control systems.
- Commissioning & startup costs: Trades need more familiarity with products in order to properly commission these systems for use. Manufacturers need to provide better support, along with commissioning and O&M instructions that are easy for installers to follow.

Better test procedures and protocols are also needed for this technology. There is an AHRI test procedure for AWHPs (AHRI 550-590), but further work would be useful for providing energy factor (EF), used for evaluating and modeling water heating.

➔ *KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES*

Haile, J., Springer, D., & Hoeschele, M. (2016). *Field Assessment of Residential Radiant Ceiling Panel Space Conditioning Systems.* Retrieved from ETCC-CA website: http://etcc-ca.com/reports/field-assessment-residential-radiant-ceiling-panel-space-conditioning-systems

➔ *ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES*

TECH NAME	**CO2 Heat Pump Water Heaters**	**TECH ID**	**T130**
CATEGORY	Water heating and water reuse related energy use		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Heat pump water heaters using CO2 as the refrigerant. CO2 has low global warming potential when compared to other refrigerants, has zero ozone depletion potential, is very inexpensive, and is not flammable.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	**AT MATURITY**	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Potential for improved performance over traditional HPWHs and low GWP refrigerant. Split system design allows for installation flexibility	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Cost reduction, more approved products, 2- and 3-function products

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	**O&M COST**	50% or greater
COST BARRIERS	Product issues (e.g., manufacturing/raw material costs), Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Early market phase (not yet mature)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Policy, Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Standards development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, High energy savings potential
TEAM REVIEWER NOTES	CO2 HPWH do have application to some commercial buildings (HRMF Hotels Hospitals so I would categorize Column AX as Med. I would classify current market status (Column CA) as Demonstration. There are a few installed in CA but on research homes. Significant cost reductions could be seen when there are more manufacturers on the market. This has potential for improved performance over traditional HPWHs

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

CO2 technology can provide higher supply water temperatures, operate in colder outdoor ambient conditions than traditional HPWH products at good efficiencies. Current products are split system designs, which can allow for more design and installation flexibility than the traditional packaged units. Also lower GHG refrigerant. Requires low entering water temperatures to maintain capacity so use wtih hot water recirculation or space heating applications have to be carefully designed.

TECH NAME	CO2 Heat Pump Water Heaters	TECH ID	T130
CATEGORY	Water heating and water reuse related energy use		

➔ **RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE**

CO_2 heat pump water heaters are more expensive than traditional HPWHs, and not common in the US. There currently is only one manufacturer distributing this product in California. CO_2 heat pumps are much more common in Europe and Asia. Very few plumbing contractors are familiar with the technology and installation of the equipment is complicated.

Performance testing and validation of CO_2 heat pump water heaters have validated performance of the technology. Research on CO_2 HPWHs has focused on laboratory and field tests in the Pacific Northwest (Washington State University, NEEA, Ecotope & Further research is needed in systems integration to make it a viable product for heating water.

Further product design development is also needed for use in a wider variety of applications. The current product is well suited for residential water heating applications, but this technology can also be used for commercial, industrial and multifamily water heating, as well as space heating applications. Future applications to provide chilled water would also be valuable.

Because of small number of available products and manufacturers, these systems tend to be much more expensive than traditional equipment. Cost reductions can occur in the following areas:

- Equipment costs: If more manufacturers provided products for North American market, there would be more competition.
- Supply chain efficiency: Increased demand for technology could lead to improved supply chain efficiency. There is currently very limited distribution for these products.
- Installation costs: Need for increased trades training to be more familiar with installation and startup requirements. Plumbing contractors are not familiar with this technology. Trades in general not trained in systems that may have complex control systems.
- Commissioning & startup costs: Trades need more familiarity with products in order to properly commission these systems for use. Manufacturers need to provide better support, along with commissioning and O&M instructions that are easy for installers to follow.

➔ **KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES**

Laboratory Assessment of Sanden GES-15QTA Heat Pump Water Heater. Northwest Energy Efficiency Alliance, Prepared by: Ecotope, Inc., Ben Larson and Michael Logsdon http://neea.org/docs/default-source/reports/laboratory-assessment-of-sanden-ges-15qta-heat-pump-water-heater.pdf?sfvrsn=8

Laboratory Assessment of Sanden GAU Heat Pump Water Heater. Washington State University, Prepared by: Ecotope, Inc., Ben Larson.
http://www.energy.wsu.edu/documents/Sanden_CO2_split_HWPH_lab_report_Final_Sept%202013.pdf

CO2 Heat Pump Water Heater Project DOE, 12/01/2014. U.S. Department of Energy, Oak Ridge National Laboratory. https://energy.gov/eere/buildings/downloads/residential-co2-heat-pump-water-heater

CO2 Combination Space Conditioning and Water Heating Stress Tests in the PNNL Lab Homes. Pacific Northwest National Laboratory, Metzger CE, et al, Sept, 2017. https://labhomes.pnnl.gov/documents/PNNL-26462_Technical_Report.pdf

Advanced Heat Pump Water Heater Research: Final Report, Washington State University, Eklund, K, B. Larson, December 2015. http://www.energy.wsu.edu/Documents/Final%20Report%20TIP%20292_Dec%202015.pdf

➔ **ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES**

APPENDIX K:
Whole House Building Solutions

TECH NAME	**3D Printed Buildings**	**TECH ID**	**T168**
CATEGORY	Whole-Building Design		
→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES			
3D printed buildings using different compositions of materials as well as different strategies, including on-site 3D printing or off-site 3D printing with assembly on-site. Initial 3D printed buildings have been single family residential.			
APPLICABILITY			
GREATEST OPPORTUNITY	New Construction		
RESIDENTIAL TYPE	Single Family	**COMMERCIAL BUILDING TYPE**	None
APPLICABLE IN CLIMATE TYPES	All		
ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?			
TODAY	10-25%	**AT MATURITY**	10-25%
TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.			
TODAY	Proof of concept	**IN 5-7 YRS.**	Demonstration/pilot phase
PERFORMANCE			
CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	High performance walls (comparable r-values to typical construction) with shortened build times (1-2 days) and reduced labor cost. Limited by size of building. Lack of integration of plumbing and electrical chassis.	**PERFORMANCE TARGET FOR 2025**	Expansion to new building types with larger, more building inclusive 3D printers. Integration of plumbing and electrical chassis into product.
COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?			
FIRST COST	25-50%	**O&M COST**	10% or less
COST TARGET FOR 2025	3D printing is best for building a limited number of products. Early demonstrations claim costs as low as $17 per square foot for complete wall installation. Due to reduced construction time and waste, the cost is competitive with regular stick framing. However, this is for small scale residential (<1000 square feet). As building sizes increase and floors are added, per square foot material and labor costs may rise due to the increased need of materials per square foot and increased human interaction with the 3D printers (labor).		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, policy, product availability, architect acceptance/familiarity, builder/trades acceptance/familiarity, developer/building owner acceptance/familiarity, occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Product certifications/labeling, Improved production equipment or tools, Standards development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, High energy savings potential, Very cost-competitive when mature, Adds value, e.g., improved occupant comfort, control or amenities
TEAM REVIEWER NOTES	

TECH NAME	**3D Printed Buildings**	***TECH ID***	**T168**
CATEGORY	Whole-Building Design		

→ **RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH**

X-factor of 1 due to the high potential for GHG reduction and reduced waste (through the entire construction process, not just post-construction) and the potential for quicker construction timelines. Could be very applicable in disaster recovery and housing homeless populations. Look at AMIE from ORNL for initial research on 3D printed buildings.

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE***

The potential for scaled penetration of 3D printing building into the construction market is still unknown, especially with current 3D buildings being mostly used for testing and demonstration purposes. In addition, the 3D building technology itself is not at a stage where these machines can be mass manufactured and deployed for construction of new housing developments.

1) **Material Composition:** One key research gap is the identification of the most effective 3D printing material to optimize envelope performance (R-value, sealing, high thermal mass) while maintaining structural integrity and minimizing total material use and waste (i.e. is there a material that provides the same performance values but uses only 80% as much material as the other).
2) **Insulation Integration:** Since 3D printing only prints the façade, research is needed in how to go about efficiently integrating insulation (whether during the print process or after). Are there materials that are structural and can simultaneously provide high r-values
3) **Optimal Design:** 3D printing is not as effective when building using typical existing building designs meant for more standard framing techniques. For example, typical stress points (corners, etc.) require added material when 3D printing. Need research to identify the best design elements (i.e. natural curves) to reduce material use and maximize interior space.
4) **Application Expansion:** The capability of 3D printing allows for thinking outside of the box in terms of building design and functionality. What functionality can be explored that typical construction practices cannot provide?
5) **Demonstration Projects:** Needed in order to better understand actual performance of air sealing and thermal efficiency. How does the material composite perform after many years? There is currently little data on future performance.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Izabela Hager, Anna Golonka, Roman Putanowicz. *3D printing of buildings and building components as the future of sustainable construction?* Cracow University of Technology, 2016. Found on ScienceDirect.
https://www.researchgate.net/publication/305822454_3D_Printing_of_Buildings_and_Building_Components_as_the_Future_of_Sustainable_Construction

Mehmet Sakin, Yusuf Caner Kiroglu. *3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM*. Hasan Kalyoncu University, Turkey, 2017. Found on ScienceDirect. https://ac.els-cdn.com/S1876610217346969/1-s2.0-S1876610217346969-main.pdf?_tid=a96e0645-c0fa-40ac-a5ac-b03265e3eba9&acdnat=1524775446_2dceb0fadf624e6f3ed33c49e42f2dba

Steadman, Ian. Woollaston, Victoria. "The race to build the first 3D-printed building." *WIRED*. March 6, 2017.
http://www.wired.co.uk/article/architecture-and-3d-printing

https://3dprint.com/201970/future-for-3dp-construction/

https://www.iconbuild.com/

➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Roderick Jackson – Buildings Energy Research at NREL, Gaps #: 1,2,3,4

"A big challenge with 3D-printing homes, Tang admits, is the question of how "a regular person" feels about living in such a strange environment, in terms of texture as well as aesthetics. "A lot of it is limited by the technology. We would love to print something from steel, or fabric, but that's limited." - Wired

"…with 3D printing it's all about whether it makes sense to replace an existing form of construction with a completely new one, or whether it'd be better to mix and match." – Wired

TECH NAME	**Advanced pre-fabricated buildings assembled on site**	**TECH ID**	**T169**
CATEGORY	Whole-Building Design		
→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES			
Assembly of sustainable, pre-fabricated components (wall panels, steel beams, etc.) on-site to create energy efficient, zero net ready homes or buildings. The off-site fabrication of components allows for quicker build times, reduced site waste and the ability to scale. This includes modular buildings which can range from single family residential to larger multi-story office buildings. These advanced buildings are designed for HERS 0 assembly using advanced sealing techniques and reduction of thermal bridging.			
APPLICABILITY			
GREATEST OPPORTUNITY	New Construction		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	Small office, Large office, Lodging, K-12 school
APPLICABLE IN CLIMATE TYPES	All		
ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?			
TODAY	25-50%	**AT MATURITY**	25-50%
TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.			
TODAY	Early Market Adoption	**IN 5-7 YRS.**	Market Maturity
PERFORMANCE			
CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Speed of construction and reduction of waste and labor needs. High efficiency, designed for near HERS 0. R-26 to R-29 Walls ~R-49 Roofs 1-2 ACH50	**PERFORMANCE TARGET FOR 2025**	“Zero Energy Ready” construction. Build to a point in which only renewable energy resources are needed to reach a zero net energy target. Much of this field is close to this target due to the highly efficient envelope and air sealing provided by the manufacturers. Key target is continued reduction of site construction waste and reduced build times.
COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?			
FIRST COST	10-25%	**O&M COST**	10% or less
COST TARGET FOR 2025	Reach level of cost associated with typical T24 shell/envelope construction. Depending on the technology, some are already cost competitive when comparing to California’s T24 requirements, but for others, reductions of over 50% are still needed to be cost competitive.		
OTHER INFO ON THE TECHNOLOGY			
OTHER BARRIERS	Product availability, architect acceptance/familiarity, builder/trades acceptance/familiarity, developer/building owner acceptance/familiarity, occupant acceptance/familiarity		
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Product certifications/labeling		
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Adds value, e.g., improved occupant comfort, control or amenities		
TEAM REVIEWER NOTES			

TECH NAME	**Advanced pre-fabricated buildings assembled on site**	*TECH ID*	**T169**
CATEGORY	Whole-Building Design		

→ **RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH**

Large potential for GHG reduction due to improved construction techniques and timelines as well as reduced waste production. Market penetration for modular building types has been increasing, but there are many other new building technologies that focus on building a zero net energy ready shell that need further research and understanding of implementation. A number of these types of buildings are being evaluated in EPRI projects, but the quantities of scaled research have not been met.

→ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE***

1) **Product Improvement:** Continued product testing and development to reduce amount of materials required for the product and during construction. Can the same structural integrity and energy efficiency exist while also reducing the amount of materials consumed?

2) **Scaled Demonstrations:** Need for scaled demonstrations in order to prove viability of construction methods. Single projects do not make sense when dealing with a new building technology that the trades and builders will likely be unwilling to accept.

3) **Development of ancillary products:** Research into other products that can be integrated with the technology and within the construction timeline to add value to the nascent highly energy efficient design. For instance, creating a technology to replace stucco on one of the manufactured walls in order to reduce build times and improve product performance.

4) **Education of Trades:** It is necessary to educate the trades on new technologies and processes in order for them to accept these new technologies. There must be great enough incentive for them to change their ways.

→ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

www.mdpi.com/2071-1050/8/6/558/pdf
https://web.ornl.gov/sci/buildings/conf-archive/2004%20B9%20papers/174_Gorgolewski.pdf

Examples:
- https://bonestructure.ca/en/
- https://hercutechinc.com/

→ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

C.R. Herro – Meritage Homes

Chris DeBone – HercuTech

Guillaume Bazouin – BONE Structure

APPENDIX L:
Distributed Generation

Tech Name	**Community Scale Solar (Virtual net metering)**	***Tech ID***	**T161**
Category	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

Community scale solar (CSS) refers to projects under 10 MW that are interconnected to the grid (as defined by RMI). Projects are typically situated near the communities, helping to drive down transmission losses. The critical item with CSS is understanding how to implement and finance virtual net metering for the community, in which each household receives a portion of the benefit while typically providing a portion of the financing.

Applicability

Greatest Opportunity	Equal for both new construction and Existing Building Retrofit		
Residential Type	All	***Commercial Building Type***	All
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	50% or more	***At Maturity***	50% or more

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Demonstration/pilot phase	***In 5-7 yrs.***	Early Market Adoption

Performance

Current Performance, Features, Functionality	The technology for community scale solar (PV and integration hardware) is cost competitive and reliable.	***Performance Target for 2025***	Efficiency performance will match that of PV panel improvements, but otherwise it is difficult to quantify a direct performance target. The main target is to have a standard framework for virtual net metering that will help to incentivize further CSS.

Cost decrease required to be competitive relative to currently available technology?

First Cost	10% or less	***O&M Cost***	10% or less
Cost Target for 2025	Current levelized costs: $50/MWh Current costs for CSS are competitive with central generation and distribution. A monetary target will be to have appropriate compensation through virtual net metering.		

Tech Name	**Community Scale Solar (Virtual net metering)**	***Tech ID***	**T161**
Category	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		
Other info on the technology			
Other Barriers	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Early market phase (not yet mature), Policy, Occupant acceptance/familiarity. The cost challenge is relative to the financing structure required for community solar. how do you get dozens if not hundreds of entities to contribute, agree, and finance community solar? then, who is in charge of it? does it become a municipality utility?		
Research Focus Areas Identified by Survey Participants	Demonstration projects, Government grant program to assist with setting up legal structure / financing for community solar projects?		
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Very cost-competitive when mature, Public/occupants will like it		
Team Reviewer Notes			

→ Rationale the X-factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

Community scale solar (virtual net metering) is given an x-factor of one as this is the last piece that needs to be figured in order to incentivize all of the stakeholders. The physical technology is available and tested.

➔ Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE

Unified virtual net metering framework: There is currently no unified regulatory framework to support virtual net metering for community scale solar. Proper valuation of CSS (and other DERs), is critical to market adoption and effective operation.

Packaging of CSS with other distributed energy resources: There is ongoing research to identify packages that pair CSS with other DERs (storage, energy efficiency, etc.) to provide increased value to the customer and the grid. As system complexity increases, the compensation framework will be forced to evolve.

Real world demonstrations: Once the virtual net metering framework has been established, demonstration projects will be needed to evaluate performance and acceptance of the framework. Real world demonstrations will also be key in evaluating and optimizing the packaging of CSS with other DERs.

Innovative financial models: There is a need for innovative financial models to finance CSS, especially in disadvantaged communities.

➔ Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references

https://cleantechnica.com/2018/02/27/community-scale-solar-fastest growing-us-solar-segment-barriers-fall/

http://www.renewableenergyworld.com/articles/2016/03/5-reasons-community-scale-solar-is-a-multi-gw-market-opportunity.html

https://www.rmi.org/wp-content/uploads/2018/04/Progress-and-Potential-for-Community-Scale-Solar.pdf

https://rmi.org/wp-content/uploads/2017/06/RMI_Financing_Community_Scale_Solar_Insight_Brief_2017.pdf

➔ Any Subject Matter Expert Names, Affiliation, Comments and Quotes

Thomas Koch Blank, a principal at RMI:

"In demonstrating the ability to already today deliver clean energy at or below 5 cents per kilowatt-hour on the distribution grid, CSS can be the 'killer app' for cooperatives, supplying a cost-competitive, locally sourced, clean energy resource that also provides resilience benefits to their members"

Ram Narayanamurthy, EPRI
Sudeshna Pabi, EPRI

TECH NAME	**Higher efficiency PV integrated electrochromic windows**	**TECH ID**	**T162**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		
→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES			
While electrochromic (EC) technology has been developed for some time, the integration with photovoltaic (PV) and electrochromic (EC) devices provides better efficiency in energy saving without additional power sources. Researchers that integrate photovoltaic technology have provided diverse application of electrochromic devices, for instance, building integrated photovoltaic (BIPV) solar cells may be incorporated with the electrochromic technology to automatically adjust the colors of electrochromic windows to reduce indoor heat. (source: NREL)			
APPLICABILITY			
GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	High-rise multifamily residential	**COMMERCIAL BUILDING TYPE**	Large office, Retail, Healthcare/medical, Lodging
APPLICABLE IN CLIMATE TYPES	All		
ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?			
TODAY	10% or less	**AT MATURITY**	25-50%
TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.			
TODAY	Theoretical	**IN 5-7 YRS.**	Proof of concept
PERFORMANCE			
CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	- Delta SHGC ~ 0.46/0.47 - Visible transmittance sufficient for daylighting - Most integration of PV with electrochromic is a small number of cells to provide the necessary voltage for the electrochromic effect	**PERFORMANCE TARGET FOR 2025**	- Integration of electrochromic windows with storage, generation and control. - actively controlled windows with a visible transmittance (Vt) of >0.6 for bleached state in residential and >0.4 in the commercial sector. - PV generation needs to hit 10% efficiency (lab), 8% for full window - 50% potential reduction from lighting consumption - 10 yr lifetime
COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?			
FIRST COST	50% or greater	**O&M COST**	10-25%
COST TARGET FOR 2025	For electrochromic technology (not PV integrated): current costs are $8/square foot with $2/square foot install premium; payback period of 7-21 years. Installed cost premium <$5/square foot. For PV integrated electochromic technology, costs need to reach targets for the standalone electrochromic tech (above) while also matching the installed cost of a separate PV system ($2.5-$4/watt)		

TECH NAME	**Higher efficiency PV integrated electrochromic windows**	***TECH ID***	**T162**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

A new technology, so scoring is low. X-factor of 1 indicates that, once the technology is ready, integration into new buildings and retrofit applications can have a large impact on energy use/generation, especially if customer/developer acceptance improves for BIPV.

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE

Gaps for solely electrochromic technology [2]:

- Improved materials performance and cost reductions
- Reduction of manufacturing time and process; specifically, the glazing coating process
- High throughput manufacturing to enable scaled deployment of electrochromic technology
- High cost must be mitigated by reducing material constraints an integration of electrochromic windows into existing value streams.
- Market/consumer acceptance. Need testing and demonstrative evidence to prove value.
- Lack of standards for testing and certification of electrochromic technology.

Gaps for the integrated system [2]:

- Improved materials performance for higher efficiency BIPV generation.
- "High-performance electrolytes (conductivity) and robust active PV components (TCO and active layer transparency) are needed."
- Cost reduction for building integration and product manufacturing.
- Improved lifetime and durability

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

1) https://www.nrel.gov/news/features/2010/1555.html
2) https://www.energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf
3) Program on Technology Innovation: Advancing High Performance Envelopes – Impact of Electrochromic Windows, Modeling and Lab Evaluation. EPRI, Palo Alto, CA: 2018. 3002013917.

→ ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES

Tech Name	**PV + Storage**	***Tech ID***	**T163**
Category	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

Integration of PV + Storage onto the grid at a community or premise level to provide customer benefit through energy and cost savings (with quick ROI) and grid benefit through load shifting, demand response, voltage regulation etc.

Applicability

Greatest Opportunity	Equal for both new construction and Existing Building Retrofit		
Residential Type	All	***Commercial Building Type***	All
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	50% or more	***At Maturity***	50% or more

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Early market adoption	***In 5-7 yrs.***	Market maturity

Performance

Current Performance, Features, Functionality	As PV penetration continues to increase, incentives and costs will taper off, providing less incentives for PV systems. As battery costs drop and the value streams improve, solar + storage begins to make sense. Current payback for PV is 4.8-10.5 years. With storage, that drops to 4.7-8.6.	***Performance Target for 2025***	Further integration and control of PV + storage to tap into varying value streams. PV efficiencies: - Single-crystalline: 25% - Multi-crystalline: 21% - Thin film Si: 15% - CIGS: 18% - CdTe: 15% Si consumption of less than 2g/W (data from IEA)

Cost decrease required to be competitive relative to currently available technology?

First Cost	25-50%	***O&M Cost***	10% or less
Cost Target for 2025	Battery storage needs to hit \$125-\$165/kWh with solar deployed at \$1/W. At these costs, the total levelized system cost would be ~\$0.11/kWh (GTM) to ~\$0.14/kWh (EPRI).		

TECH NAME	**PV + Storage**	***TECH ID***	**T163**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, Policy, Product availability, Developer/building owner acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Step one, CEC gives fair complaince credit. Step 2, architects, builders, owners, energy consultants compare PV + storage option to others. Step 3, the free market choses the best option. Step 4, HERS inspectors confirm system installed as required to produce and store the same or greater energy than other complaicne options would have saved. Product design evolution (new/improved features, performance enhancements, etc.), Demonstration projects, Systems integration with other products, Market awareness campaign
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities, PV + storage will allow modern architeture to flurish in California.
TEAM REVIEWER NOTES	

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Driving costs down and improving integration of storage with the grid is integral to the success of site-level PV + storage. While codes are moving towards including batteries as part of a ZNE solution, they actually have a negative impact as the energy losses detract from achieving ZNE. However, the implementation of various rate structures and incentives have shown the promise of pv + storage to simultaneously provide grid and customer benefits.

Current funding: CEC GFO-16-309: Solar +: Taking the Next Steps to Enable Solar as a Distribution Asset

TECH NAME	**PV + Storage**	***TECH ID***	**T163**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE***

1) **System management and integration:** As utility rate structures adapt to incentivize PV + storage systems, there is a need for easily integrated, localized storage management for optimal performance and cost savings.

2) **System availability for small commercial sizes:** Battery system sizes have tended to be designed for residential or larger commercial applications, with little focus on small commercial with battery sizes of 10-100kW. There are few storage systems that supply 3 phase power at ~10kW range, which meet both the needs for small commercial applications (3 phase power with 10-100kW storage).

3) **Standardized communication and controls:** There is a research need for development of one, standard communication protocol that can communicate with and control all different distributed energy storage types and manufacturers.

4) **Interconnection issues for battery storage:** Process and rule constraints for interconnection of batteries are complex and expensive. There is a need for a streamlined process.

5) **Further project demonstrations:** As solar + storage proves its capabilities, further demonstrations at both a community level and a premise level are needed to quantify the actual value (both monetary and synergistic) of the controllability and grid applications that battery storage paired with PV can have. Which value streams and control strategies make the most sense in practice (highest ROI) and are most utilized?

- Within demonstration projects, varying rate structures and market signals (TOU, DR, ancillary services etc.) need to be tested and their impact quantified. At the right rates and with the right value streams, PV + storage makes financial sense. Once addressed and implemented, adoption of PV + storage should increase.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

https://www.greentechmedia.com/articles/read/were-still-underestimating-cost-improvements-for-batteries#gs.5ngM3yI

https://www.cleanegroup.org/wp-content/uploads/Closing-the-California-Clean-Energy-Divide.pdf

http://www.communitysolarvalueproject.com/uploads/2/7/0/3/27034867/2017_09_30_final_6_solar__storage_guide.pdf

https://www.iea.org/publications/freepublications/publication/pv_roadmap_foldout.pdf

Electric Power Research Institute (EPRI2017). *Pairing Community Solar with Battery Storage*. 3002010287. December. Palo Alto, California.

➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Seth Mullendore, Clean Energy Group – Gap #:

Nick Tumilowicz, EPRI

TECH NAME	**Fuel Cells**	**TECH ID**	**T153**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Fuel cells convert a range of fuels (including hydrogen, natural gas and biogas) into electricity with no combustion, resulting in lower GHG emissions and oil consumption, high efficiency conversion, and reliable electricity production.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	**AT MATURITY**	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	As of 2015: - Natural gas: 34-40% electrical efficiency with a durability of 12,000-70,000 hours - Hydrogen: 50% electrical efficiency with a durability of 8,000 hours	**PERFORMANCE TARGET FOR 2025**	2020 DOE goals: - Natural Gas: 5kW system with 45% electrical efficiency and a 60,000-hour durability. 90% with CHP - Hydrogen: 60% electrical efficiency with 10,000 hour durability

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	**O&M COST**	10-25%
COST TARGET FOR 2025	Current: - Natural gas: $2,300 - $2,8000/kW - Hydrogen: $6,100/kW 2020 DOE goal: - Natural gas: $1,500/kW - Hydrogen: $1,000/kW		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Systems integration with other products, Training materials development (curricula, manuals, videos, etc.), Improved production equipment or tools
IMPORTANCE TO ZNE	High energy savings potential, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature
TEAM REVIEWER NOTES	

Tech Name	**Fuel Cells**	***Tech ID***	**T153**
Category	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ Rationale the X-Factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

Current DOE research focuses on cost, performance and durability improvements. Cost improvements focus on increasing the utilization of platinum group metal (PGM) within the fuel cell as well as developing non-PGM catalysts. https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_myrdd_fuel_cells.pdf

Performance improvements include, "developing ion-exchange membrane electrolytes with enhanced efficiency and durability at reduced cost; improving membrane electrode assemblies (MEAs) through integration of state of the art MEA components; developing transport models and in-situ and ex-situ experiments to provide data for model validation; identifying degradation mechanisms and developing approaches to mitigate their effects; and maintaining core activities on components, sub-systems, and systems specifically tailored for stationary and portable power applications,"(Energy.gov, https://www.energy.gov/eere/fuelcells/fuel-cells)

The National Fuel Cell Research Center at UC Irvine currently conducts research on product and chemistry development, beta testing to analyze performance and reliability, and the market dynamics that shape the fuel cell industry. http://www.nfcrc.uci.edu/3/ABOUTUS/overview/default.aspx

➔ Research Gap Articulation – The critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE

Performance improvements: Need for continued research in product development through research in improved battery chemistry and increased durability to reach goals of 45-60% electrical efficiency at 60,000 hours.

Integration with other distributed energy resources: Research into the pairing of fuel cells with different distributed energy resources (namely storage or CHP) to provide increased value through improved efficiency, reliability and increased component lifetime. With this research comes a need for controls to be developed to optimize the value and performance of the integrated system in order to make the economics begin to make sense. In what applications, and with what controls, does a combined system (with battery storage or CHP) make the most sense? How will this help drive system costs down to the ~$1,500/kW target? Will it actually drive down costs? Controls development and field implementations of the controls is necessary to understand how to prioritize the energy resources.

Cost Improvement: As performance improves and integration with other resources allows for different value streams, system costs will drop. However, current costs, especially for hydrogen fuel cells, will remain a barrier to adoption, necessitating research into improved efficiencies and lifetimes of fuel cells.

➔ Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references

https://www.energy.gov/sites/prod/files/2016/04/f30/fcto_gas_cleanup_pl03-phillips.pdf

https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_myrdd_fuel_cells.pdf

http://www.nfcrc.uci.edu/3/ABOUTUS/overview/default.aspx

https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_myrdd_fuel_cells.pdf

➔ Any Subject Matter Expert Names, Affiliation, Comments and Quotes

TECH NAME	**Micro CHP**	**TECH ID**	**T154**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Micro combined heat and power (CHP) uses natural gas as an energy source for typically a fuel cell or an internal combustion engine to create electricity and simultaneously capture the heat produced for water or space heating to reach energy efficiencies above 90%. Micro CHP is deployed at the end users' location which saves on electricity transmission losses and heat transfer from large scale CHP. Combined CHP can provide peak electric load reduction and balancing.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	Low-rise multifamily residential, High-rise multifamily residential	**COMMERCIAL BUILDING TYPE**	Large office, Higher education, Gymnasiums, swimming facilities
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	50% or more	**AT MATURITY**	50% or more

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Market maturity	**IN 5-7 YRS.**	Market maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	~90% efficient Fuel-to-electricity efficiency of 25-30%	**PERFORMANCE TARGET FOR 2025**	Fuel-to-electricity efficiency at or above 40% with a system lifetime of 10 years and capacity factor of 99.9%.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	**O&M COST**	10-25%
COST TARGET FOR 2025	Current costs hover around \$6,000-\$7,000 per kW (electric). To be competitive, costs need to drop to under \$3,000 (pre-installation).		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Policy, Process load is best served by CHP, as compared to renewable sources, to approach the ZNE goal for operating buildings, not just envelop compliance
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Market awareness campaign
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Renewable cannot meet the process and plug loads easily. Adding storage is not cost-effective.
TEAM REVIEWER NOTES	

Tech Name	**Micro CHP**	***Tech ID***	**T154**
Category	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ Rationale the X-factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

Research just ended in the E.U. on deployment of over 1,000 micro-CHP units. It was determined that the technology is ready for market entrance, but costs needs to drop drastically for market adoption.

http://enefield.eu/wp-content/uploads/2017/10/ene.field-Summary-Report.pdf

➔ Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE

Operation at optimal efficiencies: During operation of micro-CHP, either heating or electricity production is prioritized. When heating is prioritized, excess electricity may be produced (i.e. during winter nights when heat is needed but electricity is not) and then wasted or fed back into the grid. When electricity is prioritized, excess heat may be produced and wasted. Both situations lower system efficiency. How to optimize performance by controlling micro-CHP systems in parallel with other systems (boiler, heater etc.)? Need for development and lab testing of an automated control algorithm to prioritize highest efficiency pathways across the systems.

Controllability and flexibility of micro-CHP: What other value can micro-CHP provide other than just higher efficiency? There is a need for research in using micro-CHP as a distributed energy resource and to look at "value stacking" of these systems including load shifting and feeding electricity/heat back to the grid.

Minimization of heat losses: In order to reach the 40% target fuel to electricity efficiency, continued improvement and product development needs to occur to minimize heat losses.

U.S. Demonstration Projects: Need for demonstrations and pilots within the U.S. to establish scalable grid impact and address the feasibility of distributed micro-CHP for different building types.

➔ Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references

http://www.enertwin.com/enertwin-en/micro-chp

http://enefield.eu/wp-content/uploads/2017/10/ene.field-Summary-Report.pdf

https://arpa-e.energy.gov/sites/default/files/documents/files/GENSETS_ProgramOverview.pdf

Nirvana Energy Systems – Thermoacoustics Micro Combined Heat and Power Generation Assessment. EPRI, Palo Alto, CA: 2016. 3002007482.

➔ Any Subject Matter Expert Names, Affiliation, Comments and Quotes

Tech Name	**Piezoelectric Flooring**	**Tech ID**	**T155**
Category	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		
→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences			
Power generation harvesting the energy of human footfall. Also known as kinetic tiles. There are a few existing companies with kinetic tile technology, but most applications are for educational demonstrations or for spectacle (i.e. lights lighting up on a dance floor, but no energy harvesting capability).			
Applicability			
Greatest Opportunity	New construction		
Residential Type	All	**Commercial Building Type**	All
Applicable in Climate Types	All		
Energy benefit compared to minimally code-compliant technologies or approaches?			
Today	10% or less	**At Maturity**	10-25%
Technology readiness on the spectrum of maturity in a natural market-driven progression.			
Today	Demonstration/pilot phase	**In 5-7 yrs.**	Demonstration/pilot phase
Performance			
Current Performance, Features, Functionality	Claims of ~7-8W per step. Lab testing shows less than 1W actually produced. Currently mostly used for pilot education projects to educate people on different forms of energy harvesting. Must be used with battery storage for any sort of energy harvesting application.	**Performance Target for 2025**	Reach a consistent ~10W per step target.
Cost decrease required to be competitive relative to currently available technology?			
First Cost	50% or greater	**O&M Cost**	10-25%
Cost Target for 2025	Currently hundreds of dollars per tile. The hope would be to get this to under $100 per tile. This does not include installation and addition of battery storage. Unfortunately, there is never enough energy produced for a reasonable payback period. Realistic cost target for market penetration would be to be comparable to distributed solar or wind resources (~$1-2 per watt). It is much easier/cheaper/more effective to install a couple of solar panels with a battery than to install kinetic tiles with a battery.		
Other info on the technology			
Other Barriers	Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Occupant acceptance/familiarity, Operational cost, generally, people seem to have no idea these exist, at least in the US.		
Research Focus Areas Identified by Survey Participants	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.)		
Importance to ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Public/occupants will like it		
Team Reviewer Notes			

TECH NAME	**Piezoelectric Flooring**	**TECH ID**	**T155**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Research only being done at a product manufacturer level. The technology does not yet have enough promise (simply does not produce enough power) and the economics do not exist to warrant large scale further research.

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE

Currently piezoelectric flooring is in the very early stages of deployment. Some companies have products that have been deployed, but actual generation remains very low (under 10W per step), requiring a near-impossible number of steps to provide economic benefit. Most deployments are educational/marketing tools to help show alternatives to other renewable energy sources.

Research gaps:

Improved performance: The technology needs significant improvement in power generation in order to be competitive. What is the ceiling of power generation? Need research to understand what are the limiting factors within kinetic tiles that limit generation.

Pilot demonstrations for data analysis: Research demonstrations could be very useful to better understand field performance and optimal locations for piezoelectric flooring. Also useful for understanding useful life of products as well as susceptibility to damage due to high traffic/higher stress generation than other renewable sources. Need to look at stand-alone piezoelectric systems to determine feasibility, since typically, permanent installations are paired with solar, skewing the performance of the tiles.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Doug Lindsey, Frank Sharp. *Assessment of Kinetic Energy Tiles*. Electric Power Research Institute, Program of Technology Innovation. 3002006170.

→ ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES

Frank Sharp - Senior Technical Leader, EPRI

Tech Name	**Thin film PV**	***Tech ID***	**T156**
Category	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

PV with active layers nearly 100 times thinner than typical c-Si panels, allowing for reduced material consumption, flexibility, building integration and transparency. Technologies include Cadmium telluride, Amorphous silicon, and copper indium gallium selenide.

Applicability

Greatest Opportunity	Equal for both new construction and Existing Building Retrofit		
Residential Type	All	***Commercial Building Type***	All
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	10% or less	***At Maturity***	10-25%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Early market adoption	***In 5-7 yrs.***	Market maturity

Performance

Current Performance, Features, Functionality	6-14% efficient (varies per thin film technology), light weight; less energy embodiment; rigid or flexible configurations	***Performance Target for 2025***	15-20% efficient PV module with a 30-year lifetime

Cost decrease required to be competitive relative to currently available technology?

First Cost	Less than 10%	***O&M cost***	Less than 10%
Cost Target for 2025	Residential goal for 2030: $0.05/kWh Commercial goal for 2030: $0.04/kWh These numbers are for PV in general, not specifically thin-film. Currently thin-film and c-Si are comparable in cost.		

TECH NAME	**Thin film PV**	***TECH ID***	**T156**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		
OTHER INFO ON THE TECHNOLOGY			
OTHER BARRIERS	Architect acceptance/familiarity, Developer/building owner acceptance/familiarity, easy to use on membrane roof or metal roof...not for tiles or comp roof		
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Demonstration projects, Market awareness campaign, Product support materials development, installation on existing membrane roofs...compatibility with roofing products		
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), Relative familiarity/ease of adoption by builders/trades, better than crystaline panels in many ways		
TEAM REVIEWER NOTES			

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Product manufacturers drive current research to be cost competitive with c-Si and to discover new thin film compositions. Outside research should look at implementation and field analysis to investigate reliability and field performance.
Current research in thin film perovskite solar cells at Solliance: https://solliance.eu/perovskite-research-program/

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE

Increase in Efficiency: Research in improved design and composition of thin film PV in order to increase efficiency and reduce cost and space requirements. Reduction of production costs for Copper Indium Gallium Selenide (CIGS) and Gallium Arsenide panels in order to provide higher efficiency panels (15-20%) at a comparable cost.

Project demonstrations: Various demonstrations to identify optimal building types to benefit from thin film while also testing panel durability and reliability. Would be useful to look at a cost and energy impact assessment of thin film building integrated PV.

Emerging thin film technologies: There is a need for proven product performance since many emerging PV absorbers lose power at a fast rate and are considered unreliable. Emerging thin-film technologies (i.e. perovskites) have seen high power at low cost, but reliability remains an issue. Field testing through project deployment and analysis is needed to quantify reliability.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

https://solliance.eu/perovskite-research-program/

https://www.energy.gov/sites/prod/files/2014/08/f18/2014_SunShot_Initiative_Portfolio8.13.14.pdf

https://www.epri.com/#/pages/product/000000003002009361/

https://www.nrel.gov/docs/fy17osti/68925.pdf

https://www.nrel.gov/docs/fy17osti/68105.pdf

→ ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES

TECH NAME	**Tri-generation and Quad-generation**	***TECH ID***	**T157**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Tri-generation combines heating, cooling and electricity generation in one system using a fuel (natural gas, biofuel etc.) as the energy source. Distributed tri-generation systems improve overall efficiency of electricity production and heat production and have the capability to be used flexibly as a grid resource. Quad-generation takes tri-generation a step further and recovers the released CO2 which can either be sequestered or used in an industrial or agricultural application.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	Low-rise multifamily residential, high-rise multifamily residential	***COMMERCIAL BUILDING TYPE***	Large office, higher education, lodging, healthcare/medical, restaurant, grocery stores
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	>50%	***AT MATURITY***	>50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	***IN 5-7 YRS.***	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	85-90% lab tested efficiency. Few real-world research demonstrations performed up to this point.	***PERFORMANCE TARGET FOR 2025***	>90% efficiency (field performance) 20 year lifetime ~100% zero net energy with quad-generation capture of carbon

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10-25%	***O&M COST***	10-25%
COST TARGET FOR 2025	Cost targets are very difficult to quantify since systems are customized due to the differing quantities of electricity, heating, and cooling needs as well as the various rate structures and cost of gas and electricity. Typical target for installation is an ROI of 2 years or less, which would lead to scaled adoption. Current paybacks vary from 3-10 years. https://www.hydrogen.energy.gov/pdfs/review12/an027_ruth_2012_o.pdf		

TECH NAME	**Tri-generation and Quad-generation**	***TECH ID***	**T157**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		
OTHER INFO ON THE TECHNOLOGY			
OTHER BARRIERS	Product availability, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity		
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Prototype development, Demonstration projects, Systems integration with other products		
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities, High energy savings potential		
TEAM REVIEWER NOTES			

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Tri/quad generation has been given an x-factor of one due to the high potential for GHG reduction, nearing efficiencies of 90%. Additionally, quad-generation can reach 100% zero net energy due to the carbon capture. Past research has been funded by the CEC as well as the DOE.

http://www.energy.ca.gov/2015publications/CEC-500-2015-026/CEC-500-2015-026.pdf

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE

Performance Improvement: Tri and quad generation are nascent technologies with promising trajectories of high energy efficiency and little to no carbon emissions. That being said, research needs to be conducted to better understand product performance outside of lab environments to evaluate the impact that the different loads (electric, heating, cooling) have on the efficiency of generation. In most scenarios, one type of load will always be prioritized (i.e. electricity demand must be met with little thought to whether heating or cooling loads are needed to be met), leading to possible excess production of at least one resource. The high efficiencies currently met are only achieved when all three (or four) load types are weighted properly.

Controls development: To mitigate excess heat/cooling/electricity production during system run times, automated controls to balance and store thermal resources should be explored. Pre-cooling/heating of space and pre-heating of water can be useful tools to improve system efficiency. Research is also needed in controls that utilize the flexibility of tri and quad gen systems to provide grid benefit through decreased consumption and load shift, improving the value proposition of such systems.

Economic understanding: The monetary value of tri and quad gen systems is difficult to quantify due to the range of sizes, applications, and customizability of the systems. Not to mention, different rate structures will incentivize different use cases.

Real world demonstrations: Through field testing, the implementation and economic feasibility of tri and quad generation can be explored to better understand optimal applications, system sizes and control strategies to provide highest value and quickest ROI.

TECH NAME	**Tri-generation and Quad-generation**	*TECH ID*	**T157**
CATEGORY	Distributed generation (e.g., solar PV, tri-/quad-gen, CHP, wind)		

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

http://www.energy.ca.gov/2015publications/CEC-500-2015-026/CEC-500-2015-026.pdf

https://aip.scitation.org/doi/pdf/10.1063/1.5014015

https://www.energy.gov/sites/prod/files/2014/09/f18/DOE_ZEH_M_Street_09-20-14.pdf

https://www.clarke-energy.com/gas-engines/quadgeneration/

https://www.hydrogen.energy.gov/pdfs/review12/an027_ruth_2012_o.pdf

➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

APPENDIX M:
Energy Storage

TECH NAME	**Solid State Batteries**	**TECH ID**	**T164**
CATEGORY	Energy storage (thermal and electric)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Battery technology with a solid electrolyte layer instead of a liquid electrolyte. The solid electrolyte layer allows for longer lifetimes, increased safety and higher energy density.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10% or less	**AT MATURITY**	10% or less

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Current solid-state batteries are “microbatteries” with capacities ~0.001-0.01 Ah	**PERFORMANCE TARGET FOR 2025**	**Performance Target:** 80-90% depth of discharge, 10,000 cycles - 200-250 Wh/kg - 300-400 W/kg

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	50% or greater	**O&M COST**	10% or less
COST TARGET FOR 2025	**Cost Target:** ~$0.20/kWh life cycle cost. Comparable to lithium ion and lead acid. More typical metric is to look at upfront cost: Will need to reduce to ~$100/kWh to compete. Projected 2030 cost of lithium ion is $73/kWh.		

TECH NAME	**Solid State Batteries**	***TECH ID***	**T164**
CATEGORY	Energy storage (thermal and electric)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Policy, product availability, reliability,
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Product certifications/labeling, Standards development
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Adds value, e.g., improved occupant comfort, control, or amenities, improves resiliency
TEAM REVIEWER NOTES	

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Ongoing research by manufacturers to have a market ready product within the next ~5 years. It was given an x-factor of one due to the many benefits of solid state batteries over lithium ion and the broad range of applicability once market ready. Third party research should focus on implementation and field testing to determine optimal applications and real-world performance.

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE

1) **Improvement of Lithium Ion mobility:** Continued research in improving the mobility of lithium ions through materials and across interfaces. Need research into ideal material and interface configurations.
2) **Pilot Projects:** Need for testing outside of lab environments to understand in field performance of solid state (includes EVs since EVs drive the market; the solid-state technology will then trickle down to residential/commercial storage applications)
3) **Cost reduction:** Cost is a big deal breaker for solid-state battery technology. Costs can be driven down through research into inexpensive chemicals to replace the semiconductor grade chemicals, as well as development of high throughput manufacturing processes once scale is achieved.
4) **End of life disposal:** As the technology evolves, the end of life disposal must always be kept in mind from a cost and sustainability perspective. Steps should be taken to understand what the recycling/decommissioning of the battery units will look like.

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

https://share-ng.sandia.gov/news/resources/news_releases/battery-interface/#.WubhdsgvyiO

https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf

http://www.ehcar.net/library/rapport/rapport206.pdf

→ ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES

Brittany Westlake, EPRI, Gaps #: 2, 4

TECH NAME	**Lithium-ion Batteries**	**TECH ID**	**T158**
CATEGORY	Energy storage (thermal and electric)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Lithium-ion batteries for residential and commercial storage applications. From a ZNE perspective, storage is not necessary, but it is essential to mitigating the negative impact that ZNE has on the grid (the duck curve) and can provide other ancillary services. Driving lithium-ion costs down and improving performance and life cycle will be crucial to increasing adoption.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10% or less	**AT MATURITY**	10% or less

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	**IN 5-7 YRS.**	Market maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	(Capacity = 10 kWh; Depth of discharge = 90-100%; round trip efficiency = 75-90%; Battery life = 60-80% capacity after 10 years, ~5-7,000 cycles)	**PERFORMANCE TARGET FOR 2025**	95% round trip efficiency, 20 yr battery life, 7000 cycles (consistent), equivalent to natural gas turbine in terms of safety and performance

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25-50%	**O&M COST**	10% or less
COST TARGET FOR 2025	Cell level: - DOE: Cost target of $125/kWh by 2022 - Bloomberg New Energy Finance: Target of $70/kWh by 2030, ~$96/kWh by 2025 System level: - By 2020: $500-600/kWh		

Tech Name	**Lithium-ion Batteries**	***Tech ID***	**T158**
Category	Energy storage (thermal and electric)		
Other info on the technology			
Other Barriers	Policy, Product availability, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, lack of incentive (utility rate structure)		
Research Focus Areas Identified by Survey Participants	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Product certifications/labeling, Standards development		
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Adds value, e.g., improved occupant comfort, control, or amenities, improves resiliency		
Team Reviewer Notes			

→ Rationale the X-factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

Continued incremental improvements by product manufacturers warrant less research by third parties. Research by outside entities remains limited to economic research, state of the technology and applications.

→ Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE

1) Combination of improved cathodes and electrolytes without sacrificing cycle life. Although the performance characteristics of cathodes, anodes, electrolytes and separators continue to improve, the low number of cycles, along with safety and capacity degradation remain as concerns.
2) Research is needed to understand the expected life cycle cost through the disposal and recycling of batteries. Research into the design of better systems to prepare for ease of disposal and recycling.
3) "focus areas include new chemistry blends, resilient electrolytes, material and system design for better thermal management, and battery energy and power density improvements." – EPRI, 3002013047
4) From a system perspective, research into the value of stacked benefits of storage is crucial to improving adoption. Not to mention, this is a more feasible research opportunity for the CEC as much of the performance and technology research is performed at a product manufacturer level.

→ Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references

https://www.greentechmedia.com/articles/read/were-still-underestimating-cost-improvements-for-batteries#gs.5ngM3yI

https://www.energy.gov/sites/prod/files/2016/06/f32/es000_howell_2016_o_web.pdf

https://www.iea.org/media/workshops/2017/egrdjunebluesky/1.JCESR_Crabtree_STFC_53117.pdf

http://web.luxresearchinc.com/hs-fs/hub/86611/file-442189130-pdf/outlook

https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf

Electric Power Research Institute (EPRI2018). *Energy Storage Landscape*. 3002013047. April. Palo Alto, California.

→ Any Subject Matter Expert Names, Affiliation, Comments and Quotes

Brittany Westlake, EPRI, Gaps #: 2,4

TECH NAME	**Redox Flow Batteries**	***TECH ID***	**T159**
CATEGORY	Energy storage (thermal and electric)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Rechargeable energy storage using reduction-oxidation reactions across stacked cells, known for their long life, safety, recyclability, and independently scalable power and energy, while suffering from low energy density and large size. Due to the economies of scale as well as the size of these systems, flow battery systems have typically been installed at grid scale, but residential and commercial applications are increasing.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	Hot dry, Hot humid		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	***AT MATURITY***	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	10-30 Wh/kg Efficiencies of 70-90% Lifetime of 10-20 years	***PERFORMANCE TARGET FOR 2025***	Increase in energy density while balancing the resulting increased internal resistance to not sacrifice efficiency. Expanded operating temperature range.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	25-50%	***O&M COST***	10-25%
COST TARGET FOR 2025	Life cycle: $0.10 per kWh $100 per rated kWh At economies of scale, redox flow battery storage becomes cost competitive.		

Tech Name	**Redox Flow Batteries**	***Tech ID***	**T159**
Category	Energy storage (thermal and electric)		

Other info on the technology

Other Barriers	Policy, Product availability
Research Focus Areas identified by survey participants	Product design evolution (new/improved features, performance enhancements, etc.)
Importance to ZNE	High energy savings potential
Team Reviewer Notes	

→ Rationale the X-factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

There is ongoing research by several institutions. Researchers at Harvard have created a redox flow battery that loses 1% of its capacity every 1000 cycles (showing the upside of redox flow against lithium ion): https://www.seas.harvard.edu/news/2017/02/long-lasting-flow-battery-could-run-for-more-than-decade-with-minimum-upkeep

Research is also being conducted by the Joint Center for Energy Storage Research: https://www.jcesr.org/research/redox-flow/

→ Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE

Much of the current research in flow batteries is on improving battery performance through modification of the electrolyte and increasing the energy density of the battery without sacrificing efficiency. Further research, in parallel with the current research, should focus on implementation, since, as a relatively nascent technology, there is a need for field demonstration and experimentation to better understand deployed performance and lifetime cost competitiveness. Current performance testing has been limited to lab testing and claims 10-20-year lifetimes with minimal degradation. Field demonstration and product deployment will lead to better understanding of the range of applications of redox flow batteries and the challenges to implementation.

→ Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references

https://cleantechnica.com/2017/11/21/vanadium-flow-batteries-for-cost-effective-energy-storage/

https://www.energy.gov/sites/prod/files/VRB.pdf

https://www.seas.harvard.edu/news/2017/02/long-lasting-flow-battery-could-run-for-more-than-decade-with-minimum-upkeep

Program on Technology Innovation: Assessment of Flow Battery Technology for Stationary Applications. EPRI, Palo Alto, CA: 2016. 3002006915

→ Any Subject Matter Expert Names, Affiliation, Comments and Quotes

Brittany Westlake, EPRI

APPENDIX N:
Grid Interaction – Smart Grid Connections

TECH NAME	**DC Microgrid/Buildings**	**TECH ID**	**T165**
CATEGORY	Grid interaction		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Introduction of DC electric distribution and appliances, instead of AC, inside buildings in order to reduce conversion losses. The DC current produced from a PV panel (and stored in a DC battery) is typically converted to AC and then converted to DC at the appliance/product level. Exploration of hybrid AC/DC systems in which a building is simultaneously using DC and AC.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10% or less	**AT MATURITY**	10% or less

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Commercial DC buildings coupled w/DG, EV & storage could payback in as little as 5 years. Resilience & easier renewable energy opportunities - can be done at district scale rather than property limited. Elimination of conversions from AC to DC could save up to 5% (typically 1-3%)	**PERFORMANCE TARGET FOR 2025**	Systems that are as safe as AC systems. Hybrid AC/DC systems that run both AC and DC at the same time.

COST - DECREASE IN COST REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST		**O&M COST**	No
COST TARGET FOR 2025	If creating a DC microgrid, costs decline due to the less amount of equipment needed (i.e. inverter), but the appliances and DC products within the building have an added cost. Need for DC appliances and equipment costs to decline to AC product levels.		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, Policy, Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Product certifications/labeling, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Standards development, Product support materials development, Natural' monopolies must be removed and market opened to small energy distributers and developers.
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), Very cost-competitive when mature, Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Very cost-competitive when mature, resilience
TEAM REVIEWER NOTES	

TECH NAME	DC Microgrid/Buildings	TECH ID	T165
CATEGORY	Grid interaction		

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

Relatively novel technology which needs more proven environment where a DC microgrid would be useful and the benefits are substantial.
On-going research: https://www.energy.gov/eere/buildings/downloads/direct-current-dc-buildings-and-smart-grid

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1) How can DC arcing be prevented, detected and extinguished effectively at a low cost?
   - DC arcing can be quite stable and prolonged which does tend to cause more damage, and is harder to detect with protection equipment like AFCIs due to the different signature frequencies. This characteristic is not desired or safe in homes and buildings.
2) Higher efficiency DC:DC conversion for MPPT and charge control, as well as for utilization equipment.

Efficient DC:DC conversion is possible, however many of the existing charge controllers are less efficient than available inverters. A Schneider XW charge controller maxes out at 94%, while some single stage inverters max out at 99%. And even once that is done, utilization equipment also still needs another DC:DC conversion stage to get from the battery voltage to the voltage needed by the connected equipment. So the expected efficiency gain may not be there with current technology.

3) Is installation of high voltage DC distribution in buildings safe or can it be made safe?
   - Low voltage distribution is less efficient and would require impractically thick copper cable size, but can high voltage DC be safely implemented?
4) How can we create small, inexpensive, consumer grade VFDs that can be embedded in products designed for direct DC input to run motors in common applications such as air conditioners, dryers, pool pumps, ceiling fans, garage door openers, etc.?
5) What are the real benefits of DC utilization, and how can they be clarified to consumers?
   - Selection of consumer devices that will run from higher voltage DC without modification is quite limited to non-existent. Materials for creating DC utilization infrastructure (breakers, outlets, switches, boxes, wiring) that are designed and listed for DC are either expensive or non-existent.
6) The apparent benefit to consumers of having a DC bus are minimal, perhaps a small efficiency gain. So the benefits need to be maximized and clarified in order to generate consumer interest. If no consumer interest is generated companies will not enter this market to fill the niche.

Tech Name	DC Microgrid/Buildings	Tech ID	T165
Category	Grid interaction		

→ ***Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references***

IEEE article: https://spectrum.ieee.org/green-tech/buildings/dc-microgrids-and-the-virtues-of-local-electricity

"More demonstrations and lab studies are critically needed for ZNE buildings with battery storage and EV charging to validate the performance, costs, resilience, GHG savings, integration with the smart grid, digital networks and overall electric system benefits."

- https://aceee.org/files/proceedings/2016/data/papers/10_780.pdf

Direct Current as an Integrating Platform for ZNE Buildings with EVs and Storage: DC Direct Systems – A Bridge to a low Carbon Future.

https://www.energy.gov/eere/buildings/downloads/direct-current-dc-buildings-and-smart-grid

"Plug-and-play DC architectures would require the development of new protocols that enable device identification and packet routing in this more complex network architecture."

- https://www.energy.gov/sites/prod/files/2015/03/f20/DC_Microgrid_Scoping_Study_LosAlamos-Mar2015.pdf

→ ***Any Subject Matter Expert Names, Affiliation, Comments and Quotes***

Morgan Smith, EPRI, Gaps #: 1-5

Dean Weng, EPRI, Gaps #: 1,3

Tech Name	**DER Integration Controls**	***Tech ID***	**T166**
Category	Grid Interaction		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

Utility level controls of distributed energy resources (PV, battery storage, thermal storage, controllable loads, etc.) to balance the "duck curve" load shape caused by the implementation of uncontrolled DERs. Controls include optimization algorithms to translate and appropriately respond to rate signals and other utility signals.

Applicability

Greatest Opportunity	Equal for both new construction and Existing Building Retrofit		
Residential Type	All	***Commercial Building Type***	All
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	10% or less	***At Maturity***	10-25%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Demonstration/pilot phase	***In 5-7 yrs.***	Early market adoption

Performance

Current Performance, Features, Functionality	Controls available only for individual DERs, not cohesive. No way to optimize the delivery of stored energy.	***Performance Target for 2025***	Ability to control at a premise or community level as opposed to individual widget based controls. Ability to optimize storage assets (thermal and battery) by controlling responses to varying signals.

Cost decrease required to be competitive relative to currently available technology?

First Cost	10-25%	***O&M Cost***	10% or less
Cost Target for 2025	There is a need for a utility TOU rate to encourage adoption of DER controls which would result in product manufacturers to innovate and build to interoperability specifications. The rate needs to understand societal cost and must reflect decarbonization goals. ROI from implementing controls must be greater than the ROI of infrastructure upgrades to deal with high fluctuations in load shapes (especially as a push for electrification increases overall demand). The added cost from a product perspective is minimal (i.e. controllable smart thermostats are cost competitive). Cost of data access and storage will be substantial, but it is difficult to quantify.		

TECH NAME	**DER Integration Controls**	***TECH ID***	**T166**
CATEGORY	Grid Interaction		
OTHER INFO ON THE TECHNOLOGY			
OTHER BARRIERS	Institutional, Policy, Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Occupant acceptance/familiarity		
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Standards development		
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities, Assists Utilities with Grid stability		
TEAM REVIEWER NOTES			

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

EPRI is currently building the Demand Side Resource Integration Platform to aggregate and integrate residential and commercial DERs as part of a CEC GFO.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

1) Standardization of impact analysis and baselining as well as a common controls platform for all DERs. There is a need for cohesive controls that are compatible with all DERs (existing and future).
2) Field implementations to better understand operational performance of controls and the feasibility of DER controls.
3) Need for a controls platform and algorithm to optimize DERs according to pricing signals, GHG reduction goals, and grid needs while maintaining customer comfort.
4) Need to resolve interoperability issues through standards and protocols in order to reduce barriers to an open market place.
5) DOE Recommendations:
    - "Additional R&D on methods and tools to ensure appropriate time, location, and product-specific valuation of DER, efficient integration of DERs into power system planning and operations, and improved market models for more efficient pricing of the electric products and services that DERs provide."
    - "Continuing R&D on tools, including computational methods for managing operations with more dynamic and distributed grid, simulation tools to understand system behavior in high DER environment, and research on the interactions and balance in markets with DER."
    - https://www.energy.gov/sites/prod/files/2017/06/f34/4_EAC%20Smart%20Grid%20Subcommittee%20Activities%20and%20Plans%20-%20Paul%20Centolella.pdf

TECH NAME	**DER Integration Controls**	**TECH ID**	**T166**
CATEGORY	Grid Interaction		

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

https://www.caiso.com/Documents/OlivineReport_DistributedEnergyResourceChallenges_Barriers.pdf

https://www.energy.gov/sites/prod/files/2013/05/f0/GTT12_Dist-ActionPlan.pdf

https://www.energy.gov/sites/prod/files/2017/06/f34/4_EAC%20Smart%20Grid%20Subcommittee%20Activities%20and%20Plans%20-%20Paul%20Centolella.pdf

➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Ben Clarin, EPRI – Gap #: 1,2,3

Ethan Goldman, VEIC – Gap #: 1,2,3,4

APPENDIX O:
Other Technology Solutions

TECH NAME	**Real Time Energy Management (RTEM) Software**	**TECH ID**	**T116**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Real-time energy management is a general term referring to the gathering, analysis and display of equipment, system, and/or whole building level monitoring of operational performance. RTEM continuously collects data for analysis that shows the building operator how the building is performing, identifies Key Performance Indicators, and may help with performance optimization, fault detection, and building controls. This goes beyond typical Building Automation System (BAS) software by adding analytics, fault detection, and continuous commissioning capabilities.

APPLICABILITY

GREATEST OPPORTUNITY	New Construction		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	**AT MATURITY**	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	**IN 5-7 YRS.**	Market Maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	There are existing RTEM tools that address many of the barriers, but adoption is lacking. Current tools offer fault detection, automated reporting, basic control optimizations, maintenance assistance, and many other features.	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	This tool should be expanded to include model predictive control, beyond the current fault detection, load shape tracking, and energy waste management (artificial intelligence integration). Currently, the available tools are performing well within a scope of assisting with energy management, but have not yet breached into real-time building control.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10% or less	**O&M COST**	10% or less
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	This technology is currently not cost prohibitive. RTEM should not cost more than $1/ft^2$ of building area.		

Tech Name	**Real Time Energy Management (RTEM) Software**	***Tech ID***	**T116**
Category	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		
Other info on the technology			
Other Barriers	Developer/building owner acceptance/familiarity, Occupant acceptance/familiarity		
Research Focus areas identified by survey participants	Automated optimization tools and machine learning (artificial intelligence integration) to lower the technical expertise needed to take full advantage of continuous data analysis and lean sets of key performance indicators.		
Importance to ZNE	Allows for zero energy designed buildings to maintain high-level performance. Many ZNE buildings do not maintain zero energy performance over time. Reduces operator skills necessary to achieve and maintain ZNE outcomes.		
Team Reviewer Notes			

→ Rationale the X-factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

This technology already exists, but is not fully adopted. Adoption may be lagging due to cost aversion and lack of technical and skilled staff. Improvement to user-friendliness, open-source options, and low-cost solutions will all help and increase the market across smaller buildings. The potential for this technology to increase the longevity of ZNE performance warrants additional focus (X-factor).

➔ Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE – Use the guidance in the word doc shared with the team to fill this section

How can the market adoption of this technology be accelerated/incentivized? Given the potential energy savings (and equipment savings due to improved maintenance), the ongoing cost of this technology should be a minor barrier. Owner acceptance/education, technical abilities of operators, and an overall lack of appreciation for what real time energy management has to offer should all be addressed.

How can this technology ensure integration of control interfaces/languages from various proprietary systems? Equipment from different manufacturers is common in larger buildings, and they often don't 'play nice' with central control systems. An open-source solution would leverage the collective tech community's expertise to improve and expand the tool over time. Solutions from major manufacturers will limit adoption (particularly for retrofits) as they will likely not include support for equipment from all manufacturers.

Is there a method to tie a more commoditized version of RTEM systems that widely apply to smaller buildings into an "Energy Performance as a Service" or Pay for Performance model? Aggregation and centralized tracking of portfolios of buildings not currently managed by a large sophisticated owner / franchise, for example, could be a game-changing model for increasing the persistence of savings in low-and-zero energy buildings

Alignment with M&V policy and codes to make RTEM ubiquitous. Design, owner and operator training

TECH NAME	**Real Time Energy Management (RTEM) Software**	**TECH ID**	**T116**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

https://www.nyserda.ny.gov/-/media/Files/Programs/RTEM/RTEM-fact-sheet.pdf

➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

"Institutional barriers are high: No California energy program actually demands that results in each building be measured and verified, over years. This will be a cultural change, but it is not unprecedented. In Singapore, if measured results are not achieved, consistently, over a three year period, the original tax benefit of the energy improvements is rescinded, and must be paid back, by the developer."

"Because measured performance of residential buildings in California in support of Title 24 has consistently shown that 30 to 60% of energy is wasted, ie: energy reductions of 30 to 70% of actual HVAC energy are possible, given in-process and real-time measurement and verification of performance."

"Important to continually improve efficiency and help efficiency persist over time"

TECH NAME	**Occupant Behavior Modeling**	**TECH ID**	**T120**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

A component of energy modeling that takes into account the effects of occupant behavior and the resulting impacts on scheduling, plug loads, space utilization and overall energy use for various scenarios and building types.

APPLICABILITY

GREATEST OPPORTUNITY	New construction		
RESIDENTIAL TYPE	Single family residential, Low-rise multifamily residential, High-rise multifamily residential	**COMMERCIAL BUILDING TYPE**	Small office, Large office, Lodging, K-12 school, Higher education, Assembly
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10% or less	**AT MATURITY**	10% or less

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	**IN 5-7 YRS.**	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Most energy modeling software does not thoroughly take into account occupant behavior, but rather uses ideal scheduling, total occupant density and/or constant plug load assumptions.	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	Research-backed occupant behavior models incorporated into designers' energy modeling software. This should take into consideration occupant type, building type, cultural influences, and potentially the organizational hierarchy at the building (who will impact the most).

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10% or less	**O&M COST**	10% or less
COST TARGET FOR 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	Software cost of occupant behavior modeling is limited to the designer hours needed to run the models. There are free tools available for the modeling, such as EnergyPlus.		

TECH NAME	**Occupant Behavior Modeling**	***TECH ID***	**T120**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

OTHER INFO ON THE TECHNOLOGY	
OTHER BARRIERS	Product availability, Architect acceptance/familiarity, value proposition
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, relationship to potential health factors
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Occupant factors are gaining increasing attention – personal control, comfort and health issues. This tool could better inform these areas the link ZNE and occupant environments.
TEAM REVIEWER NOTES	Proper occupant behavior energy modeling could lead to better energy designs that help passively or actively shape occupant behavior in buildings.

→ RATIONALE THE X-FACTOR – PRIMARILY LISTING ANY EXISTING/ONGOING RESEARCH ON THIS TECHNOLOGY AND BY WHOM. FOR EXAMPLE, IF DOE OR DOD OR ANY OTHERS HAVE INITIATIVES TO SUPPORT OR FUND RESEARCH FOR THIS TECH

The ratio of energy use impacted by occupant behavior has grown substantially in the last decade driven by two factors – 1) regulated loads decreased by code, and 2) increased Miscellaneous Electrical Loads (MELS) – those peripherals added by occupants. Thus, occupants can now impact a significant portion of a building's energy use. Improvements in understanding of occupant behavior and the ability to provide that knowledge via technical tools can lead to improved buildings that have lower income energy outcomes as well as the designed intended health, air quality, etc. attributes.

TECH NAME	**Occupant Behavior Modeling**	***TECH ID***	**T120**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

The technical capabilities of the energy models are not the limiting factor, the assumptions designers are putting into energy models are not reflective of actual occupant behavior.

There is little to no research on how occupants are behaving in the field, taking into consideration building type, occupant type (gender, age, etc.), cultural impacts (regional, industrial, etc.), organizational structure (who can impact outcomes), and other characteristics that may arise as predictors of occupant behavior. The default assumptions are not offering designers a good understanding of the expected occupant behavior for their designs. Better modeling inputs would allow designers to influence occupant behavior toward lower energy outcomes with improved designs. Occupant behavior is not sufficiently considered in building design.

There is insufficient field research to date to properly inform future building designs and retrofits

The current defaults used about occupant behavior (schedules, manual overrides, thermal comfort needs, etc.) need to be challenged in order to improve building design for low energy outcomes. Designers should consider a range of potential outcomes, which need research to inform the range of potential occupant influence on building operation.

Variabilities need to be considered based on age, gender and culture.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

See full list of references in the literature review documentation

http://www.etcc-ca.com/reports/west-village-development-zero-net-energy-assessment-and-verification-resident-engagement

https://www.arb.ca.gov/research/apr/past/09-327h.pdf

https://www.pdx.edu/cus/sites/www.pdx.edu.cus/files/Moezzi%20%26%20Lutzenhiser%20(2010)%20Whats%20Missing%20In%20Theories%20of%20the%20Residential%20Energy%20User_0.pdf

https://www.epri.com/#/pages/product/000000000001021193/

https://www.epri.com/#/pages/product/000000003002006726/

https://www.epri.com/#/pages/product/000000003002006726/

https://diuf.unifr.ch/people/lalanned/Articles/HBI4SLL16.pdf

https://wcec.ucdavis.edu/wp-content/uploads/2013/06/364_2010ACEEE_Meier_Final3.5._06.04.101.pdf

➔ ***ANY SUBJECT MATTER EXPERT NAMES, AFFILIATION, COMMENTS AND QUOTES***

Karen Ehrhardt-Martinez, Associate Director at Navigant:

> *"Building efficiency isn't enough. People aren't machines. We need to model specific population and occupant types"*
>
> *"There isn't enough information out there to get better assumptions for energy models"*

TECH NAME	**Fault Detection and Diagnostics**	**TECH ID**	**T091**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Fault detection and diagnostics (FDD) analyze building or system (e.g. economizer, scheduling, etc.) level data to identify potential issues that are in conflict with design or operational benchmarks. The analysis can happen at the building dashboard level and/or be available remotely, and is typically automated to some degree. FDD allows for improved upkeep of mechanical systems and optimized building performance.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	Low-rise multifamily residential, High-rise multifamily residential	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10%-25%	**AT MATURITY**	10%-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Market maturity	**IN 5-7 YRS.**	Market maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Fault diagnostics can detect equipment failures and major malfunctions. Energy management systems can identify high usage patterns.	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Integration of energy usage for key systems with operational data to identify when equipment is operating inefficiently, and diagnose the cause so homeowners and building managers can address it quickly.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10% or less	**O&M COST**	10% or less
COST BARRIERS	Cost of metering equipment is primary concern.		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Operational cost
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Systems integration with other products, Product certifications/labeling
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	Established technology with multiple vendors. There is some room for further developments, but it should not be a priority.

TECH NAME	**Fault Detection and Diagnostics**	***TECH ID***	**T091**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Operational cost
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Systems integration with other products, Product certifications/labeling
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	Established technology with multiple vendors. There is some room for further developments, but it should not be a priority.

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

This topic has already been researched by the CEC back in 2008. FDD is also now partially required as part of Title 24. Barriers are not technology developments so negative X factor given.

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

This technology has arguably reached market maturity. Any further development would be focused on improvements to the technology (increased user friendliness, improving diagnostic accuracy, identifying further optimization potential, incorporating more equipment, etc.).

Increased application and market/operator response to FDD signals could have an 'auto-commissioning' benefit. How to increase the benefits of FDD and yield the savings associated with monitoring and detecting failures?

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

http://www.energy.ca.gov/2013publications/CEC-500-2013-054/CEC-500-2013-054.pdf

https://www.nist.gov/programs-projects/fault-detection-and-diagnostics-commercial-heating-ventilating-and-air

http://www.energy.ca.gov/title24/equipment_cert/fdd/index.html

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

TECH NAME	**GHG Modeling Tools for Building Design**	**TECH ID**	**T113**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

A Green House Gas (GHG) Emissions tool would provide designers with the ability to incorproate assessment of building design and technology options with hourly carbon emissions based on the generation mix used at the site from energy usage. Energy modeling tools and algorithms highlight expected carbon outcomes from the whole building and system options.

APPLICABILITY

GREATEST OPPORTUNITY	New Construction		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10% or less	**AT MATURITY**	10% or less

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early Market Adoption	**IN 5-7 YRS.**	Market Maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	CO_2 and other GHG emissions can be estimated using existing tools, such as EnergyPlus. In addition, particulate emissions may also be estimated in the building energy model. Estimates are typically based on annualized state-by-state factors by fuel type used in the building	**PERFORMANCE TARGET FOR 2025** State this as best applicable to the technology. Either in terms of absolute number with metrics or relative to current baseline or market standard	Ideally, this technology would allow for a more customized analysis, using localized factors for emissions based on the buildings location, utility, etc. Further, improvements in reporting results from the analysis could improve adoption and impact of the analysis for new building design and existing building retrofits that include energy modeling There are no hard metrics that can be applied to adequately quantify the performance of this technology.

Tech Name	**GHG Modeling Tools for Building Design**	***Tech ID***	**T113**
Category	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

Cost decrease required to be competitive relative to currently available technology?

First cost	No	***O&M cost***	No
Cost Target for 2025 Describe this as best applicable to the technology. Either in terms of absolute or relative to current baseline or market standard.	At least one instance of this tool (Energy Plus) is already available at no cost as provided by the Department of Energy. Any other tools offering a similar analysis should target a minimal-to no-cost structure		

Other info on the technology

Other Barriers	Policy, Reliability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity
Research Focus Areas identified by survey participants	Product design evolution -new/improved features, performance enhancements, etc., Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Training materials development (curricula, manuals, videos, etc.)
Importance to ZNE	Greenhouse gas reduction potential, Adds value, e.g., improved occupant comfort, control, or amenities, Provides designers with direct feedback on the predicted impact of the building design which can be aligned with government policy and carbon markets.
Team Reviewer Notes	

→ Rationale the X-factor – Primarily listing any existing/ongoing research on this technology and by whom. For example, if DOE or DOD or any others have initiatives to support or fund research for this tech

X-factor takes into account non-energy benefits. One large benefit is that a GHG tool would pave the way for carbon-based policy and codes and better align the ultimate goal of carbon reduction with ZNE design, given that ZNE design isn't necessarily zero carbon. DOE maintains ongoing support of Energy Plus, which is a free tool that includes this technology.

Tech Name	**GHG Modeling Tools for Building Design**	***Tech ID***	**T113**
Category	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

➔ ***Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE – Use the guidance in the word doc shared with the team to fill this section***

Designers may not have the familiarity or training to properly model the GHG impacts of building designs using existing tools. Further, building owners are not currently requiring GHG targets for their building, so there is little demand for architects and engineers to use the technology.

How can GHG emissions be properly characterized? There will be debate as to how to characterize GHG emissions from a potential or existing building. Properly accounting for the source of the energy along with the time of use may be challenging to incorporate into a simple tool with any transparency for the user to grasp. Emissions "on the margin" have some existing research, but change all the time. Average hourly values for California that are agreed upon from a policy standpoint will be an important first step to standardize assumptions across various tools.

Will there be any conflicts with Time Dependent Valuation of energy use and savings that is currently required in California? GHG emissions alone may not be a priority for CA given the existence of TDV which is more comprehensive. Low GHG emission designs may conflict with TDV in unexpected ways (e.g. Lower GHG design decisions could increase TDV for some other unforeseen reason).

Should the tool take into account embodied carbon? Having a comprehensive database of carbon for materials may require substantial research, but would further advance carbon goals. Over the life of a building, the impact of material selection could outweigh marginal increases in efficiency when comparing lifecycle carbon.

➔ ***Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references***

https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert

https://www.wbdg.org/resources/greenhouse-gas-emissions-federal-buildings

https://energyplus.net/documentation

➔ ***Any Subject Matter Expert Names, Affiliation, Comments and Quotes***

Ryan Sit, Integral Group:

> *"In terms of carbon footprint analysis tool, I don't think this is a gap. From my understanding, most buildings in California are not subject to carbon policy instruments. Cap and trade regulations are limited to larger campus entities. Thus, there is no real impetus to design ZNE buildings with low embodied carbon (e.g., having a carbon footprint analysis tool would do nothing to dissuade from designing a ZNE building with imported PV panels, which would have high embodied carbon)."*

Christopher M. Jones, Ph.D., Program Director, CoolClimate Network:

> *"If the accurate carbon impact of buildings was fully integrated with the energy assessment the transparency of this relationship would shift the decisions to lowest carbon rather than simply lowest energy design. It would also raise the collective awareness of the true goal of energy reduction to offset GHG emissions which has immeasurable value societally across the population's activities and choices – ideally of course."*

TECH NAME	**Building Design Tool Integrator**	***TECH ID***	**T114**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

A tool which combines data (input and outputs) from code compliance, climate spreadsheets, design and energy models, and other tools. The tool would create a uniform set of standardized inputs and outputs across platforms to facilitate coordination between stakeholders and tools, thereby cutting down on time-intensive model building hours.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	<10%	***AT MATURITY***	<10%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of Concept	***IN 5-7 YRS.***	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY		***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Standardization of inputs/outputs, Inclusion of all CA climate zones, integration with existing tools

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	No	***O&M COST***	No
COST BARRIERS	Not integrated into code software		

TECH NAME	**Building Design Tool Integrator**	**TECH ID**	**T114**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, Product availability, Architect acceptance/familiarity, Regulatory- codes and standards are not consistent in requirements
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Systems integration with other products, Standards development
IMPORTANCE TO ZNE	Relative familiarity/ease of adoption by design professionals, Integrated modeling will connect all building, energy, code, space programs, and other spreadsheets to allow for sharing across platforms using consistent datasets. An automated process reduces the most significant cost and time factor to modeling which is data input and ensures accuracy of data across platforms.
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

The X-factor is high in this case due to the potential for large time savings and efficiency of resources. Many hours are spent building out discrete tools and models with poor conductivity of data between each one. A single integrated tool can improve time-efficiency and has the potential to integrate future add-ons (e.g. carbon calculator, lifecycle cost estimator, etc.) on a single unified platform with standardized inputs/outputs.

→ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

The gap isn't necessarily research based, but rather development based. An (ideally open source) integrated tool made available to designers that takes into account feedback and needs from stakeholders with some funds to increase adoption would have the potential to improve design and operational efficiency and coordination.

What existing or emerging tools most influence the final energy design of buildings?

Would an "Integrator" tool improve the use of a wider range of tools and consideration of energy/carbon in final designs?

What is technically necessary to develop an Integrator tool and how can it be made to interface and modify as various tools change?

What are the building and the market adoption baselines and projections and their relationship to energy savings impacts?

→ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

→ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

"An automated process reduces the most significant cost and time factor to modeling which is data input and ensures accuracy of data across platforms."

TECH NAME	**Residential Connected Devices Commissioning App (Res Cx App)**	***TECH ID***	**T119**
CATEGORY	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

User friendly tool (e.g. phone app) that informs occupants when their connected devices need a tune-up or maintenance. Would ideally include instructions for the occupants to make adjustments themselves whenever possible (simlar to diagnostic code reader for cars). Anticipates the performance issues and absence of optimization due to a dramatically increasingly connected home.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	Single family residential, Low-rise multifamily residential, High-rise multifamily residential	***COMMERCIAL BUILDING TYPE***	NA
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	<10%	***AT MATURITY***	10-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	***IN 5-7 YRS.***	Proof of concept

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY		***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Additional development, including user-friendly software.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10% or less	***O&M COST***	10% or less
COST BARRIERS	Market size, Early market phase (not yet mature)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Training materials development (curricula, manuals, videos, etc.)
IMPORTANCE TO ZNE	High energy savings potential, With the increase in sensors and connected technologies there is a gap in ensuring effective operations for functionality and energy savings potential. Defaults or errors may be using more energy than optimum settings.
TEAM REVIEWER NOTES	There is likely a large barrier of connectivity of various proprietary equipment using different communication protocols. Maybe something like a “universal translator” could allow the tool to connect to most devices.

Tech Name	**Residential Connected Devices Commissioning App (Res Cx App)**	***Tech ID***	**T119**
Category	Technology solutions for implementation/operation aspects (e.g., construction/commissioning, energy modeling and design, tools and technologies)		

→ Rationale for scores, especially the X-Factor

Residential application only envisioned and unknown energy impact currently due to evolving IoT, but barriers to adoption could be minimized easily. Development should be relatively straightforward with advancements in the private sector.

→ *Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE – Use the guidance in the Word doc shared with the team to fill this section*

Some tools exist, particularly for HVAC technicians. However, improvements can be made to make the tool more effective for technicians and to include building occupants in the target audience.

What current and next stage residential equipment and systems are sensored and designed for connectivity with other home systems and have the ability for impacting energy use?

What is the connectivity potential of residential equipment and systems through a singular app? Can an app assess both energy and operational performance and optimization?

How should the app be designed in order to ensure it is user-friendly and to what affect the degree to which occupants can make changes to optimize the equipment? Having to hire someone to leverage the insights from the commissioning app each time would hinder energy impacts.

Once developed, how can this tool connect to all the available devices with minimal troubleshooting (cost)?

How can we encourage market adoption of this tool? Occupants may find it daunting. It will help residential maintenance techs, but limiting the tool to techs will also limit the overall energy impacts.

→ *Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references*

Some existing work:

https://play.google.com/store/apps/details?id=ibn.helfer

https://play.google.com/store/apps/details?id=com.igdit.ntti.hvac_calc

→ *Any Subject Matter Expert Comments and Quotes*

APPENDIX P:
Plugloads

TECH NAME	**Efficient Cooking Appliances**	**TECH ID**	**T105**
CATEGORY	Plug and equipment loads		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

New electric appliances and cookware facilitate cooking with electricity, provide new services, and save energy. Stove-top technologies include induction heating elements and optimized cookware. Standalone technologies include Instant Pots, sous vide, advanced toaster ovens, and advanced pressure cookers. Reduced combustion emissions is another benefit.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	Lodging
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10-25%	**AT MATURITY**	10-25%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Market maturity	**IN 5-7 YRS.**	Market maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Overcomes a major psychological hurdle to all-electric homes by putting electric cooking in a different light vs gas cooking and appealing to different features.	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Marketing!!

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	Perhaps – depends on consumer	**O&M COST**	No
COST BARRIERS	Induction stovetops are significantly more expensive than alternative cooktops – sometimes more than a thousand dollars.		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Occupant acceptance/familiarity, must overcome people's dislike of ER cooking by showing it is not even similar. Existing homes may lack adequate electrical infrastructure. Not all cookware is compatible with induction heating.
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Demonstration projects, Market awareness campaign, Establishing distribution network/infrastructure
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, biggest reason CBIA gives for avoiding all-electric ZNE is that "people want their gas stoves."
TEAM REVIEWER NOTES	There are several new, counter-top cooking solutions, many of which will save energy (though a pressure cooker on an induction stovetop will have the greatest savings.) Most people won't use pressure cookers very often. 2% is probably high but perhaps a small fraction of people will switch substantially to pressure cookers, sous vide, etc.; then the savings will be much larger.

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

This technology is fully ready for wide deployment, except they cost too much and consumers are not aware of their benefits. Stand-alone appliances, especially Instant Pots, are becoming popular without emphasizing efficiency benefits.

TECH NAME	Efficient Cooking Appliances	TECH ID	T105
CATEGORY	Plug and equipment loads		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

The principal research gap is devising methods to shift the market from selecting electricity when gas is present and selecting a higher-cost electric option. Non-cost benefits need to be better explained and articulated.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

http://www.nytimes.com/2010/04/07/dining/07induction.html

https://www.consumerreports.org/ranges/gas-or-electric-range-which-is-better/

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

TECH NAME	**Efficient Cookware**	**TECH ID**	**T106**
CATEGORY	Plug and equipment loads		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Insulated cookware. Many procedures for food preparation result in accumulation of residual heat that is ultimately disipated into the kitchen. By insulating the cookware and switching off heating element prior to target cooking time, the residual heat can be used to enable the food to thermally "coast" to completion. Techniques to avoid heating excessive amounts of water are also available. These techniques can save up to 20% of cooking energy for specific meals and items.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit. Some commercial applications, too.		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	NA
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	Don't know	**AT MATURITY**	Don't know

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Market maturity	**IN 5-7 YRS.**	Market maturity

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Decarbonize cooking, low cost, can be used by tenants, no building modifications, reduce energy compared to electric resistance or induction	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	marketing

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	Yes	**O&M COST**	No
COST BARRIERS	Dishes may look different.		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Demonstration projects, Training materials development (curricula, manuals, videos, etc.)
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, High energy savings potential, Public/occupants will like it, Health benefit vs. gas cooking
TEAM REVIEWER NOTES	This technology/measure/modified practice complements efficient appliances.

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

These technologies are mostly available today and await only consumer acceptance.

TECH NAME	**Efficient Cookware**	**TECH ID**	**T106**
CATEGORY	Plug and equipment loads		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

It's not clear if consumers will accept these changes unless they are packed with other features and benefits.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Stamminger, Rainer. 2017. "Consumer Behaviour in Food Preparation and Its Impacts on Energy Consumption." presented at the EEDAL, UC Irvine. http://eedal2017.uci.edu/wp-content/uploads/Thursday-23-Stamminger-smaller.pdf.

Murray, D. M., J. Liao, L. Stankovic, and V. Stankovic. 2016. "Understanding Usage Patterns of Electric Kettle and Energy Saving Potential." *Applied Energy* 171 (June): 231–42. https://doi.org/10.1016/j.apenergy.2016.03.038.

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

TECH NAME	**Efficient GFCIs**	***TECH ID***	**T107**
CATEGORY	Plug and equipment loads		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Ground Fault Circuit Interrupts (GFCIs) are a safety measure to prevent accidental electrocution. They are placed in outlets. California building codes require installation of GFCIs in all locations where standing water—and electrocution—is possible. Each GFCI draws about 1 watt and there may be as many as 20 GFCIs in a home. Lower-power GFCIs are feasible.

APPLICABILITY

GREATEST OPPORTUNITY	New construction and retrofits.		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	50% or more compared to current practice.	***AT MATURITY***	50% or more

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Non-optimized fault detection circuitry	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Updated circuitry

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10-25%	***O&M COST***	10-25%
COST BARRIERS	Early market phase (not yet mature)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Institutional, Policy, Product availability, Builder/trades acceptance/familiarity, Occupant acceptance/familiarity, Health and safety
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Performance validation/product testing/simulation
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), Relative familiarity/ease of adoption by design professionals, Very cost-competitive when mature
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

This technology is not yet ready for the market. It saves only a little energy (per installation) but has wide applicability once perfected.

TECH NAME	**Efficient GFCIs**	**TECH ID**	**T107**
CATEGORY	Plug and equipment loads		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

This efficiency improvement requires a straightforward path of technical development – the design has not changed much in 30 years – from prototype development, testing, and pilot field testing. One important issue is demonstration of safety: any new design must pass rigorous testing protocols. The final designs must also overcome strict cost constraints because saving 0.5 W (4 kWh/year) generates savings of less than a dollar per year.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Meier, Alan, and Quentin Alliot. 2015. "Builder-Installed Electrical Loads in New Homes." In *Energy Efficient Domestic Appliances and Lighting*. Luzern, Switzerland.

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

Other, related equipment are Arc-fault interrupts. Here, too, energy savings are possible.

TECH NAME	**Efficient Residential and Small-Commercial Security Systems**	**TECH ID**	**T108**
CATEGORY	Plug and equipment loads		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Circuitry and battery-charging of security systems (that is, intrusion, fire, video surveillance) leads to a continuous power consumption of around 10- 200 W. Each camera can add 2 – 6 W. More careful design and efficient charging technology can probably reduce this by half.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	Single family residential	**COMMERCIAL BUILDING TYPE**	Small office, Retail, Lodging, Restaurant
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	No code requirements. Most efficient on market can probably save 30%	**AT MATURITY**	50% or more.

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	**IN 5-7 YRS.**	Proof of concept

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Conventional batteries and charging systems. Inefficient circuitry, power management, data compression.	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Improved power management and circuitry, more efficient batteries, PV back-up?, data compression.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10-25%	**O&M COST**	10-25%
COST BARRIERS	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Early market phase (not yet mature), Don't know, Equipment designed and owned by security firm, who don't pay electricity costs. Presently exempt from efficiency standards.		

Tech Name	**Efficient Residential and Small-Commercial Security Systems**	***Tech ID***	**T108**
Category	Plug and equipment loads		

Other info on the technology

Other barriers	Institutional, Policy, Product availability
Research focus areas identified by survey participants	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Product certifications/labeling, Market awareness campaign, Standards development
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Relative familiarity/ease of adoption by builders/trades
Team reviewer notes	This is a rapidly-growing and evolving end use, especially w/r to video surveillance.

→ Rationale for scores, especially the X-Factor

The technology is not ready for the market but, when it becomes available, could be steadily adopted.

➔ ***Research Gap Articulation – the critical unanswered research question/s that would make the tech ready for full market adoption and enable ZNE – Use the guidance in the Word doc shared with the team to fill this section***

Previous research has demonstrated that most of the components in security systems can be designed to draw less power; however, little work has been directed towards systems integration and achieving a lower-energy package. Furthermore, most alarm companies offer a service and are less concerned about the energy use (because the customer pays this). Prototype systems need to be built, tested, and demonstrated to be cost-effective. An energy labeling system – beginning with a test procedure – would also push the market towards more efficient products.

➔ ***Key References – such as CEC, ETP, CPUC, DOE, NREL or other state or federal sponsored studies and reports. Add URLs or report references***

http://www.energyrating.gov.au/sites/new.energyrating/files/documents/sb200415-burglaralarms2_0.pdf

https://reolink.com/cctv-ip-security-camera-power-consumption/

https://www.energy.gov/sites/prod/files/2016/05/f31/Battery%20Chargers%20Final%20Rule.pdf

➔ ***Any Subject Matter Expert Comments and Quotes***

Tech Name	**Energy Use Accounting**	***Tech ID***	**T109**
Category	Plug and equipment loads		

→ Tech Description – enter text here to briefly describe the technology in 1-2 sentences

A combination of advanced power sensing and software enables a home's total energy use to be disambiguated into the major contributing end uses. In this way, the energy use of different appliances can be identified and inefficient technologies (or practices) isolated without entering the building and separately metering each device. When coupled to feedback systems, consumers are more likely to save energy. The technology can, at best, explain about 90% of a home's total energy use. Systems built around existing smart meters are less accurate but may help identify key end uses. The same approach is also being applied to small commercial buildings.

Applicability

Greatest Opportunity	Existing Building Retrofit		
Residential Type	All	***Commercial Building Type***	Small office
Applicable in Climate Types	All		

Energy benefit compared to minimally code-compliant technologies or approaches?

Today	10-25%	***At Maturity***	10-25%

Technology readiness on the spectrum of maturity in a natural market-driven progression.

Today	Demonstration/pilot phase	***In 5-7 yrs.***	pilot phase

Performance

Current Performance, Features, Functionality	Under best conditions, the technology can explain 75% of energy use, possibly leading to a 10% savings	***Improvements Needed to be Ready for Mainstream Adoption***	State-wide marketing/outreach/education

Cost decrease required to be competitive relative to currently available technology?

First Cost	10% or less	***O&M Cost***	10% or less
Cost Barriers	Some systems exploait existing smart meters but most require a new meter attached to smart meter, along with communications to cloud. Cost, when scaled, is still modest.		

Other info on the technology

Other Barriers	Institutional, Policy, Builder/trades acceptance/familiarity, Developer/building owner acceptance/familiarity, Facility operator acceptance/familiarity, Occupant acceptance/familiarity, Plug loads will account for more than 100% of projected increases in
Research Focus Areas Identified by Survey Participants	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Market awareness campaign, Training materials development (curricula, manuals, videos, etc.), Standards development
Importance to ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature, Public/occupants will like it, In many California climates, Plug Loads are bigger than HVAC loads in existing homes.
Team Reviewer Notes	There will be a wide range of savings depending on user engagement and plug loads present. Savings may not persist beyond a few years unless user is regularly engaged. Note that these solutions are weakest in detecting and identifying continuous loads, e.g., standby, "idle power", vampire loads, etc.

TECH NAME	**Energy Use Accounting**	**TECH ID**	**T109**
CATEGORY	Plug and equipment loads		

→ **RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR**

This technology offers both energy and load savings potentials. It's not clear how widely it would be adopted.

→ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

Lots of commercial solutions here but all have limitations. Some require installation of extra sensors (with an electrician) while others are not able to detect very much without considerable training. Major research gaps include:

- Easy installation without need of electrician
- Improved machine training/learning techniques, possibly in collaboration with occupants
- An open-source library of power/voltage/phase "fingerprints" for all common appliances
- New algorithms to interpret variable-speed and inverter-powered appliances

→ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

For an overview of non-intrusive metering, see

https://en.wikipedia.org/wiki/Nonintrusive_load_monitoring

Other references:

Berges, Mario E., Ethan Goldman, H. Scott Matthews, and Lucio Soibelman. 2010. "Enhancing Electricity Audits in Residential Buildings with Nonintrusive Load Monitoring." *Journal of Industrial Ecology* 14 (5): 844–58. https://doi.org/10.1111/j.1530-9290.2010.00280.x.

Examples of current solutions:

https://sense.com/

https://www.smappee.com/us/home

https://www.whiskerlabs.com/

→ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

TECH NAME	**Variable Power Wifi Router**	**TECH ID**	**T110**
CATEGORY	Plug and equipment loads		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Current wifi routers are unable to modulate power consumption in response to data transfer rates. However, relatively modest changes in firmware and software can make this possible. This is accomplished by extending the beacon intervals, which decreases load on the network. Most of the routers out of the box have the default Beacon Interval function value set at 100 ms but this approach raises it to 1 second (and could extend to over 60 sec). In addition, beacons enable devices to have power saving modes. Access points will hold on to packets destined for stations that are currently sleeping.

At least one model is already available (developed originally to minimize EMF exposure in homes). The solution can be either scheduled (such as during nights) or by sensing periods of low demand.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	**AT MATURITY**	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Prototype on market (but to reduce EMF rather than energy use)	**IN 5-7 YRS.**	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Constant power consumption regardless of data transmission load	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Adjusts power power consumption depending on data transmission rate

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10%	**O&M COST**	none
COST BARRIERS	Market size, Early market phase (not yet mature)		

TECH NAME	**Variable Power Wifi Router**	***TECH ID***	**T110**
CATEGORY	Plug and equipment loads		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Product availability, Architect acceptance/familiarity, Builder/trades acceptance/familiarity, Occupant acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Market awareness campaign
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), Relative familiarity/ease of adoption by builders/trades, Very cost-competitive when mature
TEAM REVIEWER NOTES	Many kinds of data devices – servers, switches, etc. – can't modulate output with changes in data transmission loads, so this solution could have wider applicability.

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

This technology exists but hasn't been widely commercialized.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

Further refinement of the technology is needed to assure a level of service similar to less efficient designs. It's not clear how easy it will be for a user to select performance (from "high efficiency" to "low-latency at all times").

Widespread field testing of technology is still required.

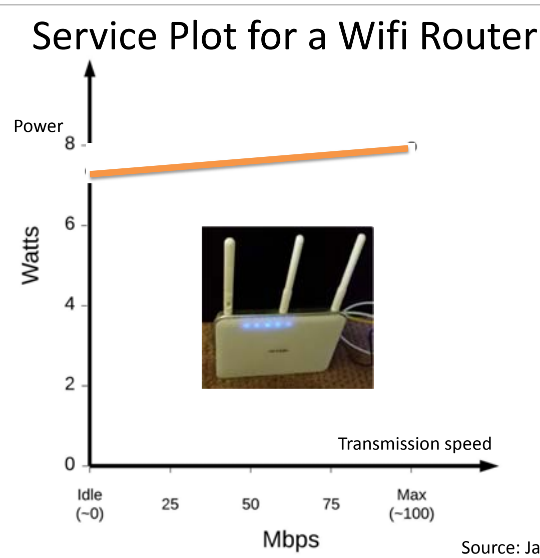
➔ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

See https://www.jrselectrohealth.com/?c=cf13ce20305c for a description of a modified wifi router with these characteristics.

The beacon interval is described here:

https://en.wikipedia.org/wiki/Beacon_frame

➔ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES



Source: James Allen

TECH NAME	**Zero Standby Power Remote Control System**	**TECH ID**	**T111**
CATEGORY	Plug and equipment loads		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Standby power consumption in certain appliances can be reduced to zero by installing energy-harvesting capability to operate the power switch. The source of the harvested energy would be the remote control (either the IR or a laser assist). The solution works for remotely controlled devices with no additional loads, such as ceiling fans, powered speakers, and lights.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	These products are not covered by codes so they draw 0.5 – 1W continuously.	**AT MATURITY**	These products would draw zero power. A typical home has several remote-controlled devices in this category.

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Proof of concept	**IN 5-7 YRS.**	commercialization

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	conventional power supply	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Capability to harvest sufficient ambient energy (or beamed power from a remote control) to switich on a appliance's primary power.

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	10-25%	**O&M COST**	none
COST BARRIERS	To be determined		

TECH NAME	**Zero Standby Power Remote Control System**	**TECH ID**	**T111**
CATEGORY	Plug and equipment loads		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Prototype development, Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products, Product certifications/labeling, Standards development
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.)
TEAM REVIEWER NOTES	LBNL is doing research in this area.

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

This technology requires considerable research to increase reliability and decrease costs. Once accomplished, it should be widely applicable.

➔ RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION

This technology is still in the development stage, although several prototypes have been made and shown to successfully activate a primary power switch with only ambient energy. Once reliable technologies have been demonstrated, they still need to be miniaturized and then simplified to lower costs.

Several other zero-standby solutions have also been demonstrated, which may permit even wider application.

➔ KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES

Meier, Alan, and Hans-Paul Siderius. 2017. "Should the next Standby Power Target Be 0-Watt?" In *Eceee 2017 Summer Study – Consumption, Efficiency & Limits*. Presqu'île de Giens, Hyeres, France: European Council for an Energy-Efficient Economy.

Kang, S., K. Park, S. Shin, K. Chang, and H. Kim. 2011. "Zero Standby Power Remote Control System Using Light Power Transmission." *IEEE Transactions on Consumer Electronics* 57 (4): 1622–27. https://doi.org/10.1109/TCE.2011.6131134.

Yamawaki, Akira, and Seiichi Serikawa. 2015. "Power Supply Circuit with Zero Standby Power Consumption on Infrared Remote Controlled Product by Using Energy Harvesting." In *Proc. of the International MultiConference of Engineers and Computer Scientists 2015*.

➔ ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES

APPENDIX Q:
Behavior

TECH NAME	**Gamification as a Strategy to Reduce Energy Use**	**TECH ID**	**T092**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Energy-themed games aimed at informing and shaping occupant behavior and energy use.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	5 out of 13
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	Don't know	**AT MATURITY**	Don't know

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY		**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST		**O&M COST**	
COST BARRIERS			

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	
IMPORTANCE TO ZNE	
TEAM REVIEWER NOTES	Lighting; Office Equipment; Applicability extends beyond plug loads

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Many games at reducing energy have been developed and tested in many different contexts. They have broad applicability to various technologies and building types. Games are a relatively low-cost investment that many entities – public and private - have invested in developing. They are assigned a “2” for the X-factor because there will likely continue to be lots of disbursed efforts to invest in games which can be leveraged.

TECH NAME	**Gamification as a Strategy to Reduce Energy Use**	**TECH ID**	**T092**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1. Research is needed to test and measure energy games' impact on behavior over the long-term, across various user groups and relative to the cost of game development. Differences in user groups may be defined by readily observable characteristics (e.g., business type) or more hidden ones (e.g., internal vs. external locus of control).

2. Research is needed to test how the length of time between engaging with energy games and engaging with energy-consuming technologies impacts behavior.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Grossberg, F., Wolfson, M., Mazur-Stommen, S., Farley, K., & Nadel, S. (2015). Gamified Energy Efficiency Programs. Washington, DC: ACEEE, Report Number B1501.

Reeves, B., Cummings, J. J., Scarborough, J. K., & Yeykelis, L. (2015). Increasing Energy Efficiency with Entertainment Media: An Experimental and Field Test of the Influence of a Social Game on Performance of Energy Behaviors. *Environment and Behavior*, 47(1), 102-115.

Yang, J. C., Lin, Y. L., & Liu, Y.-C. (2017). Effects of locus of control on behavioral intention and learning performance of energy knowledge in game-based learning. *Environmental Education Research*, 23(6), 886-899.

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

TECH NAME	**Occupant Level Controls**	**TECH ID**	**T093**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES
Occupant-level controls (for HVAC, lighting, etc.) that promote and attempt to influence engagement with technology.

APPLICABILITY			
GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	NA	**COMMERCIAL BUILDING TYPE**	Small office, Large office
APPLICABLE IN CLIMATE TYPES	All		
ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?			
TODAY	10-25%	**AT MATURITY**	10-25%
TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.			
TODAY	Early market adoption	**IN 5-7 YRS.**	Early market adoption
PERFORMANCE			
CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Not sure	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Not sure
COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?			
FIRST COST	Don't know	**O&M COST**	Don't know
COST BARRIERS	Early market phase (not yet mature)		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Developer/building owner acceptance/familiarity
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Market awareness campaign
IMPORTANCE TO ZNE	Greenhouse gas reduction potential, Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Relative familiarity/ease of adoption by builders/trades, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities
TEAM REVIEWER NOTES	Heating; Cooling; Ventilation

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Occupant level controls are a necessary component to building energy systems and are relatively low-cost items to purchase. For that reason, we expect that advancements in technology would be readily adopted. It is expected that commercial entities will continue to invest in technology development for occupant-level controls (hence the "1" for X-factor), but more fundamental research is required to understand how to use controls to influence behavior, and how they interact with other factors that influence behavior.

TECH NAME	**Occupant Level Controls**	***TECH ID***	**T093**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1. Research is needed to measure the theoretical drivers of energy saving behavior – as it relates to occupant controls - to better understand the relative influence/importance of the variety of factors. Such research could include explorations into intrinsic and extrinsic motivations, and whether better information actually stimulates persistent behavior change.

2. Fundamental research on occupant behavior within organizations is needed to understand how to engage non-facilities occupants and address the principal-agent problem in commercial settings, as it relates to the use of occupant level controls.

3. Research is needed to evaluate forms of intervention not yet investigated in a rigorous manner, including: coercion, restriction, training and enforcement of rules on energy consumption, in the context of the workplace and beyond.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Bull, R. et al (2015). Moving beyond feedback: Energy behaviour and local engagement in the United Kingdom. *Energy Research & Social Science.* Volume 8, July 2015, Pages 32-40.

Dakin, B. et al. (2014). Early Performance Results from A Zero Net Energy Community. Conference Paper: ACEEE Summer Study on Energy Efficiency in Buildings.

Staddon, S. et al (2016). Intervening to change behaviour and save energy in the workplace: A systematic review of available evidence. *Energy Research & Social Science*.

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

R. Bull and co-authors: *"For energy research to reach its potential much more work is required into understanding a wide range of organisation types and how different organisational contexts affect behaviour."*

S. Staddon et al.: *"We urge other researchers reporting on energy saving interventions to consider and measure the theoretical reasons behind energy saving behaviour, more systematically report and analyse their findings, and where possible to undertake further longitudinal evaluations."*

TECH NAME	**Predictive Building Controls**	**TECH ID**	**T094**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Predictive building controls refers to "smart" controls of HVAC, plug load, lighting, etc. that utilize data on occupant and technology "behavior" to save energy by anticipating the occupants' needs and reducing waste.

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and Existing Building Retrofit		
RESIDENTIAL TYPE	NA	**COMMERCIAL BUILDING TYPE**	6 out of 13
APPLICABLE IN CLIMATE TYPES	All		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	25-50%	**AT MATURITY**	25-50%

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Early market adoption	**IN 5-7 YRS.**	Early market adoption

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	It interfaces with BAS for all energy consuming systems	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Electrical circuiting and HVAC distribution

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	Don't know	**O&M COST**	Don't know
COST BARRIERS	Installation issues (e.g., installer costs/lack of familiarity/installation difficulty), Immature older BAS would not interface well enough to make this easy for a retrofit		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Facility operator acceptance/familiarity, Occupant acceptance/familiarity, Operational cost, Health and safety, Design of Mechanical and electrical systems is not aligned with this application yet
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Performance validation/product testing/simulation, Demonstration projects, Systems integration with other products
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), High energy savings potential, Very cost-competitive when mature
TEAM REVIEWER NOTES	HVAC; Heating; Cooling; Ventilation; Lighting; Interior Lighting; Exterior Lighting; Water Heating; Office Equipment

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Predictive building controls are promising because they take occupant behavior into account in a dynamic way and can accumulate energy savings by shaving off around the margins. They do not attempt to save greater portions or energy or peak demand by influencing behavior or energy needs.

TECH NAME	**Predictive Building Controls**	***TECH ID***	**T094**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1. Research is needed on how to collect data from building owners, users, and operators (especially during the design process) to understand objectives for the building and occupant behavior and use those as inputs to refine the building energy model to better reflect the energy usage of the building.
2. Research is needed to advance building information systems that integrate an early warning system to identify meaningful deviations from predicted and actual energy consumption.
3. Research is needed to better understand the impact of occupant behavior (including conservation efforts) on building energy performance, to better enable Predictive Building Controls to anticipate the impacts of behavior change campaigns. Human-in-the-loop (HIL) interaction technologies (sensing/controls) is a promising area of inquiry that should continue to be explored.
4. Research is needed to improve technologies and algorithms that can accurately sense and quantify occupants and provide inputs to the ventilation control system. Research in this area would need to address concerns about privacy and data security.
5. Research is needed to determine the cost effectiveness for PBC for various building types.

TECH NAME	**Predictive Building Controls**	*TECH ID*	**T094**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Advanced Research Projects Agency. Saving Energy Nationwide in Structures with Occupancy Recognition (SENSOR). Description of the ARPA-E's SENSOR projects. https://arpa-e.energy.gov/?q=arpa-e-programs/sensor

Carnegie Mellon University. Human-in-the-Loop Sensing/Control for Commercial Building Energy Efficiency and Occupant Comfort. 2016-2019 (summary of a current DOE-funded project)

Chou, J. et al (2017). Early-warning application for real-time detection of energy consumption anomalies in buildings. *Journal of Cleaner Production*.

Delzendeh, E., et al (2017) The impact of occupants' behaviours on building energy analysis: A research review, *Renewable and Sustainable Energy Reviews*, Volume 80, 2017, Pages 1061-1071.

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Hong, T. et al (2016). Advances in research and applications of energy-related occupant behavior in buildings. *Energy and Buildings.*

Jia, M. et al (2017). From occupancy to occupant behavior: An analytical survey of data acquisition technologies, modeling methodologies and simulation coupling mechanisms for building energy efficiency. Renewable and Sustainable Energy Reviews.

Pacific Northwest National Lab. Energy Savings for Occupancy-Based Control (OBC) of Variable Air-Volume. 2013 (VAV) Systems. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22072.pdf

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Shaikh, P. H., Nor, N. B. M., Nallagownden, P., Elamvazuthi, I., & Ibrahim, T. (2014). A review on optimized control systems for building energy and comfort management of smart sustainable buildings. *Renewable and Sustainable Energy Reviews*, 34, 409-429.

Timm, S. et al (2016). Effective or ephemeral? The role of energy information dashboards in changing occupant energy behaviors. *Energy Research and Social Science*.

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

Jia et. al.: *"Occupant behavior needs to be fully understood for better building performance prediction and energy optimization."*

Timm et al.: *"Future research should also focus on the development of robust tools that can more readily measure the efficacy of energy conservation behavior approaches in commercial and educational buildings."*

TECH NAME	**Dashboard/Display for Shaping Occupant Behavior**	**TECH ID**	**T095**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		
→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES			
Display for conveying energy-related information to building occupants. Displays can be used for a range of things including communicating information on energy consumption, PV generation, and energy storage, as well as trying to influence occupant behavior to save energy.			
APPLICABILITY			
GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	All	**COMMERCIAL BUILDING TYPE**	All
APPLICABLE IN CLIMATE TYPES	All		
ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?			
TODAY	10% or less	**AT MATURITY**	10% or less
TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.			
TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase
PERFORMANCE			
CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	PV generation & consumption monitoring	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Add in benchmarking/comparisons & occupant engagement aimed at behavior change
COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?			
FIRST COST	Don't know	**O&M COST**	Don't know
COST BARRIERS	Early market phase (not yet mature)		
OTHER INFO ON THE TECHNOLOGY			
OTHER BARRIERS	Product availability, Developer/building owner acceptance/familiarity, Occupant acceptance/familiarity		
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Systems integration with other products, Integration into building plans		
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), Relative familiarity/ease of adoption by builders/trades, Relative familiarity/ease of adoption by design professionals, Public/occupants will like it, Adds value, e.g., improved occupant comfort, control, or amenities		
TEAM REVIEWER NOTES			

TECH NAME	**Dashboard/Display for Shaping Occupant Behavior**	***TECH ID***	**T095**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Energy feedback displays have been tested mostly in residential contexts, but there is applicability in commercial buildings, too. The technical barriers are addressable, though fundamental research is required to better understand how information can be used to influence behavior. The technology could be ready for wide adoption across a range of building types. An X-factor score of "1" was given to reflect the fact that dashboard technologies could integrate a very broad range of building energy data, including PV generation, energy storage, electric vehicle charging, etc.…

➔ *RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION*

1. Research is needed to understand the theoretical drivers of energy-related behaviors, building upon existing knowledge from behavior science. In particular, further investigation is needed to understand the role of information/feedback, to determine whether, and under what conditions, providing better information (alone) stimulates persistent behavior change, the nature of those changes, and the relative effectiveness of various feedback mechanisms.

2. Research is needed to better understand the interactions between feedback, energy pricing and control technology. Such work could further develop on-demand energy savings platforms/programs that use dashboards/displays to provide information on real-time energy use, strategies for curtailing demand, and available financial incentives, and measure the impact on peak demand and energy consumption.

3. Research is needed to understand how to engage building occupants to use energy dashboards, promote active participation, and retain dashboard users. Research is also needed to understand how the optimal techniques may vary by building or organization type, demographic or other factors.

➔ *KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES*

Bates, N. et al (2016). Re-Examining HPC Energy Efficiency Dashboard Elements. *IEEE Xplore Digital Library*.

Matenaer, M. et al. (2016). On Demand Savings: Introducing Demand Management in an Efficiency World. Conference Paper: *ACEEE Summer Study on Energy Efficiency in Buildings*.

Moezzi, M., & Janda, K. B. (2014). From "if only" to "social potential" in schemes to reduce building energy use. *Energy Research & Social Science*, 1, 30-40.

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Staddon, S. et al (2016). Intervening to change behaviour and save energy in the workplace: A systematic review of available evidence. *Energy Research & Social Science*.

Stuart, G. et al (2016). Closing the Feedback Loop: A Systems Approach to Supporting Community-wide Behaviour Change in Non-Domestic Buildings. Conference Paper: *ACEEE Summer Study on Energy Efficiency in Buildings*.

➔ *ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES*

TECH NAME	**Social Media Platforms**	**TECH ID**	**T096**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Social media platforms to convey information to and engage one or more groups of occupants around energy-related issues in buildings.

APPLICABILITY			
GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	Single family residential, Low-rise multifamily residential, High-rise multifamily residential	**COMMERCIAL BUILDING TYPE**	Small office, Large office, K-12 school, Higher education
APPLICABLE IN CLIMATE TYPES	All		
ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?			
TODAY	10% or less	**AT MATURITY**	10% or less
TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.			
TODAY	Demonstration/pilot phase	**IN 5-7 YRS.**	Demonstration/pilot phase
PERFORMANCE			
CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Digital forum for communication	**IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION**	Platform to implement behavior change efforts (e.g., comparison, competition, social marketing, crowdsourcing information)
COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?			
FIRST COST	No	**O&M COST**	No
COST BARRIERS	Cost reductions, if any, would come from designing flexible tools that can be easily customized to different buildings/occupants/behavior-change objectives		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Occupant acceptance/familiarity, Privacy Heterogeneity in buildings
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects
IMPORTANCE TO ZNE	Very cost-competitive when mature, Public/occupants will like it
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

Social media platforms have been used in a variety of contexts, but more so for residential. They are fairly inexpensive to develop, and is being pursued by many entities, along for a greater pool of knowledge that can be leveraged for technology advancement (hence the X-factor of 1).

TECH NAME	**Social Media Platforms**	***TECH ID***	**T096**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

1. Research is needed to determine how best to adjust occupant engagement strategies across multiple social media applications (i.e., web vs. mobile) and ensure interoperability.
2. Research is needed to determine how best to leverage storytelling and the use of compelling narratives in social marketing campaigns launched on social media platforms.

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

Gordon, R. et al (2018). Storying energy consumption: Collective video storytelling in energy efficiency social marketing. *Journal of Environmental Management*.

Munoz, A. et al (2016). Mobile social media for smart grids customer engagement: Emerging trends and challenges. *Renewable and Sustainable Energy Reviews*.

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***

Munoz et al: *“Engagement strategies need adjusting [for] multiple delivery channels, including web and mobile applications. To facilitate the emergence of the smart customer, service providers need to address several market challenges, such as the need to design for interoperability and to consider how to better integrate existing standards from different applications domains.”*

TECH NAME	**Software & Platforms for Behavior Change Programs**	***TECH ID***	**T097**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

→ TECH DESCRIPTION – ENTER TEXT HERE TO BRIEFLY DESCRIBE THE TECHNOLOGY IN 1-2 SENTENCES

Occupant engagement

APPLICABILITY

GREATEST OPPORTUNITY	Equal for both new construction and retrofit		
RESIDENTIAL TYPE	All	***COMMERCIAL BUILDING TYPE***	All
APPLICABLE IN CLIMATE TYPES	Benefits in all climates, but greatest benefits in more severe climates		

ENERGY BENEFIT COMPARED TO MINIMALLY CODE-COMPLIANT TECHNOLOGIES OR APPROACHES?

TODAY	10% or less	***AT MATURITY***	10% or less

TECHNOLOGY READINESS ON THE SPECTRUM OF MATURITY IN A NATURAL MARKET-DRIVEN PROGRESSION.

TODAY	Demonstration/pilot phase	***IN 5-7 YRS.***	Demonstration/pilot phase

PERFORMANCE

CURRENT PERFORMANCE, FEATURES, FUNCTIONALITY	Custom programs (with or without digital tools) that leverage competition, social comparisons, motivation, encouragement/feedback, community-based social marketing or benchmarking	***IMPROVEMENTS NEEDED TO BE READY FOR MAINSTREAM ADOPTION***	Robust software & platforms to integrate multiple behavioral levers in a single, flexible tool with broad applicability

COST DECREASE REQUIRED TO BE COMPETITIVE RELATIVE TO CURRENTLY AVAILABLE TECHNOLOGY?

FIRST COST	Don't know	***O&M COST***	Don't know
COST BARRIERS	Software development, data integration, user recruitment		

OTHER INFO ON THE TECHNOLOGY

OTHER BARRIERS	Occupant acceptance/familiarity, Data privacy/comparability
RESEARCH FOCUS AREAS IDENTIFIED BY SURVEY PARTICIPANTS	Product design evolution (new/improved features, performance enhancements, etc.), Performance validation/product testing/simulation, Demonstration projects, For commercial buildings, integration with utility data and benchmarking tools
IMPORTANCE TO ZNE	Broad applicability (e.g., to number of buildings, building types, etc.), Very cost-competitive when mature
TEAM REVIEWER NOTES	

→ RATIONALE FOR SCORES, ESPECIALLY THE X-FACTOR

TECH NAME	**Software & Platforms for Behavior Change Programs**	*TECH ID*	**T097**
CATEGORY	Occupant behavior focused technology (e.g., controls, dashboards)		

➔ ***RESEARCH GAP ARTICULATION – THE CRITICAL UNANSWERED RESEARCH QUESTION/S THAT WOULD MAKE THE TECH READY FOR FULL MARKET ADOPTION AND ENABLE ZNE – USE THE GUIDANCE IN THE WORD DOC SHARED WITH THE TEAM TO FILL THIS SECTION***

➔ ***KEY REFERENCES – SUCH AS CEC, ETP, CPUC, DOE, NREL OR OTHER STATE OR FEDERAL SPONSORED STUDIES AND REPORTS. ADD URLS OR REPORT REFERENCES***

➔ ***ANY SUBJECT MATTER EXPERT COMMENTS AND QUOTES***