Commercial Replacement & Attachment Window Solutions

Market Transformation Initiative Plan

June 26, 2026

CalMTA is a program of the California Public Utilities Commission (CPUC) and is administered by Resource Innovations

Commercial Replacement and Attachment Window Solutions

Market Transformation Initiative Plan

June 26, 2026

Prepared by:
Rick Dunn, Strategy Manager
Nick Fiore, Program Manager

Resource Innovations
719 Main Street, Suite A
Half Moon Bay, CA, 94019
(888) 217-0217
info@calmta.org

CalMTA is a program of the California Public Utilities Commission (CPUC) and is administered by Resource Innovations

Purpose

This Market Transformation Initiative (MTI) Plan describes the business case for investment in the MTI including strategic interventions, intended market outcomes, and evaluation activities that will be implemented during Phase III: Market Deployment. This investment would result in long-term energy efficiency and other benefits for California. The MTI Plan was developed using the findings of Phase II assessment and research, which are detailed in the appendices of this document. Development of the MTI Plan followed the stage gate process described in the approved Market Transformation Framework in D.19-12-021. The research findings and plan elements have been shared with CalMTA's Market Transformation Advisory Board (MTAB) throughout development. The MTAB also had the opportunity to review and provide comments and feedback on the plan, which are included in Appendix I of this plan. All MTAB meetings are public and interested parties will have an opportunity to comment via a California Public Utilities Commission (CPUC) application proceeding.

MTI development documents by phase

Additional information on CalMTA and the MTI development process can be found at https://calmta.org.

The Advancement Plan for this MTI can be found at https://calmta.org/resources-and-reports/.

Contents

List of Abbreviations

Abbreviation	Definition
ACEEE	American Council for an Energy-Efficient Economy
AERC	Attachments Energy Rating Council
AHAM	Association of Home Appliance Manufacturers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMA	Baseline Market Adoption
BOMA	Building Owners & Managers Association
BPS	Building Performance Standard
BTO	Building Technologies Office
BUILD	Building Initiative for Low-Emissions Development
CalEHP	California Electric Homes Program
CalMTA	California Market Transformation Administrator
CalSHAPE	California Schools Healthy Air, Plumbing and Efficiency Program
CAMR	Comprehensive Affordable Multifamily Retrofits
CARB	California Air Resources Board
CBEA	Commercial Building Efficiency Accelerator
CBO	Community-Based Organization
CEC	California Energy Commission
CEDA	California Energy Design Assistance
CERI	Commercial Energy Reduction Initiative
ComEd	Commonwealth Edison
C-PACE	Commercial Property Assessed Clean Energy
CPUC	California Public Utilities Commission
CRAWS	Commercial Replacement and Attachment Window Solutions
CRE	Commercial Real Estate
CRTU	Commercial Rooftop Units
CSW	Commercial Secondary Window
DEER	Database for Energy Efficiency Resources
DOE	Department of Energy
DR	Demand Response
EPA	Environmental Protection Agency
EPIC	Electric Program Investment Charge
ESA	Energy Savings Assistance
ESCO	Energy Service Company
ESJ	Environmental and Social Justice
ESRPP	ENERGY STAR Retail Products Platform
eTRM	Electronic Technical Reference Manual
GHG	Greenhouse Gas
GSA	General Services Administration
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IFMA	International Facility Management Association
IMT	Institute for Market Transformation
IOU	Investor-Owned Utility

Abbreviation	Definition
LADWP	Los Angeles Department of Water and Power
LBNL	Lawrence Berkeley National Laboratory
Low-e	Low emissivity
MC3	Multi-Craft Core Curriculum
MNCEE	Minnesota Center for Energy & Environment
MPI	Market Progress Indicator
MT	Market Transformation
MTAB	Market Transformation Advisory Board
MTI	Market Transformation Initiative
MUSH	Municipal, University, Schools and Hospitals
NCCT	Northern California Construction Training
NEB	Non-Energy Benefit
NEEA	Northwest Energy Efficiency Alliance
NEEP	Northeast Energy Efficiency Partnerships
NFRC	National Fenestration Rating Council
NLR	National Laboratory of the Rockies
NOx	Nitrogen Oxides
NYCHA	New York City Housing Authority
NYSERDA	New York State Energy Research and Development Authority
OBF	On-Bill Financing
ORNL	Oak Ridge National Laboratory
PA	Program Administrator
PAC	Program Administrator Cost
PAWS	Partnership for Advanced Window Solutions
PG&E	Pacific Gas and Electric
PNNL	Pacific Northwest National Laboratory
REEO	Regional Energy Efficiency Organization
ROI	Return on Investment
RFI	Request for Ideas
SB48	Senate Bill 48
SCT	Societal Cost Test
SEM	Strategic Energy Management
SHGC	Solar Heat Gain Coefficient
SoCalREN	Southern California Regional Energy Network
SPR	Single-pane replacement
TOU	Time-of-Use
TSB	Total System Benefit
TMA	Total Market Adoption
TRC	Total Resource Cost
USGBC	US Green Building Council
VIG	Vacuum Insulated Glass
WE&T	Workforce Education and Training

1 Executive summary

The Commercial Replacement and Attachment Window Solutions (CRAWS) Market Transformation Initiative (MTI) offers a significant opportunity to improve energy efficiency and reduce carbon intensity of buildings through improved building envelope thermal performance and downsized heating, ventilation, and air conditioning (HVAC) systems. The retrofit technologies of Commercial Secondary Windows (CSW) and Vacuum Insulated Glass (VIG), as defined in Section 1.1 below, offer a simpler installation process and substantially lower installation costs compared to full window replacements. Although windows on average comprise approximately 15% of a building's exterior surface, they are responsible for HVAC losses of approximately 40%. This equates to approximately 12% of a typical building's overall energy use.[1]

There is a growing recognition that replacing poor-performing windows should be a prerequisite to decarbonization in existing commercial buildings. Statewide building performance standards (BPS) are in the early development phase in California, creating a sense of urgency to prepare the existing commercial building market to enable compliance. Improving window performance has historically been a higher priority in colder climates, but high solar heat gains in California, particular during peak load periods, create a need for better window performance to meet the state's aggressive decarbonization goals.

California did not mandate double-pane glass in commercial new construction until the year 2000 and early versions of double-pane windows did not include low-emissivity (low-e) coatings that reduce solar heat gain.[2] This MTI will seek to address the 73% of commercial building floor space in California that still contain single-pane and double-pane clear windows.[3,4] The initial target market for this MTI will be owner-occupied buildings in the municipal, university, school, and hospital (MUSH) market with an emphasis on the installation of CSW and VIG in buildings within environmental and social justice (ESJ) communities. Long-term, this MTI will target all commercial building types, with the exception of those with very low window-to-wall ratios, such as warehouses.

---

[1] Pratt & Wynne. (2023). Commercial Secondary Windows Field Test (Report #E23-341). Prepared by Energy 350 for the Northwest Energy Efficiency Alliance (NEEA).

[2] Eley & Pennington. (2002). Requiring High Performance Windows in California. Eley Associates & California Energy Commission (CEC).

[3] For more information related to California's commercial building window characteristics, please refer to Section 4 of Appendix D: Market Characterization.

[4] Glass without low-e coatings is known as "clear" glass. Please refer to Section 3 for more information related to the impacts of low-e coatings.

1.1 Technology overview

CSWs are retrofit solutions designed to improve the energy efficiency of existing buildings by adding panes of glass, polymer, or acrylic to current windows, without the need for existing window and frame replacement. These products, which may feature low-e coatings, insulating gases, thermal films, or VIG units, offer easier and more cost-effective installation compared to traditional glazing or window replacement. CSWs are particularly advantageous in California's mild climate, where they help reduce cooling loads and enhance envelope performance.

VIG are high-performance glazing units with a vacuum between the glass panes, designed to fit existing window frames that have either single-pane or double-pane clear glass. Improved technology has made vacuum-sealed glass more durable and thinner, enabling slim VIG units to be used for glass replacement where single-panes or double-panes once were.

The CRAWS MTI will include CSW and VIG products with the following attributes:

- For all products, a maximum solar heat gain coefficient (SHGC) of 0.25[5]
- For CSW products, a maximum U-factor of 0.35[6]

By targeting buildings with clear glass windows, this MTI can deliver substantial energy savings. CalMTA models estimate that adoption of CSW and VIG would save about 9% annually in whole-building energy costs, averaged across building types and California climate zones.[7]

1.2 Market overview

Single-pane and double-pane clear windows are installed in 4.8 billion square feet, or 73%, of commercial building floor space in California.[8] This represents a substantial addressable market for retrofit solutions. In the commercial window market, replacements are rare unless there is a failure, often resulting in windows remaining in place for 40 to 70 years.[9] When building owners evaluate window upgrade options, architects and glazing contractors are the primary sources of

---

[5] SHGC is a ratio where 1 equals the maximum amount of solar heat allowed through a window, and 0 equals the least amount possible allowed through. A SHGC rating of 0.25 means that approximately 25% of the available solar heat is able to pass through the window. For more information related to SHGC requirements in California, please refer to Section 6.1 of Appendix C: Product Assessment.

[6] U-factor measures a window's insulation efficiency, with lower values indicating better energy performance. For more information related to U-factor requirements in California, please refer to Section 6.1 of Appendix C: Product Assessment.

[7] For details related to CalMTA's energy modeling and customer bill impact analysis, please refer to Section 8 of Appendix C: Product Assessment.

[8] For more information related to California's commercial building window characteristics, please refer to Section 4 of Appendix D: Market Characterization.

[9] Birchfield et al. (2024). Commercial Windows Market Study and Measure Package Development (Report #ET23SWE0018). Prepared for CalNEXT by Energy Solutions.

information and guidance. However, HVAC engineers and designers exert a notable influence during the early stages of building renovation planning and are typically involved before façade or window specialists. This creates a structural market dynamic that places window solutions at a lower priority compared to other renovation elements.

Several factors play a key role in shaping decisions about window upgrades and an "envelope-first" approach. Utility incentives, regulatory compliance requirements (such as Title 24 and BPS), and the availability of public funding (e.g., rebates and tax credits) are identified as important levers. Energy Service Companies (ESCOs) highlight that windows are rarely upgraded unless the out-of-pocket expense for building owners is low, emphasizing the importance of incentives for retrofit projects.

CalMTA's research indicates CSWs represent a very small share of the California commercial window retrofit market. VIG is a nascent technology with near-zero market adoption. The business benefits for consumers of CSW and VIG include:

- Energy benefits such as reduced HVAC load in both heating and cooling-driven climates, even in California's mild climate, resulting in reduced peak load impacts, decreased energy consumption, and added potential for peak-shifting.[10]
- Non-energy benefits (NEBs) like increased thermal comfort, noise reduction, maximized daylighting, climate resilience during extreme weather events, more comfortable participation in demand response (DR) events, and as a tool for making historic building improvements without disruption to existing frames.
- Compared to traditional full window replacement, both CSW and VIG installations are minimally disruptive to occupants, often requiring no displacement.
- Compared to traditional full window replacement, and depending on the application, CSW installations can be as much as 90% less expensive.[11]

Barriers to the adoption of CSW and VIG include misperceptions about the energy impacts of single-pane windows in mild climates, product costs, lack of awareness of both the products and the benefits of taking an envelope-first approach, and the challenge of quantifying both CRAWS technologies' significant NEBs. CalMTA believes that given time to intervene in the market, these barriers can be overcome to achieve widespread acceptance and adoption of CSW and VIG.

[10] For more information related to the benefits of peak-shifting, please refer to Section 2.6.
[11] Pratt & Wynne. (2023). Commercial Secondary Windows Field Test (Report #E23-341). Prepared for NEEA by Energy 350.

1.3 Vision

The overall MTI goal is for 14% of California's commercial window square footage (approximately 64 million square feet) in the addressable market to adopt CSW by 2047.[12] Commercial building owners will value the business benefits of taking an envelope-first approach and invest in these products as a key strategy to fully decarbonize their buildings. The imperative to act now is to help prepare the market and build awareness of CSW and VIG before BPS becomes a significant policy driver in California, thus preventing a situation where building owners install oversized heat pumps. If they invest in heat pumps first, it is unlikely that it will ever be cost effective to improve window performance, and California will permanently forfeit envelope-related benefits.[13] By overcoming awareness barriers, establishing the business case for CSW and VIG, addressing supply chain barriers, and thus altering the default "do-nothing" behavior, this MTI will increase the frequency with which CSW and VIG are evaluated by building owners as viable and cost-effective envelope upgrades.

1.4 Strategic interventions for Phase III

Based on learnings from the Phase II research, CalMTA proposes the following strategic interventions to overcome market barriers and drive market adoption during Phase III:

1) Leverage strategic interventions of Commercial Rooftop Units (CRTUs) and Commercial Building Efficiency Accelerator (CBEA) MTIs
2) In-field demonstrations
3) Development of envelope-first business case for commercial buildings
4) Awareness-building with strategic partners and California external programs (e.g., SEM, commercial utility commercial energy efficiency programs, etc.)
5) Industry engagement for technical support and demand creation
6) Supply chain engagement for product enhancement and workforce development
7) Demand-generating marketing and support: awareness-building, education, and financial tools

For a detailed explanation of each strategic intervention, please refer to Section 2.2. Through these strategic interventions, California can accelerate the adoption of CSW and VIG.

---

[12] VIG for SPR is an emerging solution. Although there is not enough data yet to model its adoption, VIG plays an important role in the MTI. This MTI will update adoption figures, milestones, and market impact statements as VIG barriers are addressed and new data becomes available.

[13] For additional narrative related to forfeiting envelope-related benefits, please refer to the final paragraph of Section 2.1.1.

1.5 Recommendations

The CRAWS MTI plays a pivotal role in accelerating California's transition to improved building envelopes. Advancement to Phase III: Market Deployment will result in increased CSW and VIG adoption, deeper knowledge of envelope impacts on whole building efficiency, and enhanced supply chain development, all supported by targeted awareness-building and demand-generating strategies. By continuing field validation and scaling deployment, California can unlock cost-effective energy savings, reduce peak load impacts, and drive meaningful progress toward future commercial building energy efficiency goals. Advancing the CRAWS MTI to Phase III is recommended to leverage these insights and maximize impact.

A summary of investment and projected savings are shown in Table 1.

Table 1. Overview of the CRAWS MTI

Investment cycle	**Projected investment**		
Total Phase III investment needed to achieve TSB forecast (2027 - 2046):			$40,745,000
Phase III investment over initial CalMTA funding cycle (2027 - 2031):			$16,030,000
Phase II investment (2024 - 2027):			$4,225,000
Total investment including Phase II and Phase III investment (2024 - 2046):			$44,970,000
TSB (2028 - 2047)[14]	TSB - Energy	TSB - Grid	TSB - GHG
	$130.0M	$78.6M	$419.9M
TSB - Total			$628.5M
Cost Effectiveness (2024 - 2047)	TRC	PAC	SCT Base/High
	1.31	19.19	1.82/1.84

2 Market transformation theory & opportunity

2.1 Theory of market transformation

2.1.1 Brief product definition and benefits

CSW and VIG units are advanced window retrofit solutions that improve energy efficiency of existing building envelopes at a lower cost and with less complex installation than typical full window replacement. Both products are installed without removal of the existing window frame,

[14] Modeling starts in 2028, despite Phase III budget starting in 2027, because we only expect the enter the market in the fourth quarter of 2027 and modeling is done on an annualized basis.

which greatly simplifies installation, reduces or eliminates occupant disruption, and decreases installation costs.

CSWs are composed of a frame and one or more glass panes with optional low-e coatings. The CSW is installed over an existing window. The original window and frame remain in place and work in concert with the CSW to deliver improved efficiency. The added insulating pocket created between the CSW and the existing window improve the overall U-value of the system, reducing undesirable conductive energy transfer. Low-e coatings produce lower solar heat gain coefficients (SHGC), thus reducing undesirable solar heat gain. The seal created by the secondary window reduces air leakage.

VIG is a glass unit composed of two panes of glass, separated by spacers, and hermetically sealed with a vacuum drawn on the empty space between the panes. The vacuum seal significantly improves the U-value of the window and optional low-e coating reduces the SHGC. Installation requires replacement of the existing window glass with the VIG but retains use of the existing frame. Installation involves removal of original window seals and replacement with new seals, which reduces air leakage. The superior R-value performance of the VIG unit, even when combined with original frames, provides for a significantly more efficient window.

Both CSW and VIG deliver improved envelope energy efficiency, which reduces HVAC loads and enables HVAC downsizing when replacing equipment. They both contribute to peak-load reduction and enable peak-shifting while improving building resilience during extreme weather load-shedding events. Both technologies also deliver multiple NEBs, which have become an important driver for market uptake. Past programs and MTI research have identified that NEBs, such as improved thermal comfort and noise reduction, are primary drivers of adoption. In contrast, building owners and managers rank energy savings as a lower priority compared to NEBs.[15] Improved Indoor Air Quality (IAQ) is an additional benefit of the reduced air leakage offered by CSW and VIG. Areas with greater atmospheric pollution and elevated noise levels or near industrial areas, which are often ESJ communities, can particularly benefit from the improved IAQ and reduced noise. Reduced solar heat gain enables removal of, or lowers dependency upon, opaque shading devices, resulting in improved daylighting.

Action on the CRAWS MTI is time sensitive. The CRAWS MTI should create market awareness of the benefits of an envelope-first strategy for building retrofits *before* BPS or a similar statewide policy take effect in California and trigger large-scale building retrofits. Shifting from the incumbent "HVAC only" strategy to an envelope-first strategy for building retrofits will enable HVAC downsizing, which will deliver additional efficiency gains for California. For example, if building owners invest in heat pumps before evaluating the impact of envelope retrofits on HVAC

[15] Fernandes et al. (2025). Energy impacts of nationwide window upgrades in commercial buildings. Lawrence Berkeley National Laboratory

sizing, larger heat pumps will be installed, placing greater demand on the grid than if the envelope was first improved. Also, once an HVAC system is upgraded, it is highly unlikely that a subsequent envelope upgrade would take place, largely due to the HVAC system being up-sized to overcome an inefficient envelope and a longer return on investment (ROI) for the envelope upgrade, since the capital and operational cost-savings associated with HVAC downsizing is no longer a factor. The net result is permanently forfeited envelope-related peak load reduction and peak-shifting potential. The CRAWS MTI is *not* dependent upon BPS for success, but CRAWS interventions will be amplified by BPS and the proper sequencing of envelope and HVAC upgrades.

2.1.2 Target market

The target market for CRAWS is existing commercial buildings that were built before 2000 that still have windows with single-pane glass or double-pane glass without low-e coatings, often referred to as "double-pane clear."

Many commercial buildings in California have these types of inefficient windows because the state did not mandate double-pane glass for new commercial buildings until 2000; most buildings built before 2000 have retained their single-pane windows. Early versions of double-pane windows also did not include low-e coatings. Efficient window retrofits are therefore key to building decarbonization. According to CalMTA's Market Characterization, there are approximately 3.35 billion square feet of commercial floor space in California that utilize single-pane glazing and an additional 1.37 billion square feet that utilize double-pane clear glazing, representing approximately 73% of California commercial floor space.

CalMTA has near-term and long-term market strategies based on technology and market segments.

Initially, CalMTA will focus on owner-occupied submarkets (beachheads) within the commercial building sector because owner-occupied buildings have a longer ownership horizon and a stronger business case for efficient window investments. CSW, being a more mature technology with energy ratings from the Attachments Energy Rating Council (AERC), will be the near-term technology focus. Key beachhead markets that CalMTA will target in early Phase III activities include the MUSH market (municipal, university, schools, and hospitals). CSW also have a significant value proposition for hospitality and historic buildings because they offer valued NEBs like sound and comfort improvements. They also maintain the integrity of the original façade, which is required for updates to historical buildings. In addition, commercial buildings of any type that are already considering major retrofits or in need of HVAC replacement are also prime targets for CSW given the potential for a reduced investment in HVAC if poor-performing windows are improved.

For near-term ESJ opportunities, this MTI will specifically focus on CSW for small commercial buildings. CSW provide lower product and installation costs than VIG and are therefore more accessible solutions for small buildings within ESJ communities that have inefficient envelope performance and/or lack efficient HVAC. Because ESJ communities are often located in closer

proximity to commercial and industrial zones, they often experience poor IAQ due to atmospheric pollution and higher levels of noise pollution. The reduced air leakage and noise-reduction properties of CSW can be especially beneficial in ESJ communities.

Simultaneously, the MTI will work to address barriers and create longer-term opportunities in the broader commercial market, including commercial office space. Examples of barriers that require longer-term interventions include developing a rating methodology for VIG for single-pane replacement (SPR) and, for both technologies, overcoming high vacancy rates currently common in commercial office space. Longer-term opportunities include leveraging forthcoming CA BPS to drive adoption across broad commercial building segments.

This MTI recognizes that VIG for SPR is a less mature technology and application than CSW, but VIG plays an important and specific role in transforming the commercial building envelope market. VIG will be the preferred solution for architecturally driven projects like deep-energy retrofits, building renewal, and building repurposing (e.g., converting commercial office space to other uses). Offering the right product to the right market actors for the right application will create a larger addressable market, will help reduce market resistance to envelope retrofits, and will accelerate market transformation. Numerous activities must take place to prepare the market for VIG uptake and to reliably forecast VIG adoption.

2.1.3 Initiative vision

The cost and complexity of typical window replacements have prevented building owners from including window upgrades or replacements in standard building lifecycle management schedules, locking in HVAC losses of 40% across billions of square feet of commercial buildings.[16] Similarly, the cost of typical window replacements have precluded building owners from addressing non-energy-related window problems, such as noise and thermal discomfort caused by high solar heat gain. This default "do-nothing" behavior can be shifted with the emergence of window solutions that lower the cost and complexity of window retrofits that deliver energy and non-energy benefits.

The HVAC downsizing opportunity and recurring operational savings offered by window upgrades when HVAC replacement is undertaken provide another discrete market entry point for CSW and VIG.

Lastly, Senate Bill 48 (SB48) and the California Energy Commission's (CEC) forthcoming strategy for reducing energy use and emissions in California's commercial buildings, which is likely to result in a statewide BPS for California, is a powerful policy-related leverage point that can help drive adoption of CSW and VIG.

---

[16] (2022). Pathway to Zero Energy Windows Advancing Technologies and Market Adoption. National Laboratory of the Rockies (NLR).

By overcoming awareness barriers, establishing the business case for CSW and VIG, addressing supply chain barriers, and thus altering the default "do-nothing" behavior, this MTI will increase the frequency with which CSW and VIG are evaluated by building owners as viable and cost-effective envelope upgrades. The overall MTI goal is for 14% of California's commercial window square footage (approximately 64 million square feet) in the addressable market to adopt CSW by 2047, thus maximizing the impact of forthcoming climate policy.

2.1.4 Key market barriers

CRAWS faces the following key barriers that this MTI needs to overcome before broad market adoption can take place. Appendix A: Logic Model summarizes these barriers and maps them to the planned strategic interventions listed below.

- There are awareness and understanding-related barriers associated with the CRAWS MTI:
  - Low awareness of the energy and non-energy problems associated with single-pane and double-pane clear windows, even in mild climates.
  - Low awareness of energy and NEBs of alternative solutions to full window replacement.
  - Limited understanding of CSW and VIG performance characteristics.
  - Broad misunderstanding of the product costs among decision-makers.
  - Limited knowledge of cost and benefit tradeoffs between envelope and HVAC retrofits
- High first cost relative to the "do-nothing" incumbent behavior. Although CRAWS technology is less expensive than a full window replacement, it is more expensive than inaction.
- NEBs are not well-quantified for CRAWS technology and thus are difficult to monetize, handicapping ROI calculations that might otherwise drive increased adoption. NEBs are especially important to quantify because NEBs such as thermal comfort and noise-abatement are the top drivers considered by building owners when planning window upgrades. NEB quantification is also important because thermal comfort problems may actually be envelope performance problems, despite common association with HVAC performance.
- There are barriers related to supply chain immaturity:
  - CSW have several mature manufacturers with AERC-rated products, but the remaining supply chain is underdeveloped. Due to current low demand, manufacturers are the primary sellers and installers of equipment rather than distributors and third-party installers. This inhibits market awareness and product accessibility and may contribute to higher prices.
  - VIG is an emerging technology with several new companies beginning investment in manufacturing capacity. While VIG for new construction is a more mature market and therefore has more mature sales channels, VIG for replacement is a nascent market with

developing sales channels. Broad adoption of VIG for single-pane or double-pane replacement will also be dependent upon development of a rating methodology that establishes performance metrics when installing VIG in an existing window frame.

2.1.5 Market opportunities and key leverage points

This MTI will capitalize upon both market opportunities and preexisting points of leverage. Market opportunities are the market activities and forces that enable this technology to reach greater adoption. These are called out in Appendix A: Logic Model and are also mapped to the planned interventions that seek to exploit these opportunities in the strategic interventions below.

- Forthcoming policies limiting energy use and greenhouse gas (GHG) emissions in commercial buildings, resulting from SB48, will compel building owners to evaluate whole-building energy efficiency strategies. Market research conducted by the Northwest Energy Efficiency Alliance (NEEA) in 2021 reported that commercial window upgrades are far more likely to occur as part of larger retrofits projects.[17] In pre-2000 buildings, the dominance of single-pane glass will drive demand for affordable window solutions. The policy shifts will likely increase whole-building retrofit projects, which will increase the opportunity for wide-scale commercial window upgrades due to the state of California commercial building stock.
- The rollout of BPS nationally has resulted in development of new financial instruments to fund efficiency upgrades that have previously been difficult to finance because of long ROI measures and split incentives. Examples include green banks, green bonds, Commercial Property Assessed Clean Energy (C-PACE) loans, on-bill financing (OBF), and evolving ESCO models.
- Utilities' growing need for technologies that deliver load-shift, load-flex, and resiliency benefits aligns with the benefits provided by CRAWS technology. These benefits increase the likelihood for utility incentives, which are relatively rare for window solutions. Under normal operating conditions, CRAWS technology enables building operators to pre-cool or pre-heat a building to shift load to off-peak times and benefit from time-of-use (TOU) rates and future dynamic rates. During load-shedding events (load flex) and extreme heat events (resiliency), CRAWS technology will help maintain comfortable temperatures for longer periods of time.
- Federal and State investment in window solutions:
    - Federal:
        - In 2023, the Department of Energy (DOE) awarded $5.9 million to Alpen, a United States manufacturer of CSW, and $31.7 million to LuxWall, a manufacturer of VIG, to

[17] Hessels et al. (2021). Commercial Secondary Window Program Development Research (Report #E21-430). Prepared for NEEA by Cadeo Group.

expand domestic production capability. Both organizations leveraged those awards to attract additional private investment to expand production capabilities.

- In early 2024, DOE launched an American-Made Building Envelope Innovation Prize — Secondary Glazing Systems, which offers up to $2 million to encourage production of high-performance, cost-effective secondary glazing systems to improve efficiency of commercial windows.
- In January 2026, DOE's Advanced Research Projects Agency – Energy (ARPA-E) announced $5 million for 4four projects under the Galvanizing Leaps in Advanced Super Insulating Glass (GLASING) program to research new technologies, optimize existing technologies, and optimize manufacturing processes for low-cost, high-performance VIG that will deliver triple the thermal performance of today's widely used double-pane windows while maintaining competitive costs.

- California:
  - In 2023, the CEC approved agreement PIR-23-003 to support the evaluation of CSW technologies with GTI Energy for $864,506. The grant supported the installation of high-performance windows in an existing commercial building in Indian Wells, CA, in order to demonstrate and evaluate high-performance, energy-efficient, and cost-effective secondary window retrofit systems.

Key leverage points are points of aggregation that enable the MTI to reach a broader set of market actors at a reduced level of investment. Leverage points in market transformation often draw in other sources of funding to substantially amplify the market impact of the initial investment of ratepayer funds. CalMTA has identified several key leverage points and product benefits that this MTI will utilize to accelerate market adoption. These include:

- Partnership for Advanced Windows (PAWS): The DOE funds PAWS, led by Lawrence Berkeley National Laboratory (LBNL) and Pacific Northwest National Laboratory (PNNL) with support from Oak Ridge National Laboratory (ORNL) and the National Laboratory of the Rockies (NLR),[18] to address technology and market barriers associated with the performance and adoption of high-performance window solutions including CSW and VIG.
- BPS Hubs: In response to implementation of BPS in other states and jurisdictions, BPS Hubs have been established to deliver customizable best-practice and educational resources to support BPS policy compliance. These hubs, including the US Green Building Council - California (USGBC-CA) California Building Performance Standards Peer Learning

[18] The National Renewable Energy Laboratory (NREL) was renamed to the National Laboratory of the Rockies (NLR) in December 2025.

Collaborative (CalBPS PLC), provide critical market and technical support for building owners and service providers as BPS policy goes into effect.[19]

- Energy efficiency programs, including CalMTA's CBEA MTI that are engaged in market activities to drive improved envelope performance in a range of building types: numerous utilities and energy efficiency organizations, including MNCEE, NEEA, Commonwealth Edison (ComED), and New York State Energy Research and Development Authority (NYSERDA) have programs whose focus is the promotion and adoption of high-performance window solutions. While some of these programs focus on residential windows, their efforts include overall market awareness and education, which can be translated to commercial buildings. Program efforts can specifically influence the acknowledgment of the problems caused by poor-performing windows and the energy and NEBs of advanced window solutions. CalMTA's CBEA program includes numerous strategic interventions that are common to the CRAWS MTI including driving awareness of whole-building efficiency solutions, promoting benefits of an envelope-first strategy, and planning tools and savings calculators that help build the business case for whole-building retrofits. For more details on the CBEA program, visit CalMTA's CBEA webpage or reference the CBEA Advancement Plan. [20,21]
- Local codes: Local reach code programs and Climate Action Plans often encourage public sector building energy roadmaps that could include windows. Local energy benchmarking programs, such as San Francisco's, require periodic ASHRAE Level II energy audits which are a detailed facility analysis that identifies actionable energy efficiency upgrades.
- VIG manufacturers and LBNL are leading technical assessments, durability testing and VIG rating activities. CalMTA will participate in and influence these activities to ensure fit for CA markets without having to fund them using ratepayer dollars. VIG manufacturers, such as LuxWall, are actively field-testing and assertively marketing their solutions, validating performance, developing case studies and driving market awareness without dependency upon CalMTA funding. Other organizations are also driving awareness of innovative solutions like VIG. Fast Company, a leading business media brand with an editorial focus on technology innovation, recently recognized LuxWall as one of 2026's Most Innovative Companies in the energy efficiency category.

2.1.6 Conditions that would trigger transitioning out of market

Once this MTI achieves the market conditions detailed below, there will be sufficient momentum to allow CalMTA to begin to transition out of the market while continuing to monitor adoption

---

[19] Building Performance Hubs Accelerating the High-Performance Transition. Institute for Market Transformation (IMT) & Building Energy Exchange.
[20] CalMTA's CBEA webpage: https://calmta.org/commercial-building-efficiency-accelerator/.
[21] CalMTA's CBEA Advancement Plan: https://calmta.org/resourcereport/commercial-building-efficiency-accelerator-advancement-plan/.

progress. This is the point in time when funding levels reduce substantially while benefits continue to grow. For details on tracked MPIs and milestones, see Appendix F: Evaluation Plan.

- There is widespread availability of CSW and VIG solutions that are rated by AERC with a robust network of trained installers and glaziers.
- A majority of market actors in the building retrofit market (e.g., architects, design firms, ESCOs) and in the building operations market (e.g., owners, management groups) are aware of and understand the energy and NEBs provided by CSW and VIG.
- A majority of planned HVAC replacement or upgrade events include an envelope evaluation to quantify the impact of CRAWS technology for HVAC downsizing.

2.1.7 Market end state

CalMTA envisions a market end state where the following scenarios exist:

- California BPS or similar policies require envelope assessments as part of prescriptive and performance-based pathways.
- Gas and electric utilities promote CSW and VIG as envelope-first approaches to secure grid flex benefits.
- Building owners and operators use CRAWS technology to achieve energy and non-energy benefits, improve building resilience, and position buildings to be grid assets.
- 30% of the existing commercial building sector square footage that currently has single-pane or double-pane clear windows utilize CRAWS technology.[22,23]

2.1.8 ESJ approach

This MTI seeks to accelerate the adoption of high-performance window solutions while ensuring ESJ communities are not left behind in the transition. Many of these communities face poor-performing building envelopes and limited access to capital for upgrades. To address these challenges, the MTI integrates targeted interventions that expand equitable access, reduce upfront costs, and strengthen workforce participation, while embedding procedural equity through community engagement, co-design, and transparent reporting. Interventions are as follows:

- ESJ communities are disproportionately impacted by poor-performing building envelopes, inefficient HVAC systems, and proximity to commercial and industrial operations that worsen

[22] 30% represents the MTI reaching its estimated achievable potential. For more details see Appendix B: Market Forecasting & Cost-Effectiveness Modeling Approach, Section 2.1.
[23] Market share of 14% by 2047 for CSW in existing commercial window square footage is a market progress indicator (MPI) for this MTI. For details on tracked MPIs and milestones, see Appendix F: Evaluation Plan.

air quality and generate higher levels of noise. These communities often lack the financial capacity to pursue costly envelope upgrades, such as full window replacements. In collaboration with community-based organizations (CBOs), this MTI will focus early field demonstrations in ESJ communities to showcase practical pathways for accessing and implementing the energy, comfort, and IAQ benefits of affordable CRAWS technologies. Procedural equity will be embedded through community engagement, multilingual communication, and transparent reporting of the lessons learned.

- The envelope-first business case will emphasize the disproportionate benefits of CSW and VIG for ESJ communities, where improvements can lower operating costs, enhance comfort, and support better health outcomes in underperforming buildings. By positioning envelope upgrades as a prerequisite for HVAC right-sizing, this approach will help to establish long-term affordability and resilience for ESJ-priority buildings.
- This MTI will prioritize financing models that reduce or eliminate upfront costs for ESJ communities, leveraging tools such as green banks, green bonds, C-PACE, and OBF to expand equitable access to energy efficiency and emissions reduction projects. These models will also be designed to minimize long-term financial risk exposure for ESJ-serving building owners, ensuring sustainable participation.
- In partnership with manufacturers and CBOs, this MTI will develop inclusive training and outreach materials. Market-based training programs will prioritize accessibility for installation contractors located in and/or serving ESJ communities. Outreach materials will be designed to address diverse learning needs, including language accessibility, literacy levels, and technological fluency.

2.1.9 Theory and assumptions

The following conditionals explain the theory of market change for this MTI and the key assumptions the theory is based on.

- **If** we drive awareness of real-world energy and NEBs of CSW and VIG, **then** we will dispel myths that windows don't impact building energy performance in mild climates, and we will increase market commitment to exploring solutions that lower the cost and complexity of window retrofits.
    - Assumes that awareness and education programs can reach decision makers such as architects, design firms, building management firms, and ESCOs.
- **If** we develop a cohesive strategy for addressing envelope and HVAC solutions concurrently, **then** we will bring down the capital and operational costs of electrification and can create an envelope-first business case for commercial building retrofits.
    - Assumes field demonstrations can document the incremental savings opportunity and incremental value proposition associated with an envelope-first approach.

- Assumes that tools and processes can be deployed for the mass market to evaluate and communicate the interaction between building envelope and HVAC.
- Assumes that short- and medium-term utility incentives are available to include envelope evaluations as part of any HVAC upgrade or replacement.

- **If** we bring down the capital costs and/or improve the ROI of envelope upgrades, **then** we will be able to leverage green banks, ESCOs, C-PACE, and OBF to finance window solution projects.
  - Assumes that bundling of envelope and HVAC upgrades overcomes the ROI challenges of envelope-only projects and attract ESCOs and other financing entities to the opportunity.
  - Assumes that, while the MTI will focus initially on owner-occupied segments of the commercial building market, OBF and green leases can help overcome the split-incentive barrier common in the commercial office space market.
- **If** California implements a state-wide BPS or similar policy to manage energy efficiency and emissions of existing commercial buildings, **then** the occurrence of whole-building retrofits will increase significantly above the current rate of approximately 1% per year[24] and demand for window solutions will increase.
  - Assumes that BPS targets will be aggressive enough to require envelope upgrades in a significant percentage of existing buildings using single-pane or double-pane clear glass.
  - Assumes that BPS enforcement will drive building retrofits as opposed to other responses such as paying fines or installing renewable energy resources.
- **If** building owners are compelled to investigate window solutions, either voluntarily by the strength of the business case or mandated by state policy and have the financial tools to fund or finance window upgrades, **then** they will demand CSW and VIG products.
  - Assumes a rating methodology is developed for VIG.
  - Assumes utilities include CSW and VIG as part of their commercial energy efficiency programs.
  - Assumes incentives are available to evaluate envelope upgrades as part of HVAC projects.

[24] Burns. (2023). US will need to triple retrofit rate to meet decarbonization targets: JLL.

2.2 Strategic interventions

Below are the strategic interventions that this MTI will deploy to overcome barriers in the commercial retrofit windows market. The list includes a general description of the intervention, market barriers the intervention will work to address, market opportunities it will exploit, and key outcomes. Many of the interventions will work to support multiple outcomes as detailed in the graphic Logic Model contained in Appendix A: Logic Model. Barrier and opportunity numbers referenced below correspond to the barriers and opportunities as displayed in the graphic Logic Model. Please also see the "Evaluability Map" Attachment to Appendix F: Evaluation Plan for details on the outcomes, their associated MPIs, and expected Milestones.

Strategic intervention 1	**Leverage strategic interventions of CRTU and CBEA MTIs** The CRAWS MTI will coordinate with and leverage the interventions in two CalMTA MTIs: CRTU and CBEA, both of which are currently in Phase II. Coordination will aim to overcome barriers associated with CRAWS and to amplify the effects of CBEA interventions. This MTI is not dependent upon advancement of either the CRTU or CBEA MTI, but can benefit from coordination and collaboration where interventions overlap or offer synergies that amplify outcomes. **CRAWS and CRTU MTIs strategic intervention coordination:** Coordination with the CRTU program will include field pilots that demonstrate the incremental HVAC savings opportunity when windows are upgraded as part of a planned retrofit project. This coordination will explore two scenarios; in each scenario, the building will have to demonstrate characteristics that make it a good candidate for a window upgrade (e.g., pre-2000 construction, single-pane or double-pane clear windows, reported thermal comfort issues): 1. **Concurrent window/HVAC upgrade.** We will seek out planned CRTU replacement projects where timelines allow for a proposal to include an envelope evaluation and documentation of HVAC downsizing potential, should windows first be upgraded with CRAWS technology. This scenario will allow us to document both **one-time capital equipment cost-savings** and **recurring HVAC operational savings**. We will work with the building owner to pitch the value proposition of, and business case for, a combined envelope/HVAC upgrade. Where possible, we will include ESCOs to learn how these projects can be structured to present a strong business case for ESCO financing, how ROIs are impacted by a portfolio approach of combining a historically difficult-to-finance measure (window upgrades) with shorter ROI measures (HVAC). One of the largest CSW manufacturers already works with ESCOs on envelope-only projects, providing confidence that ROI enhancement via this intervention is a reasonable strategy to explore with willing financial partners. 2. **Window upgrade post-HVAC upgrade.** The primary market for the CRTU MTI is the "unplanned replacement" market, which is not conducive to introducing envelope retrofit opportunities. When the CRTU team is engaged in field pilots where the HVAC upgrade is completed or far enough along that window upgrades *cannot* be included in time to downsize the HVAC system, we will pursue a window upgrade following the HVAC installation. We will then leverage the presence of connected controls to evaluate the HVAC performance before and after the window upgrade to evaluate **recurring HVAC operational savings**. We can potentially use operational data to estimate downsizing potential.

	Both approaches will also inform CBEA strategic interventions, providing real-world data, business cases, and case studies that can be used to promote envelope measures in pathways to BPS compliance, resulting in greater TSB gains than if envelope upgrades are assumed to be cost-prohibitive. **CRAWS and CBEA MTIs strategic intervention coordination:** The CRAWS MTI will coordinate with and leverage the strategic interventions of the CBEA MTI. This collaboration is synergistic in that the collaboration will enhance the efforts and amplify the impacts of both MTI programs. Collaboration will include coordinated outreach by the two programs in order to optimize communications and avoid competing for market actor time. CRAWS benefits from, but is not dependent upon, advancement of the CBEA MTI. Should the CBEA initiative not advance, the interventions described below would still be carried out independently by the CRAWS MTI team. • **Market actor engagement. Engagement with commercial building market actors, including building owners and management professionals,** will be used **to create a business case** for window upgrades (CRAWS) and for long-term planning (CBEA). Coordinated engagement with these market actors will hope to increase inclusion of window upgrades in long-term planning with two intended results: (1) an increased adoption of CSW and VIG; (2) greater savings potential for whole building retrofits that historically exclude window upgrades, which aims to benefit CBEA. By approaching market actors together with a unified value proposition, we expect a greater likelihood of building owners and operators receiving these related efforts as part of a cohesive building management strategy to increase asset value via accumulation of energy and non-energy benefits, instead of discrete and/or unrelated opportunities to achieve energy savings alone. • **Identification and promotion of financing mechanisms** such as green leases, C-PACE, and ESCOs. Both programs face similar barriers associated with financing larger-scale projects such as window upgrades and whole-building retrofits. A coordinated effort between programs to inventory existing financing mechanisms, identify appropriate use-cases for each mechanism, and identify financing mechanisms specific for ESJ communities will avoid duplicative efforts. • **Development of financial calculators.** CRAWS will collaborate with the DOE to expand the functionality of an existing CSW savings calculator that was originally developed by NEEA and now managed by LBNL as part of the DOE's PAWS collaborative, to ensure applicability for California climate zones and building stock. The CSW savings calculator delivers estimated energy savings associated with window upgrades. The energy savings estimates can then be an input into the whole-building financial planning tool that is currently under

development by the CBEA program. Once completed, the CBEA tool will help articulate the value proposition for an envelope-first approach to whole building retrofits, which benefits both programs.

CRAWS, CBEA, and CRTU MTIs strategic intervention coordination:

- **Collaboration with utilities' commercial energy efficiency programs.** A coordinated outreach effort and engagement with utility commercial energy efficiency programs will simplify channels of communication, avoid duplicative effort, and present the portfolio of CalMTA commercial MTIs in a cohesive and holistic manner that enhances CalMTA's role as a valued partner.

CRAWS and CBEA MTIs synergistic benefits:

In addition to coordination on specific interventions, the CRAWS MTI will benefit from CBEA's intervention to engage with state and local jurisdictions to align policy development with market needs. This includes advocating for compliance deadlines that align with long-term capital planning timelines, thus enabling building owners and operators to schedule investments for high-cost measures (e.g., window upgrades) that would otherwise be bypassed due to high upfront costs and/or condensed compliance timelines.

This MTI will also benefit from coordination to help identify entry points for ESJ-serving contractors and training pathways by linking workforce preparation to broader whole-building retrofit planning and market education efforts. In addition, specifically benefiting from CBEA's workforce development activities to include creating a pool of qualified energy professionals who can deliver critical services to building owners, using benchmarking data to identify and prioritize holistic retrofit measures (e.g., window upgrades), developing comprehensive cash-flow analyses, and promoting upgrades aligned with ownership tenure and equipment life cycles.

CBEA has an additional intervention to engage with DOE, IMT, and NYSERDA because they are closely involved in supporting existing or forthcoming BPS. All three organizations have activities or advocacy promoting the benefits of an envelope-first approach to building retrofits via BPS. The BPS can inform CRAWS efforts to develop an "envelope-first" business case for compliance scenarios.

Market barrier(s) addressed and opportunities to exploit	**Barriers** • Barrier #2: High first cost relative to do-nothing; unfavorable ROI when HVAC benefits omitted • Barrier #4: High vacancy rate in commercial office space market, reducing appetite for improvements **Opportunities** • Opportunity #1: SB48 and forthcoming policy on commercial building energy use and emissions reduction • Opportunity #2: Meeting climate policy goals in pre-2000 buildings necessitates envelope improvement • Opportunity #3: DOE, National Labs, U.S. General Services Administration (GSA), CEC, Regional Energy Efficiency Organizations (REEOs) such as NEEA and MNCEE, and utilities (ComEd) testing and promoting window solutions; CalMTA MTIs (CBEA and CRTU) • Opportunity #5: BPS nationally is driving new financial and financing models for building upgrades
	Outcomes
Short-term outcomes (1-2 years)	Awareness of problem, solutions, and business case grows among market actors External energy efficiency programs include CRAWS technology in list of measures
Medium-term outcomes (3-5 years)	Municipalities include CRAWS as part of climate/energy action plans
Long-term outcomes (6-10+ years)	More municipalities include CRAWS as part of climate/energy action plans California BPS or similar policy includes CSW and VIG in prescriptive and performance-based pathways as means to meet California state efficiency and decarbonization goals

Strategic intervention 2  [25]	**In-Field demonstrations** Activities of the in-field demonstrations are as follows: • Document energy and NEBs of CSW and VIG in target markets

[25] Icon represents interventions with a focus on equity considerations.

	• Target sites where HVAC is being replaced to evaluate HVAC/envelope interactions • Demonstrate installation simplicity • Engage ESCOs where possible to evaluate business model and financing factors The above activities will be used to: • Generate case studies that use gathered field data to build the case for an envelope-first approach for retrofits and document energy and non-energy benefits • Support inclusion of CRAWS technology in the electronic Technical Resource Manual (eTRM) • Document best-practices and lessons learned about implementing envelope improvements In-field demonstrations are particularly important for the CRAWS MTI as the benefits of window upgrades are most compelling when experienced and socialized via case studies, as opposed to simply being modeled or estimated. Market characterization studies and field test reports from NEEA and market characterization reports from CalMTA have documented that key drivers for window upgrades – from building owner perspectives – are *NEBs,* such as thermal comfort, noise-reduction, and safety.[26,27] While modeling and/or lab-testing provide directional indication of how window upgrades deliver on these benefits, real-world data presents a stronger case that is more relatable to market actors and accounts for variables that may not be accounted for in modeling exercises. The demonstrations will also help overcome one of the awareness barriers relating to the role that windows play in thermal discomfort, even in mild climates. High solar heat gain from single-pane and double-pane clear windows is often attributed to or conflated with poor HVAC performance. Field data from demonstrations will allow us to disaggregate these issues and document the independent contribution of windows to thermal discomfort. Even energy savings estimations, for which there are numerous modeling software tools, rely on many assumptions that may or may not reflect the real-world condition of glazing in older buildings. Air-leakage is one

[26] Bensch et al. (2020). Commercial Window Attachments: Secondary Window Market Characterization (Report #E20-399). Prepared for NEEA by Evergreen Economics, Inc.
[27] Hessels et al. (2021). Commercial Secondary Window Program Development Research (Report #E21-430). Prepared for NEEA by Cadeo Group.

	example where modeling software may underestimate energy impacts by not sufficiently accounting for the real-world condition of windows in older buildings. Field data can also overcome limitations of modeling, such as underestimating heating/gas savings, to better inform the MTI's strategies on HVAC-envelope interactions, and can create a more compelling case study to market actors compared to models and extrapolations. For example, field data from this MTI's Phase II testing at Madison Elementary documented significant gas savings for rooms treated with CSW (44% and 35% savings respectively, for December 2025 and January 2026) compared to untreated rooms, even as modeling estimates forecasted more modest savings. A key benefit of CSW and VIG is that they can be installed more quickly and with far less disruption to occupants than a full replacement. CSW also has the benefit of local assembly, which provides local workforce development opportunities. Field demonstrations that highlight this benefit will support subsequent work with manufacturers and other supply chain actors to co-develop marketing and outreach materials. Field demonstrations will initially target our beachhead MUSH markets and buildings built before 2000 that still utilize single-pane or double-pane clear glass. We will engage with manufacturers who are seeking field validation opportunities in order to secure co-investment and/or in-kind contributions of material and labor. We will specifically seek opportunities in ESJ communities where we can evaluate IAQ improvements and noise-reduction and engage with CBOs for workforce development activities including on-site assembly and installation services for CSW. This focus also creates an opportunity to test how affordable CRAWS pathways, trusted-messenger outreach, accessible financing, and workforce strategies can support adoption in building types and communities that are often least well-served by traditional retrofit markets. Where possible, we will collaborate with other organizations who are conducting similar field work, including manufacturers (testing VIG secondary windows in California hospitality), CEC (testing CSW in Palm Springs hospitality), and DOE (funding demonstration projects as part of their $2 million Envelope Innovation Prize). As discussed in strategic intervention 1, we will also collaborate internally with the CRTU field demonstrations where possible. Including ESCOs where possible will provide early insights into the opportunities and challenges associated with creating favorable ROI scenarios that enable ESCO investment in window upgrades. While projects may be partially or fully funded via the MTI, we will investigate financing mechanisms suitable for the project scope and

	costs. These will include green banks, C-PACE loans, and OBF. Green leases are more applicable to commercial office space and other leased spaces and will be investigated when the MTI expands beyond beachhead markets.
Market barrier(s) addressed and opportunities to exploit	**Barriers** • Barrier #1: Building owners are not aware of the impact that poor-performing windows have on energy use, even in mild climates, and are not aware of CSW, VIG, and associated energy and NEBs • Barrier #3: NEBs are key drivers, but not well-quantified **Opportunities** • Opportunity #3: DOE, National Labs, GSA, CEC, REEOs (NEEA, MNCEE), and utilities (ComEd) testing and promoting window solutions; CalMTA MTIs (CBEA and CRTU)
	Outcomes
Short-term outcomes (1-2 years)	Awareness of problem, solutions, and business case grows among market actors CRAWS included in eTRM External energy efficiency programs include CRAWS technology in list of measures Market actor offerings reflect value proposition of NEBs in determining incentives and financing terms
Medium-term outcomes (3-5 years)	Municipalities include CRAWS as part of climate/energy action plans External energy efficiency programs increasingly offer incentives for CRAWS products. Incentives offered for evaluating envelope as part of HVAC updates CRAWS are increasingly recommended or evaluated by architects, design firms, ESCOs, CBOs, HVAC installers (i.e., specifier and influencer engagement increases) Adoption of CRAWS technology grows in CRE and MUSH markets and in ESCO portfolios Market actors, including funding and financing entities, recognize monetary value of NEBs and provide tailored and accessible mechanisms for ESJ financing

Long-term outcomes (6-10+ years)	More municipalities include CRAWS as part of climate/energy action plans Majority of market with single-pane and double-pane clear windows view CSW and VIG as standard products for improving building comfort and energy efficiency and as a standard practice for optimal HVAC sizing By 2045, 50% of planned HVAC replacements or upgrades include envelope evaluation Market penetration of CSW and VIG increase in target commercial building market sectors

Strategic intervention 3 	**Build envelope-first business case for commercial buildings** Strategic intervention 3 will develop business cases for each target market. Business cases will directly draw from real-world energy and NEB data from field demonstrations described in strategic intervention 2. Subsequent interventions describe how the business case will be communicated out to the market. The business case will include a problem statement, identification of solutions, the impact of those solutions on the problem, the cost to implement solutions and mechanisms for financing, and analysis of ROIs. The business cases will explore window-only upgrade scenarios as well as window/HVAC upgrade scenarios. Business cases will need to reflect the incumbent do-nothing behavior towards poor-performing windows. These business cases will be different from many other MT scenarios where the objective is to alter behavior from selecting an incumbent technology to selecting a new technology. CRAWS not only needs to create a value proposition for building owners and operators to select CSW or VIG, but **it also first** needs to compel building owners to see their existing windows as a significant problem worthy of any action at all. The team will tackle the activities below to create the business cases. **Document the problem**: We'll use data from field demonstrations to quantify the impacts of CRAWS to get building owners to recognize that windows are meaningful contributors to energy and non-energy problems and to view them as an actionable problem. For demonstrating energy impacts of CRAWS, we will focus on using field data to establish that conducted losses, air-leakage, and solar heat gain have significant detrimental impacts on energy usage. However, energy impacts alone do not present a compelling business case. Thermal comfort, noise abatement, and safety are key drivers of building owner action to address window-related problems. Research indicates that IAQ is a high priority for ESJ communities. We will use this information and results from the field studies to

	establish the role that older windows have on non-energy problems. Field data will be backed up by previous field work performed by other organizations, such as NEEA, and supported by laboratory data from LBNL and PNNL. **Document the benefits:** The team will calculate the financial savings from energy benefits using HVAC and utility bill data. Capital cost savings associated with HVAC downsizing are also quantifiable. To quantify the monetary value of NEBs, we will take a two-pronged approach. We will use previous research that documented the value estimation of NEBs for utility programs' cost effectiveness.[28] We will also conduct surveys with building owners, operators, appraisers and commercial real estate professionals. The goal of the survey is to determine the value difference (e.g., rent prices, occupancy rates, appraisal value, absenteeism, healthcare costs, occupant impacts, etc.) between spaces that have single-pane and double-pane clear windows and those with more-efficient windows. **Document the direct and indirect costs of solving the problem and accumulating the benefits:** Field demonstrations will document the purchase process and installation of CSW and VIG solutions. Installation documentation will focus on the simplicity of installation relative to window replacement and qualitative information relating to minimal occupant disruption and minimal impact on normal building operations. Material and labor costs will be documented. As discussed in strategic intervention 2, field demonstrations will explore financing mechanisms. The costs of financing will also be included in financial analyses and ROI calculations. **Establish the value proposition:** The most important part of establishing a value proposition is understanding what the decision-maker values. This will be different for different building types and ownership models. Different business cases will be developed for owner-occupied versus leased spaces. For example, the relatively short ownership periods of many commercial office spaces means that increased asset value may be more valued by this segment than higher rents or increased occupancy. Owners looking for a competitive advantage in a high-vacancy commercial real estate market may value thermal comfort, reduced noise, and IAQ. We expect owner-occupied MUSH market actors will similarly value these NEBs. Building upon existing market characterization work, this MTI will use the opportunity of field demonstrations to document the value system of the associated building owners to inform the development of the business case.
Market barrier(s) addressed and	**Barriers** • Barrier #1: Building owners are not aware of the impact that poor-performing windows have on energy use, even in mild climates, and are not aware of CSW, VIG, and associated energy and NEBs

[28] Caputo et al. (2017). Non-Energy Impacts Approaches and Values: an Examination of the Northeast, Mid-Atlantic, and Beyond. Northeast Energy Efficiency Partnerships (NEEP).

opportunities to exploit	• Barrier #2: High first cost relative to do-nothing; unfavorable ROI when HVAC benefits omitted • Barrier #3: NEBs are key drivers, but not well-quantified **Opportunities** • Opportunity #1: SB48 and forthcoming policy on commercial building energy use and emissions reduction • Opportunity #5: BPS nationally is driving new financial and financing models for building upgrades
	Outcomes
Short-term outcomes (1-2 years)	Awareness of problem, solutions, and business case grows among market actors Market actor offerings reflect value proposition of NEBs in determining incentives and financing terms
Medium-term outcomes (3-5 years)	CRAWS are increasingly recommended or evaluated by architects, design firms, ESCOs, CBOs, HVAC installers (i.e., specifier and influencer engagement increases) Adoption of CRAWS technology grows in: • CRE market • MUSH market • ESCO project portfolios Market actors, including funding and financing entities, recognize monetary value of NEBs and provide tailored and accessible mechanisms for ESJ financing
Long-term outcomes (6-10+ years)	Majority of market with single-pane and double-pane clear windows view CSW and VIG as standard products for improving building comfort and energy efficiency and as a standard practice for optimal HVAC sizing Market penetration of CSW and VIG increase in target commercial building market sectors Increasing number of funding and financing pathways for CRAWS including ESJ solutions

Strategic intervention 4 	**Awareness-building with strategic partners and California external programs (e.g., SEM, commercial utility Programs, etc.)** This intervention will utilize the outputs of strategic interventions 1 through 3 to create awareness and educate the market about the problems associated with single-pane and double-pane clear windows and the benefits of CRAWS technology. We will engage with a variety of strategic partners and California energy efficiency programs to provide and/or co-develop resources for driving awareness with their constituents and educating the market on the CRAWS value proposition specific to each audience. We will collaborate to leverage partners' existing program activities and/or develop new program activities to deliver the market outcomes described below. Stakeholders form two distinct groups. The first group is industry actors that work with building owners on upgrade and retrofit projects. The second group is utility and energy-related programs, which design, promote, and incentivize efficiency and decarbonization measures. Where possible, we will use existing communication channels. Where appropriate, engagement will be coordinated with the CBEA MTI team. Strategic industry partners will include: • Architects and trade organizations such as the American Institute of Architects (AIA) • Historic preservationists • Design-build firms • Building management organizations such as Building Owners and Managers Association (BOMA) • Facility management organizations such as International Facilities Management Association (IFMA) • American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) • CRE investment firms • ESCOs Strategic utility, policy, and energy program partners will include one or more of the following: • Utility commercial energy efficiency programs such as SCE Commercial Energy Reduction Initiative (CERI) and California Energy Design Assistance (CEDA)

	• Multifamily programs (for common areas) such as IOU Energy Savings Assistance (ESA) Multifamily Energy Savings Program, SoCalREN Multifamily Program, LADWP Comprehensive Affordable Multifamily Retrofits (CAMR) program • Utility programs focused on the MUSH market such as PG&E Government and K-12 Comprehensive Program, CEC California Schools Healthy Air, Plumbing, and Efficiency Program (CalSHAPE) • Utility SEM programs • Local and state energy benchmarking programs that require periodic energy audits • ESJ advocacy organizations • CBOs • Climate Action Plan and local reach code programs • BPS Hubs and utility accelerator programs Awareness and educational resources will include: • Technical product information on CRAWS technology, to address barriers associated with performance, ratings and specifications • Market sector specific case studies, testimonials and videos • Savings calculators • Business cases and ROI analyses • Available incentives • Funding and financing resources • Inventory of trained installers Awareness-building and education for the HVAC industry presents a challenge because improved windows can cause HVAC downsizing when the two systems are modified simultaneously. This works against the HVAC business model. However, thermal comfort issues can often be attributed to poorly performing HVAC even when the root cause is more attributable to poorly performing windows. Therefore, we will take different approaches to the HVAC opportunity for different market actors. Education about HVAC downsizing opportunities will be focused on market actors who are engaged in building design and retrofit because the building design phase represents the best opportunity to realize the cumulative effects of downsizing HVAC and performing envelope retrofits simultaneously. These include architects, design-build firms, building owners, and building managers.

	Education about window-related thermal comfort problems that are mistakenly attributed to HVAC performance will be the focal point for engagement with the HVAC industry, installers, and organizations such as ASHRAE. Case studies from previous CSW field pilots have highlighted the impact of window upgrades for improved HVAC performance, possibly eliminating a pain point for HVAC professionals. The MTI will participate in market-specific conferences and tradeshows. Hands-on lunch-and-learn events and site visits to view installations can be effective mechanisms for getting market actors comfortable with unfamiliar technology and overcoming pre-conceived notions.
Market barrier(s) addressed and opportunities to exploit	**Barriers** • Barrier #1: Building owners are not aware of the impact that poor-performing windows have on energy use, even in mild climates, and are not aware of CSW, VIG, and associated energy and NEBs **Opportunities** • Opportunity #5: BPS nationally is driving new financial and financing models for building upgrades
	Outcomes
Short-term outcomes (1-2 years)	Awareness of problem, solutions, and business case grows among market actors CRAWS included in eTRM External energy efficiency programs include CRAWS technology in list of incentivized measures Market actor offerings reflect value proposition of NEBs in determining incentives and financing terms
Medium-term outcomes (3-5 years)	Municipalities include CRAWS as part of climate/energy action plans External energy efficiency programs increasingly offer incentives for CRAWS products. Incentives offered for evaluating envelope as part of HVAC updates CRAWS are increasingly recommended or evaluated by architects, design firms, ESCOs, CBOs, HVAC installers (i.e., specifier and influencer engagement increases) Adoption of CRAWS technology grows in CRE and MUSH markets and in ESCO portfolios

	Market actors including funding and financing entities recognize monetary value of NEBs and provide mechanisms for ESJ financing
Long-term outcomes (6-10+ years)	More municipalities include CRAWS as part of climate/energy action plans Majority of market with single-pane and double-pane clear windows view CSW and VIG as standard products for improving building comfort and energy efficiency and as a standard practice for optimal HVAC sizing By 2045, 50% of planned HVAC replacements or upgrades include envelope evaluation Market penetration of CSW and VIG increase in target commercial building market sectors

Strategic intervention 5	**Industry engagement for technical support and demand creation** The MTI will engage with industry stakeholders who are already independently funded to resolve barriers to adoption of CRAWS technologies or that are in a position to help resolve barriers. • **DOE's American-Made Program**: The Building Envelope Innovation Prize for Secondary Glazing Systems was launched in 2024 with $2.1 million grant funding via the DOE's American-Made Program. This Prize grants financial awards for the development and production of high-performance, cost-effective secondary glazing systems to improve efficiency of commercial windows. CalMTA is a member of the Technical Advisory Group and is able to influence which technologies receive awards. 2024 Awardees are associated with numerous products that meet this MTI's product definition. The team did not include products and awardees in this report because they are currently confidential as of October 2025. • **DOE's PAWS**: PAWS is a collaborative effort that promotes cost-effective, high-performance window solutions for new and existing building stock. It includes supply side and demand side members, including government agencies and research organizations, REEOs, utilities, builders, and window-solutions manufacturers. The CSW working group is currently working on activities that will benefit this MTI. For example, the group is expanding an existing NEEA-developed CSW savings calculator to include California climate zones, building stock, and common HVAC types. The calculator is a valuable tool for estimating HVAC-related savings and downsizing opportunities when modeling and/or measurement and verification (M&V) are impractical. PAWS, via LBNL and PNNL, provided testing equipment and technical support to CalMTA for the Madera USD strategy test. Funded by the Building Technology Office (BTO), PAWS can influence the activities of BTO's

	Commercial Building Initiative Program, which researches and promotes innovative energy-saving building technologies. • **ENERGY STAR**: This MTI will work to influence ENERGY STAR® to develop a CSW product category. ENERGY STAR certifies residential interior and exterior storm windows but does not currently have a commercial secondary window category. At least one of the manufacturers of ENERGY STAR-rated residential storm windows, QuantaPanel, also produces CSW. Though most recognized for its residential program, ENERGY STAR does certify commercial products in three categories: appliances, food equipment, and Networking Infrastructure. AERC, another DOE-funded program, already provides a rating methodology for CSW, satisfying a key prerequisite for an ENERGY STAR certification program. • **AERC**: In addition to the aforementioned ratings for CSW, AERC's commercial working group, led by LBNL, is actively working to develop a VIG rating methodology. CalMTA is a member of the working group. • **National Labs (LBNL, PNNL, NLR):** In addition to the roles and work previously described for LBNL and PNNL, the labs conduct both field and laboratory testing to evaluate window performance and assist manufacturers in improving technical performance. NLR is active in testing VIG durability. LBNL conducted a VIG summit in 2023 where they brought together supply and demand side actors to strategize on barriers and opportunities relating to VIG adoption.
Market barrier(s) addressed and opportunities to exploit	**Barriers** • Barrier #1: Building owners are not aware of the impact that poor-performing windows have on energy use, even in mild climates, and are not aware of CSW, VIG, and associated energy and NEBs • Barrier #2: High first cost relative to do-nothing; unfavorable ROI when HVAC benefits omitted • Barrier #6: VIG: no standard methodology to rate installed performance **Opportunities** • Opportunity #3: DOE, National Labs, GSA, CEC, REEOs (MN CEE) and utilities (ComED) testing and promoting window solutions
	Outcomes
Short-term outcomes (1-2 years)	Awareness of problem, solutions, and business case grows among market actors

Medium-term outcomes (3-5 years)	AERC funding stable; commercial workgroup initiates VIG rating work CRAWS are increasingly recommended or evaluated by architects, design firms, ESCOs, CBOs, HVAC installers (i.e., specifier and influencer engagement increases) VIG rating method published; increase in number of manufacturers and products rated by AERC Adoption of CRAWS technology grows in target markets
Long-term outcomes (6-10+ years)	Majority of market with single-pane and double-pane clear windows view CSW and VIG as standard products for improving building comfort and energy efficiency and as a standard practice for optimal HVAC sizing ENERGY STAR agrees to include CSWs Market penetration of CSW and VIG increase in target commercial building market sectors

Strategic intervention 6 	**Supply chain engagement for product enhancement and workforce development** This MTI will engage with manufacturers of CSW and VIG on the following activities: • **Product enhancements**: There are already a wide range of CSW from multiple established manufacturers. The main focus of this effort will be to evaluate the need for additional features such as expanded options for operability, which can be important in schools, historical buildings, and other market segments. Historically, operable CSW present challenges for utility incentive programs due to lack of savings certainty. However, BPS will require solutions for all building types, including those with operable windows, and building owners will be required to submit annual data demonstrating that installed measures are meeting energy and GHG reduction targets. • **Documentation of product performance**: Encourage and, as needed, incentivize CSW manufacturers to submit products to AERC for rating. Work with manufacturers, NLR, and LBNL to test and document VIG durability. • **Product performance improvement**: Although reported occurrences of condensation issues with CSW are uncommon, concerns about condensation have been reported to be a significant barrier to adoption. This MTI

	will work with manufacturers and national labs to document the conditions that promote condensation and identify best practices for prevention and remediation.
	• **Material and installation cost reduction**: The greatest opportunity for reduced CSW material costs is to drive increased demand to achieve economies of scale. Most of the material components of CSW are used in volume in other window products, so source materials already benefit from broader market scale. However, the relatively small order sizes from manufacturers undermine buying power and bulk order discounting at a local level. Installation costs can be reduced by developing local workforces, thus eliminating the need for manufacturers to do direct install that is both more expensive and non-scalable. For VIG, cost-reduction opportunities will come with increased demand and maturing production processes that reduce product rework and/or failure. Little is known about installation costs or opportunities for reduction. VIG can be installed by existing networks of professional glaziers, so workforce development efforts will focus on training rather than organic development of new installers.
	• **Workforce development**:
	  ○ **CSW**: As part of go-to-market plans, manufacturers will need to develop strategies to transition from direct manufacturer install to using local installer companies. There is no obvious existing market actor to target for CSW installation. Window film installers have been used by some manufacturers in a limited capacity, but the skillsets for CSW installation are different than for film. Professional glaziers are likely not cost effective for a relatively simple CSW installation, but we will research this option. To facilitate workforce development, this intervention will prioritize training access for installation contractors, training centers, technical schools, and community colleges located in or serving ESJ communities. Universally offered pre-apprenticeship trade programs, as well as comprehensive and foundational training programs for various construction and manufacturing industries (such as the Multi-Craft Core Curriculum [MC3]), were identified as Workforce Education and Training (WE&T) opportunities relevant to CRAWS. These programs would benefit ESJ communities by job creation and benefit manufacturers by relieving them of the burden of delivering training programs themselves.
	  ○ **VIG**: Existing networks of professional glaziers are an appropriate resource for VIG installation but familiarity with VIG is low. This MTI will work with VIG manufacturers and organizations such as Northern California Construction Training to establish VIG training programs.

	○ Engage with existing trade allies and, particularly for CSW where limited installer and trade networks currently exist, work to develop new trade allies as appropriate.
Market barrier(s) addressed and opportunities to exploit	**Barriers** • Barrier #2: High first cost relative to do-nothing; unfavorable ROI when HVAC benefits omitted • Barrier #5: CSW & VIG: immature supply chain **Opportunities** • N/A
	Outcomes
Short-term outcomes (1-2 years)	Manufacturers provide installer training and self-installation resources
Medium-term outcomes (3-5 years)	Increase in number of regional suppliers and installers selling CRAWS product
Long-term outcomes (6-10+ years)	N/A

Strategic intervention 7	**Demand-generating marketing and support: awareness-building, education, and financial tools** Strategic intervention 7 focuses on assisting manufacturers to develop their own demand-generating marketing plans, messaging and go-to-market strategies for the California market. This intervention will leverage manufacturers' existing marketing budgets while improving messaging with data, case studies, and lessons learned from CRAWS field studies. The manufacturer-focused approach is in contrast to the other interventions, which focus on CalMTA-led awareness-building and market education efforts. Given the nascent stage of the CSW market, and as evidenced by low market awareness reported during the CSW market characterization, manufacturers either have limited marketing capabilities and/or are not getting traction with their marketing programs. There are three aspects to this intervention: • **Assimilating the various awareness and education materials generated via other interventions**

	• **Developing additional resources (e.g., financial tools) to aid in business development activities** • **Enable manufacturers to more effectively socialize the value proposition to broader audiences than current efforts are reaching** In addition to using awareness and education materials developed via other interventions, the MTI will work to identify and inventory relevant funding and financing resources and, where possible, collect or develop case studies showcasing how those financial resources have been utilized for commercial window upgrades. We will prioritize financing models such as green banks, green bonds, C-PACE, California's GoGreen Financing Program, and OBF to reduce or eliminate upfront costs in ESJ communities. We will specifically research and identify financial options that mitigate split-incentive barriers, such as green leases and energy savings agreements. We will work with financiers and financing programs to educate them about the value of NEBs and ensure that NEB value is reflecting in financing structure. We will identify and facilitate the dissemination of these information and financial resources to the relevant market actors while collaboratively working with CBO's and ESJ advocacy groups to effectively reach ESJ community decision-makers. We will work with manufacturers to identify industry conferences that reach target audiences such as school building decision-makers, lodging, architects, designers, building operations and maintenance organizations, municipalities, and utilities. We will identify audience-specific messaging that will overcome preconceived notions and outdated assumptions about window upgrades. One example is going beyond the energy-savings messaging for utilities and incorporating messaging about peak load reduction, load-shift, grid-flex, resiliency, and correcting faulty assumptions about costs and cost effectiveness.
Market barrier(s) addressed and opportunities to exploit	**Barriers** • Barrier #1: Building owners are not aware of the impact that poor-performing windows have on energy use, even in mild climates, and are not aware of CSW, VIG, and associated energy and NEBs **Opportunities** • Opportunity #5: BPS nationally is driving new financial and financing models for building upgrades (Green Banks, evolving ESCO models, C-PACE, OBF) enabling windows to be bundled and financed with other measures.
	Outcomes
Short-term outcomes (1-2 years)	Awareness of problem, solutions, and business case grows among market actors

	External energy efficiency programs include CRAWS technology in list of measures Market actor offerings reflect value proposition of NEBs in determining incentives and financing terms
Medium-term outcomes (3-5 years)	Municipalities include CRAWS as part of climate / energy action plans CRAWS increasingly recommended or evaluated by architects, design firms, ESCOs, CBOs, HVAC installers (i.e., specifier and influencer engagement increases) Adoption of CRAWS technology grows in CRE and MUSH markets and in ESCO portfolios Market actors including funding and financing entities recognize monetary value of NEBs and provide mechanisms for ESJ financing
Long-term outcomes (6-10+ years)	More municipalities include CRAWS as part of climate/energy action plans Majority of market with single-pane and double-pane clear windows view CSW and VIG as standard products for improving building comfort and energy efficiency and as a standard practice for optimal HVAC sizing By 2045, 50% of planned HVAC replacements or upgrades include envelope evaluation. Market penetration of CSW and VIG increase in target commercial building market sectors Increasing number of funding and financing pathways for CRAWS including ESJ solutions

2.3 ESJ communities

This MTI will serve the needs of ESJ communities and ensure they are not left behind in the transition toward high-performance window retrofit technologies. Poor-performing envelopes, inefficient HVAC systems, and limited access to financing create disproportionate burdens for low-income, pollution-burdened, and historically excluded communities. By embedding equity considerations directly into several of its strategic interventions, this MTI seeks to expand access, reduce cost barriers, and create workforce and wealth-building opportunities for ESJ-serving contractors and building owners through demonstrations, business-case development, awareness-building, and improved access to funding and financing pathways

Strategic Intervention 2 will conduct in-field demonstrations in ESJ communities, in partnership with CBOs. These demonstrations will highlight affordable CRAWS solutions and provide visible examples of energy, improved comfort, noise reduction, and IAQ benefits while also documenting resiliency impacts such as improved indoor comfort during heat waves, reduced exposure to outdoor pollutants (such as wildfire smoke events and agricultural dust), and enhanced resiliency that protects building operations during grid stress or outages. Demonstration sites in ESJ communities will help illustrate how building-level resilience supports community resilience by preserving safe and healthy spaces under extreme conditions. The MTI will emphasize procedural equity by ensuring multilingual engagement, community participation, and transparent sharing of results so that lessons learned are accessible and useful to the targeted communities and decision-makers.

Strategic Intervention 3 will build an envelope-first business case that emphasizes the disproportionate benefits of CRAWS for ESJ communities, including reduced operating costs, improved comfort, reduced disruptions to occupants, and healthier indoor environments. By positioning envelope upgrades as a prerequisite for HVAC right-sizing, the business case will support long-term affordability and demonstrate resilience by stabilizing indoor conditions during power outages or extreme temperature events, reducing reliance on oversized mechanical systems, and lowering peak energy demand that stresses the grid in ESJ commercial buildings. This work will also help to identify and communicate financing approaches that better reflect the full value proposition of CRAWS, including pathways responsive to ESJ community needs.

Strategic Intervention 4 will expand awareness by engaging strategic partners such as architects, design-build firms, utilities, and program administrators, while explicitly including ESJ advocacy organizations. This approach will ensure that the team includes ESJ advocates as trusted messengers on two key topics. First, advocates will increase awareness of poor-performing windows issues. Advocates will also work to increase the knowledge of ESJ-community based commercial building decision makers about CSW and VIG, including the technology's capacity for energy efficiency improvements and thus potentially reducing energy burdens. In addition, these strategic partners will support communicating the improved resiliency attributes of CRAWS technologies such as durability under extreme weather conditions, and

ability to mitigate smoke infiltration during wildfire events. They will also help share available information and financing resources relevant to adoption and highlight the appropriate outreach roles and feedback loops necessary to cultivate accessible education and adoption for the communities they serve.

Strategic Intervention 6 will engage the supply chain to improve product performance, reduce installation costs, and strengthen workforce pathways. By working with manufacturers and CBOs to co-develop inclusive training and outreach materials, this intervention will prioritize training access for installation contractors located in or serving ESJ communities, expanding workforce participation, and wealth-creation opportunities.

Strategic Intervention 7 will combine demand-side marketing, education, and financing to increase equitable access to the technologies. The intervention will provide clear and accessible education on CRAWS technology through tailored outreach and simplified savings tools. Simultaneously, the intervention will prioritize financing models such as green banks, green bonds, C-PACE, OBF, and other CBEA leveraged research and interventions to reduce or eliminate upfront costs in ESJ communities. Together, these activities will reduce both informational and financial barriers that have historically limited adoption in commercial buildings in ESJ communities.

2.4 Workforce development

Manufacturers will need to develop strategies to transition from direct manufacturer sales and installation to utilizing local sales distributors and installer companies as part of go-to-market strategies. Where possible, the MTI will focus on ESJ opportunities for workforce training and development.

This MTI will work with manufacturers and other relevant market actors to identify scalable workforce pathways that support broader market adoption. Early workforce approaches may be most viable when CRAWS-related skills are incorporated into adjacent existing work as a value-add capability, rather than relying on stand-alone demand for CRAWS installation.

Additionally, relevant training approaches may need to extend beyond installation technique to include recognizing appropriate project opportunities and communicating basic project needs and value propositions to customers and decision-makers. Demonstration projects and other field-based learning opportunities may also help market actors build familiarity with CRAWS technologies in a low-volume market.

This MTI will also engage with existing trade allies and, particularly for CSW where limited installer and trade networks currently exist, work to develop new trade allies as appropriate.

2.4.1 CSW

There is no existing market actor to target for all-in-one CSW sales and installation. As a result, sales and installation activities may need to be split in the early stages of the MTI. Manufacturers have used window film installers in a limited capacity for installation after the direct sale has been secured. However, window film installers are not the ideal CRAWS installer because window film is a competing and lower cost alternative to CSW that does not meet the CRAWS product specifications and does not provide the same level of energy and non-energy benefits. Additionally, the skillsets for CSW installation are different than for window film installation. This poses the risk of film installers converting CSW sales opportunities to film sales.

We will work with manufacturers to develop scalable go-to-market strategies that include the eventual expansion to independent sales distributors through existing commercial building material supply businesses. For installation services, we will work with manufacturers to provide training services to film and/or residential window installers. For the former, engaging film installers only after the sale has been secured mitigates the potential for lost opportunities. For the latter, because CSW install in a manner very similar to residential storm windows, these installers would see CSW as an incremental business opportunity rather than a competitive threat.

Glaziers are another industry stakeholder that are not ideal for sales and installation because they also offer a competing solution. Glaziers are also overqualified for simple CSW installations. Window replacements also offer a higher price product with more expensive labor, thus making CRAWS less attractive to glaziers (in fact, this could even undermine CSW sales). Previous market characterization research recommended segmenting the glazier population to identify smaller businesses that offer maintenance or daily repair services to buildings that could benefit from CSW.[29] This group is less likely to be performing larger scale window upgrades and therefore less likely to promote competing solutions. The skill level of technicians at smaller glaziers is also better aligned with the skills needed for CSW installation.

2.4.2 VIG

The workforce development needs for VIG are less complex than for CSW and can more easily leverage existing channels because VIG presents a sales and installation case that is more similar to typical window replacement. Existing networks of professional glaziers are an appropriate resource for VIG sales and installation, and the premium product offering of VIG would add value to the portfolio of products offered. However, familiarity with VIG is low and there are special handling and installation techniques. This MTI will work with VIG manufacturers and organizations

[29] Bensch et al. (2020). Commercial Window Attachments: Secondary Window Market Characterization (Report #E20-399). Prepared for NEEA by Evergreen Economics, Inc.

such as Northern California Construction Training (NCCT) to incorporate VIG training into existing training programs.

2.4.3 ESJ workforce education and training (WE&T)

The team identified two primary WE&T opportunities relevant to CSW and VIG: universally offered pre-apprenticeship trade programs and comprehensive and foundational training programs for various construction and manufacturing industries such as the Multi-Craft Core Curriculum (MC3). For CSW, this MTI will prioritize training access for installation contractors, training centers, technical schools, and community colleges located in or serving ESJ communities. These programs would benefit ESJ communities by job creation and benefit manufacturers by relieving them of the burden of delivering training programs themselves.

2.5 Total system benefit & cost-effectiveness forecast

CalMTA estimated Total System Benefit (TSB) and cost-effectiveness for the CRAWS MTI, including the Total Resource Cost (TRC), Program Administrator Cost (PAC), and two Societal Cost Test (SCT) results. The current market forecasting and cost-effectiveness model quantifies the adoption, TSB benefits, and incremental costs for CSW only. Although the CRAWS MTI includes both CSW and VIG, CSW is the only technology modeled at this time because it has a more mature retrofit pathway, more developed product-rating infrastructure, and sufficient information to support reasonable assumptions for per-square-foot adoption, savings, and installed costs. VIG remains within the CRAWS MTI strategy and theory of market change and will be modeled when product ratings, installed-cost data, supply-chain information, field-performance data, and adoption pathways are more mature.

The modeled measure is the installation of CSW on existing commercial single-pane or double-pane clear windows, relative to the baseline condition of leaving the existing window in place. This "do-nothing" baseline reflects the current market condition in which many commercial windows remain in place until failure or major renovation.

To develop the TSB and cost-effectiveness estimates, CalMTA developed a model to forecast incremental units of market adoption resulting from the MTI and combined the net incremental CSW adoption forecast with avoided costs, per-square-foot unit energy impacts, hourly load shapes, initiative costs, incremental measure costs, and measure-life assumptions using the CPUC Avoided Cost Calculator framework.[30] CalMTA applied IOU-specific avoided-cost inputs for PG&E, SCE, and SDG&E and used CPUC cost-effectiveness test definitions for the TRC, PAC, and SCT. The TRC and SCT include both CalMTA initiative costs and participant incremental measure costs, while the PAC includes CalMTA initiative costs but excludes participant incremental

[30] Energy and Environmental Economics (E3). 2024 Distributed Energy Resources Avoided Cost Calculator Workbooks, Version V1b.

measure costs. Details of these analyses are documented in Appendix B: Market Forecasting & Cost-Effectiveness Modeling Approach.

Table 2 shows estimated TSB for the 2028–2047 forecast period, broken out by energy, grid, and GHG benefits. Under the TRC/PAC avoided-cost basis, the CRAWS MTI is forecast to deliver $628.5 million in present-value TSB, including $130.0 million in energy benefits, $78.6 million in grid benefits, and $419.9 million in GHG benefits. The SCT results are higher because the SCT includes additional societal avoided-cost components and applies societal discounting.

Table 2. CRAWS MTI TSB estimates

TSB ($M)	Energy ($M)	Grid ($M)	GHG ($M)
628.5	130.0	78.6	419.9

Table 3 summarizes the resulting cost-effectiveness ratios. The MTI is cost effective under the TRC, PAC, and SCT perspectives. These results should be considered conservative because they do not include potential VIG adoption, monetized non-energy benefits, potential infiltration savings, potential HVAC downsizing benefits, or potential installed-cost reductions from supply-chain maturation and market scale.

Table 3. CRAWS MTI cost-effectiveness estimates

TRC	PAC	Base SCT	High SCT
1.31	19.2	1.82	1.84

The TSB value used for formal cost-effectiveness testing reflects net incremental adoption that produces IOU-applicable benefits after removing estimated PA-verified units to avoid double counting. Because CRAWS affects both electricity and natural gas, IOU applicability is applied by fuel: adoption in electric and gas IOU territory receives both electric and gas benefits, adoption in gas IOU-only territory receives gas benefits and zero electric benefits, and adoption outside both electric and gas IOU territory is excluded from the primary cost-effectiveness result. Appendix B also presents broader co-created and statewide TSB estimates to characterize the statewide impact of the CRAWS MTI, but those supplemental values are not used as the numerator for the formal cost-effectiveness ratios.

2.5.1 Market adoption forecast

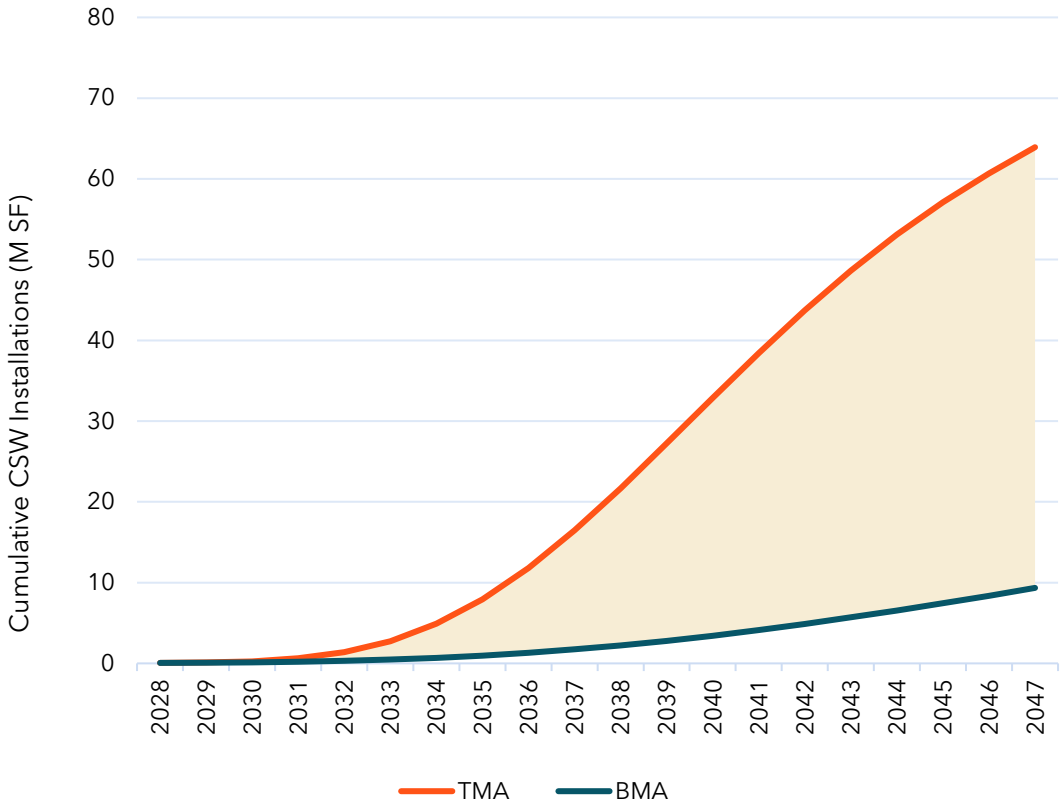
This section summarizes CalMTA's forecast of baseline market adoption (BMA) and total market adoption (TMA) for CSW. BMA represents expected naturally occurring adoption absent the CRAWS MTI, considering current market, policy, and technology conditions. TMA represents the additional market adoption expected from the strategic interventions described in this MTI Plan, including awareness-building, in-field demonstrations, technical-resource development, supply-

chain engagement, installer training, and efforts to establish the envelope-first business case for commercial buildings.

CalMTA developed a statewide CSW adoption forecast using a Gompertz S-curve framework over a 20-year forecast period from 2028 through 2047. This framework is appropriate for an emerging commercial retrofit technology because it represents adoption that begins slowly, accelerates as awareness and market infrastructure increase, and eventually tapers as the most accessible portion of the market is served. Adoption is expressed in million square feet of installed CSW window area because window area is the common unit used for stock sizing, unit energy impacts, incremental measure costs, and avoided-cost calculations.

Figure 1 compares cumulative CSW adoption under the BMA and TMA scenarios. The gap between the two curves represents the net incremental CSW adoption that CalMTA attributes to the MTI.

Figure 1. Cumulative CSW adoption forecast, BMA vs. TMA, 2028 - 2047



The adoption model begins with commercial floor area from the 2022 California Commercial End-Use Survey (CEUS). CalMTA excluded warehouses and a portion of miscellaneous floor area, mapped the remaining stock to Database for Energy Efficient Resources (DEER) prototype

buildings, and converted floor area to window area using DEER prototype geometry assumptions. Because CEUS does not directly identify window type or low-e status, CalMTA used building vintage as a proxy for identifying buildings likely to retain single-pane or double-pane clear windows. This process produced an estimated 445.1 million square feet of technically addressable window area. Applying customer-economics filters for positive net present value and simple payback of eight years or less produced an estimated achievable potential of approximately 145.4 million square feet statewide.

The model separately tracks municipal, university, school, and hospital (MUSH) buildings and non-MUSH buildings. This segmentation reflects the CRAWS strategy that MUSH buildings are expected to be a stronger early market because they are more likely to be owner-occupied, have longer ownership horizons, use structured capital planning and ESCO channels, and face stronger pressure to prepare for decarbonization and building-performance requirements. Non-MUSH buildings represent approximately 82 percent of forecasted MTI cumulative incremental adoption. While they remain important to long-term transformation, adoption is expected to occur more slowly because decision making is more fragmented and split-incentive barriers are more common.[31] In the BMA scenario, CSW remains a niche retrofit solution and adoption grows slowly. This reflects a market in which most building owners do not routinely evaluate window performance as part of capital planning or in response to occupant discomfort, and HVAC investments often occur before envelope upgrades are considered. In the TMA scenario, the MTI accelerates adoption by increasing awareness of the CSW value proposition, building market-actor confidence, supporting product ratings and technical resources, strengthening supply-chain and installer capacity, and making envelope evaluation more routine during major retrofit and HVAC decision points.

Table 4 summarizes the cumulative adoption forecast. Over the 2028 – 2047 period, CalMTA forecasts 63.9 million square feet of CSW adoption under TMA and 9.4 million square feet under BMA, resulting in 54.6 million square feet of statewide incremental adoption. Consistent with the CalMTA MTI Evaluation Framework, CalMTA then adjusts statewide incremental adoption to reflect IOU-applicable benefits and subtracts estimated PA-verified units to avoid double counting with PA-claimed program activity. For CRAWS, this adjustment is applied by fuel: adoption in gas IOU-only territory is retained for gas avoided-cost benefits, receives zero electric avoided-cost benefits, and includes only an allocated share of incremental measure costs based on the gas share of total electric-plus-gas TSB benefits. After these adjustments, the forecast includes 37.6 million square feet of net incremental CSW adoption for TSB and cost-effectiveness estimation.

[31] Incremental adoption is presented in Appendix B (Market Forecasting & Cost-Effectiveness Modeling Approach) in Table 6.

Table 4. Forecast of CSW adoption (in millions square feet of window area, 2028-2047)

Segment	TMA	BMA	Total incremental adoption	Estimated PA-verified adoption	Net incremental adoption for TSB and CE estimation
Electric IOU & Gas IOU territory	42.3	6.2	36.1	7.1	29.0
Gas IOU Only territory	12.2	1.6	10.7	2.0	8.6
Non-IOU territory	9.4	1.6	7.8	0.0	NA
Statewide Total	**63.9**	**9.4**	**54.6**	**9.1**	**37.6**

Note: PA verified units include adoption estimated to be associated with PA programs statewide.

In addition to the net incremental adoption estimates, the TSB and cost-effectiveness calculations also considered initiative costs, incremental measure cost, avoided costs, load shapes, unit energy impacts, and effective useful life. A detailed explanation of the methodology, models, inputs, assumptions, and results is provided in Appendix B: Market Forecasting & Cost-Effectiveness Modeling Approach.

2.6 Other benefits

The NEBs discussed so far provide benefits to occupants and building owners. They include thermal comfort, noise reduction, maximized daylighting, reduced air leakage, improved indoor air quality, and safety.

CRAWS provides the following additional NEBs to utilities:

- **Grid benefits:** CRAWS technology contributes to peak load reduction, particularly during cooling season. By improving the building envelope, it can also enable pre-cooling and pre-heating, which contributes peak-shifting benefits. It also allows buildings to coast longer through Demand Response (DR) events before temperature thresholds trigger reenergization of HVAC equipment. Peak load and peak-shift benefits are especially valuable as the transition to heat pumps adds cooling capability to buildings that previously lacked cooling and where misalignment exists between peak generation from distributed energy resources and peak demand.
- **Resiliency:** CRAWS technology improves building resiliency during extreme weather events, maintaining safe and comfortable temperatures for longer periods than in buildings with untreated windows. A notable case study from the NEEA CSW Field Study documented the resiliency benefits experienced during an extreme heat dome event in the Pacific Northwest in

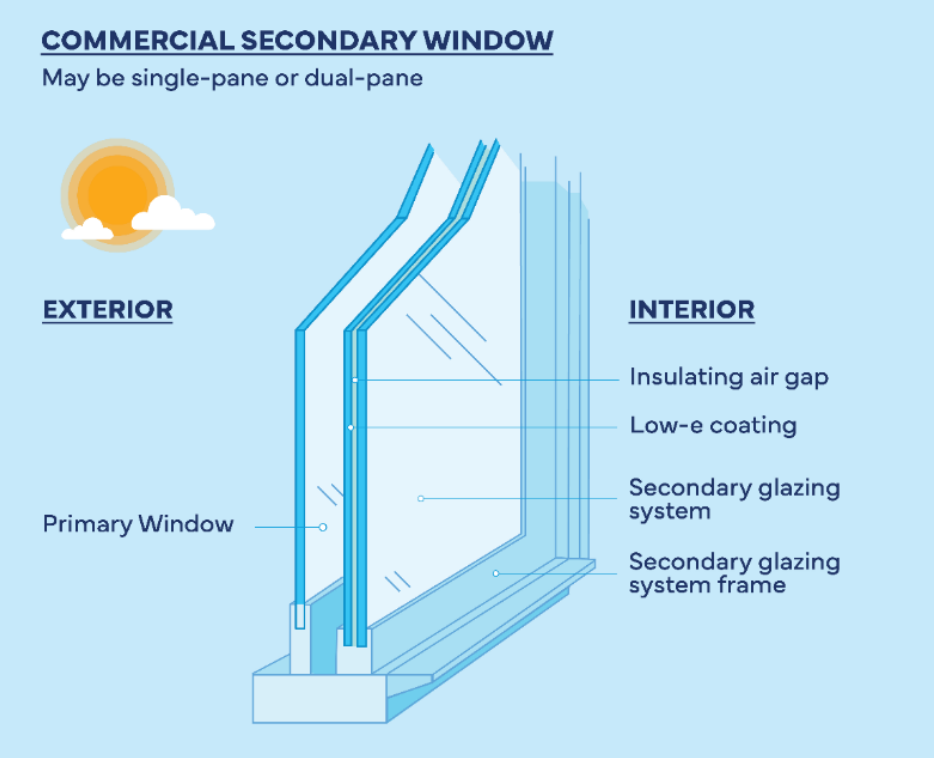
June 2021 when outdoor temperatures exceeded 110° F and reached a peak of 118° F during a three-day period. A building recently outfitted with Alpen Winsert Plus CSW easily maintained setpoint temperatures throughout the event when, prior to installation, HVAC struggled to maintain comfortable temperatures during routine summer weather.

- **Electrification enablement:** Window upgrades have a disproportionately larger benefit on overall envelope U-value than improving insulation (which is already much more insulative). By improving the worst-performing part of the envelope, window upgrades facilitate the transition to heat pump technology.
- **Savings certainty:** CRAWS technology provides a level of savings certainty to utilities not achievable by user-operable solutions such as shades and blinds.

3 Product definition & assessment

Commercial secondary windows (CSWs): CSWs are retrofit products comprised of one or more panes of glass, polymer, or acrylic, which are mounted in a fixed or operable frame that is attached either on the interior or exterior of existing windows without replacing the primary glass or frame (Figure 2). CSWs meeting CalMTA's product definition includes low-e coatings, which reduce solar heat gain, reduce cooling loads, and provide a significant advantage in California's relatively mild climate. CSWs may include insulating gases, thermal films, and/or VIG units in their construction. They may be permanently installed or removable. Because CSWs are installed over the existing window and because lightweight options are available, installation can be substantially easier, faster, and less expensive than glazing or full window replacement, making CSWs an attractive solution for any building that needs to address envelope performance and may not be undergoing a deep retrofit.

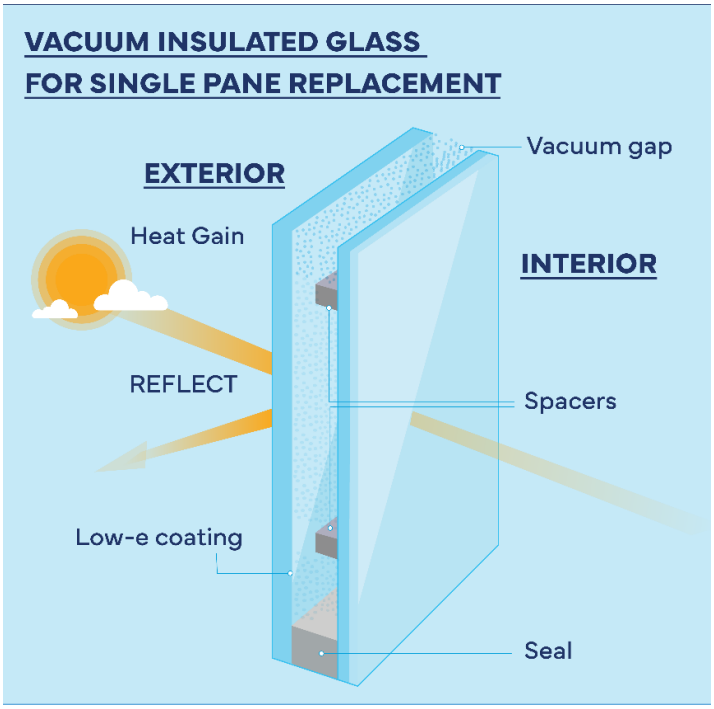
Figure 2. Commercial secondary window illustration



Vacuum insulated glass (VIG) for single-pane replacement (SPR): Commercial VIG units replace existing SPC glass while retaining use of the existing frame. VIG units are comprised of two glass panes, separated by spacers, and hermetically sealed around the edges (Figure 3). A vacuum is drawn in the void space between the glass panes resulting in a center-of-glass R-value of R-10 to R-15. The R-value does not include frame effects, which can reduce the whole-window R-value.[32] The VIG unit may also include low-e coatings that reduce solar heat gain and further improve energy performance.

[32] R-value is a measure of a material's ability to restrict heat flow; the higher the R-value, the greater the insulating power.

Figure 3. Vacuum insulated glass window illustration



The CRAWS MTI will include products with the following attributes:

- For all products, a maximum solar heat gain coefficient (SHGC) of 0.25
- For CSW products, a maximum U-factor of 0.35

CRAWS is targeting existing buildings with clear glass windows (i.e., buildings without low-e or reflective coatings), because CRAWS technologies can offer these buildings the largest energy savings and best payback.

3.1 Competitive analysis

3.1.1 CSWs

Energy efficiency is not necessarily the primary driver of window upgrades, and the optimal solution may not provide the greatest energy savings. Market characterization studies show that building owners often invest in window solutions to address thermal comfort and noise concerns,

with energy and HVAC savings sometimes seen as secondary benefits.[33,34] Therefore, no single window technology can be deemed superior based solely on energy performance; the option building owners choose must offer them a compelling value proposition, often driven largely by NEBs.

There are several categories of window attachment products that consumers might consider as alternatives to CSWs:

- **Frame-mounted stretched film panel**: Products that use a pliable, stretched film in a frame with weatherstripping seals around the perimeter.
- **Glazing-mounted (frameless) panels**: Acrylic or copolyester panels that attach directly to the original window glazing, creating an unsealed air space.
- **Window film**: Thin laminate film, permanently applied directly to the original window glass, and optimized for a variety of energy and non-energy benefits.
- **Window shades**: This product category includes cellular shades, roller shades, and solar screens, that are installed on the interior or exterior of an existing window. While they are typically operable, some products are fixed and installed like residential window screens.

CSWs outperform competing solutions in energy savings and noise attenuation and perform at least as well in thermal comfort enhancement, air infiltration reduction, safety, aesthetics, daylight transmittance, and large-size availability. However, some alternatives have advantages in installed cost, operability, weight, and supply chain maturity.

Primary strengths

- **Cost Advantage:** Equal or better energy performance at up to 90% lower cost than full window replacement
- **Indoor Environmental Quality:** Strong improvements in thermal comfort and noise reduction
- **Heat Control:** Reduces conductive, radiant, and air leakage heat transfer
- **Optical Clarity:** High transparency and light transmittance
- **Flexible Sizing:** Accommodates larger and more varied dimensions than many competing technologies

---

[33] Bensch et al. (2020). Commercial Window Attachments: Secondary Window Market Characterization. Prepared for NEEA by Evergreen Economics, Inc.
[34] Zahid, Tambone. (2026). Commercial Replacement and Attachment Window Solutions Market Characterization Report. Prepared for CalMTA by the Cadmus Group.

- **Non-Disruptive Installation:** Quick, simple installation without envelope modifications or occupant disruption
- **Rated Options:** Available with AERC-rated product configurations
- **Aesthetics:** Visual appearance preferable to some competing technologies
- **Serviceability:** Easily removable and replaceable
- **Established Technology:** Produced by a mature and reliable manufacturing network

Primary weaknesses

- **Condensation Risk:** Potential for condensation between primary and secondary windows if the existing window is in poor condition
- **Limited Operability:** Some manufacturers do not offer operable units for all window types (e.g., hung or slider windows)
- **Higher Cost:** More expensive than other attachment products
- **Added Weight:** Heavier than most alternative attachment solutions
- **Developing Installer Base:** Installer network is still maturing

3.1.2 VIG for SPR

VIG for SPR is a more costly and labor-intensive intervention than CSWs that results in high performance and a discreet aesthetic. Consumers considering VIG for SPR might also consider alternatives such as:

- **Full window replacement**. Existing window and frame are replaced with framed double- or triple-pane windows.
- **Other competing technologies**. CSWs and the products identified in section 3.1 are also a competing solution for VIG for SPR.

A full competitive landscape analysis can be found in Appendix C.

3.2 Energy policy landscape

Title 24 applies to alterations, which it defines as any change to a building's water heating, space-conditioning, lighting, or envelope systems that is not an addition. It specifies that the Energy Code applies to the altered components of a system (i.e., the glazing units in VIG for SPR) and that alterations must comply with mandatory and prescriptive requirements for those components.[35]

[35] Section 100.0. California Energy Commission, 2022 Nonresidential and Multifamily Compliance Manual (First Quarter Errata), TN #250098 (Sacramento: California Energy Commission, May 11, 2023).

VIG glazing units meeting the CRAWS product definition exceed the prescriptive energy code requirements for glazing units.

Since the installation of CSWs leaves the existing building envelope in place, the definition of alteration does not apply. Therefore, California building codes do not cover CSWs.

Fenestration, including VIG for SPR and CSWs, is not covered by federal energy performance standards.

3.3 Product performance

The following sections summarize energy modeling, bill impacts, and avoided cost analyses that informed the development of this MTI. Expanded summaries are provided in Appendix C.

3.3.1 Energy modeling

CalMTA assessed energy consumption and peak electric load reduction benefits for CSWs and VIG for SPR using whole-building energy models run in EnergyPlus and found that the energy savings from the two products are very similar (within 1% on average). Therefore, for simplicity, savings data in this section is reported once, reflecting the performance of both products. We used the California DEER prototype models for 18 commercial building types. Table 5 shows the DEER prototype models used in the analysis, and the abbreviations used to represent them.

Table 5. Prototype building names and abbreviations

Abbreviation	Full name
Asm	Assembly
ECC	Education – community college
EPr	Education – primary school
ERC	Education – relocatable classrooms
ESe	Education – secondary school
EUn	Education - university
Hsp	Health/medical - hospital
Htl	Lodging – hotel
Mtl	Lodging – motel
Nrs	Health/medical – nursing home
OfL	Office - large
OfS	Office - small
RFF	Restaurant – fast food
RSD	Restaurant – sit down
Rt3	Retail – multistory large
RtL	Retail – single story large
RtS	Retail – small
SCn	Storage - conditioned

CalMTA used the models from the draft TRM measure for commercial windows with only window parameters modified to reflect CRAWS technology installation cases. For all energy models, the proposed window specifications are set at U=0.35 Btu/h-ft^2-°F and SGHC = 0.25. The baseline window performance for existing windows was set to U=1.03 Btu/h-ft^2-°F and SHGC varies by climate zone from 0.57 to 0.75 as set in the CSW eTRM measure. We analyzed energy consumption and bill impacts across all 16 California climate zones, since the energy savings of window upgrades is heavily climate dependent.

The three factors that influence window energy savings are U-factor, SHGC, and infiltration. The impact of each factor varies depending on the building type and climate zone. CalMTA found that CRAWS technologies can offer significant energy consumption savings across all California climate zones and utility service territories. Most of the savings are driven by the reduction in SHGC, rather than improvements in U-factor or infiltration. Improvement in infiltration was not included in the final energy models, following the framework of the TRM measure. As shown in Table 6, CSWs result in a 7% to 8% reduction in annual electricity consumption and a 17% to 22% reduction in annual gas consumption, compared to the baseline. (Negative values indicate bill savings; all scenarios modeled resulted in bill savings.) The electric savings are higher in absolute energy, but the percent facility savings in gas are higher due to the significantly lower facility gas consumption for California existing commercial building prototypes. Consumption impacts vary slightly by IOU, due to differences in the climate zones encompassed within each service territory.

Table 6. Average annual whole-building site energy consumption, by fuel type and IOU service territory

Case	Annual Electric Consumption			Annual Gas Consumption			Annual Total Consumption		
	PG&E	SCE/ SCG	SDG&E	PG&E	SCE/ SCG	SDG&E	PG&E	SCE/ SCG	SDG&E
CSW	-8%	-8%	-7%	-22%	-18%	-17%	-11%	-10%	-9%

Notes: Negative values indicate utility consumption savings. Savings are compared against the existing windows for the prototype building.

3.3.2 Bill impacts

CalMTA used energy modeling to estimate that adopting CRAWS technologies yields annual whole-building cost savings of approximately 9%, calculated as a weighted average across building types and California climate zones.

Results summarized in Table 7 represent the total whole-building annual cost savings from CSWs for each fuel type and IOU service territory.

Table 7. Average annual whole-building energy cost savings, by fuel type and IOU service territory

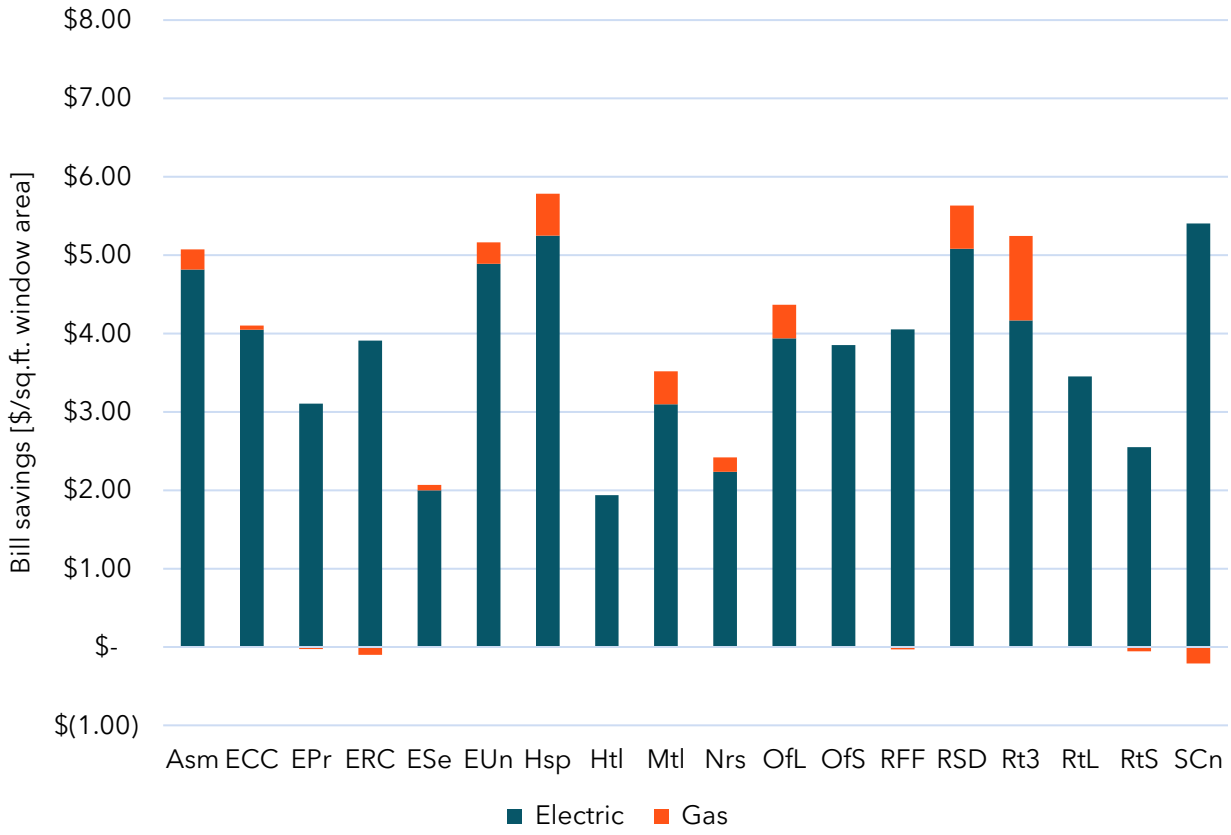
Case	Electric			Gas			Total		
	PG&E	SCE/ SCG	SDG&E	PG&E	SCE/ SCG	SDG&E	PG&E	SCE/ SCG	SDG&E
CSW	-9%	-9%	-9%	-20%	-17%	-16%	-9%	-9%	-9%

Notes: Negative values indicate bill savings. Savings are compared against the existing windows for the prototype building.

Bill impacts were calculated based on modeled energy consumption and peak demand in baseline and proposed models. For each energy model, electric and gas bills were calculated using the mainstream commercial tariffs available in each model's climate zone. Commercial electric rates are all time-of-use, so they vary by the hour of the day. These include a consumption charge ($/kWh) and in some cases a demand charge ($/kW, assessed monthly). The actual time-varying electric rates used by the three major IOUs in California were taken from CEC's MIDAS database for calendar year 2025.

Figure 4 shows the average annual bill impact by building type, per square foot of window area. Average annual electric cost savings were $3.77 per square foot of window area. All 18 building types analyzed saw reductions in annual electric costs resulting from CSWs, ranging from $1.94 (hotel) to $5.40 (conditioned storage) per square foot of window area. Average annual gas cost savings were $0.19 per square foot of window area. Eight of the 18 building types analyzed saw slight increases in annual gas costs due to reduced passive solar heating associated with lower SHGC. However, in each of these eight cases, the reduction in electric cost was far larger than the increase in gas cost – by a factor of at least 25.

Figure 4. Average annual bill savings by building type, in $/square foot window area[36]



3.3.3 Avoided costs

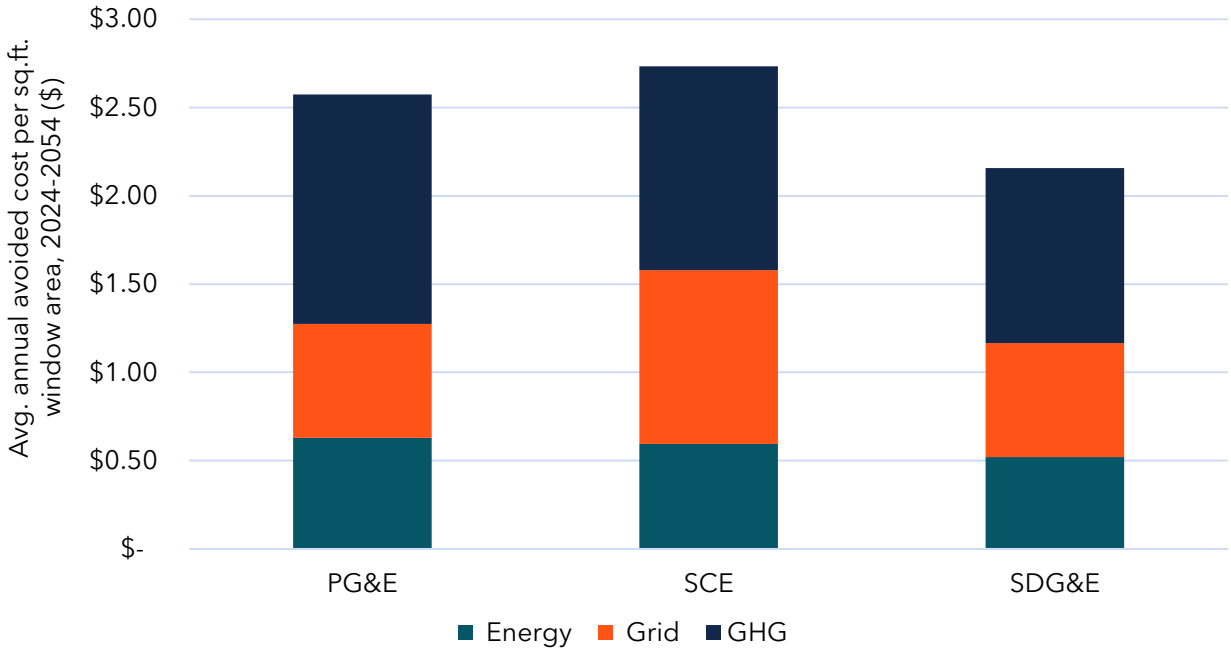
The CPUC's Avoided Cost Calculator (ACC) provides a framework for evaluating the benefits of distributed energy resources such as energy efficiency and fuel-switching measures. The ACC estimates the system-level cost of providing electric or gas service on an hourly basis, expressed in $/kWh and $/therm.[37] The ACC converts reductions in gas and electricity consumption into avoided cost dollars, a metric to quantify the value of savings attributable to fuel-switching and efficiency measures. These avoided cost factors are used to calculate the MTI's cost effectiveness and TSB.

[36] See Table 5 for definitions of the building type abbreviations.

[37] (2024). 2024 Distributed Energy Resources Avoided Cost Calculator Documentation. Prepared for the California Public Utilities Commission by Energy and Environmental Economics, Inc.

Figure 5 shows the avoided cost benefit for CSWs for each IOU service territory, broken down by energy, grid, and GHG benefits.

Figure 5. Annual average avoided cost per square foot window area benefit by IOU service territory, 2024-2054



3.4 Product plan

The product plan describes technical activities that may be undertaken during the execution of the MTI across various areas of the product, service, or practice. It focuses on two strategic interventions identified in the MTI logic model: (1) in-field demonstrations, and (2) industry engagement for technical support and demand creation.

3.4.1 In-field demonstration projects

In-field demonstration projects, such as the one currently underway at with CSWs Madison Elementary School in Madera, California, aim to raise awareness about building energy waste attributed to clear windows in California. CRAWS will expand its field study sites to encompass a wider range of building types and climate zones, and will include both CSWs and VIG for SPR.

In-field demonstration projects will collect and publish performance data on energy consumption; quantification of NEBs like thermal comfort, noise, and air quality; and best practices. Field study data will demonstrate the value proposition of CRAWS technologies to consumers and industry actors such as ESCOs.

CRAWS will collaborate with municipalities to incorporate CRAWS technologies into their climate and energy action plans, recognizing the potential to reduce GHG emissions associated with operating their building stock.

3.4.2 Stakeholder and industry collaboration

CalMTA will evaluate the need for expanded options for operable CSWs and work with manufacturers and national labs to document best practices for prevention and remediation of condensation. We'll encourage manufacturers to submit products to AERC for rating and collaborate with the DOE to expand a CSW savings calculator for California climate zones and building stock.

To expand the VIG supply chain, CalMTA will collaborate with national laboratories like NLR conducting VIG research to ensure industry standards are informed by the latest research data.

CalMTA will participate in architecture, historic preservation, and commercial real estate conventions to expand awareness of CRAWS.

3.4.3 Certifying organization collaboration

VIG for SPR lacks a methodology for commercial performance ratings. The CEC is currently developing a rating system for replacing SPC glass with VIG in residential applications; the CRAWS MTI will build on this momentum to establish a commercial rating system. A funding source will be established for AERC or a similar industry organization to develop a method for rating VIG for SPR. This method will enable more VIG manufacturers and products to be rated by AERC. AERC may lack capacity to develop a new product rating method due to commitments to other window attachment products.

CalMTA will collaborate with ENERGY STAR to certify CSWs, building on its residential storm window certification. Uncertainty around future DOE funding for ENERGY STAR may limit its ability to cover a new category of products.

4 Market characterization

4.1 Current market state summary

4.1.1 Product availability

There are multiple U.S.-based CSW manufacturers producing both standard and custom units. Products are sold under a wide variety of brand names and descriptors – storm windows, window inserts, interior glazing panels, and others – which contributes to confusion and low product differentiation in the market. Six CSW manufacturers were identified as commercially active at the national level.

The VIG supply chain in the U.S. is nascent. Of the two VIG manufacturers interviewed for this study, one was producing only prototypes and the other reported very low production volumes. Most VIG products currently available in the U.S. are imported, creating exposure to tariff risk and supply disruptions. VIG lead times, cost, and availability remain highly variable and unpredictable.

4.1.2 Technology outlook

Both technologies are positioned as envelope-first solutions that can reduce HVAC loads and enable right-sizing of mechanical systems without triggering full window replacement. CSW can reduce heating and cooling energy use by up to 20%. Depending on the application, VIG can be up to 50% less expensive and CSW can be as much as 90% less expensive than full window replacement.[38] VIG offers superior thermal performance (up to five times the insulation value of conventional double-glazing) and can achieve up to 60% reduction in solar heat gain and 45% improvement in heat loss compared to single-pane glass.

Emerging technologies of interest to market actors include electrochromic (dynamic tinting) glass, photovoltaic-integrated windows, aerogel-based insulation, and smart window systems. Most of these remain niche solutions that are limited by persistent technical, reputational, and cost barriers. VIG itself is considered an emerging technology by several manufacturers, with uncertainty remaining around long-term durability, condensation performance, and the absence of a standardized NFRC rating method for SPR applications.

BPS – including potential California statewide adoption around 2029 – 2030 – are expected to accelerate demand for high-performance window solutions. Stringent local codes like New York City's Local Law 97 are already driving VIG sales in that market.

4.1.3 Market size

California's total commercial window market (new construction and retrofit combined) is estimated at approximately $280 million annually, based on a national market projection of $3.11 billion and California's estimated 9% share of U.S. commercial floor space. Current CSW sales from three national manufacturers in California averaged roughly 20,000 square feet and $765,000 annually (2023 – 2024 average), representing approximately 18% of those manufacturers' total U.S. sales. CalMTA believes that CSW currently represents a very small share of the overall commercial retrofit market.

California's commercial building stock includes an estimated 3,284 million square feet across the target segments (college/university, healthcare, lodging, office, and school). Single-pane windows are present in buildings that account for approximately half of California commercial

[38] O'Neil. (2023). Commercial Secondary Windows Field Observations and Decision-Maker Interviews Report (Report #E23-456). Prepared for NEEA by Energy 350.

floor space – representing a substantial addressable market for retrofit solutions. In addition, approximately 44% of commercial building floorspace with double-pane windows has windows without low-e coating.

4.2 Target market overview

4.2.1 Target market

The primary target is commercial buildings constructed before 2000 that retain single-pane or double-pane clear windows (without low-e coatings). CalMTA's Phase II research focused on the MUSH market (municipalities, universities, schools, and healthcare facilities), as these are owner-occupied buildings with longer ownership horizons and stronger business cases for efficiency investment, and represent MTI beachhead markets. Hospitality and historic buildings were also included given their strong fit with the NEBs of CSW and VIG (soundproofing, preservation compatibility, and aesthetics).

4.2.2 Who makes the product?

A small number of specialized manufacturers produce CSW and VIG. CSW manufacturers are predominantly small- to mid-sized U.S. firms located across the country (Oregon, Colorado, Pennsylvania, Texas, Ohio). VIG manufacturers are even smaller and less numerous, with U.S.-based production still in early development stages. Most manufacturers sell custom-order products directly to end users or through a limited set of intermediaries.

4.2.3 Who buys the product?

Building owners and facility managers are the primary purchasers. CalMTA research found that building owners make purchasing decisions unilaterally 86% of the time, while property/facility managers more commonly share or escalate decision-making authority. ESCOs are also significant buyers, typically purchasing window solutions as part of bundled retrofit packages that also include HVAC, lighting, and envelope upgrades.[39]

4.2.4 How is the product sold?

CSW manufacturers commonly sell direct-to-end-user, bypassing traditional distribution channels such as wholesalers and retailers. This results in a lean supply chain but creates knowledge gaps among midstream actors (architects, glazing contractors, general contractors) who are not regularly exposed to the products. VIG is typically distributed through in-house manufacturer channels given the limited number of producers. ESCOs are an important sales pathway,

[39] For more information related to purchasing decisions, please refer to Section 6 of Appendix D: Market Characterization.

particularly for larger institutional clients, but windows are rarely pursued as standalone projects — they are almost always bundled with other upgrades to improve project ROI.

4.2.5 Who and what influences purchase decisions?

Architects and glazing contractors are the most frequently consulted information sources when building owners consider window upgrades (71% and 63% of surveyed owners, respectively). Independent internet research (43%) is the next most common source. HVAC engineers and designers wield disproportionate early-stage influence in building renovation planning, typically engaged before façade or window specialists — a structural market dynamic that systematically deprioritizes window solutions. Utility incentives, regulatory compliance (Title 24, BPS), and public funding availability (rebates, tax credits) are important decision factors. ESCOs noted that windows typically do not sell unless the out-of-pocket expense is low, underscoring the critical role of incentives in driving projects forward.

4.3 Market actor and end user insights

4.3.1 Non-energy benefits

NEBs are consistently cited across market actors as compelling — and in many cases, more immediately motivating than energy savings — reasons to pursue window retrofits, though they are typically insufficient on their own to drive investment.

Thermal comfort is the most universally cited NEB. Among building owners CalMTA interviewed who had not yet upgraded windows, six of six reported thermal comfort issues as a persistent problem. It was also the primary motivation among the two owners who had already completed upgrades. A survey of 114 building owners and managers asked respondents to rank the reasons they would consider upgrading or replacing windows found the most important motivators were energy efficiency (59%), noise reduction (55%), and aesthetics (48%).[40]

Soundproofing is a particularly well-documented NEB for CSW. A university building case study showed a 5.9 decibel reduction in exterior noise. Multiple manufacturers and ESCOs cited soundproofing as a differentiating value proposition, especially for buildings in urban environments or near traffic corridors.

Safety and security improvements were noted by building owners and corroborated in secondary literature, with secondary windows reducing the risk of glass breakage and improving occupant safety. This benefit is particularly significant for the older commercial building stock that comprises much of the CRAWS target market. Many of these buildings predate California's building code requirements for safety (tempered) glass, meaning existing windows may pose a

[40] For more information related to survey results, please refer to Section 6 of Appendix D: Market Characterization

heightened breakage risk. CSW provides an added layer of protection without requiring full window replacement, making them a practical safety upgrade for this segment.

Ease and speed of installation represent important operational NEBs, particularly for healthcare and school environments where disruption must be minimized. CSW installation averages approximately 20 minutes per window and does not require structural modifications. One case study documented installation of 331 window attachments in 3.5 days. Notably, CSW installations in healthcare settings do not trigger California's permitting and field review process (unlike full frame replacements), which is a significant operational advantage that most healthcare decision makers are unaware of.

Long warranties were cited by manufacturers as an additional benefit supporting long-term value propositions.

CSW also offers a significant value proposition for hospitality and historic buildings. In both contexts, soundproofing and thermal comfort represent compelling NEBs that align with improved occupant experience. For historic buildings in particular, CSW preserves the integrity of the original façade, which is a requirement under historic preservation standards that typically makes full window replacement infeasible. This positions CSW as one of the only viable energy upgrade pathways for this building segment.

Despite broad recognition of NEBs, several building owners commented that NEBs are "secondary" to quantifiable energy cost savings in terms of motivating window upgrades. One university administrator stated directly that "non-energy benefits are more of a luxury." These findings are in contrast to other research and reinforce the criticality of developing the business case for and monetizing the value associated with NEBs.

4.3.2 Other insights

Awareness of CSW is limited. Although survey results indicated high reported familiarity with CSW, in-depth interviews tell a very different story: five of eight building owners interviewed had never heard of CSW prior to the interview. This discrepancy likely reflects confusion between CSW and standard storm windows, a known challenge given the inconsistency of product terminology across manufacturers and market channels.

VIG awareness is critically low. Among interviewed owners, only one had direct experience with VIG, and they were highly positive – noting they would have chosen VIG over double-pane replacement had they known about it at the time of their renovation. Only 23% of building owners/managers reported familiarity with VIG, and just 4% described it as very familiar. This suggests a significant unrealized conversion opportunity for buyers who engage directly with the technology.

There is a disconnect on cost perception between the supply and demand sides of the market. Manufacturers characterize CSW as affordable and easy to install, while ESCOs frequently cite cost and installation complexity as primary barriers. This informational asymmetry may stem from a lack of price transparency, outdated ESCO assumptions, or real additional costs (supply chain, project management, procurement) not reflected in manufacturer pricing. This disconnect should be addressed through clearer cost communication and demonstration projects.

Window upgrades tend to be reactive rather than proactive. Fifty-four percent of building owners and managers reported replacing windows only when they fail, and 40% reported replacing them proactively on schedule. College/university owners reported being particularly reactive, with 92% reporting they replace only upon failure. These survey findings conflict with other market data such as a 2024 study by Energy Solutions which report that window replacements are rare overall and are typically replaced upon failure.[41] This pattern reinforces the need for market transformation strategies that create proactive demand rather than relying on failure-triggered replacement cycles.

Bundling with HVAC and other upgrades is the predominant sales model. ESCOs consistently noted that CSW and VIG are most viable when packaged with broader retrofit projects. This limits standalone market development but creates a clear integration opportunity: positioning CRAWS as a cost-effective complement to HVAC upgrades that improves system sizing and efficiency.

Tariffs and supply chain instability are emerging risks. All ESCO respondents and multiple manufacturers flagged tariffs on Chinese imports as a significant and unpredictable cost pressure, particularly for VIG. Some manufacturers reported extreme lead time volatility. These risks add uncertainty to project planning and may dampen adoption, particularly for VIG, where U.S. manufacturing capacity is still limited.

Incentive awareness and utilization remain low. Only 42% of building owners/managers are aware of available energy efficiency programs supporting window upgrades, and of those, only 38% have taken advantage of them. This represents a substantial gap in program outreach and engagement that should be addressed to accelerate market adoption.

5 External program alignment & coordination

Following guidance provided in the Market Transformation (MT) Framework attached to CPUC D.19-12-021 and reinforced by CPUC D.25-11-023, which approved CalMTA's first MTIs for market deployment, CalMTA intends for the CRAWS MTI to complement, add value to, and minimize overlap with existing programs serving the target market for the technology.

[41] Birchfield et al. (2024). Commercial Windows Market Study and Measure Package Development (Report #ET23SWE0018). Prepared for CalNEXT by Energy Solutions.

Throughout MTI development, the team pursued and will continue to pursue substantial coordination, outreach, engagement, and collaboration with key groups and intends to identify points of alignment that: 1) eliminate duplication or redundancy in market activities; 2) ensure that the MTI adds value to the market and fills any gaps needed to drive long-term market change; and 3) increase scalability and the efficiency with which desired results are achieved by leveraging existing work.

Important aspects of CalMTA's approach to achieving these coordination and alignment goals with external programs are summarized below. A more detailed description of this work can be found in Appendix E: External Program Alignment & Coordination.

5.1 Collaboration at all phases of MTI development

Engagement with key parties related to the CRAWS MTI occurs at each stage of CalMTA's three-phase development process. Activities completed prior to finalization of this MTI Plan include:

- **Request for Ideas (RFI) to Phase I MT Idea Selection (Aug. 2023 – Feb. 2024):** After selecting the CRAWS idea for initial development following CalMTA's first RFI, the team 1) shared MTI development updates and solicited feedback at MTAB meetings and through the CPUC's Public Document Area website; 2) held recurring meetings with the IOU energy efficiency portfolio directors, IOU Codes and Standards working group, and CalNEXT to maximize alignment and identify additional areas of coordination; and 3) identified a preliminary set of local, state, and national programs for future coordination and inclusion in Phase II activities.
- **Phase II Advancement Plan Research to MTI Plan Finalization (Feb. 2024 – April 2026):** To gain deeper knowledge about other market-level efforts and their potential impact on the development of the MTI, CalMTA 1) completed additional research to expand the list of external programs and activities with potential relevance to this market; 2) engaged directly with organizations and programs pursuing window-related market transformation, research, and emerging technology efforts; 3) conducted structured interviews with important stakeholders and subject matter experts to inform our market characterization report; and 4) engaged CalMTA's Equity Sounding Board to inform development of equity-oriented interventions and metrics.

After submitting the CPUC application requesting approval for the CRAWS MTI Plan and throughout Phase III implementation, CalMTA will continue to engage external programs and entities in this market, which are offering or planning to offer incentives or other aspects related to the MTI, to minimize conflicts and create opportunities for collaboration. Critically, CalMTA will conduct ongoing meetings with IOUs and third-party implementers of related programs to define activities that will avoid market confusion, ensure points of alignment are maintained and leveraged, and identify any need to adjust MTI strategies.

Explicit needs for coordination with existing resource acquisition programs and codes and standards activities will be addressed and prioritized in the RFP used to solicit an implementation contractor for this MTI, as well as the subsequent contract, implementation plan, and in the Market Progress Evaluation Reports used to measure progress toward MTI objectives. These activities, in tandem with work to align with the PAs on savings goals and attribution as defined in the MTI Evaluation Plan, will result in implementation work plans cocreated with PAs and be shared with the CPUC for approval prior to MTI market deployment.

5.2 Related programs for potential alignment

In developing the market transformation theory for the CRAWS MTI, CalMTA identified several areas where coordination with external programs in California and nationally offer significant opportunities for collaboration or leverage. Recognizing that external programs vary widely in terms of scale and scope, CalMTA will prioritize engagement with those that have the greatest potential market impact (e.g., statewide programs) or those that fill a particularly critical role in intervention strategy implementation.

Table 8 below, which also appears in Appendix E, summarizes representative active programs identified by CalMTA as important points of alignment and coordination for the CRAWS MTI during Phase III: Market Deployment. We do not intend for this to be a fully comprehensive list but rather illustrative of CalMTA's proposed approach to coordinating with specific types of programs. We also recognize the importance of market-level coordination and alignment beyond the California energy efficiency/decarbonization program landscape, including local BPS/benchmarking ordinances or green certification programs like LEED.

Table 8. CRAWS external program coordination approach

MTI alignment goal	Targeted program(s)
Codes and standards programs and other regulatory efforts provide a critical point of coordination and leverage as CalMTA seeks to align MTI activities with California code development/ enforcement and collaborate on engagement with federal test procedures, standards-setting, and qualified product lists.	• IOU Codes & Standards Working Group • DOE/ENERGY STAR

MTI alignment goal	Targeted program(s)
Existing **research and development projects/programs** provide leverage for CalMTA to develop and launch the MTI more quickly. They also create opportunities to collaborate on research, including pilots, to better understand product performance and necessary enhancements	• The IOUs' Emerging Technologies Program (ETP), which includes CalNEXT, the electric ETP, and Gas Emerging Technologies Program (GET), the gas ETP • DOE National Labs (e.g., LBNL or PNNL) and research universities • CEC Energy Research and Development Division projects, particularly the Electric Program Investment Charge (EPIC) and Gas Research and Development Program
Statewide or regional incentive programs can provide an important point of leverage for reducing upfront product cost directly through inclusion of CRAWS in the measure mix or bundling with other measures. CalMTA also seeks to collaborate with these programs on awareness-building and education about the benefits of CRAWS technology – a key intervention designed to address this significant market barrier. Specifically, CalMTA is interested in alignment with: • Commercial sector programs that encourage whole building energy optimization or incentivize custom projects that are likely to include HVAC • Multifamily programs that include common area or envelope measures • Programs focused on beachhead MUSH market	• California Energy Design Assistance (CEDA) Program major retrofit projects • SCE Commercial Energy Reduction Initiative (CERI) Program and Willdan's Comprehensive Commercial Program • IOU Energy Savings Assistance (ESA) Multifamily Energy Savings Program • SoCalREN Multifamily Program • LADWP Comprehensive Affordable Multifamily Retrofits (CAMR) • SCE Public Energy Performance (PEP) and Higher Education Energy Performance programs • SoCalGas Public Direct Install Program • PG&E Government and K-12 Comprehensive Program • CEC California Schools Healthy Air, Plumbing, and Efficiency Program (CalSHAPE)
Programs or services that address whole building energy performance improvements or strategic energy management can be motivated to include envelope-first upgrades and specifically CRAWS measures in building energy plans. These programs create a particularly appealing opportunity for collaboration on market education and awareness-building efforts, as they are not	• SCE Local Commercial Strategic Energy Management (SEM) Program • SoCalGas Commercial SEM Program • PG&E's Commercial SEM Program • Technical/planning support programs (e.g., Central California Rural Regional Energy Network Public Equity Program)

MTI alignment goal	Targeted program(s)
focused on a single measure but rather holistic energy performance.	• Local reach codes and Climate Action Plans
Workforce education and training (WE&T) programs will be a critical point of coordination for the training activities and partnerships described in strategic intervention #6, particularly those focused on job creating in ESJ communities.	• The IOUs' Statewide WE&T programs (Energize Careers and Energy is Everything [EisE]) • SoCalREN E-Contractor Program • Central California Rural REN Climate Careers • MCE's Green Workforce Pathways

6 Data management

CalMTA will implement a comprehensive data collection and management strategy throughout the MTI's life that includes collection and ongoing management and analysis of these data:

- MTI program data and materials
- Secondary data and information on population characteristics, market trends, and other programs
- Product category sales and shipment data – either purchased or negotiated as part of the MTI
- Data collected via primary research
- MPIs

Data will be securely stored, allowing for both longitudinal tracking and efficient access to data for analysis activities. This data will support market progress evaluation and updates/true-up analyses to MTI incremental impacts and CE, as well as assessment of market trends and progress toward MTI goals.

6.1 MTI program data and materials

CalMTA will create a repository of program data and materials that includes a detailed record of stakeholder and market actor communications, program data including agreements and data provided by market partners; market adoption and cost-effectiveness models and forecasts with fully documented inputs, assumptions, and calculations; MTI MPIs; and market and product research data and reports.

CalMTA team members log communication with stakeholders, partners, and clients to enable a comprehensive tracking and reporting of activities, outreach, and events. This will act as a record of CalMTA's interventions and their timing and be a resource for evaluators to monitor MPIs and investigate the causal relationship and impact of interventions.

The CalMTA website includes a Resources and Reports section that catalogues program material and public communication from CalMTA.

CalMTA will conduct market and product research in support of specific MTIs, and regularly true up the CRAWS products market adoption forecast by incorporating actual sales or shipment data as it becomes available. These program data, market and technology data, summary findings and other work products resulting from research conducted by CalMTA and third-party evaluators will be securely stored as part of CalMTA's ongoing data management activities.

6.1.1 Secondary data and information

CalMTA will collect data from secondary sources regarding population characteristics (such as California commercial building characteristics), market trends, and other programs. Secondary data and information sources may include:

- Trade association industry statistics
- PA Program and CEDARS data
- California Commercial end-use survey
- Market studies and external evaluation-related materials

6.1.2 Product category sales and shipment data

Data on CRAWS sales and shipments are critically important for evaluating the MTI incremental impacts, yet such data can be difficult to obtain. Given how crucial it is, CalMTA negotiated agreements with market partners that include sales or shipment data. CalMTA will supplement what can be obtained from market partners with other sources of sales and shipment data that can be purchased or acquired via primary research.

Appendix F provides a detailed description of the sales, programs, and shipping data the MTI will maintain.

6.1.3 Data collection via primary research

CalMTA will collect primary data through various research activities to generate ongoing market insights to inform MTI strategy and tactics and support market progress evaluation, including longitudinal tracking of MPIs and assessment of progress toward milestones and outcomes. Appendix F provides detailed descriptions of data collection activities, including:

- MTI staff interviews
- Market actor interviews & surveys
- Utility/program administrator interviews
- Building owner/operator surveys

- Manufacturer & supply-chain interviews
- Industry stakeholder interviews
- Financing entity interviews
- Supplemental adoption estimation data collection

6.1.4 Market progress indicators

MPIs correspond with the MTI's theory of market transformation, as represented in Appendix A: Logic Model, and are critical to ongoing market and MTI performance tracking. The data collection described in Appendix F: Evaluation Plan will enable CalMTA and evaluators to assess progress against these metrics.

7 Evaluation & market research

Ongoing evaluation and market research are essential to the development and successful management of market transformation programs. CalMTA and the CPUC's Energy Division will oversee implementation of rigorous and strategically focused evaluation, measurement, and verification (EM&V) practices, which will enable CalMTA management and stakeholders to gauge the performance of CalMTA and MTIs, verify incremental impacts, and improve the design and success of future MTIs.

Ongoing program evaluation that provides timely feedback to support program decision making, which is also known as "real-time" or "embedded" evaluation, will provide MTI program managers and implementers with continual feedback and allow them to pivot strategies as needed to maximize the value delivered to California ratepayers. Per the Decision and the MTI Evaluation Framework, CalMTA and an independent third-party evaluator each have important evaluation roles in MTI evaluation. CalMTA will conduct ad hoc market research and develop forecasts of MTI incremental impact and CE, while an independent third-party evaluator is responsible for evaluating market progress and causal influence of the MTI, and for reviewing estimates of MTI incremental impacts and cost-effectiveness. CalMTA developed a preliminary plan for third-party evaluation of the MTI with input from the Evaluation Advisory Group, a group of three independent evaluation experts, the CPUC project manager, and the CalMTA market research and evaluation lead (see Appendix F for details). Final evaluation plans will be developed by an independent third-party evaluator to be selected via a competitive RFP process after the MTI advances to Phase III.

7.2 Evaluation approach overview

CalMTA and its third-party evaluator will employ a theory-based evaluation (TBE) approach to evaluating the MTI, which is widely accepted as a best practice for market transformation program evaluation. TBE uses the program theory as the point of reference for market progress evaluation

– assessing market progress against the theorized short-, medium-, and long-term outcomes and corresponding MPIs, and the extent to which the market interventions addressed the market barriers identified and caused the outcomes theorized in the Logic Model.

The evaluation will address these high-level objectives:

- Monitor market dynamics and characteristics; assess market developments
- Review and assess the MTI program theory and logic model
- Measure market progress and equity, per the MPIs
- Assess MTI causality per the logic model, using evidence-based assessments that use a "preponderance of evidence" approach and established market transformation evaluation best practices
- Identify gaps in implementation and opportunities to adjust MTI strategy and tactics, to improve MTI effectiveness
- Review CalMTA's BMA and TMA forecasts, unit energy savings, incremental net MTI impacts and co-created MTI impacts,42[1] and cost-effectiveness inputs and assumptions
- Assess ancillary benefits and costs

Through the market evaluation findings, the third-party evaluator will determine if the original BMA forecast, program attribution, and calculation of incremental impacts require adjustment. Additional guidance on these issues can be found in the Market Transformation Evaluation Framework

7.3 Market progress indicators

The evaluation plan identifies 21 MPIs that correspond with the MTI program theory. While the ultimate market progress indicator is market adoption of CRAWS technologies (CalMTA will track this metric from the outset), this metric can be a misleading indicator of success during the first several years of MTI implementation because market share and adoption will accelerate only after the MTI addresses critical market barriers (such as reduction in incremental cost difference and limited availability) and improved awareness of the benefits. Therefore, to appropriately evaluate market progress and ensure accountability, the evaluator must assess short- and medium-term MPIs that align with the Logic Model, including:

- Percent of each market actor groups that understand the energy and non-energy problems associated with SP/DPC windows as well as CRAWS solutions
- CSW and VIG included in TRM
- Number of external programs that include CRAWS technology
- Funding of external programs that include CRAWS technology

- Number of AERC-rated CSW and VIG
- Number of installers who completed manufacturer training.
- Number of manufacturers providing self-installation resources
- Percent of trained installers reporting increased confidence or capability to install CRAWS products
- Percent of customers who are offered CRAWS
- Percent of customers who are offered CRAWS that include NEBs in the value proposition
- Percent of municipalities include CRAWS as part of climate/energy action plans
- Number of CA external programs that include CRAWS measures
- Number of CA external programs that offer incentives for evaluating envelope as part of HVAC updates
- Percent of market actors (such as specifier/influencers, ESCOs) recommending CRAWS solutions
- AERC developed and published a VIG rating method
- Number of manufacturers and products rated by AERC
- Percent of trained installers who have recommended CRAWS to at least one customer in the past 12 months
- Number of suppliers and installers selling CRAWS products
- Square feet of CRAWS technology sold by market segment
- Percent of ESCO projects incorporating CRAWS
- Number of program administrators and commercial financing pathways that factor NEBs into asset value
- Percent of installers, architects/engineering firms/specifiers who routinely recommend CSW/VIG during building envelope assessments or HVAC system sizing consultations
- Percent of planned HVAC replacement/upgrades that include envelope assessment
- ENERGY STAR includes CSW technology in ES list
- Number of CSW models that meet proposed ENERGY STAR criteria
- CA BPS or similar policy including CSW and VIG in a pathway
- Number of financing pathways that fund CRAWS installation in ESJ communities

Appendix F provides a complete list of MPIs and how they will be assessed. It also describes data sources and evaluation approaches that the third-party evaluator can use to assess market progress, MTI causality, equity, and CalMTA's estimates of MTI incremental impacts and cost-effectiveness. The evaluator will conduct ongoing market monitoring via secondary data analysis and primary research to assess market progress and causality and, importantly, to provide ongoing market insights that provide real-time information to inform MTI strategy and confirm performance or provide recommendations for improvement.

CalMTA identified these primary and secondary data collection activities and associated analysis tasks that would allow the third-party evaluator to evaluate the CRAWS MTI, which are described in Appendix F. CalMTA anticipates that the independent third-party evaluator will have suggestions for how to improve upon this plan.

7.4 Ad hoc market research

The planned evaluation activities include a breadth of planned market research activities that will provide ongoing market insights to support refinements to the MTI strategy and tactics. CalMTA expects there will also be a need for ad hoc research to help support timely implementation decisions and program effectiveness. For example, the initiative includes a strategic intervention to engage architects and building specifiers as key influencers of the CRAWS market. The market research conducted for the Market Characterization study revealed that architects and specifiers tend to associate CSW almost exclusively with historic building preservation, significantly limiting their recommendation of CSW and VIG for the much larger non-historic commercial building stock. As the MTI advances, it will be necessary to identify compelling messaging and value propositions that can reframe CRAWS technologies as standard solutions for any commercial building renovation – particularly in the context of HVAC right-sizing and envelope-first retrofit strategies. CalMTA has included a modest budget for ad hoc research needs and will identify specific research studies over the initiative lifetime.

8 Risks & mitigation

This section details the potential risks that could negatively impact the CRAWS MTI and CalMTA's plan to monitor and mitigate the risks. The risks listed in Table 9 have been identified as key risks to track. Please see Appendix G for a full list of possible risks for this MTI. We are defining "high," "medium," and "low" for each risk as follows.

For "Probability of Occurring" in the second column, CalMTA is defining:

- **High:** Through our research and discussion with market actors, CalMTA deems this risk having a high probability of occurring. The program needs to monitor closely and identify a solid backup plan with resources that can be deployed to mitigate the risk if it comes to fruition.

- **Medium:** This risk has a medium probability of occurring given what we know about the market. The MTI needs to track and have a mitigation plan.
- **Low:** The probability of this risk occurring is low based on what we know about the market to date. It could have some impact on the need for resources and timing, so the MTI needs to track.

For "Severity" in the third column, CalMTA is defining:

- **High:** If this risk plays out and our mitigation approach is unfeasible, then the success of the MTI may be in jeopardy.
- **Medium:** This may have an impact on the timing or overall success of the MTI, but the MTI will be able to pivot with more time or resources.
- **Low:** This level of risk will likely require a program intervention adjustment, but it will not jeopardize the timing or resources needed.

Table 9. Risks and mitigation

Risk	Probability of occurring (H, M, L)	Severity (H, M, L)	Possible mitigation approaches
Energy savings alone are insufficient to support an envelope-first business case in California climate zones: Energy savings are primarily from HVAC cooling savings. Some buildings and certain climate zones may have insufficient HVAC savings to justify the investment in CRAWS technology.	H	M	Demonstrate that CRAWS provided substantial NEBs, including thermal comfort, noise reduction, resilience, and increased asset value. Negotiate bulk purchase or purchase commitments with manufacturers to drive down material costs. For CSW, develop educated labor force to bring down installation costs. Demonstrate value of CRAWS technology in defining optimal pathways to meeting BPS targets.
Unable to sufficiently quantify NEBs: The first step in estimating the monetary value of NEBs is to utilize a standard method for quantifying or qualifying each NEB. A method will need to be identified or established for each NEB.	L	M	We will build upon current and past examples of NEB quantification from utility programs and other energy efficiency organizations to develop standard methods for NEB measurement. Where quantification cannot be achieved, we will utilize market actor interviews and surveys to develop qualitative estimates of NEBs.

Risk	Probability of occurring (H, M, L)	Severity (H, M, L)	Possible mitigation approaches
			Since NEBs vary by building segment, we will focus early efforts on those segments where NEBs are more easily quantified while working to develop standard methodology for remaining building segments.
Unable to determine monetary value of NEBs: If unable to estimate a monetary value for NEBs, it would negatively impact CalMTA's ability to build the business case for CRAWS technologies.	M	M	Initially focus on NEBs that don't necessarily have to be monetized to convey value (e.g., thermal comfort, noise reduction, and indoor air quality for owner-occupied buildings; increased occupancy rate for commercial office space; historical preservation, etc.). Continue to pursue more complicated monetization efforts (e.g., increased asset value for commercial office space) as market gains familiarity with CSW and VIG and other barriers are overcome. Reinforce other elements of value stack including energy benefits, HVAC downsizing, and BPS compliance (fine avoidance) to reduce reliance on estimated monetization values.
Combined energy savings and NEBs are insufficient to establish compelling business case for beachhead markets: Modeling and measured savings from NEEA field studies indicate that energy savings alone, while significant, do not lead to ROI periods that align with building owner expectations. A value stack consisting of energy and monetized NEBs will be necessary to motivate the market to adopt CRAWS.	L	H	Continue work with manufacturers to bring down material costs. Develop local workforce including self-install programs to bring down installation costs. Leverage forthcoming BPS policy and work of CBEA MTI to highlight optimal compliance pathways that include window retrofits. Continue coordinating combined HVAC/window upgrades to maximize savings and shorten ROI timelines.
Combined energy and NEBs are insufficient to establish compelling	M	H	Expand trusted messenger outreach to build awareness and to better understand

Risk	Probability of occurring (H, M, L)	Severity (H, M, L)	Possible mitigation approaches
business case for ESJ communities, which commonly have more limited access to financing and funding resources, potentially leaving these communities behind in the transition toward high-performance window technologies.			what makes for a compelling business case in ESJ communities. Continue work with manufacturers to bring down material costs. Develop local workforce including self-install programs to bring down installation costs. Support programs through bulk purchase agreements in target regions to bring down material and labor costs for ESJ communities. Leverage work of CBEA MTI to promote policies that limit rent impacts and expand access to financial resources and ESJ-focused funding opportunities.
Unable to establish methodology for rating VIG for Single Pane Replacement (SPR) by AERC or National Fenestration Rating Council (NFRC). Without a rating, building designers and owners cannot receive full credit for the performance of VIG when demonstrating compliance with energy codes; uncertainty surrounding performance limits the amount that utilities can allocate in incentives	L	H	Work with national laboratories and DOE to establish rating process within DOE. Precedence exists from other rating/approval process associated with other federal agencies (e.g., EPA). Engage with DOE and manufacturers to establish self-certification process with documented methodology and verification criteria.
California external energy efficiency programs don't offer incentives for building envelope evaluation as part of HVAC upgrades. Limited field data, low awareness of benefits, and	M	M	Utilize data from field studies to demonstrate incremental energy savings, grid flex benefits, and peak-shifting delivered by combined HVAC/window upgrades. Collaborate with CBEA and CRTU MTIs and BPS Hubs – to build momentum for

Risk	Probability of occurring (H, M, L)	Severity (H, M, L)	Possible mitigation approaches
uncertainty about cost effectiveness may result in limited interest amongst energy efficiency programs in incentivizing building envelope performance during planned HVAC upgrades, bypassing the opportunity for HVAC downsizing.			holistic strategies that optimize the impact of investment in whole-building upgrades. Collaborate with financial market actors to establish incentives for building owners/operators to include envelope evaluations as standard practice during large scale retrofits (via more attractive financial terms, lower fees, promotional rates, etc.).
California external energy efficiency programs don't offer incentives for CRAWS projects. Even when successfully educating market actors about the benefits and affordability of CRAWS, early adopters may still require incentives to overcome perceived risks of an unfamiliar technology.	M	H	Same mitigation as for previous risk.
Awareness and education campaigns fail to change mindset of architects, designers, and building owners and operators. Overcoming awareness barriers are relatively easy, but if field data and case studies are insufficient to create a value proposition and support a business case amongst influencers (architects and designers) and owners/operators, then market demand will remain muted.	M	H	Conduct in-depth market actor interviews to better understand reservations and objections to utilizing CRAWS technology. Determine if barriers are cost-related (can be offset by incentives while cost reduction strategies are implemented), product performance-related (can be mitigated by manufacturer engagement to implement product enhancements) or financing related (can be mitigated by working with ESCOs and other green financiers to develop more accommodating financing mechanisms). Leverage forthcoming BPS policies to supplement "carrot" of energy and NEBs.

9 Cost estimates

Table 10 contains annual cost estimate by major program activity for the full 20-year program period, representing all Phase III costs required to achieve full market transformation and to validate all impacts. Additional detail, including estimated annual investment by year, can be found in Appendix H.

Table 10. Cost estimates[42]

Activity	Total Phase III cost estimate
Program implementation including the following line items: • MTI oversight, strategy, and management • Marketing and awareness building • Policy development and support • Demonstration projects	$18,780,000
Market Research including the following line items: • Market research • Data collection	$4,065,000
Mid/Upstream Incentives including incentives to retailers or builders that are "upstream in the market"	$750,000
Downstream incentives include a CalMTA incentive that would be provided to consumers	$15,250,000
Program evaluation	$1,900,000
Total	**$40,745,000**

[42] Cost estimates in Appendix B and used in all cost-effectiveness calculations include costs incurred during Phase II: Program Development. Total investments for Phase II and Phase III are estimated to total $44,970,000.

10 Appendices

Link to https://calmta.org/resources-and-reports/craws-mti-plan/ to access the appendices below.

Appendix A: Logic Model Packet

This appendix includes the MTI's full Logic Model. The Logic Model is a systematic and visual way of presenting CalMTA's understanding of the interventions necessary to remove barriers, expected outcomes of those interventions, and a pathway to the desired end state.

Appendix B: Market Forecasting & Cost-Effectiveness Modeling Approach

This appendix details the inputs, sources and methods used to develop the market forecasting, TSB, and cost-effectiveness model for this MTI.

Appendix C: Product Assessment Report

This appendix presents the findings on the technology research conducted in Phase II and on behalf of the MTI.

Appendix D: Market Characterization Report

This appendix includes the baseline assumptions and a thorough assessment of the market state, supply chain, market actors, and other programs that support the MTI.

Appendix E: External Program Alignment & Coordination

This appendix describes how CalMTA will communicate and collaborate with key market actors and program stakeholders.

Appendix F: Evaluation Plan

This appendix describes the plan to track the progress and assess the impact of the MTI over time.

Appendix G: Risk Management Plan

This appendix documents the potential risks and obstacles to the MTI and CalMTA plans to mitigate the risks.

Appendix H: Budget

This appendix details the budget requirements for the MTI.

Appendix I: MTAB Feedback

This appendix contains feedback on the MTI Plan from the Market Transformation Advisory Board.