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ATTACHMENT 2

COMMERCIAL REPLACEMENT & ATTACHMENT WINDOW SOLUTIONS (CRAWS)

MTI PLAN & APPENDICES

Application 26-07-XXX

California Market Transformation Administrator (CalMTA)

July 6, 2026



Commercial Replacement & Attachment Window Solutions

Market Transformation Initiative Plan

June 26, 2026





Commercial Replacement and Attachment Window Solutions

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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/>.



**Market Transformation Initiative Plan for
Commercial Replacement & Attachment Window Solutions**
*CalMTA is a program of the California Public Utilities Commission (CPUC)
and is administered by Resource Innovations*

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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



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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 0.25⁵
- For CSW products, a maximum U-factor of 0.35⁶

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



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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.
- o 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/resource/report/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 year²⁴ 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.



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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 <i>cannot</i> 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



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	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.



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	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 tradeshow. 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-

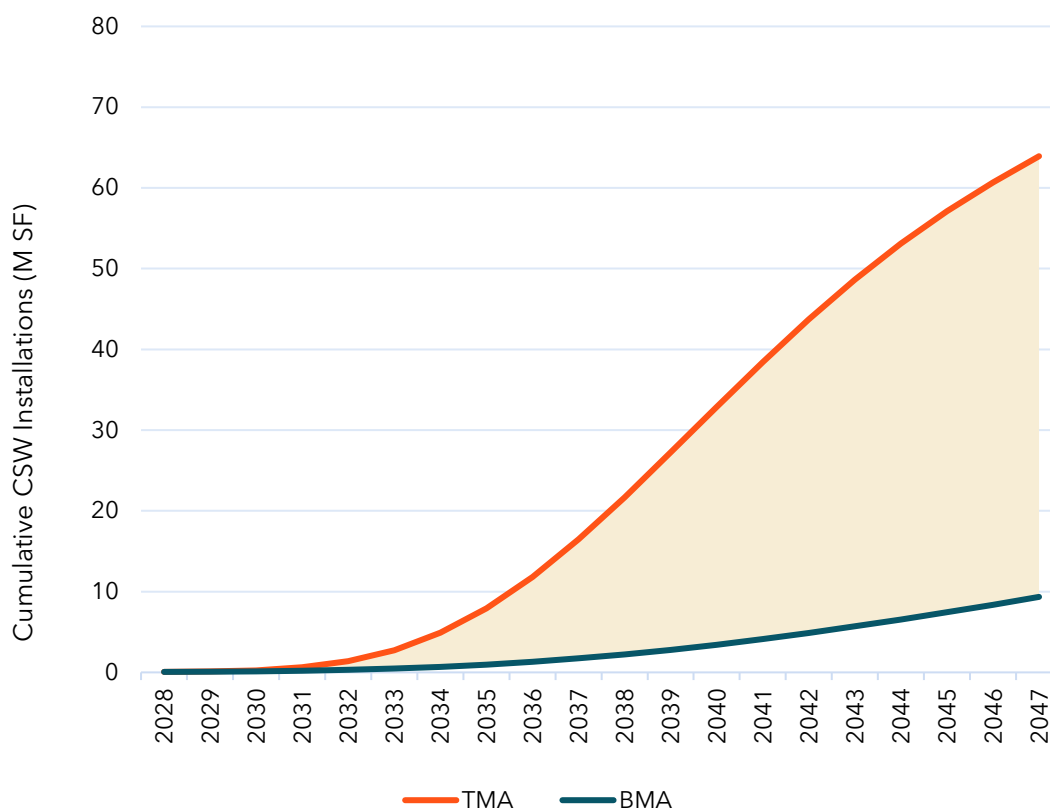


chain engagement, installer training, and efforts to establish the envelope-first business case for commercial buildings.

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



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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.

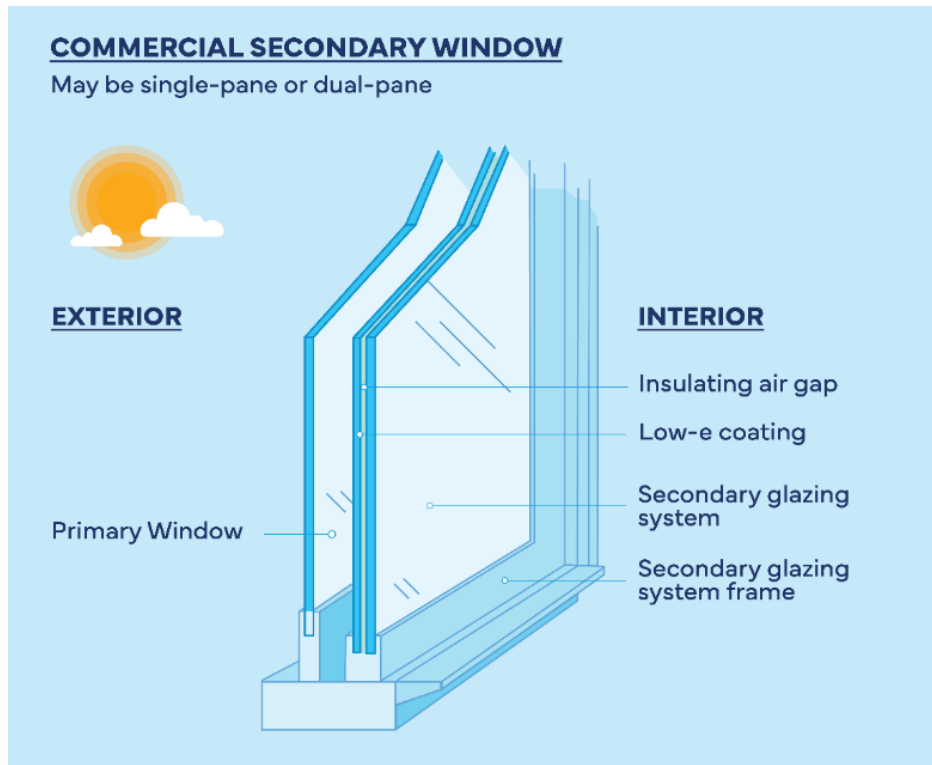
- **Electrification enablement:** Window upgrades have a disproportionately larger benefit on overall envelope U-value than improving insulation (which is already much more insulative). By improving the worst-performing part of the envelope, window upgrades facilitate the transition to heat pump technology.
- **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.



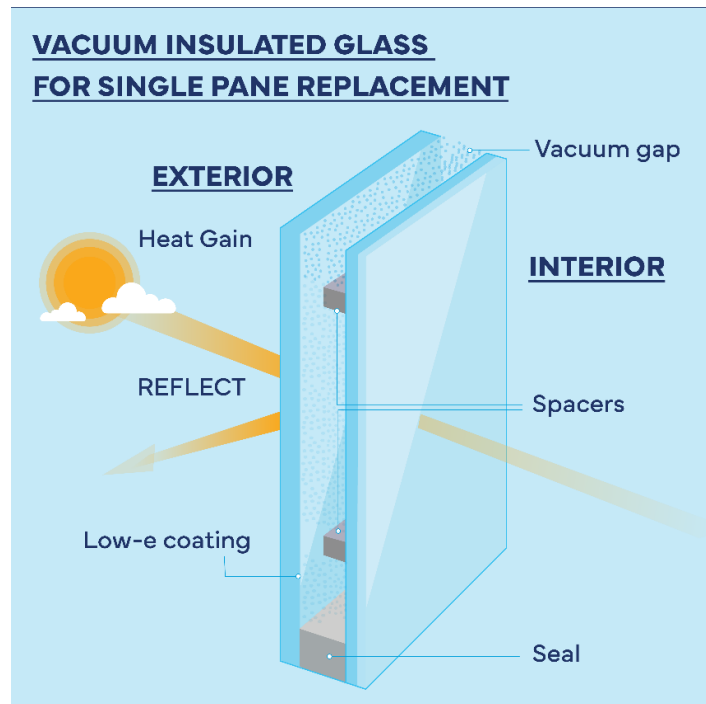
Figure 2. Commercial secondary window illustration



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 $U=0.35 \text{ Btu/h-ft}^2\text{-}^\circ\text{F}$ and $SGHC = 0.25$. The baseline window performance for existing windows was set to $U=1.03 \text{ Btu/h-ft}^2\text{-}^\circ\text{F}$ 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%

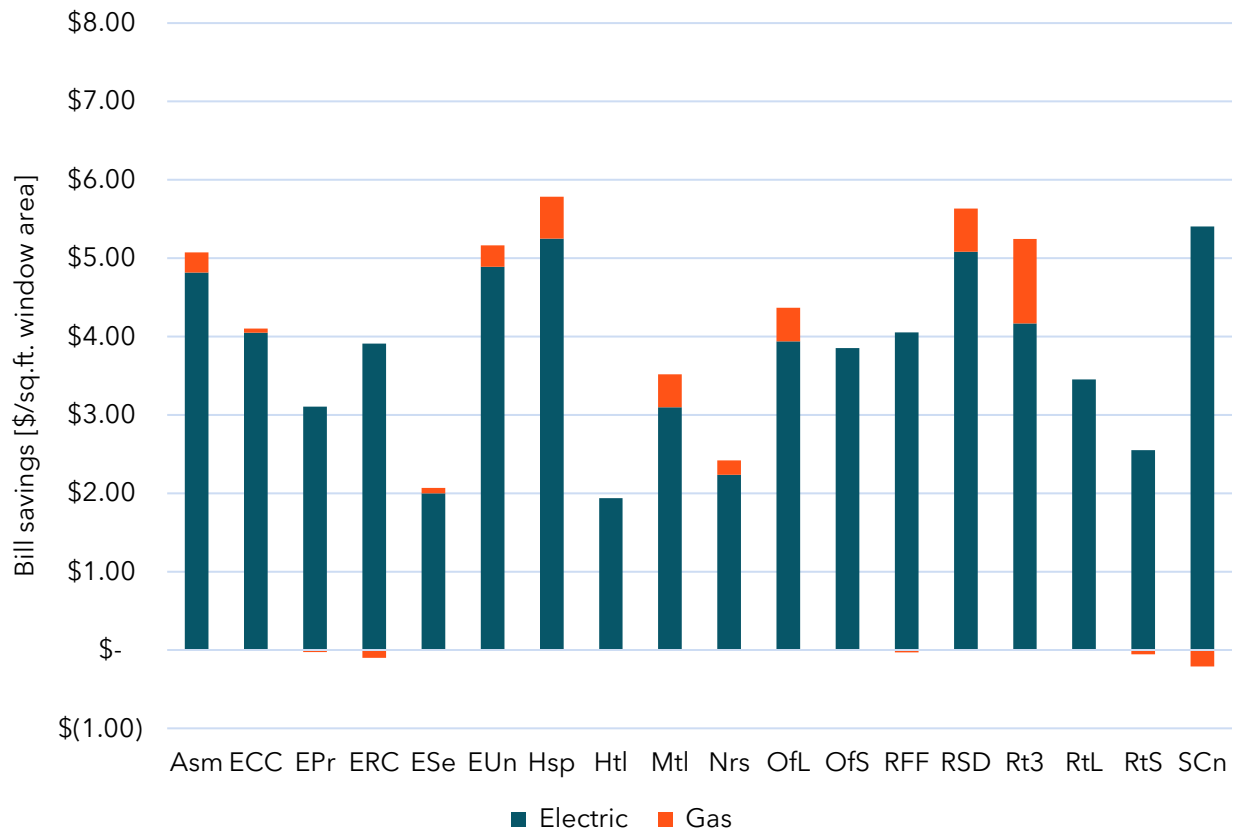
Notes: Negative values indicate bill savings. Savings are compared against the existing windows for the prototype building.

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 area³⁶



3.3.3 Avoided costs

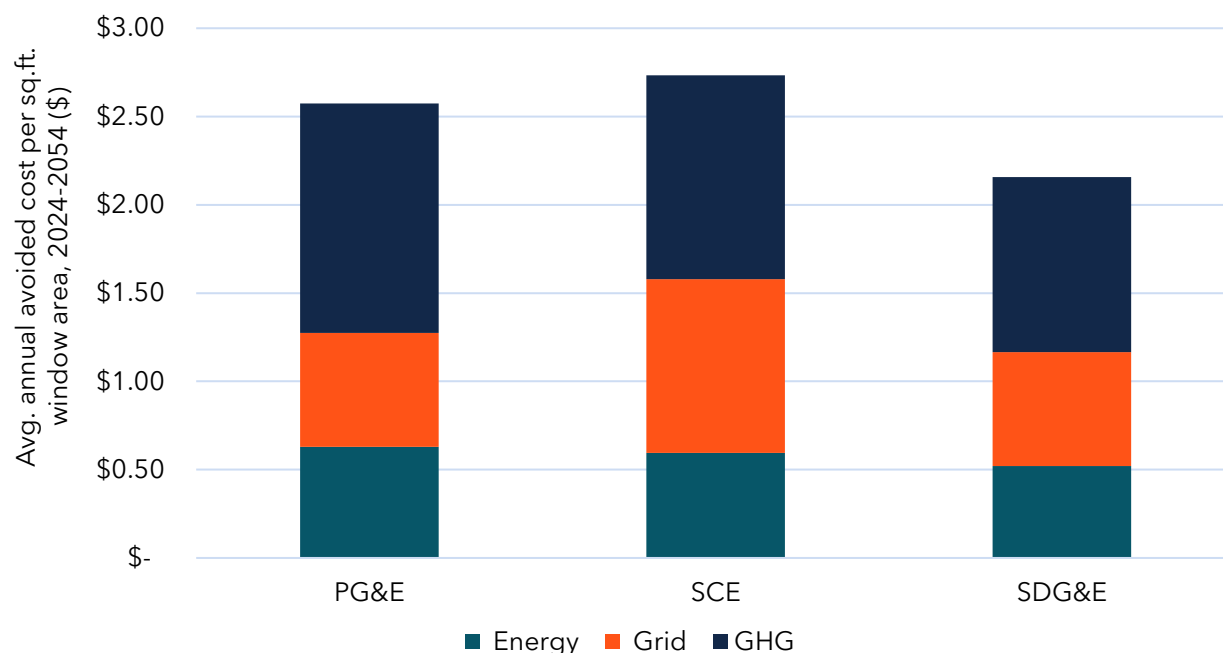
The CPUC's Avoided Cost Calculator (ACC) provides a framework for evaluating the benefits of distributed energy resources such as energy efficiency and fuel-switching measures. The ACC estimates the system-level cost of providing electric or gas service on an hourly basis, expressed in \$/kWh and \$/therm.³⁷ 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.



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

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



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- 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,⁴²¹ 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



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- 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 estimates⁴²

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.





Commercial Replacement & Attachment Window Solutions Market Transformation Initiative

Appendix A: Logic Model

June 26, 2026

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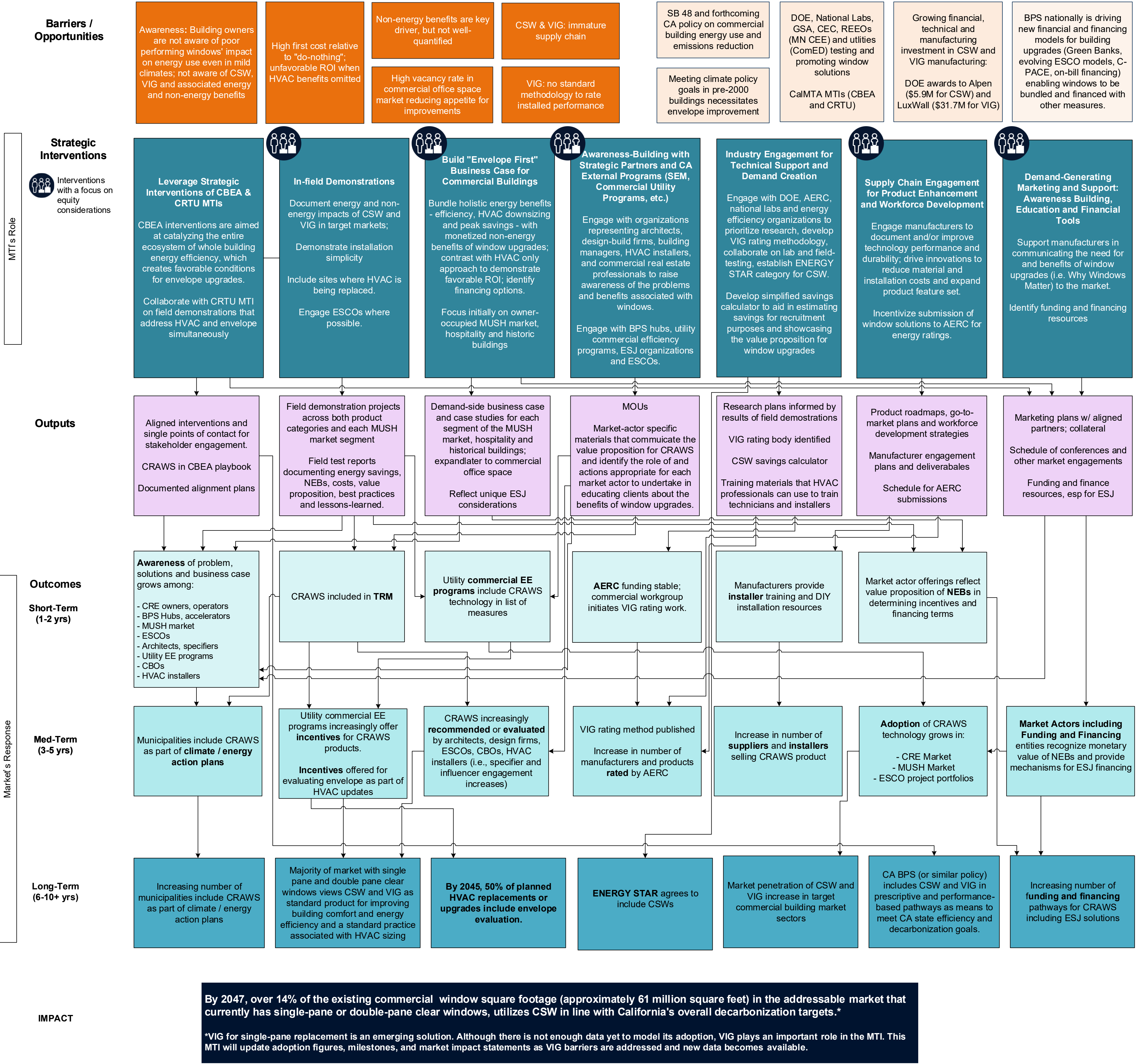
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Commercial Replacement and Attachment Window Solutions (CRAWS) - Logic Model - Draft 04.27.2026





Commercial Replacement and Attachment Window Solutions Market Transformation Initiative

Appendix B: Market Forecasting & Cost-Effectiveness Modeling Approach

June 26, 2026

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Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWS)

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Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWS)

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List of Abbreviations

Abbreviation	Definition
ACC	Avoided Cost Calculator
AERC	Attachments Energy Rating Council
AVP	Awareness of the value proposition
BMA	Baseline Market Adoption
BPS	Building Performance Standard
CalMTA	California Market Transformation Administrator
CEDARS	California Energy Data and Reporting System
CEUS	California Commercial End-Use Survey
CET	Cost-Effectiveness Tool
CRAWS	Commercial Replacement and Attachment Window Solutions
CPUC	California Public Utilities Commission
CZ	Climate Zone
CSW	Commercial secondary windows
E3	Energy and Environmental Economics
ESCO	Energy Service Company
eTRM	Electronic Technical Reference Manual
EUL	Effective Useful Life
DEER	Database for Energy Efficiency Resources
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
IMC	Incremental Measure Cost
IOU	Investor-owned utility
MPI	Market progress indicator
MUSH	Municipal, university, school, and hospital
NAICS	North American Industry Classification System
NEB	Non-energy benefit
NPV	Net present value
PA	Program administrator
PAC	Program Administrator Cost test
PG&E	Pacific Gas and Electric
PV	Present value
SCE	Southern California Edison
SCT	Societal Cost Test
SDG&E	San Diego Gas and Electric
TMA	Total Market Adoption



Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWS)

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Abbreviation	Definition
TRC	Total Resource Cost test
TSB	Total System Benefit
UEI	Unit energy impact
VIG	Vacuum insulated glass



**Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach
for Commercial Replacement and Attachment Window Solutions (CRAWS)**

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1 Purpose

Market Transformation Initiatives (MTIs) generate energy savings and related benefits by accelerating and increasing market adoption of energy-efficient technologies and practices. Estimating MTI impacts requires a documented market adoption forecast and a transparent method for translating forecasted adoption into incremental system benefits and cost-effectiveness results.

This appendix documents the approach, methods, assumptions, data sources, and key results CalMTA used to estimate incremental impacts resulting from the Commercial Replacement and Attachment Window Solutions (CRAWS) MTI. These methods are consistent with the CalMTA MTI Evaluation Framework.¹

The CRAWS MTI includes both commercial secondary windows (CSW) and vacuum insulated glass (VIG). This appendix presents the forecasted adoption, Total System Benefit (TSB), and cost-effectiveness results for CSW only. CalMTA chose to model only CSW at this point in time because CSW products are sufficiently mature to forecast market adoption and cost effectiveness: they currently have a better-defined retrofit pathway than VIG, and there is sufficient information available to make reasonable assumptions about CSW per-square-foot adoption, savings, and costs. VIG remains within the CRAWS MTI strategy and theory of market change, and CalMTA plans to model VIG adoption and cost effectiveness when product ratings, cost data, supply-chain information, and field-performance data mature.²

For this appendix, “CSW” refers to a secondary window retrofit product installed on the interior or exterior of existing commercial windows without replacing the primary glass or frame. The model’s scope focuses on existing commercial buildings with single-pane or double-pane clear windows without low-emissivity (low-e) coatings. These represent the conditions where CSW is expected to provide the strongest combination of energy savings, comfort benefits, and customer economics.³

¹ To learn more about the CalMTA MTI Evaluation Framework, please see CalMTA, Market Transformation Initiative Evaluation Framework, April 2024. Further information is also available in Appendix F: Evaluation Plan.

² VIG remains within the CRAWS MTI product scope but this Appendix B model quantifies CSW only. Additional VIG modeling will require more mature information on product ratings, installed costs, supply-chain capacity, field performance, and adoption pathways. For more information, see the CRAWS MTI Plan, Technology Overview and Strategic Interventions sections; Appendix D: Market Characterization, sections 2.1, 7, and 8; and Appendix F: Evaluation Plan, MPIs related to VIG rating methods and manufacturer participation.

³ CSWs are retrofit products attached to the interior or exterior of an existing window, creating an insulating layer without replacing the primary window glass or frame. For more information, see Appendix D: Market Characterization, section 2.1, Product Definitions; and Attachment 1 to Appendix B, Product Information.



The adoption, TSB, and cost-effectiveness forecasts presented in this appendix cover the 2028-2047 modeling period. The CRAWs MTI Plan describes market deployment, awareness-building, and implementation activities that will support the modeled adoption trajectory.

2 Executive summary

To estimate incremental impacts for the CRAWs MTI, CalMTA developed forecasts of Baseline Market Adoption (BMA) and Total Market Adoption (TMA) and, ultimately, the net incremental market adoption achieved by the MTI. Forecasted CSW adoption is a key input to the calculation of TSB and cost-effectiveness ratios: Total Resource Cost (TRC), Program Administrator Cost (PAC), and Societal Cost Test (SCT).

The CRAWs MTI addresses a large and underdeveloped retrofit opportunity in California's existing commercial building stock. Single-pane and double-pane clear windows remain common in commercial buildings, and poor-performing windows can increase HVAC loads, reduce occupant comfort, and make later electrification more expensive if building owners size HVAC equipment before evaluating envelope improvements. CalMTA designed the CRAWs MTI to help the market recognize and act on an "envelope-first" value proposition: improving window performance before or alongside major HVAC investments so that California captures durable energy, peak-load, greenhouse gas (GHG), and resilience benefits rather than locking in oversized HVAC systems.⁴

The adoption forecast that CalMTA describes in this appendix is intentionally narrower than its full CRAWs market vision. The MTI Plan and Evaluation Plan track progress toward broader CSW and VIG market transformation; Appendix B describes CSW adoption only. This treatment is conservative because it excludes potential VIG adoption and does not monetize several non-energy benefits that market actors identify as important purchase drivers, including thermal comfort, noise reduction, reduced occupant disruption, resilience, and potential HVAC downsizing value. As a result, the primary forecast should be interpreted as a CSW-only cost-

⁴ For more information about the CRAWs envelope-first theory of market change, see the CRAWs MTI Plan, Executive Summary, Vision, and Strategic Interventions sections; Appendix A: Logic Model; and CRAWs MTI Plan Messaging. The CRAWs Market Characterization Report also describes the market barriers associated with low awareness of window performance, reactive window replacement practices, and HVAC-first retrofit planning.



effectiveness forecast that does not fully represent the value associated with CRAWs market transformation.⁵

2.1 Market adoption forecast

CalMTA developed a statewide CSW adoption forecast using a Gompertz S-curve framework that estimates cumulative CSW adoption over a 20-year forecast period for two scenarios: the BMA scenario estimates adoption absent the CRAWs MTI; the TMA scenario estimates accelerated adoption expected from coordinated market transformation interventions.

BMA represents expected “naturally occurring” adoption under current market, policy, and technology conditions. In the BMA scenario, CSW remains a niche retrofit solution. Adoption growth remains slow because most building owners do not routinely evaluate window performance as part of capital planning or in response to occupant discomfort; many window upgrades occur only when windows fail, and HVAC investments often occur before envelope upgrades are considered. The BMA scenario therefore reflects a market without investment in an MTI strategically designed to catalyze adoption, resulting in low growth throughout the forecast period.

TMA represents adoption in the presence of the CRAWs MTI. The TMA forecast assumes that MTI activities increase awareness of the value proposition, build market actor confidence, support performance-rating and technical-resource infrastructure, strengthen supply-chain and installer capacity, and create a stronger business case for pairing envelope improvements with HVAC planning. In the TMA scenario, the MTI accelerates the pace at which market actors become aware of CSW, understand where it is an economically attractive retrofit option, and choose to install it.⁶

The model separately tracks the municipal, university, school, and hospital (MUSH) segment and the non-MUSH segment. This segmentation reflects the CRAWs strategy that expects MUSH buildings to be a stronger early market because they are more likely to be owner-occupied, have longer ownership horizons, use structured capital planning and Energy Service Company (ESCO) channels, and face stronger pressure to prepare for decarbonization and building-performance requirements. Non-MUSH buildings remain important to long-term transformation, but CalMTA

⁵ For more information on CRAWs non-energy benefits (NEBs) and customer value drivers, see Appendix D: Market Characterization, Executive Summary and sections 6.8, 6.10, 6.11, and 8. NEBs identified through market research include thermal comfort, noise reduction, aesthetics, reduced disruption, and resilience. These benefits are important to the MTI theory of change but are not monetized in the TSB calculation.

⁶ For more information on the CRAWs strategic interventions that inform the TMA forecast, see the CRAWs MTI Plan, section 2.2, Strategic Interventions; Appendix A: Logic Model; and Appendix F: Evaluation Plan, Table 1, CRAWs PTLM outcomes, MPIs, milestones, and current baseline.



expects a slower CSW adoption rate because decision making is more fragmented and split-incentive constraints are more common within this segment.⁷

The adoption model starts with commercial floor area from the 2022 California Commercial End-Use Survey (CEUS).⁸ CalMTA excluded all 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 clear double-pane 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 145.4 million square feet statewide.

Figure 1 compares cumulative CSW adoption under the BMA and TMA scenarios. The gap between the BMA and TMA curves represents the net incremental CSW adoption that CalMTA attributes to the MTI. In the primary forecast, TMA reaches approximately 44% of the estimated achievable potential and approximately 14% of technical potential by the end of the forecast horizon. The forecast does not assume that the MTI captures the full technical opportunity; substantial addressable stock remains after the forecast period, which makes the estimate more conservative and consistent with the long-run nature of market transformation.

⁷ For more information on the initial target market and MUSH focus, see the CRAWs MTI Plan, Executive Summary and Target Market sections; Appendix D: Market Characterization, section 2.2, Target Market; and Appendix F: Evaluation Plan, MPIs and data sources related to MUSH and CRE market adoption.

⁸ California Energy Commission. 2022 California Commercial End-Use Survey Final Report. [2022 California Commercial End-Use Survey \(CEUS\): Final Report | California Energy Commission](#).



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

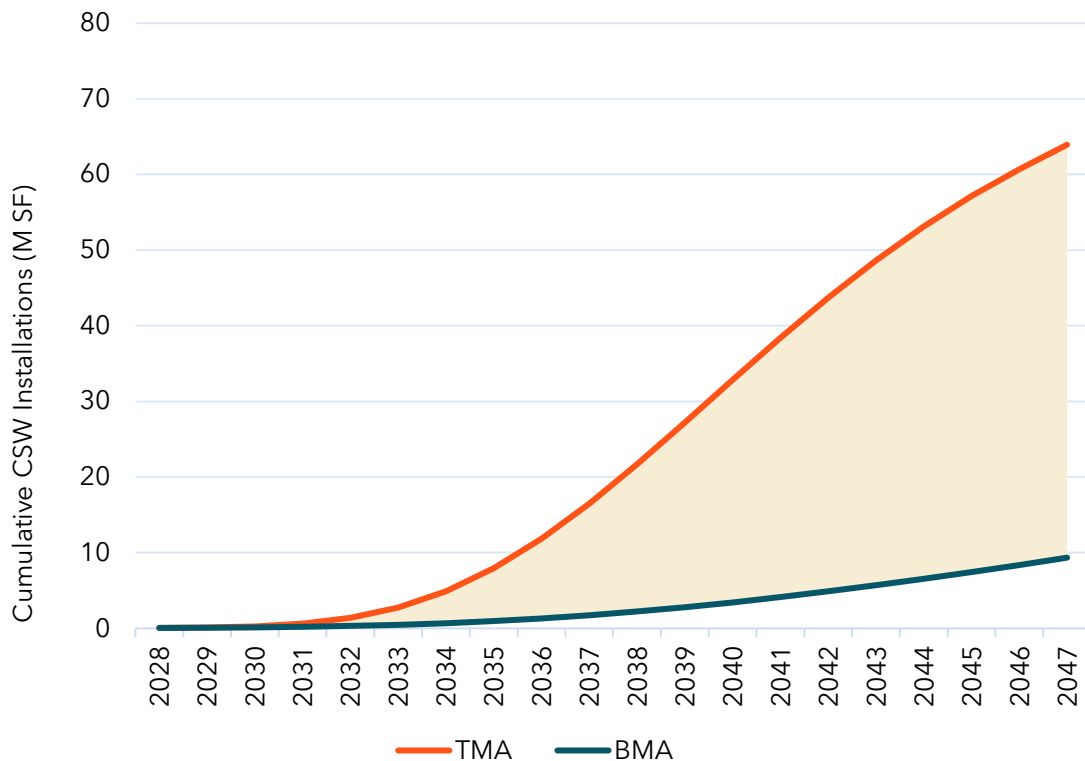


Table 1 summarizes the BMA and TMA market adoption forecast results. Cumulative TMA reaches approximately 63.9 million square feet of CSW installations over the forecast period, compared with 9.4 million square feet under BMA. The difference between the two scenarios represents approximately 54.6 million square feet of statewide incremental adoption.

Consistent with the CalMTA MTI Evaluation Framework, CalMTA makes two adjustments to the statewide incremental adoption forecast before calculating TSB and cost-effectiveness. First, CalMTA excludes the portion of incremental adoption attributed to buildings outside investor-owned utility (IOU) service territories. Second, CalMTA subtracts estimated PA-verified units associated with incremental adoption 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. These adjustments are described in greater detail in sections 3.4 & 3.5.



Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWs)

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

Table 1. 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 (Source: CalMTA estimates). Values are cumulative 2028-2047 million square feet of CSW window area. Electric IOU and gas IOU territory receives both electric and gas avoided-cost benefits. Gas IOU-only territory receives gas avoided-cost benefits but zero electric avoided-cost benefits. Non-IOU territory is excluded from the primary TSB and cost-effectiveness calculation. PA-verified adoption is deducted to avoid double counting with PA-claimed program activity. Values may not sum exactly due to rounding.

2.2 Total system benefit and cost-effectiveness forecast

After developing BMA and TMA forecasts, CalMTA translated net incremental CSW adoption into TSB and cost-effectiveness results using avoided costs, per-square-foot unit energy impacts, hourly load shapes, initiative costs, incremental measure costs, and measure-life assumptions. The analysis uses the CPUC Avoided Cost Calculator (ACC) framework, 2024 ACC workbooks, IOU-specific avoided-cost inputs, and CPUC cost-effectiveness test definitions for the TRC, PAC, and SCT.⁹

Table 2 summarizes the value of net incremental TSB, by benefit category and cost-effectiveness test, and

⁹ Avoided costs were developed using the CPUC ACC framework and 2024 ACC workbooks. Cost-effectiveness tests are based on CPUC Standard Practice Manual concepts for the TRC, PAC, and SCT tests. For more information, see CPUC, DER Cost-Effectiveness and 2024 ACC Documentation v1b; and CPUC, California Standard Practice Manual.



Table 3 reports the cost-effectiveness ratios.¹⁰ Under the TRC and PAC cost tests, forecast net incremental TSB is \$628.5 million, with a TRC ratio of 1.31 and a PAC ratio of 19.2. Table 2 also shows total societal benefits of greater than \$1.1 billion, which are higher than the TRC and PAC value because the SCT includes additional societal avoided-cost components (primarily air-quality and methane-leakage adders) and uses a lower societal discount rate. The benefit-cost ratio under the SCT cost test is 1.82 (Table 3).

Table 2. CSW estimated TSB (2028-2047)

Cost Effectiveness Test	TSB (\$M)	Energy (\$M)	Grid (\$M)	GHG (\$M)
TRC and PAC	628.5	130.0	78.6	419.9
SCT Base	1,151.4	215.8	130.2	805.5
SCT High	1,161.1	215.8	130.2	815.2

Source: CalMTA estimates. Values are present value 2027 dollars. GHG values exclude refrigerant benefits because CSW does not change refrigerant type or quantity relative to the baseline condition.

Table 3. CSW cost-effectiveness estimate (2028-2047)

TRC	PAC	Base SCT	High SCT
1.31	19.2	1.82	1.84

Source: CalMTA estimates. Ratios are calculated over the 2028-2047 forecast period using net incremental adoption for TSB and CE estimation.

Although CPUC requires CalMTA to use net incremental benefits to calculate cost effectiveness, CalMTA also reports statewide TSB and “co-created” TSB, which represent the broader market effects of the CRAWs MTI.¹¹

The results presented in this Appendix are the product of these conservative modeling assumptions:

- The primary forecast includes CSW only and excludes potential VIG adoption.

¹⁰ All present values in this appendix are reported in 2027 dollars unless otherwise noted. CalMTA uses 2027 as the common present-value base year to ensure results are aligned and to allow for consistent comparisons of results across MTIs. All benefits and costs occurring during the forecast period are discounted back to 2027 dollars for reporting.

¹¹ The CalMTA MTI Evaluation Framework requires CalMTA to estimate incremental adoption using BMA and TMA forecasts and to avoid double counting with PA-verified savings. Broader incremental TSB results, including IOU-territory co-created TSB and statewide incremental TSB, are shown in Table 11.



- CalMTA excludes monetized non-energy benefits (NEBs).¹²
- CalMTA does not include additional avoided costs that could arise if CSW enables HVAC downsizing during future equipment replacement.
- The cost-effectiveness calculation removes adoption outside IOU territories and PA-verified units, even though those installations are likely to grow as a result of the MTI and contribute to broader statewide market transformation and California policy goals.

3 Market adoption forecast

This section describes the framework CalMTA used to estimate statewide CSW adoption over the 2028-2047 forecast period and to calculate the net incremental adoption attributed to the CRAWs MTI. This document expresses adoption in square feet of installed CSW window area because window area is the common unit used for stock sizing, unit energy impacts, incremental measure cost, and avoided cost calculations.

This framework separates the physical and economic size of the market from the pace at which the market is likely to act. The model does not assume that all technically addressable buildings will install CSW. Instead, it first narrows the market to buildings where CSW appears economically plausible, then estimates how much of that market becomes aware and engaged and adopts CSW under BMA and TMA conditions.

Throughout this appendix, the term “primary forecast” refers to CalMTA’s central set of adoption, cost, avoided cost, and cost-effectiveness assumptions for the CRAWs MTI. Section 6 presents sensitivity cases that vary selected assumptions to test how results change under alternate market, cost, policy, and adoption conditions.

3.1 Model structure

CalMTA used a Gompertz S-curve framework to forecast cumulative CSW adoption. This framework is appropriate for an emerging commercial retrofit technology because it estimates adoption to occur slowly at first, then accelerate as awareness, professional recommendation, field evidence, and market infrastructure build, and finally taper as the most accessible portion of the market is served.

The model estimates cumulative adoption in year t as:

¹² Because the TSB calculation includes only avoided-cost benefits, the cost-effectiveness ratios understate the value building owners may perceive from CSW in applications where thermal comfort, noise reduction, occupant disruption, resilience, or future HVAC right-sizing are important purchase drivers.



$$Adoption_t = AVP_t * M * e^{-e^{-r(t-t_0)}}$$

Where:

$Adoption_t$ = cumulative CSW adoption in year t, expressed as square feet of installed CSW window area

AVP_t = awareness of the value proposition multiplier in year t

M = the Gompertz model maximum, which CalMTA approximates using the estimated achievable potential described in section 3.2.3, expressed as square feet of window area

r = growth rate, which determines the steepness of the adoption curve

t = forecast year

t_0 = inflection year, when annual adoption reaches its maximum

e = exponential function

The Gompertz parameters translate the estimated achievable potential into an annual adoption trajectory. For this analysis, CalMTA uses estimated achievable potential as the model's practical upper bound because it reflects the portion of technical potential that passes both the positive-net-present-value and the simple-payback filters. This approach does not imply that the full technical market is unavailable or that all remaining buildings could never adopt CSW. Rather, it provides a conservative proxy for the portion of the market for which CSW retrofits are likely to offer a strong value proposition.¹³

After estimating the Gompertz adoption trajectory, CalMTA applies an additional awareness-of-the-value-proposition (AVP) constraint. AVP represents the share of the economically attractive market that is sufficiently aware of CSW and its value proposition to consider CSW as a potential retrofit solution. Market actors cannot evaluate CSW as an option if they are not aware of the product category, do not understand the problems it can solve, or do not have enough confidence in its performance and installation pathway. See sections 3.3 & 0 for additional details on the AVP constraint.¹⁴

¹³ CalMTA previously used a Gompertz S-curve framework in the Room Heat Pumps MTI, Appendix B, because the model structure can be linked to MTI market interventions and milestones. For additional diffusion-modeling context, see Geroski, P.A. 2000. "Models of Technology Diffusion," Research Policy 29(4-5): 603-625; Meade, N. and Islam, T. 2006. "Modelling and Forecasting the Diffusion of Innovation: A 25-year Review," International Journal of Forecasting 22(3): 519-545; and Lee, J.C., Lu, K.W., and Horng, S.C. 1992. "Technological Forecasting with Nonlinear Models," Journal of Forecasting 11(3): 195-206.

¹⁴ AVP is a CalMTA modeling construct representing awareness of the value proposition. It is used to reflect non-price barriers such as information gaps, lack of product familiarity, limited professional recommendation, limited



Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWS)

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3.2 Inputs and assumptions

The BMA and TMA forecasts use the same underlying building stock, technical-potential, customer-economics, and geography assumptions. They differ in the assumed pace and extent of market engagement, including the AVP trajectory and adoption growth-rate assumptions. These differences reflect the expected effect of CRAWs MTI activities on awareness, confidence, market infrastructure, and adoption over time.

3.2.1 Market size and segmentation

The forecast begins with 2022 CEUS commercial floor space data. CEUS is the most current California-specific commercial building stock source available for this analysis and provides floor space by building type, utility territory, and building vintage. CalMTA used CEUS because the adoption model must allocate the building stock to IOU territories and building types in a way that can be reconciled with energy impacts and cost-effectiveness calculations.¹⁵

The CRAWs model uses CEUS as the primary stock basis for market sizing, window-area estimation, and utility-territory allocation. This approach keeps the stock, adoption, unit energy impact, and avoided cost calculations reconciled to a common framework. The model also maintains separate electric and gas IOU indicators so that benefits and associated costs can be assigned appropriately to buildings in each of three IOU segments, as described in section 3.4

CalMTA excluded warehouse floor area and part of the miscellaneous category before calculating addressable stock. CalMTA excluded warehouses because they typically have low window-to-floor-area ratios and therefore limited CSW opportunity relative to floor area. Additionally, CalMTA excluded 50% of the miscellaneous building category because it contains a heterogeneous mix of uses, some of which are expected to have limited addressable window area or limited relevance to the CRAWs value proposition. These assumptions are conservative because they reduce the modeled stock before the adoption forecast.¹⁶

The remaining floor area was divided into two market segments: MUSH and non-MUSH. The MUSH segment includes municipal, university, school, hospital, and related institutional building types, represented by the DEER education, hospital, nursing home, assembly, and library prototypes. The non-MUSH segment includes the remaining targeted commercial stock. This

availability of decision-support tools, and lack of routine envelope evaluation in building retrofit planning. For supporting market barriers and MPIs, see Appendix D: Market Characterization, Findings 3 through 5 and sections 6.7 through 6.11; Appendix A: Logic Model; and Appendix F: Evaluation Plan, Table 1.

¹⁵ The 2022 CEUS final report states that CEUS estimates commercial floor stocks, fuel shares, energy use, and hourly whole-building load profiles by commercial building type and electric utility service area.

¹⁶ Warehouse and miscellaneous-category exclusions are CalMTA modeling assumptions based on expected limited addressable window area and the heterogeneous composition of miscellaneous commercial floor space. For the modeling presentation of this assumption, see May 6, 2026, MTAB Presentation, CRAWs Market Adoption Forecast slides on commercial floor space and exclusions.



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segmentation aligns the adoption model with the MTI strategy, which identifies owner-occupied and institutionally managed buildings as the likely early market for CRAWs because these buildings have longer investment horizons, greater ability to capture operational benefits, and stronger channels for ESCO and public-sector engagement.¹⁷

3.2.2 Addressable stock and prototype mapping

CEUS does not directly identify window type, pane count, or low-e coating status, but does track building vintage in categories. CalMTA therefore used building vintage as a proxy for identifying addressable stock. Buildings constructed before 1997 are included in the addressable stock because they are more likely to retain single-pane or clear double-pane windows without low-e coatings. Buildings constructed from 1998 onward are excluded from the addressable stock because they are more likely to have been built with, or subsequently upgraded to, higher-performing glazing. Screening for building vintage is consistent with the CRAWs target market of pre-2000 commercial buildings with single-pane or double-pane clear windows and is also conservative because it excludes post-1998 buildings, even though some may still contain poor-performing windows.¹⁸

After identifying addressable floor area, CalMTA mapped CEUS building categories to DEER commercial prototype buildings. Each CEUS category maps to one or more DEER prototypes, and DEER floor-area weights were used to split floor area across prototypes where needed. Using DEER prototypes provides a common geometry basis for the adoption, savings, cost, and avoided cost calculations. This is important because the model converts commercial floor area into window area, applies per-square-foot unit energy impacts, and calculates incremental measure costs on the same per-square-foot window-area basis.

Each DEER prototype has a window-to-floor-area ratio. CalMTA applies those ratios to the filtered CEUS floor area to estimate addressable window area. This process produced an estimated 445.1 million square feet of technically addressable CSW window area statewide.

¹⁷ For more information on owner-occupied and institutional market prioritization, see the CRAWs MTI Plan, Target Market and Strategic Interventions sections; Appendix D: Market Characterization, section 2.2; and Appendix F: Evaluation Plan, Table 1.

¹⁸ Appendix D: Market Characterization identifies the CRAWs target market as commercial buildings constructed before 2000 that have single-pane or double-pane clear windows. The market characterization also shows that low-e coatings are much less common in older building vintages and that post-2000 buildings are substantially more likely to have low-e coatings.



3.2.3 Estimated achievable potential

CalMTA applies sequential filters to move from technical potential to the estimated achievable potential. These filters are intended to approximate the practical decision screens that commercial building owners use when evaluating discretionary envelope investments.

The first filter identifies technical potential: existing commercial window area that is physically addressable based on building type, vintage, and window-area assumptions. This step estimates where CSW could plausibly be installed before considering customer economics.

The second filter identifies economic potential: the subset of technical potential that produces positive net present value using a 10% customer discount rate. The 10% rate is intended to reflect a private-sector investment perspective rather than a utility or societal cost-effectiveness perspective. Commercial building owners often evaluate envelope retrofits against competing capital uses, including deferred maintenance, tenant improvements, HVAC replacement, and other operational investments. Using a higher customer discount rate in the adoption model is therefore conservative relative to the lower discount rates used in TRC and SCT calculations.¹⁹

The third filter identifies the subset of economic potential with simple payback of eight years or less. This filter recognizes that a project can be cost effective over its life but still fail to meet the shorter investment horizon many commercial building owners use for discretionary envelope improvements. CalMTA selected an eight-year threshold as a moderate screen to represent projects with a credible near- to medium-term business case within the MTI horizon, while still being more conservative than a lifetime NPV test alone. Buildings that clear the NPV test but fail the payback screen may still be viable under stronger policy, financing, incentive, or non-energy benefit conditions.²⁰

These three screening filters reduce total existing window area to 445.1 million square feet of technical potential, 165.9 million square feet of economic potential, and 145.4 million square feet of estimated achievable potential. The model uses the 145.4 million square feet value as a conservative proxy for the Gompertz M parameter in both BMA and TMA. In other words, BMA

¹⁹ The 10% customer discount rate is a CalMTA modeling assumption intended to approximate private-sector commercial investment screening rather than public-sector or utility cost-effectiveness discounting. For related commercial retrofit decision-making literature, see Anderson, S.T. and Newell, R.G. 2004. "Information Programs for Technology Adoption: The Case of Energy-Efficiency Audits," *Resource and Energy Economics* 26(1): 27-50; Jones, C.B. and Bogus, S.M. 2010. "Decision Process for Energy Efficient Building Retrofits: The Owner's Perspective," *Journal of Green Building* 5(3): 131-146; and Kontokosta, C.E. 2016. "Modeling the Energy Retrofit Decision in Commercial Office Buildings," *Energy and Buildings* 131: 1-20.

²⁰ The eight-year simple-payback screen is a CalMTA modeling assumption used to represent a moderate commercial decision threshold for discretionary envelope investments. It is intended to identify the subset of positive-NPV projects with a strong enough customer value proposition to support adoption within the MTI horizon.



and TMA use the same estimated achievable potential; the MTI accelerates how much of that market is reached within the forecast period.

Table 4. Stages used to derive estimated achievable potential for CSW

Filter stage	Description	Window area (million square feet)
0	Existing windows in commercial buildings	620.0
1	Technical potential / addressable stock	445.1
2	Economic potential (positive NPV at 10% discount rate)	165.9
3	Achievable potential (payback <= 8 years)	145.4

Source: CalMTA estimates. Values represent window area in million square feet. Technical potential reflects and achievable potential apply customer-economics screens to the technical potential.

3.3 Baseline market adoption

BMA represents expected CSW adoption in the absence of the CRAWs MTI. The BMA forecast assumes that the CSW market grows slowly because the market remains constrained by information gaps, limited performance-rating visibility, limited professional recommendation, reactive window replacement practices, and competition for capital from other building improvements.

The BMA scenario assumes that without coordinated market transformation, most building owners continue their current practice of addressing windows only when a failure, tenant complaint, historic preservation need, or isolated project opportunity arises. As such, market adoption remains low and does not reach a natural inflection point (when annual adoption reaches its maximum) within the forecast period.

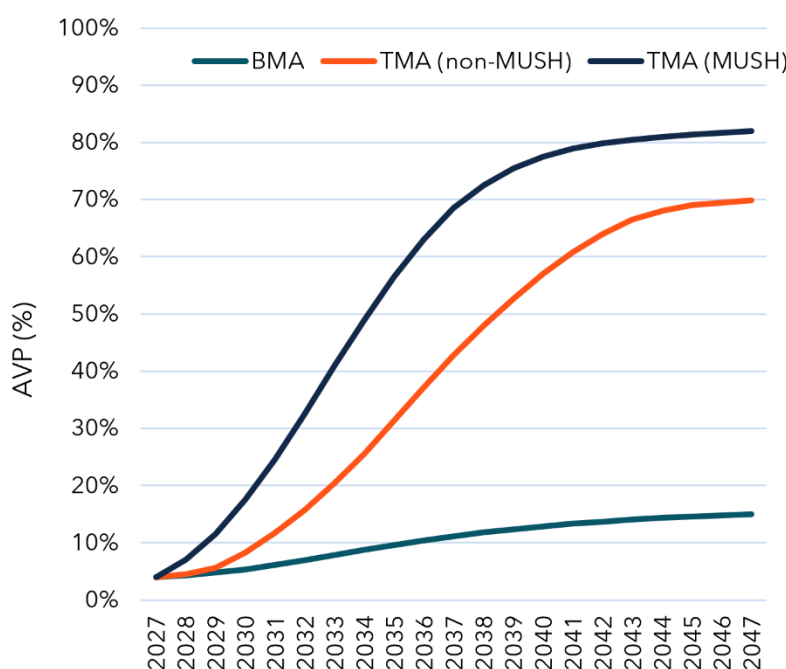
CalMTA modeled BMA using a growth rate of 0.07 and an inflection year of 2050.²¹ Because the inflection year falls after the 2028-2047 forecast period, annual BMA adoption remains in the pre-inflection accelerating growth phase throughout the full duration of the modeled period, and cumulative adoption does not enter the rapid middle stage of the S-curve before the end of the forecast period. CalMTA selected this slow-growth trajectory because CSW has existed in the market for years without achieving broad commercial uptake, while market characterization findings found that CSW remains a niche retrofit option with limited owner awareness, largely

²¹ In the Gompertz S-curve model, the growth rate is a curve-shape parameter that controls how quickly adoption ramps up over time. A lower growth rate produces a flatter adoption curve, meaning adoption increases gradually from year to year. A higher growth rate produces a steeper curve, meaning adoption accelerates more quickly as the market approaches its inflection year. The inflection year is the point when annual adoption reaches its highest level, not the point when adoption stops.

reactive adoption, and little evidence of the professional recommendation, policy pressure, or delivery-channel maturity needed for broad market acceleration.²²

Figure 2 shows the BMA AVP trajectory which starts at approximately 1% and rises slowly to approximately 5% by 2047. The BMA AVP trajectory is deliberately above zero. This avoids overstating MTI impact by recognizing that some adoption is likely to occur naturally as awareness of building decarbonization, building performance standards, and high-performance retrofit solutions increases over time.

Figure 2. AVP trajectories by scenario and segment, 2028-2047



Note: AVP values represent a constraint on market adoption – not market adoption; an AVP of 0% implies that zero potential purchasers are sufficiently aware of CSW to consider it as a solution, and an AVP of 80% implies that 80% of potential purchasers are sufficiently aware to consider CSW.

3.3.1 Total market adoption

TMA represents the CSW adoption trajectory expected in the presence of coordinated CRAWs MTI interventions. Relative to BMA, TMA assumes faster growth, earlier inflection, and a higher

²² For baseline market barriers, see Appendix D: Market Characterization, Finding 5 and sections 6.7 through 6.11. The report describes reactive replacement practices, information-source patterns, limited use of tools and calculators, limited incentive awareness, and the importance of quantifying benefits beyond energy savings.

AVP trajectory because the MTI is designed to reduce the non-price barriers that keep economically attractive CSW projects from being identified, recommended, financed, and installed.

Under TMA, the market transformation effect is modeled through three linked mechanisms. First, MTI activities increase market awareness of the CSW value proposition. Second, field demonstrations, technical resources, product ratings, and training increase confidence among market actors who influence building owner decisions, including ESCOs, architects, specifiers, HVAC designers, and installers. Third, integration with external programs, building decarbonization planning, and potential building performance standards makes envelope evaluation more routine during major retrofit and HVAC decision points.²³

CalMTA modeled TMA using growth rates of 0.18 for non-MUSH and 0.22 for MUSH, with inflection years of 2038 and 2036, respectively. The higher MUSH growth rate and earlier MUSH inflection reflect the expectation that institutional procurement channels, ESCO delivery models, public-sector planning, and longer ownership horizons allow MUSH adoption to accelerate sooner once the value proposition is demonstrated. Table 5 summarizes the corresponding model inputs.

Table 5. Key adoption forecast parameters by scenario and segment

Scenario	Segment	Growth Rate	Inflection Year
BMA	MUSH and Non-MUSH	0.07	2050
TMA	MUSH	0.22	2036
TMA	Non-MUSH	0.18	2038

Source: CalMTA estimates.

Figure 2 shows the AVP trajectories used in the BMA and TMA forecasts. These values represent the share of the economically attractive market that is aware enough of CSW and its value proposition to *consider* CSW as a potential retrofit solution.

The difference between the BMA and TMA parameter sets reflects CalMTA's theory of market change. In BMA, CSW remains a niche solution that grows slowly as the market responds to general decarbonization and retrofit pressures. In TMA, targeted interventions accelerate awareness, increase confidence among market actors who influence building decisions, and help make envelope evaluation a more routine part of retrofit and HVAC planning.

²³ For TMA causal logic, see the CRAWs MTI Plan, Strategic Interventions section; Appendix A: Logic Model; and Appendix F: Evaluation Plan, Table 1. These materials link MTI activities to awareness-building, market actor recommendations, technical-resource development, installer training, product ratings, municipal policy integration, and envelope-HVAC integration.



3.4 IOU territory and program-administrator-verified units

CalMTA applies two sequential adjustments to forecast statewide incremental adoption before calculating MTI TSB and cost-effectiveness.

3.4.1 IOU service territory adjustment

First, CalMTA identifies the portion of statewide incremental adoption that is applicable to IOU TSB and cost-effectiveness calculations. The CRAWs MTI is statewide in strategy and market impact, but formal cost-effectiveness calculations are based on IOU-applicable benefits. Because CRAWs affects both electricity and natural gas consumption, the model applies the IOU-territory adjustment separately by fuel rather than removing all adoption outside electric IOU territory.

The model classifies adoption into three utility-territory segments:

- 1) Adoption in territory served by both electric and gas IOUs receives both electric and gas avoided-cost benefits and associated incremental measure costs.
- 2) Adoption in territory served by a gas IOU only receives gas avoided-cost benefits, zero electric avoided-cost benefits, and an allocated share of incremental measure costs.²⁴
- 3) Adoption in territory served by neither an electric or gas IOU is excluded from the net incremental adoption used for the primary TSB and cost-effectiveness forecast.

Table 1 shows forecast adoption in each of these three segments.

CEUS provides the commercial floor-space foundation used for market sizing and electric utility territory assignment.²⁵ To estimate commercial floor space served by a gas IOU that is not served by an electric IOU, CalMTA made the simplifying assumption that buildings identified by CEUS as being served by SMUD or LADWP are also served by Pacific Gas and Electric Company (PG&E) or Southern California Gas Company, respectively. The CRAWs forecasting model represents

²⁴ For adoption in gas IOU-only territory, the model includes only the portion of incremental measure costs associated with the gas benefits counted in the TSB and cost-effectiveness calculation. The cost allocation is based on the relative share of gas TSB benefits compared with total electric-plus-gas TSB benefits for the same adoption segment. For example, if gas avoided-cost benefits represent 70% of total electric-plus-gas TSB benefits for units in the gas IOU-only segment, the model includes 70% of the incremental measure costs for that segment. This approach aligns the included costs with the portion of benefits retained in the primary cost-effectiveness calculation.

²⁵ CalMTA reviewed EIA electric and natural gas data as an independent reasonableness check because prior CalMTA Appendix B models often used EIA-based customer, sales, or revenue data to estimate IOU and non-IOU allocation. For CRAWs, CEUS was retained as the primary allocation source because the model is built from commercial floor space and window area, and using CEUS consistently avoids mixing floor-space data from one source with allocation factors from another source. The EIA comparison was generally consistent with the CEUS-derived IOU/non-IOU allocation and did not indicate that a blended allocation was warranted.



incremental adoption in gas-only IOU service territory separately, so that these areas are not incorrectly excluded from gas benefits. This approach is particularly important for CRAWs because the measure produces both electric and gas impacts.

Operationally, the TSB calculation applies avoided costs by fuel: electric avoided costs are applied only to adoption in electric IOU territory, while gas avoided costs are applied to adoption in gas IOU territory, including gas IOU-only areas.²⁶ The non-IOU segment is retained separately in the forecasting model for transparency but is excluded from the primary TSB and cost-effectiveness calculation. Broader statewide and co-created impacts are reported separately in Section 4.3.

3.4.2 Program-administrator-verified units adjustment

Second, CalMTA removes estimated PA-verified units. PA-verified units represent the portion of incremental adoption estimated to be reported as verified savings by Program Administrators. CalMTA subtracts these units from the incremental adoption estimated in IOU service territories to avoid double counting benefits that are forecast to be claimed through PA programs. This treatment does not mean that PA-supported installations are unrelated to the MTI. Rather, it means that for formal IOU cost-effectiveness accounting, CalMTA removes units expected to be claimed by PA programs and presents broader influenced benefits separately in the co-created TSB results in Table 11.²⁷

For the primary forecast, CalMTA assumes that PA-verified units represent 10% of incremental IOU-territory CSW installations during the early years of Phase III, rise to 40% during the medium term as utility CSW program activity increases, and decline to zero by the end of the forecast period as CSW market infrastructure matures and adoption becomes less dependent on program support. This assumption is based on CalMTA's expected program-availability timeline for CSW. In the short term (2027-2030), CalMTA assumes a 10% share because no PA programs currently incentivize CSW and the measure is expected to be added to the eTRM during this period. In the medium term (2030-2035), CalMTA assumes the PA-verified share rises to 40% as programs that include CSW become more widely available. In the later period (2035-2047), CalMTA assumes the PA-verified share tapers to zero as the technology matures and a declining share of installations is expected to occur through utility programs. CalMTA will update this assumption annually based on actual data, including PA activity, eTRM status, incentive offerings, and California Energy Data and Reporting System (CEDARS)-reported units.

²⁶ "Gas IOU-only territory" refers to areas outside electric IOU service territory where the model assigns gas impacts to an IOU gas territory. These areas receive gas avoided-cost benefits only. Electric avoided-cost benefits are not applied unless the adoption occurs in PG&E, SCE, or SDG&E electric territory.

²⁷ To avoid double counting, the CalMTA MTI Evaluation Framework requires PA-verified units associated with incremental adoption to be subtracted from MTI-attributed net incremental adoption used for TSB and cost-effectiveness.



3.5 Net incremental market adoption

After developing the BMA and TMA forecasts, CalMTA calculated net incremental adoption for use in the TSB and cost-effectiveness forecasts, using the equation below:

$$\gamma^{N.incremental} = \gamma^{TMA} - \gamma^{BMA} - \gamma^{non-IOU} - \gamma^{PA}$$

Where:

$\gamma^{N.incremental}$ = net incremental adoption used for TSB and cost-effectiveness

γ^{TMA} = Total Market Adoption

γ^{BMA} = Baseline Market Adoption

$\gamma^{non-IOU}$ = incremental adoption attributed to buildings outside IOU service territories

γ^{PA} = PA-verified units associated with incremental adoption

The order of subtraction does not change the result; the equation is written to match the order in which the adjustments are described above. Table 6 reports net incremental adoption by segment. Under the primary forecast, after excluding adoption attributed to non-IOU territory and the estimated PA-verified units, the net incremental adoption used for TSB and cost effectiveness is shown in the right-most column of Table 6.

Table 6. Net incremental adoption, million square feet of CSW window area

Segment	Statewide incremental units	Adoption attributed to non-IOU territory	PA-verified units	Net incremental adoption for TSB and CE estimation
MUSH buildings	9.9	1.9	2.2	5.8
Non-MUSH buildings	44.7	5.9	6.9	31.8
Total	54.6	7.8	9.1	37.6

Source: CalMTA estimates. Values are cumulative 2028-2047 million square feet of CSW window area. Values may not sum exactly due to rounding.

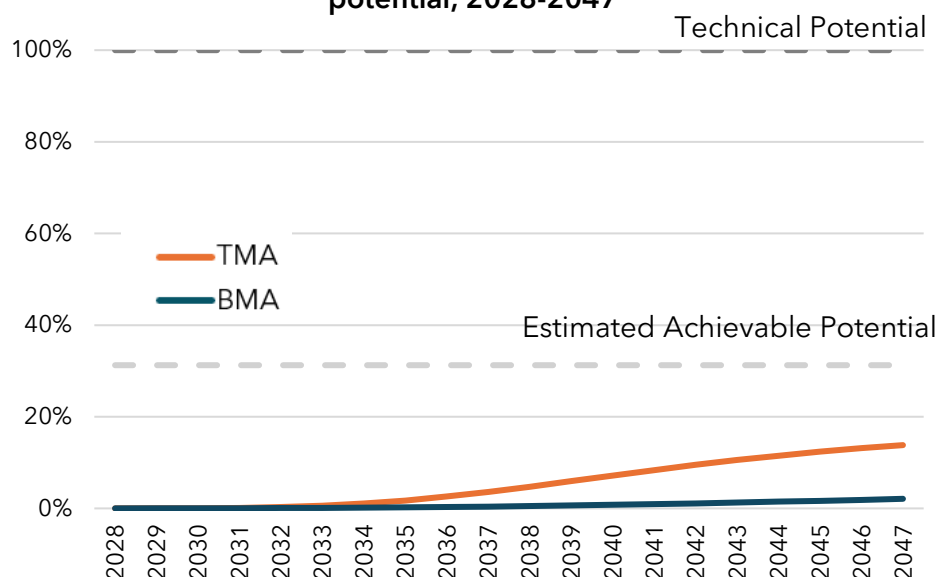
Figure 3 shows the modeled TMA trajectory relative to both technical potential and estimated achievable potential. The forecast does not assume that the MTI reaches the full technical opportunity. Instead, adoption remains constrained by the economic-potential and payback filtering screens described in Section 3.2.3, as well as the AVP and Gompertz diffusion assumptions.



Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWS)

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

Figure 3. CSW adoption as a proportion of technical potential and estimated achievable potential, 2028-2047



3.6 Load shapes

CalMTA used hourly electric and gas savings shapes developed from building energy simulations of baseline and proposed CSW cases. These hourly profiles capture the seasonal and time-of-use patterns of CSW-related electricity and gas savings and are used to weight avoided costs from the 2024 ACC workbooks. This approach allows the TSB calculation to reflect annual energy savings and also the time-dependent value of those savings to the electric and gas systems.

CalMTA expresses the load shapes on a per-square-foot-of-window-area basis. Attachment 1: Documentation of unit energy savings and avoided cost calculations for commercial replacement and attachment window solutions (CRAWS) documents the energy-modeling methods, case definitions, climate-zone weighting, and avoided cost calculations used for this MTI.²⁸

3.7 Unit energy impacts

CalMTA expresses unit energy impacts on a per-square-foot-of-window-area basis and includes both electricity and natural gas impacts. The underlying unit energy impacts were developed using EnergyPlus whole-building simulations based on DEER commercial prototype buildings.

²⁸ For detailed load-shape development methods, see Appendix B, Attachment 1: Documentation of Unit Energy Savings and Avoided Cost Calculations for Commercial Replacement and Attachment Window Solutions, Energy Modeling Software, Building Models, Climate Zones, Avoided Cost Calculations, and Weighting Factors sections.



CalMTA developed unique unit energy impact values for each California climate zone and DEER prototype combination.

CRAWS has a single modeled installation condition: installation of CSW on an existing commercial single-pane or clear double-pane window, relative to the equipment baseline of leaving the existing window in place. This “do-nothing” installation condition reflects the fact that CSW is modeled as a retrofit attachment to an existing window rather than as a full window replacement

These per-square-foot unit energy impacts are used in two places in the model. First, they are used to calculate NPV and payback periods in the estimation of achievable market potential. Second, they are used in the TSB calculation to translate net incremental CSW adoption into electric, gas, grid, and GHG benefits. Using one common savings unit across the adoption and cost-effectiveness models ensures that stock, savings, costs, and avoided costs reconcile to a consistent window-area basis.

Summary energy savings results are presented in Appendix C: Product Assessment Report, section 8.1. Attachment 1 of this appendix documents the modeling inputs, case definitions, weighting assumptions, hourly unit energy impact profiles, and avoided-cost calculation approach used for the CRAWS TSB and cost-effectiveness analysis.

DEER prototype building simulations do not include additional savings that may result from reduced air infiltration after CSW installation. This exclusion results in a conservative estimate of unit energy impacts because secondary windows can reduce uncontrolled air leakage in some buildings. CalMTA’s current modeling follows the draft measure framework and does not claim additional benefits in the primary UEI values.²⁹

3.8 Effective useful life

CalMTA uses a 30-year effective useful life (EUL) for CSW installations in the primary forecast, consistent with the value CPUC staff recently recommended CSW measure package.³⁰ The 30-year EUL is applied consistently in the TSB and cost-effectiveness calculations and reflects the expected duration over which installed CSW products produce energy and system benefits.

²⁹ Attachment 1 notes that CSWs can reduce air infiltration in some cases, but the energy modeling did not include reduced infiltration benefits. Excluding infiltration savings is a conservative modeling treatment because the primary UEI values include only the modeled thermal-performance improvement associated with the CSW cases. Attachment 1 cites Henderson et al. 2007, “Mitigating the Impacts of Uncontrolled Air Flow on Indoor Environmental Quality and Energy Demand in Non-Residential Buildings,” Final Report DOE Project No. DE-FC-36-02GO12012, as supporting evidence that uncontrolled air leakage can affect nonresidential building energy demand.

³⁰ Measure SWBE012-01 draft high efficiency window commercial measure; Biermayer, P. Email message to Jeff Mitchell, May 15, 2026.



4 Total system benefits

CalMTA calculated TSB as the present value (2027 dollars) of avoided electric, gas, and GHG impacts associated with net incremental CSW adoption. TSB is calculated by pairing annual net incremental adoption with per-square-foot unit energy impacts, hourly load shapes, and avoided-cost values. The analysis uses net incremental adoption to calculate IOU cost-effectiveness. CalMTA also reports co-created and statewide TSB estimates to provide a fuller view of market impacts.

TSB includes avoided energy, grid, and GHG benefits to the energy system calculated using standard avoided-cost methods, in accordance with the CPUC ACC.³¹ It does not include monetized customer non-energy benefits such as thermal comfort, noise reduction, reduced disruption, resilience, or improved ability to right-size HVAC equipment during future replacements. As a result, the TSB and cost-effectiveness results likely understate the full value that some building owners may derive from CSW, particularly in applications where comfort, acoustics, resilience, or HVAC planning benefits are important drivers of adoption.

TSB is a function of the inputs described in earlier sections: net incremental adoption, unit energy impacts, hourly load shapes, avoided costs, measure life, and discounting assumptions. For CRAWs, TSB is driven by avoided electric, gas, grid, and GHG benefits. Refrigerant benefits and costs are not included because CSW does not change refrigerant type or quantity relative to the baseline condition.

$$TSB = (Electric\ Benefits + Gas\ Benefits) \\ - (Electric\ Supply\ Cost + Gas\ Supply\ Costs)$$

CalMTA categorized the avoided cost components into three categories: energy benefits, grid benefits, and GHG benefits. Table 7 lists the ACC workbook factors from the electric and gas models by the three categories for reporting.

Table 7. Avoided cost components by category

Category	Electric Model	Gas Model
Energy	Energy	Market (commodity)
Grid	Generation capacity	Transmission and distribution
	Transmission capacity	
	Distribution capacity	
	Ancillary Services	
	Losses	
GHG	Cap and trade	Environment (CO ₂ and NO _x emission)

³¹ California Public Utilities Commission, 2024 Avoided Cost Calculator Documentation, Version 1b; see also CPUC DER Cost-Effectiveness Tools and Updates.



Category	Electric Model	Gas Model
	GHG adder	Upstream methane leakage
	GHG rebalancing	Behind-the-meter methane leakage
	Methane leakage	Gas air quality adder
	Air quality adder	N/A

Source: CalMTA summary of 2024 ACC V1b electric and gas avoided-cost components. Refrigerant avoided costs are not applicable to CSW.

4.1 Avoided costs

CalMTA developed measure-specific avoided-cost values using the CPUC ACC framework and the 2024 Distributed Energy Resources ACC workbooks developed by Energy and Environmental Economics (E3), Version 2024 V1b. CalMTA used IOU-specific electric and gas avoided-cost inputs for PG&E, SCE, and SDG&E and included avoided costs through the final year needed to capture the full benefit stream from installations occurring during the 2028-2047 adoption forecast period. For CSW benefits extending beyond the final year available in the ACC workbook, CalMTA used the final available avoided-cost year as a proxy. Avoided cost inputs used for TSB calculations are shown in Table 8.

Table 8. Avoided-cost inputs

Input	Assumption
Avoided-cost framework	CPUC ACC
ACC version	2024 ACC workbooks, Version 2024 V1b
Electric avoided costs	PG&E, SCE, SDG&E
Gas avoided costs	PG&E, SCE, SDG&E
Refrigerant avoided costs	Not Applicable
Installation years	2028-2047
Post-2054 avoided-costs	2054 avoided-cost values used as proxy
TRC / PAC discounting	Average nominal discount rate of 7.30%
SCT discounting	3% real (5.06% nominal)
Representative climate zones	PG&E-CZ12, SDG&E-CZ7, SCE-CZ10

Source: 2024 ACC Guidance. Average discount rate reflects the simple average of the PG&E, SCE, and SDG&E nominal discount rates used in the cost-effectiveness model.

Table 9 shows the discount rates per IOU used in avoided cost and TSB calculations.



Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWS)

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Table 9. Discount rate by IOU

IOU	Discount Rate
PG&E	7.27%
SCE	7.44%
SDGE	7.18%
Average discount rate	7.30%

For the SCT, CalMTA applies the base and high SCT-specific avoided-cost values from the ACC to incremental adoption for PG&E, SCE, and SDG&E. As with the TRC and PAC analyses, CalMTA aggregated and discounted these benefits to estimate base and high SCT benefits in 2027 dollars.

Avoided-cost benefits are applied by fuel and utility-territory segment. Electric avoided-cost benefits are applied only to adoption in electric IOU territory using the applicable PG&E, SCE, or SDG&E electric avoided-cost values. For adoption in gas IOU-only territory, the model assigns zero electric avoided-cost benefits but applies gas avoided-cost benefits using the applicable mapped gas utility territory. Adoption outside both electric and gas IOU territory is excluded from the primary TSB and cost-effectiveness calculation. This treatment allows the model to count gas benefits in portions of the state served by a gas IOU but not an electric IOU, while preserving the CPUC cost-effectiveness convention of excluding non-IOU electric benefits from the primary cost-effectiveness result.

4.2 TSB results

Table 10 shows estimated TSB by cost-test basis and benefit category for the 2028-2047 forecast period. Under the TRC/PAC basis, total TSB is estimated at \$508.8 million, consisting of energy, grid, and GHG benefits. Under the SCT basis, total societal benefits are higher because the SCT includes additional societal avoided-cost components and applies societal discounting.

Table 10. TRC, PAC, base SCT, and high SCT TSB estimates, 2028-2047

MTI Approach	TSB (\$M)³²	Energy (\$M)	Grid (\$M)	GHG non-refrigerant (\$M)
TRC	628.5	130.0	78.6	419.9
SCT base	1,151.4	215.8	130.2	805.5
SCT high	1,161.1	215.8	130.2	815.2

³² TSB refers to Total System Benefits for the TRC test and Total Societal benefits for the SCT.



4.3 Co-created and statewide TSB

The TSB value reported for cost effectiveness uses net incremental IOU-territory adoption after removing PA-verified units. This is the appropriate value for CPUC cost-effectiveness testing, but it does not fully represent the statewide market impact of the CRAWs MTI. The distinction between the primary cost-effectiveness result and the broader statewide result is especially relevant for CRAWs because some adoption outside electric IOU territory will still produce gas benefits in gas IOU territory, and additional adoption outside IOU territory may contribute to broader statewide market transformation even though it is not included in the primary cost-effectiveness calculation.

CalMTA therefore also presents co-created and statewide TSB estimates. Co-created TSB includes PA-verified units within IOU service territories because those installations may be influenced by the MTI even if the verified savings are claimed through PA programs. Statewide co-created TSB includes statewide incremental adoption, including adoption outside IOU service territories, and applies population-weighted average avoided costs where IOU-specific avoided-cost values are not available. These supplemental results show the broader statewide benefits of market transformation while preserving the narrower net incremental value for formal cost-effectiveness tests.³³ Table 11 compares the narrower IOU-territory TSB used for formal cost-effectiveness testing with broader co-created and statewide TSB estimates that include additional influenced adoption.

Table 11. Co-created and statewide TSB

TSB Basis	TSB (\$M)
Net incremental TSB used for cost effectiveness (IOU service territory, excluding PA-verified units)	628.5
Incremental co-created TSB (IOU service territory, including PA-verified units)	803.3
Incremental statewide TSB (statewide, including PA-verified units and non-IOU territory)	957.3

Source: CalMTA estimates. Values are present value 2027 dollars. Co-created IOU TSB includes PA-verified units within IOU territory. Co-created statewide TSB includes PA-verified units and adoption outside IOU territories.

5 Cost effectiveness

CalMTA estimated cost effectiveness by combining the net incremental CSW adoption forecast with avoided costs, unit energy impacts, load shapes, initiative costs, and incremental measure

³³ For co-created and statewide TSB framing, see the CalMTA MTI Evaluation Framework and Appendix F: Evaluation Plan. Co-created TSB includes PA-verified units influenced by the MTI; statewide TSB includes adoption outside IOU service territories to provide context on broader California market effects.



costs. The analysis reports TRC, PAC, and SCT ratios consistent with CPUC cost-effectiveness practice. The TRC and SCT include participant incremental measure costs and CalMTA initiative costs. The PAC includes CalMTA initiative costs but excludes participant incremental measure costs.

5.1 Initiative costs

Initiative costs represent the cost of implementing the CRAWs MTI over the forecast period. These costs include the activities required to develop and support the market, including MTI management, research and evaluation, data and market intelligence, field demonstrations, marketing and awareness-building, technical-resource development, and market engagement. Total initiative costs including Phase II and Phase III costs, are \$44.97 million (see Appendix H, Phase III Cost Estimate of the MTI plan).

Initiative costs are used as inputs for all cost-effectiveness tests. All test parameters are in line with California Cost-Effectiveness standard practices.³⁴

5.2 Incremental measure cost

Incremental measure cost (IMC) represents the total incremental cost to the purchaser of installing an MTI measure relative to the applicable baseline condition. CRAWs has one modeled installation condition, as described in section 3.7: installing CSW on an existing commercial single-pane or clear double-pane window relative to the equipment baseline of leaving the existing window in place. Because CSW is modeled as a retrofit add-on to existing windows, the baseline cost is zero and the full installed cost of CSW is treated as incremental. CalMTA's primary forecast uses an installed cost of approximately \$34 per square foot of CSW window area.³⁵

The CalMTA primary forecast assumes that IMC does not decline over the MTI period. This is conservative relative to the MTI theory that supply-chain development, installer training, product standardization, and market scale may reduce soft costs over time. The model therefore gives the MTI credit for accelerating adoption, but not for reducing installed costs in the primary forecast. Total incremental measure costs total approximately \$448.6 million in 2027 dollars.

5.3 Total resource cost test

The TRC test compares lifecycle benefits delivered by the MTI to the costs borne by both the PA and participating customers. For this analysis, the TRC numerator is the present value of avoided-

³⁴ CPUC (2001). California Standard Practice Manual. [cpuc-standard-practice-manual.pdf](#).

³⁵ The primary installed-cost assumption is \$34.1 per square foot of CSW window area based on the measure cost listed in draft measure SWBE012-01 from the California electronic technical reference manual. See Appendix D: Market Characterization, section 8, which discusses CSW cost data limitations and installed-cost information from field studies, case studies, pilot projects, and industry sources for more information on CSW costs.



cost benefits from net incremental CSW adoption. The TRC denominator includes present-value initiative costs, excluding future direct implementation costs where applicable, and present-value incremental measure costs.

$$TRC = (Electric\ Benefits + Gas\ Benefits + Other\ Benefits) / TRC\ Cost$$

5.4 Program administrator cost test

The PAC test compares lifecycle benefits to costs from the PA perspective. For this MTI analysis, the PAC numerator is the present value of avoided-cost benefits from net incremental CSW adoption, and the PAC denominator is the present value of CalMTA initiative costs. Participant incremental measure costs are not included in the PAC denominator because the PAC test reflects costs incurred by the PA, not costs paid by participating building owners.

$$PAC = (Electric\ Benefits + Gas\ Benefits + Other\ Benefits) / PAC\ Cost$$

5.5 Societal cost test

The SCT compares lifecycle benefits and costs from the broader societal perspective. Like the TRC, it includes participant incremental measure costs and initiative costs, but it applies societal avoided-cost assumptions and societal discounting. The societal framework places greater weight on long-term public benefits, including GHG and other societal avoided-cost components, than the TRC framework. Because CRAWs produces long-lived building envelope savings, the SCT is sensitive to the discount rate and to the treatment of long-term avoided emissions and grid benefits. Lower societal discounting generally increases the present value of benefits that occur later in the measure life.

$$SCT_{base} = (Base\ SCT\ Electric\ Benefits + Base\ SCT\ Gas\ Benefits + Other\ Benefits) / SCT\ Cost$$

The high SCT ratio is calculated as:

$$SCT_{high} = (High\ SCT\ Electric\ Benefits + High\ SCT\ Gas\ Benefits + Other\ Benefits) / SCT\ Cost$$

5.6 Cost-effectiveness results

Table 12 provides the MTI cost-effectiveness estimates over the 2028-2047 forecast period. These results indicate that the CSW-only forecast is cost effective under the TRC, PAC, and SCT tests, even before monetizing several non-energy benefits, potential infiltration savings, potential HVAC downsizing benefits, or potential VIG adoption.

Table 12. MTI cost-effectiveness estimates, 2028-2047

TRC	PAC	Base SCT	High SCT
1.31	19.19	1.82	1.84



5.7 Cost-effectiveness schedule

Table 13 shows cumulative TSB, cost-effectiveness estimates, and incremental investment at five-year intervals. MTI cost-effectiveness is properly assessed over the full MTI lifecycle rather than at interim points because MTIs typically require the greatest investment during early years to address market barriers, but they accrue the bulk of benefits in later years as removal of market barriers enable growth in awareness, development of market infrastructure, and changes in standard practice. CalMTA presents this schedule to show the expected timing of benefits and investment rather than to indicate that early-year cost effectiveness should be used to assess actual MTI cost-effectiveness.

Table 13. Incremental Investment and Cost effectiveness, at five-year timepoints

Estimated incremental investment required over period	2028-2032	2033-2037	2038-2042	2043-2047
Nominal dollars (\$M)	20.2 ^a	15.9	3.6	1.1
Cost-Effectiveness Forecast at time point	2032	2037	2042	2047
TSB (\$M)	13.1	165.3	446.8	628.5
TRC ratio	0.39	1.00	1.22	1.31
PAC ratio	0.61	5.35	13.77	19.19

^a Includes Q4 2027 expenses

6 Sensitivity analysis

CalMTA conducted sensitivity analysis to test the robustness of the primary forecast results to changes in key assumptions. These sensitivity scenarios show which assumptions have the largest effect on adoption, TSB, and cost-effectiveness, and show how the result changes under plausible alternative assumptions. The sensitivity scenarios are not probability-weighted scenarios.

The sensitivity scenarios test five types of uncertainty: measure life, installed cost, policy environment, awareness of the value proposition, and the rate of adoption. The higher-cost case shows that installed cost is an important downside risk, and the 20-year EUL case shows that measure life is a key parameter in assessing CSW cost-effectiveness. Table 14 summarizes the sensitivity scenarios that CalMTA tested, including the resulting TRC ratio, TSB, and net incremental adoption.

CalMTA also analyzed results for two combinations of variables: a “low adoption” scenario that considers the combination of conditions that would be less favorable to market transformation, and a “high adoption” scenario that considers the combination of conditions that would be more favorable to market transformation. These scenarios are not probability-weighted; they are



intended to bracket plausible downside and upside outcomes for adoption, TSB, and cost-effectiveness.

Table 14. Sensitivity analysis results

#	Sensitivity scenario	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
NA	Primary forecast	1.31	628.5	37.6
1	20-year EUL	1.09	510.7	37.6
2	Higher CSW costs	1.22	505.0	27.9
3	Lower CSW costs	1.30	819.5	59.3
4	Building performance standard	1.32	827.0	48.7
5	Lower AVP in TMA	1.30	557.2	33.7
6	Slower growth rate in TMA	1.29	562.2	33.7
7	Faster growth rate in TMA	1.31	681.4	40.7
8	Low adoption scenario	1.18	411.9	22.5
9	High adoption scenario	1.30	1,120.0	79.0

6.1 20-year effective useful life

The 20-year EUL scenario reduces the benefit life from 30 years to 20 years while holding adoption and costs constant. This decreases the number of years over which each CSW installation produces avoided-cost benefits, leading to significantly lower TSB and TRC values. These results demonstrate that the forecast is materially affected by the measure-life assumption and that the 30-year EUL is a key model parameter. The results for this analysis are shown in Table 15.

Table 15. Sensitivity scenario #1 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #1	1.09	510.7	37.6

6.2 Higher CSW costs

The higher-cost scenario increases installed CSW per square foot from \$34.1 to \$40.0 (Table 16). Higher costs reduce the share of the addressable market that clears the payback filter, lowering net incremental adoption. Higher costs also increase the cost side of the TRC test. The combined effect reduces incremental adoption, TSB, and TRC. The results for this scenario are shown in Table 17.



Table 16. CSW Costs used in sensitivity scenario #2

Growth rate (r)	CSW Cost
Primary Forecast	\$34.1 per square foot
Sensitivity Scenario #2	\$40.0 per square foot

Table 17. Sensitivity scenario #2 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #2	1.22	505.0	27.9

6.3 Lower CSW costs

The lower-cost scenario reduces installed CSW per square foot from \$34.1 to \$30.0 (Table 18). Lower costs increase the share of the market that clears the payback filter, increasing net incremental adoption and TSB. The TRC ratio remains approximately the same as in the primary forecast as the increase in benefits is partially offset by the additional measure costs associated with greater adoption, and the lowered cost changes the population of buildings included in the estimated achievable potential. This result shows that lower costs expand market reach and total benefits even if the benefit-cost ratio does not increase materially. The results for this scenario are shown in Table 19.

Table 18. CSW Costs used in sensitivity scenario #3

Growth rate (r)	CSW Cost
Primary Forecast	\$34.1 per square foot
Sensitivity Scenario #3	\$30.0 per square foot

Table 19. Sensitivity scenario #3 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #3	1.30	819.5	59.3

6.4 Building performance standard

The building performance standard scenario models a policy environment in which commercial building owners face stronger requirements to evaluate and improve building performance. This



scenario assumes that a California building performance standard (BPS) or similar policy increases both the awareness of the value proposition and the adoption growth rates earlier and faster in both BMA and TMA compared to the primary forecast.³⁶

In this scenario, the BPS policy signal and the MTI compound: the policy creates a stronger reason for building owners to evaluate envelope improvements, while the MTI increases the likelihood that CSW is recognized, recommended, and specified as part of that evaluation. To reflect this effect, the BPS scenario includes a steep increase in AVP in all model scenarios and segments beginning around 2032, which is when CalMTA estimates a BPS policy could likely be in effect. The AVP values and growth rates used in this scenario are shown in Figure 4 and Table 20, respectively. See Figure 2 for the AVP values used in the primary forecast. The results for this scenario are shown in Table 21.

³⁶ The building performance standard sensitivity is a policy-environment sensitivity and is not included in the primary forecast. For CRAWs policy context, see the CRAWs MTI Plan, Energy Policy Landscape and Strategic Interventions sections; Appendix D: Market Characterization, section 5.3; and Appendix F: Evaluation Plan MPIs related to policy, market actor awareness, and envelope-first planning.



Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWs)

*CalMTA is a program of the California Public Utilities Commission (CPUC)
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Figure 4. AVP values in sensitivity scenario #4

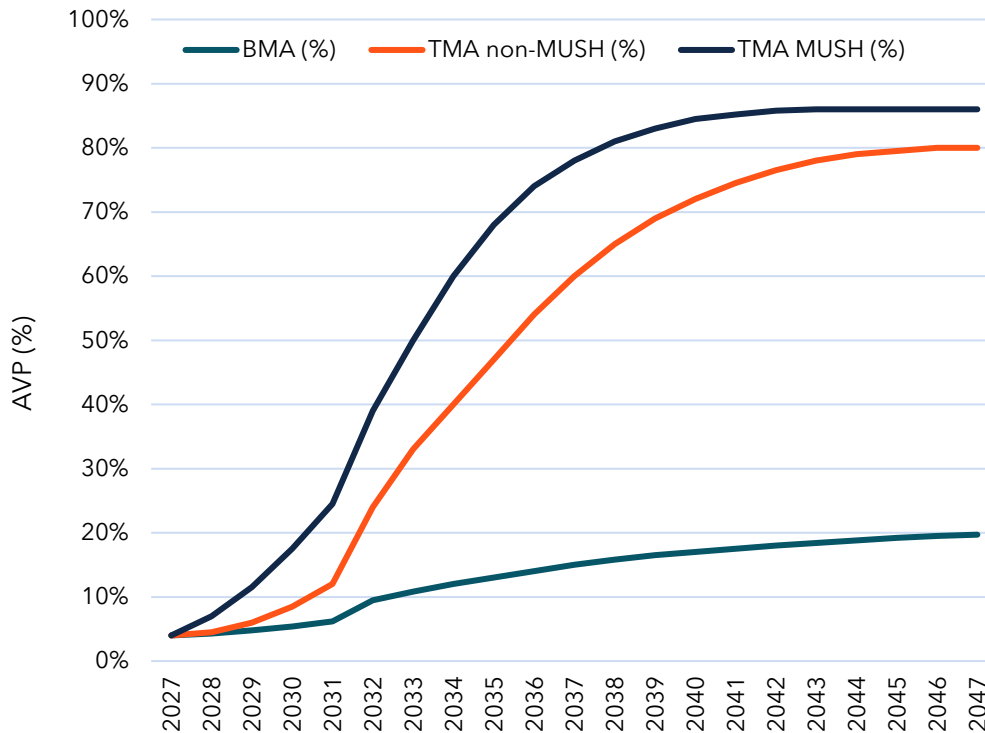


Table 20. Growth rates used in sensitivity scenario #4

Growth rate (r)	BMA	TMA non-MUSH	TMA MUSH
Primary Forecast	0.07	0.18	0.22
Sensitivity Scenario #4	0.08	0.20	0.24

Table 21. Sensitivity scenario #4 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #4	1.32	827.0	48.7

6.5 Lower AVP in TMA

The lower-AVP scenario assumes that MTI interventions are less effective at building market-actor awareness and confidence than assumed in the primary forecast. The TMA awareness trajectory still increases over time but remains lower throughout the forecast period. Figure 5 shows the AVP values used in this scenario, and the results are shown in Table 22. See Figure 2 for the AVP



values used in the primary forecast. The result remains cost effective, suggesting that the primary forecast is not highly sensitive to moderate reductions in awareness growth.

Figure 5. AVP values used for sensitivity scenario #5

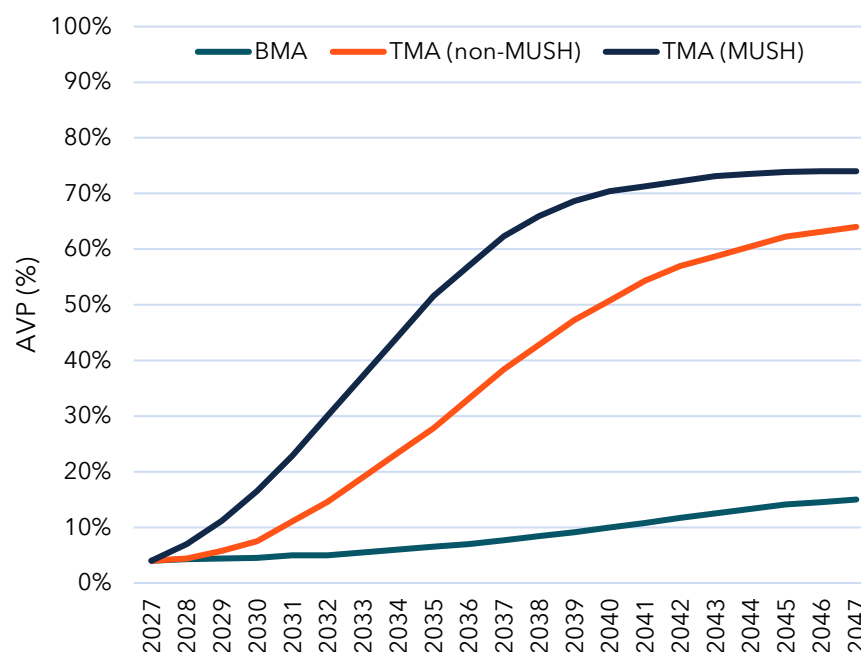


Table 22. Sensitivity scenario #5 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #5	1.30	557.2	33.7

6.6 Slower growth rate in TMA

In this scenario, CalMTA lowers the TMA growth-rate assumptions for both non-MUSH and MUSH, relative to primary forecast values. This reflects slower market diffusion compared to the primary forecast, such as if installer training, supply-chain development, or ESCO integration takes longer than expected. Table 23 shows the growth rate values used in this scenario, and the results are shown in Table 24. The result remains cost effective, suggesting that moderate delays in market acceleration do not fundamentally change the cost-effectiveness conclusion.



Table 23. Growth rates used in sensitivity scenario #6

Growth rate (r)	BMA	TMA non-MUSH	TMA MUSH
Primary Forecast	0.07	0.18	0.22
Sensitivity Scenario #6	0.07	0.15	0.19

Table 24. Sensitivity scenario #6 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #6	1.29	562.2	33.7

6.7 Faster growth rate in TMA

In this sensitivity analysis, CalMTA increases the TMA growth-rate assumptions for both non-MUSH and MUSH markets relative to the primary forecast values. The growth rates used in this analysis are shown in Table 25. The faster-growth case tests a scenario in which MTI activities catalyze adoption more quickly than assumed in the primary forecast, such as through strong early uptake in MUSH markets or rapid integration into ESCO project portfolios. Together, the slower- and faster-growth cases bracket the primary forecast and show that cost effectiveness remains positive across a plausible range of adoption-timing assumptions. Results for this analysis are shown in Table 26.

Table 25. Growth rates used in sensitivity scenario #7

Growth rate (r)	BMA	TMA non-MUSH	TMA MUSH
Primary Forecast	0.07	0.18	0.22
Sensitivity Scenario #7	0.07	0.21	0.25

Table 26. Sensitivity scenario #7 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #7	1.31	681.4	40.7

6.8 Low adoption scenario

This sensitivity analysis combines the individual assumptions that reduce CSW adoption relative to the primary forecast: higher installed CSW costs, lower awareness of the value proposition in



TMA, and slower TMA growth rates for both non-MUSH and MUSH buildings. The purpose of this case is to illustrate a plausible downside scenario in which customer economics, market awareness, and market diffusion all evolve less favorably than assumed in the primary forecast. This scenario is not intended to represent CalMTA's expected outcome; rather, it tests the robustness of the MTI under materially less favorable conditions. The result remains cost effective, with a TRC ratio of 1.18, TSB of \$411.9 million, and net incremental adoption of 22.5 million square feet. The results for this sensitivity analysis are shown in Table 27.

Table 27. Sensitivity scenario #8 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #8	1.18	411.9	22.5

6.9 High adoption scenario

This sensitivity analysis combines the individual assumptions that increase CSW adoption relative to the primary forecast: lower installed CSW costs, higher TMA awareness of the value proposition, and faster TMA growth rates for both non-MUSH and MUSH buildings. The combined case is intended to illustrate a plausible upside scenario in which multiple favorable market conditions occur simultaneously and reinforce one another. Together, these conditions improve customer economics, increase the share of the market that clears the payback filter, and accelerate market diffusion. This case provides an estimate of the MTI's upside potential if market conditions and MTI-driven improvements prove more favorable than assumed in the primary case. Net incremental adoption increases to 79.0 million square feet and TSB increases to \$1,121.0 million. The results for this sensitivity analysis are shown in Table 28.

Table 28. Sensitivity scenario #9 results

Model Run	TRC ratio	TSB (\$M)	Net incremental adoption (M sq ft)
Primary Forecast	1.31	628.5	37.6
Sensitivity Scenario #9	1.30	1,120.0	79.0



Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for Commercial Replacement and Attachment Window Solutions (CRAWS)

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Attachment 1: Documentation of unit energy savings and avoided cost calculations for commercial replacement and attachment window solutions (CRAWS)

This document provides a reference of the scenarios and methodology used to develop unit energy savings shapes and avoided cost calculations that serve as inputs to the cost effectiveness and total system benefit models for the CRAWS MTI.

Product information

The product in this MTI is CSWs, retrofit products comprised of one or more panes of glass, polymer, or acrylic that are mounted in a fixed or operable frame that is attached to either the interior or exterior of existing windows without replacing the primary glass or frame. CSWs may include low-e coatings,³⁷ insulating gases, thermal films, and/or VIG units in their construction. CSWs may be permanently installed or removable. Because CSWs are installed over the existing window and because light-weight options are available, installation can be substantially easier, faster, and less expensive than full window replacement.

The lower product costs and significantly lower installation costs of CSWs compared to primary commercial fenestration are an attractive solution for any building that needs to address envelope performance without the need to undergo a deep retrofit.

Baseline equipment

In this MTI, we are considering the installation of CSWs to be a scenario of building weatherization. In this scenario, the baseline is existing equipment rather than alternative new equipment. For the baseline scenario, the equipment is the existing windows, which are typically either single-pane or double-pane clear windows. This program is targeting existing buildings with clear glass windows (i.e., buildings without low-e or reflective coatings on their windows) because this is the type of existing condition where CSW can offer the largest energy savings and best payback. Table 29 summarizes the basic performance characteristics for the baseline existing windows. The performance values of existing windows were taken from the eTRM measure for CSWs and represent the existing commercial building stock in California.³⁸ The U-

³⁷ Low-E refers to low-emissivity coatings which are used to reduce the solar heat gain of glass. Clear glass has no low-e coating and a higher solar heat gain coefficient.

³⁸ California eTRM draft measure SWBE012-01-draft, High Efficiency Window, Commercial, Accessed February 10, 2026.



factor and SHGC of the baseline windows are comparable with single-pane and double-pane clear glass with older framing (i.e., lower insulation). CSWs have demonstrated the ability to substantially reduce air infiltration in many cases,³⁹ which contributes to energy savings. However, by following the draft CSW measure framework in the eTRM, the benefits of reduced air infiltration were not accounted for in the energy models.

Table 29. Baseline window characteristics for existing buildings

Climate Zone	U-factor (Btu/hr-ft²-°F)	Solar Heat Gain Coefficient (SHGC)
CZ01	1.03	0.707
CZ02	1.03	0.707
CZ03	1.03	0.737
CZ04	1.03	0.718
CZ05	1.03	0.753
CZ06	1.03	0.725
CZ07	1.03	0.726
CZ08	1.03	0.724
CZ09	1.03	0.723
CZ10	1.03	0.573
CZ11	1.03	0.643
CZ12	1.03	0.643
CZ13	1.03	0.635
CZ14	1.03	0.607
CZ15	1.03	0.571
CZ16	1.03	0.627

Proposed equipment

The proposed equipment is CSWs, representing typical products that might be used in existing California commercial buildings. CalMTA chose a U-factor to represent typical CSWs based upon the available products from the Attachments Energy Rating Council (AERC) database.⁴⁰ From the 28 products analyzed, we excluded the worst quartile of performing products ($U > 0.49$ Btu/hr-ft²-°F). Of the remaining 20 products with a range of U-factors from 0.16 to 0.48, we used the average of 0.35 Btu/hr-ft²-°F. For SHGC, the most popular type of low-e coatings for warmer

³⁹ Henderson, H.I., A.C. Walburger, J.B. Cummings, C. Withers, L. Gu, J. Zhang, M. Bomberg, M. Salonvaara, T. Brennan, M. Clarkin. 2007. 'Mitigating the Impacts of Uncontrolled Air Flow on Indoor Environmental Quality and Energy Demand in Non-Residential Buildings.' Final Report DOE Project No. DE-FC-36-02GO12012. April. <http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1744-07.pdf>

⁴⁰ <https://aercenergyrating.org/product-search/> Accessed August 2025.



climates have a SHGC of approximately 0.25.⁴¹ Table 30 summarizes the performance characteristics for the proposed CSW products.

Table 30. Proposed attachment and replacement window characteristics

Characteristic	Commercial Secondary Windows
Number of panes of glass	2
Low-e coating	Yes
U-factor (Btu/hr-ft ² -°F) ⁴²	0.35
SHGC	0.25

Energy modeling software

DOE's open-source building energy modeling software, EnergyPlus, is used in this analysis (version 24.2). EnergyPlus simulates whole-building energy consumption on sub-hourly timesteps and can output the energy consumption of the whole building on an hourly basis, which is used here to generate savings shapes. Each savings shape is an hourly (8760) profile of electricity consumption (in kWh) and gas consumption (in therms) that represents the difference between the baseline and proposed window specifications for different energy models. The final hourly savings shapes include contributions from multiple building types and climate zones, as discussed in subsequent sections.

Building models

Building energy modeling is performed with DEER commercial prototype building models to represent the target existing building stock in California. A total of 18 different prototype buildings were used, taken directly from the source Modelkit framework from the CSW eTRM measure. The characteristics of the prototype buildings are shown in Table 31.

⁴¹ Many CSW products are listed in the AERC database and in spec sheets with a standard SHGC ~0.35; however, in speaking with manufacturers, offering the same product with the lower SHGC (~0.25) simply requires ordering different low-e glass from the float glass manufacturer. The lower SHGC low-e coating is a widely available product used frequently in standard commercial glazing products.

⁴² Total fenestration U-factor including glass and framing,

Table 31. Description of buildings used for energy modeling

Building Code	Full name	Floor Area (ft²)	Window Area (ft²)
Asm	Assembly	68,007	2,102
ECC	Education - community college	284,193	11,564
EPr	Education - primary school	40,745	1,690
ERC	Education - relocatable classroom	2,884	64
ESe	Education - secondary school	74,402	4,518
EUn	Education - university	857,786	34,140
Hsp	Health/medical - hospital	494,056	5,083
Htl	Lodging - hotel	137,117	6,745
Mtl	Lodging - motel	29,986	4,776
Nrs	Health/medical - nursing home	110,999	6,340
OfL	Office - large	349,920	21,384
OfS	Office - small	20,005	2,286
RFF	Restaurant - fast food	3,996	581
RSD	Restaurant - sit down	11,205	510
Rt3	Retail - multistory large	240,000	998
RtL	Retail - single-story large	130,502	868
RtS	Retail - small	16,003	604
SCn	Storage - conditioned	499,990	1,358

Building HVAC

Each prototype model has a unique HVAC system that was left unmodified for this analysis. In all cases, most of the heating energy was from natural gas. CalMTA used the default efficiency settings from the DEER ModelKit framework for the CSW measure in the eTRM.⁴³ The basic HVAC properties are listed for each building in Table 32, and the detailed HVAC descriptions are listed in Table 33.

⁴³ California eTRM draft measure SWBE012-01-draft, High Efficiency Window, Commercial, Accessed February 10, 2026.



Table 32. Basic HVAC properties for prototype buildings⁴⁴

Building	HVAC System 1	HVAC System 2	Kitchen System	Data Center System	Heating Plant	Cooling Plant
Asm	Sys5-PVAV	-	-	-	2 Boilers	-
ECC	Sys6-VAV	-	Sys13	Sys11	2 Boilers	Chillers
Epr	Sys7-SZVAV-DCV	Sys7-SZCAV	Sys13	-	-	-
ERC	Sys7-SZCAV	-	-	-	-	-
ESe	Sys5-PVAV-DCV	Sys7-SZVAV	Sys13	Sys11	2 Boilers	-
Eun	Sys6-VAV-DCV	Sys1-SZAC	Sys13	Sys11	2 Boilers	Chillers
Hsp	Sys6-VAV-DCV	Sys6-VAV	Sys13	-	2 Boilers	Chillers
Htl	Sys5-PVAV	Sys1-SZAC	Sys13	-	2 Boilers	-
Mtl	Sys5-PVAV	Sys1-SZAC	-	-	2 Boilers	-
Nrs	Sys5-PVAV-DCV	Sys5-PVAV	Sys13	-	2 Boilers	-
OfL	Sys6-VAV	Sys6-VAV-DCV	-	-	2 Boilers	Chillers
OfS	Sys7-SZCAV	-	-	-	-	-
RFF	Sys7-SZCAV	-	Sys13	-	-	-
RSD	Sys7-SZCAV	Sys5-PVAV-DCV	Sys13	-	-	-
Rt3	Sys5-PVAV-DCV	Sys7-SZCAV	-	-	2 Boilers	-
RtL	Sys7-SZVAV	Sys7-SZCAV	Sys13	-	-	-
RtS	Sys7-SZVAV	Sys7-SZCAV	-	-	-	-
SCn	Sys6-VAV	-	-	-	2 Boilers	Chillers

⁴⁴ <https://calbem-benchmarking.com/docs/building-energy-models/non-residential/hvac/>



Table 33. HVAC detailed descriptions⁴⁴

System Type	Description	Detail
System 1 - SZAC	Residential Air Conditioner	Single-zone system with constant volume fan, no economizer, DX cooling and furnace
System 3 - SZAC	Packaged Single-Zone	Single-zone constant volume DX unit with gas heating
System 5 - PVAHV	Packaged VAV Unit	VAV reheat system; packaged variable volume DX unit with gas heating and with hot water reheat terminal unit
System 6 - VAVS	Built-up VAV Unit	Variable volume system with chilled water and hot water coils, water-cooled chiller, tower and central boiler
System 7 - SZVAV	Packaged Single-Zone VAV Unit	Single-zone variable volume DX unit with variable-speed drive and gas heating
System 9 - HEATVENT	Heating and Ventilation Only	Gas heating and ventilation
System 10 - CRAH	Computer Room Air Handler	Built-up variable volume unit with chilled water, no heating
System 11 - CRAC	Computer Room Air Conditioner	Packaged variable volume DX unit with no heating
System 13 - KITCH	Kitchen HVAC System	Dedicated single-zone makeup air unit (MAU) with dedicated exhaust fan.

Case descriptions

There are two different modeling cases that are used to create the proposed and baseline installations in the final scenarios for savings shapes and avoided cost calculations. Table 34 gives a description of each modeling case.

Table 34. Summary of case characteristics

#	Case name	Case description⁴⁵
1	CSW	CSW windows
2	Ex	Existing windows



Effective useful life

EUL is the estimated median life, in years, that a measure remains in operation. At the time of analysis, the CA eTRM did not have an EUL for commercial windows, but the CPUC is recommending the TRM use an EUL of 30 years which is consistent with several other efficiency programs including the Illinois state TRM⁴⁶ and the Northwest Regional Technical Forum⁴⁷ which specify an EUL of 30 years for CSWs.

Climate zones

The energy savings of window upgrades is heavily climate dependent. CalMTA analyzed energy consumption and bill impacts across all 16 California climate zones using CZ2022 weather files, which represent 20 years of weather observed from 1998 to 2017, and were adopted for Title 24 Version 2022.⁴⁸ The weather files used are shown in Table 35.

Table 35. Weather files for energy modeling in each climate zone

Climate zone	Weather file	Included in TSB Calculations
1	CA_EUREKA_725940S_CZ2022.epw	Yes
2	CA_NAPA-CO_724955S_CZ2022.epw	Yes
3	CA_OAKLAND-METRO-AP_724930S_CZ2022.epw	Yes
4	CA_SAN-JOSE-IAP_724945S_CZ2022.epw	Yes
5	CA_SANTA-MARIA-PUBLIC-AP_723940S_CZ2022.epw	Yes
6	CA_LOS-ANGELES-IAP_722950S_CZ2022.epw	Yes
7	CA_SAN-DIEGO-LINDBERGH-FLD_722900S_CZ2022.epw	Yes
8	CA_LONG-BEACH-DAUGHERTY-FLD_722970S_CZ2022.epw	Yes
9	CA_LOS-ANGELES-DOWNTOWN-USC_722874S_CZ2022.epw	Yes
10	CA_RIVERSIDE-MUNI_722869S_CZ2022.epw	Yes
11	CA_RED-BLUFF-MUNI-AP_725910S_CZ2022.epw	Yes
12	CA_STOCKTON-METRO-AP_724920S_CZ2022.epw	Yes
13	CA_FRESNO-YOSEMITE-IAP_723890S_CZ2022.epw	Yes
14	CA_DAGGETT-BARSTOW-AP_723815S_CZ2022.epw	Yes
15	CA_EL-CENTRO-NAF_722810S_CZ2022.epw	Yes
16	CA_BISHOP-AP_724800S_CZ2022.epw	Yes

⁴⁶ 2025 Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 13.0,

https://www.ilsag.info/wp-content/uploads/IL-TRM_Effective_010125_v13.0_Vol_2_C_and_I_09202024_FINAL.pdf

⁴⁷ The NW-RTF measure ran from 2017 to 2025. <https://rtf.nwcouncil.org/measure/commercial-secondary-glazing-systems/>

⁴⁸ <https://www.calmac.org/weather.asp>



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Avoided cost calculations

The CPUC's ACC⁴⁹ provides a robust framework for evaluating the benefits of distributed energy resources such as energy efficiency and fuel-switching measures. The ACC estimates system-level costs of providing electric or gas service on an hourly basis in \$/kWh and \$/therm.⁵⁰ The calculator is composed of three parts: an electric ACC, a natural gas ACC, and a refrigerant calculator. The calculator converts gas and electricity use into avoided cost dollars, providing a metric to quantify savings from fuel switching and efficiency measures. The avoided cost factors (in \$/kWh and \$/therm) are applied to a unit energy savings shape on an hourly basis to calculate the avoided cost benefit per scenario, which is an input for the estimate of the MTI's cost-effectiveness and total system benefit (TSB).

The previous TSB calculations for CRAWs in the CRAWs Advancement Plan used the 2022 version of the ACC workbook. A new version was released in 2024; all calculations in this analysis are based on the 2024 version. There are significant changes in the factors between the 2022 and 2024 ACC workbooks, including the following, as noted in CPUC documentation:⁵¹

- Energy value is more time-dependent (lower midday and higher overnight and early morning)
- Higher GHG value concentrated in evenings and early mornings
- Lower annual generation capacity value spread out over more hours
- Gas avoided costs are slightly higher, with the largest increases in winter months

CalMTA uses the electric, gas, and refrigerant workbooks. The electric and gas ACC workbook settings used to produce hourly factors are shown in Table 36.⁵² One climate zone is used for each IOU to develop avoided cost factors as a simplification due to the large amount of data required from the avoided cost workbooks for each new set of factors (the factor data file for a single climate zone contains approximately 9 million entries).

⁴⁹ Per the CPUC, "The primary benefits of demand-side resources are the avoided costs related to generation and distribution of energy. The avoided costs of electricity are modeled based on the following components: generation energy, generation capacity, ancillary services, transmission and distribution capacity, and decarbonization policy compliance. The Avoided Cost Calculator was established in 2005 and is updated biennially to improve the accuracy of how the benefits of demand-side resources are calculated."

⁵⁰ 2024 Distributed Energy Resources Avoided Cost Calculator Documentation. <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-side-management/acc-models-latest-version/2024-acc-documentation-v1b.pdf>.

⁵¹ <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/cost-effectiveness/2024-draft-acc-workshop---final.pdf>.

⁵² The final air quality adders for both electric and gas are FALSE for TRC and TRUE for SCT, as these are hard-coded settings in the workbook that adjust based on the chosen cost test.



Table 36. Avoided cost workbook settings

Cost test	Total Resource Cost (TRC)	Societal Cost Test (SCT)
ACC workbook version	2024 v1b	2024 v1b
Discount rate	7.30%	5.06%
Social cost of carbon	-	Base and high
Start year	2024	2024
End year	2054	2054
IOU climate zones		
PG&E	12	12
SCE	10	10
SDG&E	7	7
Electric components to include		
Cap & trade	TRUE	TRUE
GHG adder	TRUE	TRUE
GHG rebalancing	TRUE	TRUE
Energy	TRUE	TRUE
Generation capacity	TRUE	TRUE
Transmission capacity	TRUE	TRUE
Distribution capacity	TRUE	TRUE
Ancillary services	TRUE	TRUE
Losses	TRUE	TRUE
Methane leakage	TRUE	TRUE
Air quality adder	TRUE	TRUE
Final air quality adder	FALSE	TRUE
Gas main inputs		
Class	Commercial	Commercial
End use	Small Boiler	Small Boiler
Emission control	Low NOx	Low NOx
Gas components to include		
Market	TRUE	TRUE
Transmission & distribution (T&D)	TRUE	TRUE
Environment	TRUE	TRUE
Upstream methane leakage	TRUE	TRUE
Behind-the-meter methane leakage	TRUE	TRUE
Air quality adder	TRUE	TRUE



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Cost test	Total Resource Cost (TRC)	Societal Cost Test (SCT)
Final air quality adder ⁵³	FALSE	TRUE

6.10 Weighting factors

The final single ACC scenarios included energy modeling results from 16 climate zones, 18 building types, and two installation cases, for 576 unique load shapes. Final unit energy savings (UES) hourly profiles are weighted using the relative contribution of each building type, climate zone, and modeling case. The unit for energy savings is one square foot of window area. A single UES is derived as follows:

$$UES_n = \sum_{i=1}^{18} \sum_{j=1}^{16} w_{bldg,i} \cdot w_{cz,j} \left[\sum_{k=1}^1 w_{base,k} \cdot BLS_{base,k} - \sum_{m=1}^1 w_{prop,m} \cdot BLS_{prop,m} \right]$$

Where:

UES_n represents the savings shape for the n^{th} scenario (in either kWh or therms),

w_{bldg} is the weighting of building type,

w_{cz} is the weighting of the climate zone,

$w_{base,k}$ is the weighting of case k for the baseline equipment,

$BLS_{base,k}$ is the hourly building load for the base equipment in case k (in either kWh or therms),

$w_{prop,m}$ is the weighting of case m for the proposed equipment, and

$BLS_{prop,m}$ is the hourly building load for the proposed equipment in case m (in either kWh or therms).

The building weighting factors are derived from the Building Weights CPUC Support Table in the eTRM.⁵⁴ These weights represent the total floor area by climate zone for existing buildings. This MTI uses a normalization of window area; the floor area weights were converted to window area weights using the ratio of window area to floor area for each prototype shown in Table 31. The weights for buildings without cooling are shown in Table 37.

⁵³ The final air quality adder is controlled by the cost test and is automatically FALSE for TRC and TRUE for SCT.

⁵⁴ <https://www.caetrm.com/cpuc/table/buildingweights/>



Table 37. Building weighting factors for cooling cases

Building	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Asm	0.03	0.32	1.59	0.87	0.13	2.64	0.62	3.89	2.60	2.48	0.24	0.93	0.85	0.48	0.79	0.33
ECC	0.07	0.20	0.98	0.25	0.19	1.23	0.48	2.03	1.12	0.73	0.25	0.35	0.50	0.21	0.17	0.38
EPr	0.03	0.22	0.83	0.43	0.06	1.12	0.35	1.95	1.43	1.43	0.19	0.67	0.76	0.32	0.11	0.18
ERC	0.02	0.12	0.44	0.23	0.03	0.60	0.19	1.04	0.76	0.77	0.10	0.36	0.41	0.17	0.06	0.10
ESe	0.04	0.32	1.21	0.62	0.09	1.64	0.51	2.85	2.09	2.10	0.28	0.98	1.12	0.47	0.16	0.26
EUD	0.11	0.30	1.47	0.37	0.28	1.84	0.72	3.03	1.67	1.09	0.37	0.52	0.74	0.31	0.25	0.57
EUn	0.07	0.19	0.96	0.24	0.18	1.21	0.47	1.98	1.10	0.71	0.24	0.34	0.49	0.20	0.16	0.37
Gro	0.04	0.26	0.89	0.40	0.12	1.66	0.65	2.42	1.70	2.01	0.24	0.78	0.80	0.42	0.25	0.20
Hsp	0.01	0.07	0.20	0.09	0.03	0.34	0.13	0.38	0.33	0.21	0.05	0.15	0.16	0.03	0.04	0.03
Htl	0.01	0.05	0.28	0.10	0.04	0.42	0.21	0.29	0.33	0.09	0.03	0.09	0.07	0.04	0.18	0.06
Mtl	0.15	0.71	4.30	1.51	0.68	6.53	3.24	4.52	5.12	1.44	0.40	1.40	1.08	0.56	2.79	0.87
Nrs	0.04	0.37	1.10	0.51	0.19	1.88	0.74	2.13	1.83	1.18	0.26	0.85	0.86	0.19	0.22	0.15
OfL	0.11	1.25	13.18	5.63	0.56	16.54	5.21	21.17	21.19	5.81	0.49	4.21	2.25	1.07	1.28	0.54

**Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach
for Commercial Replacement and Attachment Window Solutions (CRAWS)**

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Building	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
OfS	0.26	0.64	3.83	3.00	0.29	7.36	5.12	9.17	7.51	7.82	0.95	3.74	4.76	0.96	1.83	0.66
RFF	0.06	0.26	1.19	0.52	0.15	3.28	0.84	3.88	3.23	3.42	0.23	0.80	0.81	0.66	0.62	0.30
RSD	0.02	0.08	0.37	0.16	0.05	1.03	0.26	1.22	1.01	1.07	0.07	0.25	0.25	0.21	0.19	0.09
Rt3	0.01	0.04	0.18	0.08	0.02	0.35	0.10	0.42	0.33	0.36	0.03	0.13	0.12	0.06	0.04	0.01
RtL	0.01	0.06	0.28	0.12	0.03	0.56	0.16	0.66	0.53	0.57	0.05	0.21	0.19	0.09	0.07	0.02
RtS	0.05	0.34	1.59	0.70	0.17	3.18	0.93	3.77	3.00	3.26	0.28	1.18	1.09	0.53	0.41	0.13
SCn	0.00	0.03	0.16	0.06	0.00	0.19	0.07	0.54	0.26	0.57	0.03	0.12	0.10	0.01	0.01	0.01

**Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach
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Avoided cost factors are calculated separately for each IOU because the avoided cost factors differ for each utility. Climate zone weighting factors vary for each utility based upon the energy consumption by IOU and climate zone. The climate zone weighting factors are shown in Table 38.

Table 38. Climate zone apportionment for investor-owned utilities

Climate Zone	PGE	SCE	SDGE	Total
CZ01	100%	0%	0%	100%
CZ02	100%	0%	0%	100%
CZ03	100%	0%	0%	100%
CZ04	100%	0%	0%	100%
CZ05	97.56%	2.44%	0%	100%
CZ06	1.43%	89.29%	9.29%	100%
CZ07	0%	0%	100%	100%
CZ08	0%	96.30%	3.70%	100%
CZ09	0%	100%	0%	100%
CZ10	0%	68.49%	31.51%	100%
CZ11	100%	0%	0%	100%
CZ12	100%	0%	0%	100%
CZ13	86.56%	13.44%	0%	100%
CZ14	1.14%	81.82%	17.05%	100%
CZ15	0%	86.11%	13.89%	100%
CZ16	68.52%	30.86%	0.62%	100%

For CRAWs, there is only a single installation scenario: CSWs installed over existing windows. The single proposed and baseline case is combined to create a single installation scenario for avoided cost calculations and market adoption. The scenario creates a savings shape based on the difference between one baseline and one proposed load shape. The weighting is very simple due to the lack of multiple blended installation cases, resulting in one case each for the baseline and proposed cases (Table 39 and Table 40, respectively).

Table 39. Weights for modeling cases for each ACC - baseline cases

Baseline load shape	S01
Ex	-1



**Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach
for Commercial Replacement and Attachment Window Solutions (CRAWs)**

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Table 40. Weights for modeling cases for each ACC - proposed cases

Proposed load shape	S01
CSW	1

Refrigerant avoided costs

In this MTI plan, there is no change in refrigerant between any baseline and proposed cases, thus refrigerant avoided costs are not included in the analysis.





Commercial Replacement and Attachment Window Solutions (CRAWS) Market Transformation Initiative

Appendix C: Product Assessment Report

June 26, 2026

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List of abbreviations

Abbreviation	Definition
AERC	Attachments Energy Rating Council
BMA	Baseline Market Adoption
BOMA	Building Owners and Managers Association
BPS	Building Performance Standards
CalMTA	California Market Transformation Administrator
CBO	Community-based Organization
CE	Cost-Effectiveness
CEDARS	California Energy Data and Reporting System
CET	Cost-Effectiveness Tool
CPUC	California Public Utilities Commission
CSW	Commercial Secondary Window
CRAWS	Commercial Replacement and Attachment Window Solutions
DOE	U.S. Department of Energy
DR	Demand Response
ESCO	Energy Service Company
ESJ	Environmental and Social Justice
EUL	Effective Useful Life
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, and Air Conditioning
IMC	Incremental Measure Cost
IOU	Investor-Owned Utility
LBNL	Lawrence Berkeley National Laboratory
Low-e	Low Emissivity
MR	Market Research
MT	Market Transformation
MTAB	Market Transformation Advisory Board
MTI	Market Transformation Initiative
MUSH	Municipal, University, School, and Hospital
NEB	Non-energy Benefit
NLR	National Laboratory of the Rockies
PAC	Program Administrator Cost
PAWS	Partnership for Advanced Window Solutions
PG&E	Pacific Gas & Electric
PNNL	Pacific Northwest National Laboratory
REN	Regional Energy Network
ROI	Return on Investment
RFI	Request for Ideas
RPR	Repeat Purchase Rate
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SME	Subject Matter Expert
TA	Technology Assessment
TSB	Total System Benefit
TMA	Total Market Adoption



Appendix C: Product Assessment for CRAWS
*CalMTA is a program of the California Public Utilities Commission (CPUC)
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Abbreviation	Definition
TRC	Total Resource Cost
UEI	Unit Energy Impacts
VIG	Vacuum Insulated Glass
WE&T	Workforce Education and Training



Appendix C: Product Assessment for CRAWs

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1 Executive summary

Windows are significant contributors to energy consumption in buildings, which constitute a substantial portion of the United States' energy usage. They influence consumers' utility bills and California's energy demands. Many of California's buildings were constructed before double-pane glass and low emissivity (low-e) coatings became common. Despite having inefficient windows, older buildings can realize energy savings and other benefits through advancement of window-retrofit technology. Commercial Replacement and Attachment Window Solutions (CRAWS) offer affordable and convenient solutions for building owners to capitalize on these technological advancements and avoid the high cost of complete window replacement.

The CRAWS market transformation initiative (MTI) currently covers two technologies: vacuum insulated glass (VIG) for single-pane replacement (SPR) and commercial secondary windows (CSWs). VIG are high-performance glazing units with a vacuum between the glass, intended to be installed within a building's existing window frames. Recent technological advances have improved the durability of vacuum-sealed glass and reduced the thickness of the glass used in VIG units. This has resulted in a reduction of the overall VIG glazing unit thickness, which allows thin-profile VIG units to fit within window frames built for single panes. CSWs are intended to be installed inside or outside existing commercial window systems, similar to how residential storm windows are installed; they are easy to install and low-cost.

Both technologies meeting CalMTA's product definition include low-emissivity (low-e) coatings, which reduce solar heat gain and cooling loads and provide a significant advantage in California's climate. VIG products meeting the CRAWS product definition must have a maximum solar heat gain coefficient (SHGC) of 0.25. CSWs meeting the CRAWS product definition must have a maximum U-factor of 0.35 and a maximum solar heat gain coefficient (SHGC) of 0.25.

1.1 Key deficiencies/barriers

1.1.1 Commercial secondary windows

Secondary windows face few technological barriers. Currently available CSWs perform well, and third-party certifications are available to inform consumer choice and utility incentive programs. However, the supply chain for distributing, selling, and installing CSWs in California is immature. Consumers may encounter a small number of CSW vendors and installers operating in their area; conversely, the low level of specialized skill required to install CSWs and scarcity of CSW vendors presents an opportunity for workforce development. Additional performance data and field installations are needed to assess the risk of condensation within the unventilated cavity created by CSWs.



1.1.2 Vacuum insulated glass

VIG has been manufactured in the United States for over 20 years but is still not deployed at scale with reasonable lead times and competitive prices. As an emerging technology, VIG for SPR is still more costly than other window upgrades, with few VIG manufacturers and products available in the market.

VIG units can be installed into existing window frames that previously housed single-pane glass. The thermal properties of existing frames vary widely, and there is currently no method for rating the window assembly U-factor of VIG for SPR. Without a certified rating, consumers must use default performance values for window assemblies that have not been rated by the National Fenestration Rating Council (NFRC). These default values assume low performance of the existing frames, and therefore VIG for SPR consumers may not be able to take full credit for VIG performance when applying for building permits and incentives. Further, utility programs cannot easily quantify savings and incentivize the products.

Additional data is needed on VIG for SPR to quantify the risk of condensation occurring on existing window frames. Additionally, the long-term degradation of VIG performance has not been quantified through field installations, preventing the development of an aged performance value for VIG units. Fabrication of VIG units requires high temperatures for the vacuum evacuation process, driving up the costs and embodied energy and greenhouse gas (GHG) emissions of VIG units.

1.2 Key recommendations for product plan

1.2.1 Collaboration with industry stakeholders

The California Market Transformation Administrator (CalMTA) will collaborate with industry stakeholders including the United States Department of Energy (DOE), national laboratories, and manufacturers to share the latest data on CRAWs technology performance to inform industry standards as they are developed for VIG and CSW products. We will collaborate with the Attachments Energy Rating Council (AERC) or a similar organization to develop a method for rating the performance of VIG for SPR. We will share data with heating, ventilation, and air conditioning (HVAC) designers¹ so that they make it standard practice to recommend CSWs and VIG for SPR prior to designing HVAC upgrades and replacements, as an opportunity to downsize equipment.

¹ CalMTA's strategy for CRAWs distinguishes between the roles of HVAC designer and HVAC installer. See the CRAWs MTI Plan section 2, Market transformation theory and opportunity, for more discussion.

1.2.2 Field demonstrations

CalMTA is conducting a field demonstration at Madison Elementary School, located in an ESJ community in Madera, California, to monitor energy consumption and non-energy benefits (NEB) of CRAWs. CalMTA will expand its field demonstration to include more sites and more building types. We will collaborate with field studies conducted by other market transformation initiatives (MTIs) such as Commercial Rooftop Units (CRTUs) and Commercial Building Efficiency Accelerator (CBEA) to boost efficiency and demonstrate synergies between CRAWs and the other MTIs. By collecting and sharing data on energy performance and NEBs from field demonstrations, we can build awareness among energy service companies (ESCOs) and equip them with data so that they increasingly include CSWs and VIG for SPR in their portfolios. We will collect data to close data gaps on condensation and VIG performance degradation.

By sharing data from analysis and field installations, the CRAWs MTI aims to enhance activity in the supply chain by encouraging HVAC designers to routinely consider the potential of CRAWs technologies in reducing HVAC system sizing during system upgrades.

1.3 Energy savings impacts

CalMTA has found that CSWs and VIG offer significant energy savings potential across all California climate zones and utility service areas. The energy savings attributable to the two CRAWs technologies are very similar. The average annual whole-building electric savings are around 8% statewide and average annual whole-building gas savings are roughly 17% to 22%, varying by investor-owned utility (IOU) service territory. Because CRAWs technologies reduce space conditioning loads, and because commercial buildings in California generally consume more energy for space cooling than space heating, most of the energy savings benefit from CRAWs technologies come from reduced cooling energy use.

1.3.1 Peak demand impacts

CalMTA analysis found that CRAWs technologies reduce peak cooling demands in California commercial buildings by about 5%-20%, depending on building type and location. For buildings with electric resistance heat, CRAWs reduce peak heating loads by about 10% on average.

1.3.2 Utility bill impacts

CRAWs technologies reduce commercial customer utility bills by around 9% annually.

2 Purpose and context

The purpose of the Product Assessment Report is to describe the methods used to refine and evaluate the target technology. This report also aims to share key findings and recommendations that directly inform development of market transformation (MT) strategy and interventions, which are described in the Market Transformation Initiative Plan (MTI Plan).



This report is not intended to provide an exhaustive examination of CRAWs products and technology. Instead, this report focuses on the key technical barriers, opportunities, and potential impacts from broader adoption of CRAWs technologies in California, which are all key components for the development of effective MT strategies to achieve that objective. This report focuses on technical aspects of the products and generally avoids discussion of the CRAWs market, which is covered in Appendix D: Market Characterization Report, although some overlap is necessary.

3 Product overview and definition

This section summarizes the status of products considered in this MTI Plan, including the definition of CRAWs products, their features, and limitations that are barriers to market adoption.

3.1 General product overview

Commercial buildings account for a substantial portion of primary energy consumption in the United States, comprising 17.9% of the total in 2021.² Among the various building components, windows play a pivotal role, contributing 12% of all energy usage within buildings.³ This highlights the significant influence of window performance on consumers' overall energy consumption and utility bills.

Building owners and tenants have numerous options available to enhance the performance of their windows, ranging from affordable to more expensive choices. Higher-cost options include replacing window glazing and either maintaining existing window frames or replacing the window frames. Lower-cost options include:

- Installing fixed and operable attachments, which include frame-mounted stretched film panels and frameless acrylic and copolyester attachment panels
- Applying window films
- Installing internal window shading devices

This MTI focuses on two mid-cost solutions that offer substantial energy and operational cost savings potential: vacuum insulated glass (VIG) as a replacement for single-pane clear⁴ (SPC) glass

² Chioke Harris, Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption (Golden, CO: National Renewable Energy Laboratory, 2022), <https://docs.nrel.gov/docs/fy22osti/80171.pdf>.

³ Stephen Selkowitz, Robert Hart, and Charlie Curcija, "Breaking the 20 Year Logjam to Better Insulating Windows," in 2018 ACEEE Summer Study on Energy Efficiency in Buildings (Lawrence Berkeley National Laboratory, August 2018), <https://windows.lbl.gov/publications/breaking-20-year-logjam-better>.

⁴ Clear glass refers to glass without a low-e, reflective, or tinted coating intended to reduce solar heat gains.

and commercial secondary windows (CSW) for windows with SPC and double-pane clear (DPC) glass.

3.2 Product definition

VIG for 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. 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.⁵ The VIG unit may also include low emissivity (low-e) coatings that reduce solar heat gain and further improve energy performance.

CSW: Commercial secondary windows 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. CSWs meeting CalMTA's product definition include low-e coatings, 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.

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

VIG can achieve higher center-of-glass insulation values than CSW but can also have higher product and installation costs. Given the cost, VIG is likely more attractive for buildings undergoing deep retrofits. In some cases, CSW can achieve better assembly U-factors than VIG for SPR, depending on the window frame properties.

No federal or state codes govern CSW attachment products, though local building codes may be triggered for VIG for SPR depending on the magnitude of the retrofit. See Section 6 for more information on codes, standards, and policies.

⁵ R-value is a measure of a material's ability to restrict heat flow; the higher the R-value, the greater the insulating power.

3.3 Energy efficiency landscape

This section describes the activities of other market actors across the U.S. who are actively investigating CSW and/or VIG for SPR (Table 1). The section also discusses major findings from research activities.

Table 1. Programs and organizations active in CRAWs

Program/Organization	Description
Northwest Energy Efficiency Alliance (NEEA)	- NEEA promoted CSWs as part of its Window Attachments Initiative until 2023, when it paused the program. - Published a study characterizing the market potential for CSWs.⁶ Conducted a multiple-site field study to validate energy savings in their region and identified market barriers of high cost and low product awareness, but found installation was easy and quantified NEBs.⁷
CalNEXT	- Assessed the market potential in California for CSWs. - Released a report in May 2024 characterizing the market for window replacements and inserts, including CSWs. This report was an initial step toward understanding the market potential for deemed savings measure packages for high-efficiency window projects in California. It found that cost, education, a lack of incentive programs, and flexible and inconsistent building energy codes are major barriers to window measures.⁸
DOE	Announced in 2023 that LuxWall, a manufacturer of VIG, was awarded a grant intended to “strengthen clean energy supply chains and accelerate domestic clean energy manufacturing,” to manufacture VIG units.⁹ In October 2025, DOE cancelled LuxWall’s

⁶ Ingo Bensch, Ross Donaldson, Lyndsey Shimazu. Commercial Window Attachments: Secondary Window Market Characterization, April 9, 2020. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>.

⁷ Jordan Pratt, Sean Wynne. Commercial Secondary Windows Field Test, December 18, 2023. <https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Windows-Field-Study.pdf>.

⁸ Julie Birchfield, Kyle Booth, Jesse Zucker, Simpson Tanner, Scott Honegger, Nancy Metayer Bowen. May 28, 2024, Commercial Windows Market Study and Measure Package Development. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf.

⁹ Biden-Harris Administration Announces Actions to Strengthen Clean Energy Supply Chains and Accelerate Manufacturing in Energy and Industrial Communities, November 27, 2023. https://www.energy.gov/articles/biden-harris-administration-announces-actions-strengthen-clean-energy-supply-chains-and?utm_medium=email



Program/Organization	Description
	grant, along with other grants targeting battery and green manufacturing projects.¹⁰ • In 2024, DOE's Building Technologies Office (BTO) initiated the Building Envelope Innovation Prize awarding up to \$2 million for secondary glazing systems.¹¹ Seven winners were announced in November 2024 for Phase 1, the Design Concept phase. At the time of writing, scheduled milestones have passed for entering Phases 2 and 3 and announcing Phase 2 winners.¹²
General Services Administration (GSA)	• Promoted CSWs in its buildings, many of which are historic. • In 2023, initiated a Green Proving Ground (GPG) collaboration with DOE to evaluate the performance of secondary windows, including secondary windows with VIG.¹³ • In 2021, the National Laboratory of the Rockies¹⁴ (NLR) released a report commissioned by the GSA that assessed the applicability of CSWs on GSA buildings with existing, SPC glass.¹⁵ It assessed thermal performance, HVAC energy reduction, thermal load reduction, and comfort improvement.
California Energy Commission (CEC)	• Commissioned a series of reports, concluding in 2021, on the current and future states of the technology, market barriers and opportunities, and recommended initiatives to promote advanced window and building envelope systems, including VIG.¹⁶

¹⁰ Dylan Berman, "American Battery Technology Company Stock is Moving Lower on Wednesday: What's Going On?" *Benzinga*, October 22, 2025. <https://www.benzinga.com/trading-ideas/movers/25/10/48366595/american-battery-technology-company-stock-is-moving-lower-wednesday-whats-going-on>

¹¹ DOE Launches \$2 Million Prize to Advance Cost-Effective, Energy-Efficient Commercial Windows, February 21, 2024. <https://aercenergyrating.org/doe-launches-2-million-prize-to-advance-cost-effective-energy-efficient-commercial-windows/>

¹² Building Envelope Innovation Prize - Secondary Glazing Systems. <https://www.herox.com/envelopeprize/updates>

¹³ Secondary Interior Window Framing with Advanced Glazing. November 2023. <https://www.gsa.gov/system/files/2023-Secondary-Interior-Window-Framing-With-Advanced-Glazing.pdf>

¹⁴ The National Laboratory of the Rockies was formerly known as the National Renewable Energy Laboratory (NREL). The U.S. DOE changed its name in December 2025.

¹⁵ Kosol Kiatreungwattana, Lin Simpson. November 2021. Demonstration and Evaluation of Lightweight High Performance Secondary Windows. <https://docs.nrel.gov/docs/fy22osti/79112.pdf>

¹⁶ William Goetzler, Kristin Landry, Micah Turner, Palak Thakur. March 2021. Next Generation Window and Building Envelope Systems. <https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2021-018.pdf>



Program/Organization	Description
Partnership for Advanced Window Solutions (PAWS)	• Collaborative organization that was funded by the DOE from 2021-2023 consisting of multiple industry stakeholders including manufacturers, government and non-government organizations, and national laboratories, to promote high-performance window solutions for new and existing buildings.¹⁷ • Aims to provide a consumer window selection tool, assist utility campaigns and incentive programs, and perform some residential-focused tasks. • In May 2025, PAWS published a savings calculator for secondary windows for commercial and multifamily buildings.¹⁸
Utilities	• Consolidated Edison (ConED) has promoted CSWs in its service area of New York City and some surrounding areas. It ran a pilot in 2020 and an incentive program in 2023 that offered a \$200 per MMBtu (\$20 per therm) incentive for energy savings achieved through CSWs.^{19,20} • In Washington state, Puget Sound Energy (PSE) awards \$15 per annual therm saved in CSW incentives.²¹

¹⁷ Partnership for Advanced Window Solutions (PAWS). July 24, 2023.

<https://www.energy.gov/eere/buildings/articles/partnership-advanced-window-solutions-paws>.

¹⁸ Secondary windows savings calculator. May 9, 2025. <https://betterbricks.com/resources/secondary-windows-savings-calculator>.

¹⁹ Danielle Meyer. AERC Launches Commercial Secondary Window Program, Moves into New Sector of Window Attachment Market. October 22, 2020. <https://aercenergyrating.org/aerc-launches-commercial-secondary-window-program>.

²⁰ DOE Recognizes 10 Storm Window and Window Attachment Programs for Their Impact and Innovation. February 8, 2024. <https://www.energy.gov/eere/buildings/articles/doe-recognizes-10-storm-window-and-window-attachment-programs-their-impact>.

²¹ Commercial Secondary Windows. <https://www.pse.com/en/business-incentives/commercial-secondary-windows>.



4 Research objectives and methodology

4.1 Research objectives

The following describes the key research objectives and questions investigated by the CalMTA team while conducting the Product Assessment:²²

- 1) Quantify energy and non-energy impacts specific to California climates through energy modeling and determine the impact of demand response events.
- 2) Quantify energy benefits by assessing the impact of CSWs and VIG on HVAC run times including evaluating air leakage, assessing the potential for the elimination of baseboard heating located under windows to counteract cold drafts, determining the additional energy savings associated with reducing HVAC sizing, and comparing these results to the potential of competing solutions such as blinds, film, and full-window replacements.
- 3) Identify the NEBs and document the dollar equivalent, when available.
- 4) Quantify peak electrical load impacts for most common HVAC types.
- 5) Investigate resiliency and grid flexibility benefits from increased CSW and VIG installation.
- 6) Evaluate product performance and durability
- 7) Review product ratings and test procedures to determine the relevant barriers and requirements to create a ratings standard for VIG.

4.2 Research methods

4.2.1 Field study/demonstration

CalMTA is conducting a field demonstration in four classrooms at Madison Elementary School in Madera, California.²³ The purpose of the demonstration is to monitor the impacts of CSWs on indoor air quality (IAQ), temperature, light quality, energy consumption, and other NEBs such as thermal comfort, visual comfort, and sound reduction. Four additional classrooms with no upgrades are being monitored to serve as a baseline. The team performed blower door testing to determine air infiltration levels before and after installation. The team also installed metering equipment to collect data on indoor environmental conditions and HVAC power consumption for

²² The CRAWs Advancement Plan included an additional technology assessment activity: *investigate financial & cost factors*. Financial and cost factors are addressed in Appendix D (CRAWs Market Characterization Report).

²³ The CRAWs Advancement Plan included laboratory testing of CRAWs products in its research plan to address product performance and durability, and product ratings and test procedures. These objectives were already being addressed by industry partners, so CalMTA reassigned costs allocated for lab testing to the field demonstration.

12 months, starting in September 2025. The census tract containing Madison Elementary School is classified as a disadvantaged community (DAC) by CalEnviroScreen, with a high pollution burden of 93 out of 100.

4.2.2 Manufacturer and expert engagement

The CalMTA team met with representatives from CSW manufacturers including Alpen and Indow, and Lawrence Berkeley National Lab (LBNL) to better understand the current state of the market for VIG and CSW products. The team discussed the number and locations of projects utilizing these technologies in California and beyond, business models for funding CRAWs installations, factors influencing consumer choices regarding CRAWs products, new products in development, and industry partnerships and collaborations.

4.2.3 Literature review

The CalMTA team compiled and reviewed reports, publications, and industry white papers that considered all aspects of CSWs and VIG for SPR. Studies were obtained from existing resource repositories, the CEC, DOE, national laboratories, the American Council for an Energy-Efficient Economy (ACEEE) website, NEEA, and sources found through internet queries. The studies formed a basis of knowledge to inform our product definition and recommendations.

4.2.4 Energy modeling

Energy modeling was conducted to assess statewide impacts and support the development of total system benefit (TSB) and bill impact calculations. Energy modeling tasks were performed using EnergyPlus, an open-source, whole-building energy simulation program developed by the DOE. CalMTA used prototype building energy models from the California Database for Energy Efficient Resources (DEER) for 18 commercial building types. The DEER models were run as-is, with only window properties changed to reflect CRAWs performance specifications. Because CSWs and VIG for SPR showed similar energy performance (within 1% on average), CalMTA used CSWs to represent all CRAWs technologies. Each prototype building was run with three window installation cases – SPC, DPC, and CSW – in all 16 California climate zones. These model runs produced electric and natural gas consumption profiles at 15-minute intervals, which were used in avoided-cost and bill-impact analyses. A detailed description of the energy modeling can be found in Appendix B of the CRAWs MTI Plan in Attachment 2.

5 Technical barriers and opportunities to broader adoption

This section reviews the barriers and opportunities for adoption of currently available CRAWs products.



5.1 Energy benefits

5.1.1 Reduces HVAC equipment sizing

CSWs indirectly contribute to capital cost savings by reducing peak building thermal loads. This can lead to a reduction in the capacity of equipment installed during HVAC retrofits. For instance, an NLR study using ResStock data found that envelope upgrades reduced heat pump size by an average of 1.4 tons, saving thousands of dollars in installation costs.²⁴ Although the study includes additional measures such as attic and wall insulation in addition to windows, it demonstrates that envelope improvements can lower electrification costs by reducing heat pump capacity. Envelope upgrades including CRAWs technologies may also eliminate the need for ductwork, electrical panel, or service wire upgrades, further reducing upfront costs.

5.1.2 CRAWs technologies provide an unintrusive compliance pathway for building performance standards

At the time of writing, over 40 states, cities, and jurisdictions nationwide have either passed or are considering some form of building performance standards (BPS). BPS are performance-based standards used to reduce energy consumption and operational costs in existing buildings.²⁵ Given the simplicity of installation and the substantial savings they provide, CSWs and VIG for SPR could offer an effective pathway for compliance with whole-building energy and emissions reduction targets set by BPS. For instance, the city of Chula Vista, California, implemented local BPS that includes window upgrades as one of nine possible compliance measures for multi-family buildings built before 2006.²⁶

BPS requirements potentially improve the economics of envelope retrofits such as CSW and VIG for owners who are out of compliance with BPS requirements by raising the cost of taking no action. Further, CRAWs technologies improve the business cases for other retrofit projects that comprise key strategies for BPS compliance, such as reducing the cost of upgrading HVAC systems to heat pumps, by reducing peak space conditioning loads and allowing consumers to downsize replacement HVAC systems.

5.1.3 Increased impacts in older buildings

Installing CSWs and VIG for SPR in older buildings can save large amounts of energy because these buildings typically have poor insulation and older windows with high U-factors and no low-e coating. Using NLR's ComStock to estimate the window market, CalMTA found that 85% of

²⁴ Prateek Munankarmi, Eric Wilson, Janet Reyna, Stacey Rothgeb. Size up or size down? National analysis of heat pump sizing and impacts. <https://docs.nlr.gov/docs/fy24osti/85347.pdf>.

²⁵ Building Performance Standards. <https://www.energycodes.gov/BPS>.

²⁶ City of Chula Vista Building Energy Saving Ordinance (BESO) Policy Summary. January 2024. <https://www.chulavistaca.gov/home/showpublisheddocument/27410/638409963775670000>.



windows in California are over 30 years old. Over 40% of commercial buildings in California have windows with U-factors exceeding 1.0, which is far less efficient than current energy code requirements.^{27,28}

5.2 Significant non-energy benefits

5.2.1 Increased thermal comfort

In a 2021 study, NREL found that CSWs can significantly reduce vertical surface radiant asymmetry (the temperature difference experienced on opposite sides of a person), which is a contributor to occupant discomfort in buildings.²⁹ Another study found that VIG retrofits can improve thermal satisfaction by 9.2%.³⁰

Work performance can serve as a proxy for the relationship between comfort and indoor thermal conditions in office buildings. LBNL conducted a meta-analysis of nine studies on the effects of temperature on productivity and established that temperature has no effect on productivity within the range of 21°C to 25°C (69.8°F to 77°F), but that there is a 2% decrease in productivity per degree when temperatures exceed 25°C (77°F) and a 4.7% decrease in productivity per degree when temperatures dropped below 21°C (69.8°F).³¹ New York State Energy Research and Development Authority (NYSERDA) found that respondents from their Commercial/Industrial Performance Program (CIPP) would be willing to pay an additional \$0.42/ft² for additional thermal comfort and HVAC effectiveness.³²

²⁷ Existing Buildings Study Building Characteristics Report. March 4, 2025.

https://www.bayren.org/sites/default/files/documents/2025/BayREN%20Detailed%20Building%20Characteristics%20Report_Final.pdf.

²⁸ Title 24-2025 requires a maximum area-weighted average U-factor of 0.47 or less for vertical fenestration products for new construction in California. California Energy Commission. Building Energy Efficiency Standards for Residential and Nonresidential Buildings, July, 2025. https://www.energy.ca.gov/sites/default/files/2025-07/CEC-400-2025-010-F_0.pdf.

²⁹ Kosol Kiatreungwattana, Lin Simpson. Demonstration and Evaluation of Lightweight High Performance Secondary Windows. <https://docs.nrel.gov/docs/fy22osti/79112.pdf>.

³⁰ Changyu Qiu, Hongxing Yang, Kaijun Dong. Energy and Thermal Comfort Performance of Vacuum Glazing-Based Building Envelope Retrofit in Subtropical Climate: A Case Study. <https://www.mdpi.com/2075-5309/15/12/2038>.

³¹ Olli Seppänen, William J. Fisk, David Faulkner. Cost benefit analysis of the night-time ventilative cooling in office building. <https://escholarship.org/uc/item/3j82f642#page-3>.

³² Brent Barkett, Nicole Wobus, Rachel Freeman, Daniel Violette. Non-Energy Impacts (NEI) Evaluation. https://www.aceee.org/files/pdf/conferences/workshop/valuation/MCAC_NEI_Report_06.pdf.

5.2.2 Reduced noise

NEEA field tests found that CSWs achieve a 6.9 decibel (dB) (12%) reduction in sound transmission under ambient conditions with an additional 5.7 dB (11%) reduction on average at a 90 dB exterior testing condition.³³ Measurements conducted by Pacific Northwest National Laboratory (PNNL) at a CRAWs field installation site in Madera, California, demonstrated a 7 dB reduction in sound transmission levels attributable to CSWs (see Section 8.1.4 for more information on the CRAWs field installation.)

Reducing ambient noise levels below an average of 55 a-weighted decibels (dBA), the maximum 24-hour limit for exposure to environmental noise recommended by the EPA, results in several positive health outcomes and improvements in quality of life.³⁴ A 2013 study cites an estimate that over 100 million Americans are exposed to unhealthy levels of noise annually.³⁵ A National Center for Biotechnology Information (NCBI) study found that reducing noise exposure for these people by 5 dB would reduce the prevalence of hypertension by 1.4%, or almost 1.2 million cases. Furthermore, it would reduce coronary heart disease by 1.8%. The associated cost savings that would be gained from this reduction in noise exposure were estimated as \$2.4 billion in annual health care costs and \$1.5 billion annually in productivity gains.³⁶

5.2.3 Improved resiliency

Extreme weather events are becoming more frequent and severe, leading to significant losses of property and lives. The National Safety Council reported a 20% increase in weather-related deaths and a 120% rise in injuries since 2019.³⁷ CRAWs technologies can enhance the resiliency of buildings by providing thermal comfort and maintaining indoor air quality (IAQ) during extreme weather events.

CSWs can also reduce air infiltration. In addition to energy benefits, increasing airtightness reduces the amount of dust and pollutants that enter a building. A meta-analysis of 20 research studies investigating the impact of increasing airtightness on IAQ found a positive correlation

³³ Commercial Secondary Windows: Better Comfort, More Savings, Easier Compliance, February 21, 2025.

<https://betterbricks.com/news/commercial-secondary-windows-better-comfort-more-savings-easier-compliance>.

³⁴ Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, March 1974.

<https://books.google.com/books?hl=en&lr=&id=sB1SAAAAMAAJ&oi=fnd&pg=PA1&ots=rK9Rw22aLv&sig=npzSiQkM4XE69Ra5P7RcLXklkY#v=onepage&q&f=false>.

³⁵ Monica S Hammer, et. al. December 2013. Environmental Noise Pollution in the United States: Developing an Effective Public Health Response. <https://pmc.ncbi.nlm.nih.gov/articles/PMC3915267/>.

³⁶ Valuing Quiet: An economic assessment of US environmental noise as a cardiovascular health hazard.

<https://pmc.ncbi.nlm.nih.gov/articles/PMC4819987/#R9>.

³⁷ Weather-Related Deaths and Injuries. <https://injuryfacts.nsc.org/home-and-community/safety-topics/weather-related-deaths-and-injuries/#:~:text=Over%20the%20last%20five%20years,the%20most%20deaths%20during%202023/>.



between reduced infiltration and decreased PM_{2.5} and NO₂ concentrations in areas where there are high outdoor contaminant levels.^{38,39} This study suggests that CSWs are particularly advantageous in locations with degraded air quality or those that are prone to wildfire smoke. Reducing envelope infiltration can increase levels of indoor air contaminants like CO₂ and formaldehyde, so building owners should ensure that ventilation systems are adequate.

5.2.4 Fast installation and workforce training opportunity for CSWs

Full window replacement can be time consuming and disruptive, ranging between 30 minutes and several hours per window to perform a full replacement, depending on the type of window and complexity. In most cases, full window replacement requires an experienced window installer.

By contrast, installing CSWs is fast, which results in low installation costs and minimal disruption to occupants, even when they are present in the building during installation. An NLR survey found that installation of secondary windows required one person and took approximately 7-10 minutes per window and can often be fully completed from the building interior.⁴⁰ Furthermore, installation of CSWs does not require specialized window replacement skills or opening the building envelope. This positions CSW installation as an accessible workforce education and training (WE&T) opportunity that bridges general multi-craft construction skills and more specialized window trades. Easy installation offers scalable job pathways without the training burden associated with full window replacement. This characteristic is particularly relevant for expanding local workforce participation in ESJ communities. See Section 2.4, Workforce Development, of the MTI Plan for additional detail on WE&T strategy and implementation.

5.2.5 Choices for operable windows

Since VIG for SPR retains existing window frames, VIG does not pose challenges where operability is required; windows that are operable before being retrofitted with VIG remain operable.

Operable CSWs are available, but at least one CSW manufacturer engaged by CalMTA has expressed that their products typically are not operable, so requirements for operability may limit choice for CSW consumers. On the other hand, all participants in a recent NEEA study on three sites that installed secondary windows had requirements for their original windows to remain

³⁸ Leela Kempton, et. al., October 2022. A rapid review of the impact of increasing airtightness on indoor air quality. <https://www.sciencedirect.com/science/article/abs/pii/S2352710222008117>.

³⁹ PM_{2.5} stands for particulate matter that is generally 2.5 micrometers and smaller. NO₂ stands for nitrogen dioxide and primarily gets into the air from fuel combustion.

⁴⁰ Kosol Kiatreungwattana, et. al. November 2021. Demonstration and Evaluation of Lightweight High Performance Secondary Windows. <https://docs.nrel.gov/docs/fy22osti/79112.pdf>.



operable. The fact that all participants were all able to proceed with CSW retrofits suggests that operability is not a barrier to choosing CSWs.⁴¹

5.3 Product performance and durability: data gaps

5.3.1 Little information on real-world performance to determine condensation risk

While several studies have attempted to simulate and quantify the condensation risk of CSWs, little data has been collected from field installations. LBNL reported that simulations of secondary windows indicate increased condensation risk over single pane base windows but notes that real-world performance might not reflect this condition.⁴² It notes that future work should include installing and monitoring CSWs in real buildings to validate the simulation results.

A NEEA report found that most respondents surveyed experienced no issues with condensation when they installed CSWs.⁴³ A United Kingdom field study found that secondary windows enhance insulation and reduce condensation on the interior glazing surface, without observing condensation forming in the cavity between the original glazing and the secondary window.⁴⁴

CSWs have been shown to significantly reduce the risk of condensation on interior window surfaces. An NLR study found that the condensation resistance of a single pane window increased from a baseline of 12 to 44 by installing single-pane secondary windows or to 46 by installing double-pane secondary windows.^{45,46} While the rating increase in both cases still did not meet the minimum recommended rating of 50, the authors considered the improvement to be substantial.

5.3.2 Little information on VIG performance degradation

Little data is available on the long-term thermal performance of VIG units, and how that performance degrades over time. Although this issue applies to all VIG applications (not only VIG for SPR) it creates uncertainty for energy code officials and energy efficiency program administrators regarding the durability of savings attributable to VIG for SPR.

⁴¹ [Commercial Window Attachments: Secondary Window Market Characterization](#).

⁴² Robert Hart, et. al. February 2015. Secondary Glazing System (SGS) Thermal, Moisture, and Solar Performance Analysis and Validation. https://www.rbbwindow.com/wp-content/uploads/LBNL_report_secondary_glazing1.pdf.

⁴³ Commercial Windows Attachment (SGS) Initiative. <https://neea.org/wp-content/uploads/2025/03/commercial-window-attachments-sgs-phase-1-research.pdf>.

⁴⁴ John Kaiser Calautit, et. al. Keeping it simple: Field testing and techno-economic assessment of a low-cost secondary quad glazing for enhanced energy efficiency in buildings. <https://www.sciencedirect.com/science/article/pii/S2666123325000273>.

⁴⁵ Condensation resistance is a rating on a scale of zero to 100 that measures a window's ability to resist condensation on the interior surface.

⁴⁶ Kosol Kiatreungwattana, et. al. November 2021. Demonstration and Evaluation of Lightweight High Performance Secondary Windows. <https://docs.nrel.gov/docs/fy22osti/79112.pdf>.



5.4 Financial & cost factors

5.4.1 Lower-cost window upgrade options for historic buildings

Many historic buildings and preservation sites have requirements to maintain the appearance of a building, which adds to the cost of window replacements with custom specifications. Conversely, CSWs can be installed inside or outside the existing window, allowing window performance to be upgraded while leaving historic windows intact. NEEA interviews have found preservation to be a main driver in secondary window installations in the Pacific Northwest.⁴⁷

5.4.2 High manufacturing costs of VIG

To retain the vacuum and efficiency of the window, VIG must be hermetically sealed. While multiple research studies explore different methods of edge sealing at lower temperatures, current manufacturing processes typically require high temperatures for the vacuum evacuation process. This process consumes significant amounts of energy, which increases costs and raises embodied GHG emissions. Newer, lower-temperature seals are being tested, but durability remains a design challenge. VIG for CSW also requires ultra-thin glass panes with precise thickness tolerances that are currently produced by less than ten global suppliers.⁴⁸

Despite the higher cost of VIG units, VIG for SPR is a more economical solution compared to full window replacement for buildings with single-pane windows. CalMTA's discussions with suppliers have indicated that the cost of VIG for SPR is approximately half that of full replacement. Suppliers also indicated that the cost of CSW is even lower, at approximately 15% to 25%.

5.4.3 Limited VIG product availability

At the time of writing, only three VIG products are commercially available. However, manufacturers may accelerate their rate of production. For example, Luxwall will open a new factory in Michigan in late 2026 and recently announced a partnership with Viracon to increase fabrication capacity.^{49,50}

⁴⁷ Ingo Bensch, Ross Donaldson, Lyndsey Shimazu. Commercial Window Attachments: Secondary Window Market Characterization, April 9, 2020. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>.

⁴⁸ Vacuum Insulating Glass (VIG) Market. <https://pmarketresearch.com/chemi/vacuum-insulating-glass-vig-market/>.

⁴⁹ LuxWall™ Showcases Preview of Detroit Factory as a Catalyst for Manufacturing Innovation and Community Growth. <https://www.luxwall.com/luxwall-showcases-preview-of-detroit-factory-as-a-catalyst-for-manufacturing-innovation-and-community-growth/>.

⁵⁰ Viracon® and LuxWall™ Partner to Set New Benchmark for High-Performance Commercial Facades. <https://viracon.com/viracon-and-luxwall-partner-to-set-new-benchmark-for-high-performance-commercial-facades/>.

6 Codes, standards, and policies

6.1 California codes

Part 6, the Building Energy Efficiency Standards, Title 24, the California Code of Regulations – often referred to simply as Title 24 – applies to buildings for which a building permit is required (those undergoing new construction and additions or alterations to existing buildings). Title 24 defines an alteration as any change to a building’s water heating, space-conditioning, lighting, or envelope systems that is not an addition.⁵¹ It specifies that glass replaced in an existing sash and frame (i.e., the glazing units in VIG for SPR) is considered a repair, and that the replacement glass must be at least equivalent to the original in performance.⁵²

Since the installation of CSW attachment products leaves the existing building envelope in place, the definition of alteration does not apply. Therefore, no state codes govern CSW attachment products.

CalMTA has set performance specifications for CRAWs that are in line with standards for new construction and alterations in Title 24-2025 to ensure that our MTI is technically feasible with readily available materials and will align with building owners’ expectations for contemporary glazing systems.

Title 24 contains mandatory requirements for all projects that fall within its scope. It also contains prescriptive requirements, which are generally more stringent than mandatory requirements. A permit applicant can document compliance with Title 24 by following all prescriptive requirements, or they can use the performance method that allows an applicant to “trade off” systems or components that perform below the prescriptive standards with other higher-performing systems elsewhere within the project, as long as the overall performance is equivalent to that of a building in which all prescriptive requirements are met. When using the performance method, all systems or components must meet or exceed mandatory requirements.

Title 24-2025 adds new mandatory maximum area-weighted U-factor requirements for fenestration (Table 2). Previously, window performance could be traded off without limit with other building systems like HVAC, allowing builders to install less-efficient glazing. To ensure that long life-cycle systems like fenestration are not traded off for less durable equipment, Title 24-2025 introduced a mandatory maximum U-factor of 0.47 for new construction and 0.58 for

⁵¹ Section 100.0. California Energy Commission, 2022 Nonresidential and Multifamily Compliance Manual (First Quarter Errata), TN #250098 (Sacramento: California Energy Commission, May 11, 2023).

⁵² Section 141.0(b)2A. California Energy Commission, 2025 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Title 24, Part 6, CEC-400-2025-010-F (Sacramento: California Energy Commission, July 2025).

alterations. Prescriptive requirements for nonresidential window U-factor in Title 24-2025 range from 0.34 to 0.46 for new construction, depending on building type and climate zone, and between 0.47 to 0.58 for alterations. Prescriptive requirements for SHGC range from 0.22 to 0.26 for new construction and from 0.31 to 0.45 for alterations.⁵³ CalMTA's specifications for CRAWs fall within these ranges.

Table 2. Title 24-2025 fenestration requirements for nonresidential buildings

Building Permit Type	U-factor, Mandatory	U-factor, Prescriptive	SHGC, Prescriptive
New Construction	0.47	0.34 - 0.46	0.22 - 0.26
Alterations	0.58	0.47 - 0.58	0.31 - 0.41

A proposed update to the 2028 Building Energy Code would improve U-factors for nonresidential windows in climate zones 1 and 16; however, current and proposed fenestration performance in Title 24 can be met by standard glazing products without the use of VIG.⁵⁴

6.2 Federal standards

Fenestration is not covered by federal energy performance standards.

6.3 Product ratings: barriers and limitations

Several barriers related to national performance ratings limit the broader adoption of VIG and CSW:

6.3.1 VIG for SPR

- To demonstrate compliance with Title 24, window assemblies must have assembly U-factors and SHGC ratings issued by the NFRC. Glazing units that have not been rated by the NFRC as an assembly must use default values that generally fall short of actual performance. The 2023 version of the NFRC-100 standard adopted U-factor calculations for VIG products. The NFRC-100 standard also added a simulation of VIG into the THERM certification software, which allowed for the standard certification of new VIG fenestration products.⁵⁵ However, there is no NFRC rating method for VIG for SPR, since the glazing unit is installed directly into existing frames. An approach similar to the "site built" calculation for fenestration that is assembled at

⁵³ Sections 120.7(d), 140.3(a), and 141.0(b). 2025 Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Nonresidential and Multifamily Compliance Manual. Sacramento: California Energy Commission, July 2025.

⁵⁴ 2028 Cycle Fenestration Improvements. Title 24. <https://title24stakeholders.com/measures/2028-cycle/fenestration-improvements/>.

the building site may be needed for VIG for SPR. Without one, the default rating for VIG for SPR will limit the amount utilities can pay out in incentives and the compliance credit builders get in their energy modeling simulations.

- Measures like VIG that degrade in performance over time are assigned performance values in energy codes and modeling software that account for degradation (an analogous example is the aged solar reflectance value for cool roofs). The lack of long-term VIG performance data has prevented development of an aged performance value. VIG will need this value before the technology will be widely adopted.

6.3.2 CSWs

- While AERC provides ratings for CSW products, the industry lacks a program like ENERGY STAR® that guides consumers by certifying only high-performing products.

6.3.3 VIG for SPR and CSWs

- Most utility incentive programs compare performance to new code-minimum equipment. However, CRAWs will motivate and enable retrofit projects that would not have otherwise happened. To accurately capture the higher energy savings (and thus the full benefit of the technology), it may be necessary for utility programs to compare the performance of CRAWs technologies to the actual window baseline of SPC glass rather than to code-minimum new glazing equipment.

6.4 Product ratings: opportunities and leverage points

6.4.1 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and International Code Council (ICC)

While California does not directly reference ASHRAE standards or ICC model building energy codes in its building energy codes, more stringent U-factor requirements for commercial new construction nationwide could accelerate the market adoption of VIG. The 2025 version of ASHRAE Standard 90.1, the Energy Standard for Buildings Except Low-Rise Residential Buildings, proposed new fenestration requirements. The changes for 2025 are incremental improvements in U-factor; only climate zone 8, which is relatively small, requires advanced glazing (e.g., triple-pane windows or VIG). Model building energy codes published by the ICC, such as the International Energy Conservation Code (IECC), typically align performance requirements with those established in ASHRAE standards. Likewise, they can accelerate adoption of advanced glazing technologies as more stringent performance criteria are adopted into the model codes.

6.4.2 Attachments Energy Rating Council (AERC)

NFRC ratings for window assemblies consider the performance of glazing units within their frames. CalMTA and AERC have begun work to develop a rating method for VIG for SPR. Default NFRC values for VIG for SPR applications assume low thermal performance of the existing frames;



therefore, building designers and owners may not receive full credit for the performance of VIG for SPR when using default values to demonstrate compliance with energy codes or energy incentive programs.

6.4.3 The American National Standards Institute (ANSI)

ANSI NRFC 100 VIG Ballot outlines procedures for determining the U-factors of fenestration products and includes VIG as a covered product. The 2023 version of NFRC 100 incorporates additional language related to VIG.

6.4.4 ASTM International

In September 2022, ASTM established two working groups, WK83379 and WK83445, to develop VIG specifications, durability, and strength standards. In the meantime, several VIG products have already passed the existing E2190 standard for insulated glazing certification.

The draft standard WK83445, Load Resistance and Deflection, covers VIG load structural calculations.⁵⁶ This standard could lead to improved confidence in the accuracy of VIG load calculations by providing engineers with consistent and accurate data, thereby increasing VIG market share.

6.4.5 International Organization for Standardization (ISO)

ISO-19916 Part 1, published in 2018, provided a specification for VIG. Part 3, which followed in 2021, introduced a test method for evaluating VIG's performance under temperature differences.

6.4.6 National Foundation for Refrigeration and Air Conditioning (NFRC)

NFRC will update the VIG simulation module that assesses thermal performance for ENERGY STAR certification through the upcoming LBNL Window 8 program.

7 Competitive landscape

Consumers with existing SPC or DPC glass might choose between replacing single-pane glazing with VIG, installing CSWs, installing a variety of other competing products described in this section – or they might choose to do nothing.

To understand the competitive landscape for CRAWs, two factors must be considered: building owners' tendency to retain existing windows and the varied factors that motivate those who choose to upgrade. First, the typical response to window-related problems is inaction; inefficient, single-pane windows often remain in place for decades. Therefore, for a window solution to be

⁵⁶ ASTM WL83445k: New Practice for Standard Practice for Determining Load Resistance of Vacuum Insulating Glass in Buildings, <https://www.astm.org/workitem-wk83445>.

selected, it must not only outperform less-efficient alternatives considered during routine or early replacement but also overcome the “do-nothing” option and motivate action to improve the building envelope. Second, energy efficiency is not the primary driver of window upgrades, and the optimal solution may not deliver the greatest energy savings. As documented in various market characterization studies, a common primary driver for building owners to invest in window solutions is to address thermal comfort and noise-related problems, with energy and HVAC savings being a secondary benefit.^{57,58} While NEBs are frequent drivers of adoption in other MTIs, NEBs are commonly the primary driver for the CRAWs MTI. Therefore, no one window technology solution can be definitively identified as superior based simply on energy performance alone; it must deliver a compelling value proposition to the building owner that, in part, is often based on NEBs.

The optimal solution for a given application is the one that overcomes the do-nothing response, most effectively addresses the non-energy problem being addressed, and provides the greatest energy savings. For example, the optimal technology solution for a building with inefficient SPC glass and well-performing window frames will be different than the optimal solution for a building with more efficient glass but with leaky window frames. The former may have a smaller impact than the latter on overall energy savings but still delivers significant improvements over taking no action.

This competitive analysis will compare the energy and non-energy performance characteristics of competing technologies and identify the strengths and weaknesses of each for defined use cases.

7.1 CSWs

CSWs can be installed quickly, with minimal disruption to occupants, and are the lower-cost option of the two considered for this MTI. There are several categories of window attachment products that consumers might consider as alternatives to CSWs:

- 1) **Frame-mounted stretched film panel with weatherstripping seals around the perimeter.** Like CSWs, these products include a frame. Unlike CSWs that use rigid glass, polymer, or acrylic panel, they use a pliable, stretched film.
- 2) **Glazing-mounted (frameless) acrylic and copolyester panels.** These products do not include a frame. Instead, the acrylic or copolyester panel attaches directly to the glazing of the original window using a variety of attachment techniques, creating an unsealed dead-

⁵⁷ Ingo Bensch, Ross Donaldson, Lyndsey Shimazu. Commercial Window Attachments: Secondary Window Market Characterization, April 9, 2020. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>.

⁵⁸ See Appendix D (Market Characterization Report) for more detail.

air space between the panel and the original glazing. Panels are sized to be slightly smaller than original glazing, leaving a small portion of the original glazing exposed.

- 3) **Window film.** Thin laminate film is permanently applied directly to the original window's glass surface. There is a wide range of window films for commercial applications that provide energy benefits and NEBs. These films are also used in the construction of CSWs.
- 4) **Window shades.** Also commonly referred to as window coverings or window attachments, this product category includes cellular shades, roller shades, and solar screens that are installed on the interior or exterior of the existing window. Most commonly they are operable and can be controlled automatically or at the discretion of the user. Some products are installed like residential window screens. They are not operable but can be removed and reinstalled as needed.

Table 3 presents a competitive analysis of the strengths and weaknesses of CSWs and competing products that consumers might consider for buildings that are not undergoing a significant retrofit.

Table 3. Competitive landscape for CSWs

Product	Strengths	Weaknesses
MTI Product - CSW	• Equal or better energy performance and up to 90% less expensive than full window replacement • Comparable performance with VIG for SPR for lower cost • Strong thermal comfort and noise-reduction benefits • Mitigates all forms of unwanted heat transfer – conductive, radiant, and air leakage • Excellent clarity and light transmittance • Larger and more flexible sizing than most competing technologies • Can be installed quickly and easily without envelope or occupant disruption	• Risk of condensation between primary and secondary window if primary window is not in good physical condition • Few options for operability. Some manufacturers may not offer operable CSWs or may not offer operable CSWs for all window configurations (e.g., hung windows, sliders) • More expensive than other attachment products • Heavier than other attachment products • Installer network is in development

Product	Strengths	Weaknesses
	- Options available for AERC-rated product - Can be removed/replaced easily - Mature supply chain	
Competing Product - Frame-mounted stretched film panel with weatherstripping seals around the perimeter	- Strong thermal comfort benefits - Mitigates all forms of unwanted heat transfer – conductive, radiant, and air leakage - U-factor and SHGC improvement can be on par with CSWs - Lightweight - Can be installed quickly and easily without envelope or occupant disruption - Can be removed/replaced easily - Lower cost than CSWs	- No noise-reduction benefits - No options for operability - Poor aesthetics due to uneven surface and strong coloration - Poor clarity - Limited sizes due to maximum film width of approximately 48 inches - No AERC-rated options - Emerging technology lacking robust supply chain - Competing technologies at higher price points (e.g., CSWs) and at lower price points (e.g., film) offer better performance, value, and more professional-looking solution
Competing Product - Glazing-mounted acrylic and copolyester panels	- Can install on many window types including sliders and hung windows while maintaining operability of the original window - Mitigates conductive and radiant energy losses, but to a lesser degree than CSWs and film panels - Lightweight – approximately 1/3 the weight of other attachment products	- No noise-reduction benefits - No air-leakage benefits - U-factor and SHGC benefits lesser than competing products - Poor aesthetics due to panel having to be slightly smaller than original glazing, making edges visible and potentially reflecting light - For larger windows, panels must be tiled to cover entire area, creating gaps and visible edge lines - No AERC-rated options

Product	Strengths	Weaknesses
	• Can be installed quickly and easily without envelope or occupant disruption • Lower cost than CSWs and frame-mounted stretched-film panels	• While panels can be removed/replaced, the adhesive mounting tabs are applied permanently to the window • Limited manufacturers lacking robust supply chain
Competing Product - Window film	• Diverse options for delivering a wide range of energy benefits and NEBs including safety and security films that contain shattered glass • Can be applied directly to the original window or applied to CSWs to enhance CSW performance • Mitigates conductive and radiant energy losses • SHGC improvement on par with CSWs • Weight is insignificant • Can be installed quickly and easily without envelope or occupant disruption • Cost varies widely based on product but in general is lower cost than other attachment products • Mature products from multiple international suppliers, robust supply chain and installer network.	• No air-leakage benefits • No noise-reduction benefits • U-factor improvement is less than CSWs or full replacement due to lack of insulating gap • No AERC-rated options • Permanent installation
Competing Product - Window coverings (e.g., cellular shades, roller shades, blinds, shutters, and screens)	• Diverse options (blinds, shades, screens) for delivering a wide range of energy benefits and NEBs • Mitigate conductive and radiant energy losses	• No air leakage benefits • No noise-reduction benefits • U-factor and SHGC benefits lesser than framed attachment products due to leakage around the window covering

Product	Strengths	Weaknesses
	• AERC-rated products • Highly customizable with diverse designer options • Most flexibility and effectiveness in addressing glare, visual comfort, and visual privacy issues • Diverse operability options; can be automated and connected to smart devices to optimize energy savings under changing environmental conditions • Lightweight • Easy to install, including DIY options • Can be removed/replaced • Mature and robust supply chain	• Energy savings is a function of user-behavior; difficult to predict, model, and guarantee • May reduce daylighting if not operated properly

7.2 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:

- 1) **Full window replacement.** Existing window and frame are replaced with framed double- or triple- pane windows, though full replacement rarely occurs due to cost and the disruptive nature of installation.
- 2) **Other competing technologies.** CSWs and the products identified in Section 7.1 are also a competing solution for VIG for SPR.

7.3 Summary of benefits for window retrofit solutions

Table 4 presents a subjective ranking of the energy benefits and NEBs of VIG, CSW, and competing products. It underscores that the optimal choice for window solutions hinges on the specific challenge the building owner is attempting to resolve. Many retrofits are driven by a confluence of factors.



Table 4. VIG, CSW, and attachment products feature comparison

	VIG	CSW	Frame-Mounted Stretched Film	Frameless Non-glass panels	Window Film	Shades, blinds, screens
Low Installed Cost (Mat'l + Labor)						
Energy Savings						
U Value						
SHGC						
Air Leakage						
Savings Certainty						
Non-energy Benefits						
Thermal Comfort						
Noise Reduction						
Safety						
Aesthetics						
Daylighting						
Operability						
Large Sizes						
Weight						
Supply Chain						

Circles represent subjective rankings of various characteristics for each window product. A filled circle indicates the greatest relative benefit in a given category, while an empty circle indicates the least benefit.

Appendix C: Product Assessment for CRAWs

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

8 Product performance

8.1 Energy consumption/UEI/peak electrical

The energy consumption and peak electric load reduction benefits for this MTI were assessed using whole-building energy models run in EnergyPlus. DEER prototype models for 18 building types were used as shown in Table 5. DEER models were run as-is, with only window parameters modified to reflect CRAWs installation cases.

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

A full description of the building characteristics, modeling assumptions, and weighting factors can be found in Attachment 2 to Appendix B.

8.1.1 Energy consumption

CalMTA found that CSWs and VIG for SPR can offer significant energy consumption savings across all California climate zones and utility service territories. Energy savings from CSWs and VIG for SPR are very similar to each other (within 1%) on average⁵⁹. Most of the savings are driven

⁵⁹ Because CalMTA found the energy performance of CSWs and VIG for SPR to be similar, and since the MTI assumes the market adoption of VIG for SPR will be low, figures in this section report the energy performance of CSWs to represent all CRAWs technologies.

by reduction in SHGC, rather than improvements in U-factor or infiltration. Results in Table 6 indicate a 7% to 8% reduction in annual electric consumption and a 17% to 22% reduction in annual gas consumption in the proposed cases, compared to the baseline. Utility consumption varies slightly by IOU because service territories cover different climate zones.

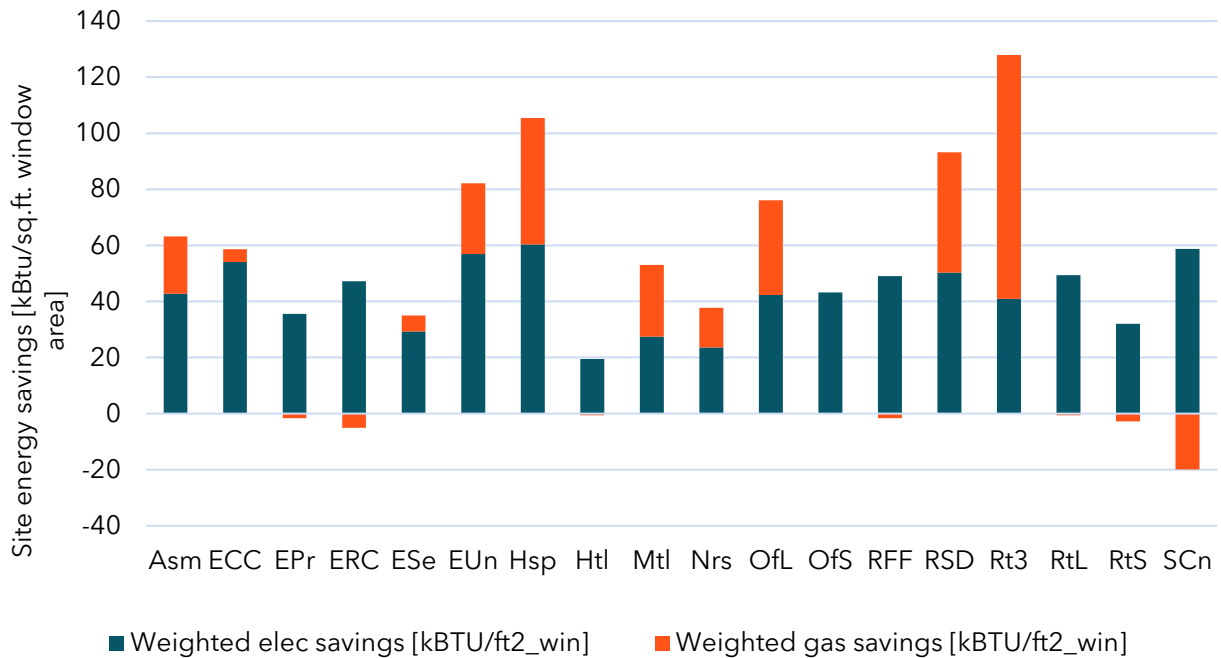
Table 6. Average annual utility consumption weighted average of climate zone and building type

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.

The commercial building prototype models analyzed demonstrated varying degrees of energy savings achieved through CRAWs. Buildings with relatively high equipment loads and low ventilation requirements (such as offices) exhibited greater energy savings compared to buildings with high ventilation requirements (such as healthcare facilities). CRAWs provided significant savings for all the analyzed building types. Figure 1 illustrates the relative energy savings achieved by CRAWs for each of the 18 building types, broken down by fuel type.

Figure 1. Average annual site energy savings, by building type⁶⁰

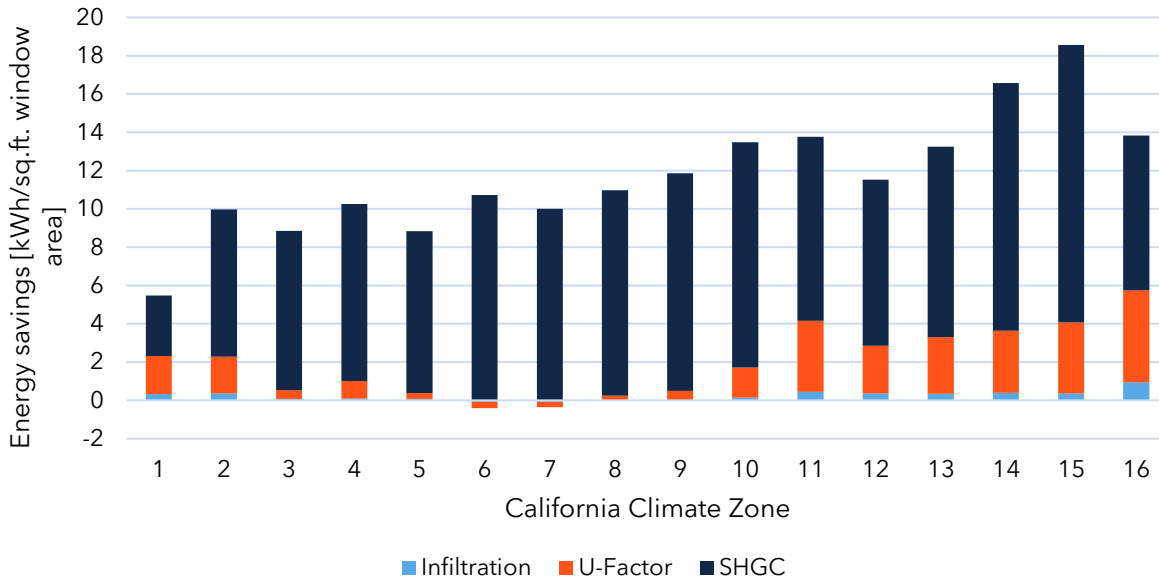


Energy cost savings from CRAWs vary depending on the climate zone. Inland climate zones with higher overall space conditioning loads (such as 14, 15, and 16) exhibit larger energy savings compared to mild coastal climate zones like 1 through 9. However, utility rates also significantly impact utility bills, so the savings are not directly proportional to space conditioning loads. CalMTA's analysis assigns utility rates based on utility service territory.

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. For commercial buildings throughout California, however, the reduction in solar heat gains achieved through low-e coatings leads to overall energy savings. In mild coastal climate zones like 6 and 7, improvements in U-factor and infiltration rates can increase building energy consumption by eliminating some passive cooling. However, these penalties are relatively small compared to the savings generated from reducing solar heat gains. Figure 2 illustrates the savings contributed by each component in one example commercial building type, the small office (OfS).

⁶⁰ See Table 5 for definitions of the building type abbreviations.

Figure 2. Average annual component energy savings for small office



8.1.2 Peak demand reduction

CRAWS technologies reduce peak cooling demands by about 5% to 20% compared to existing windows.⁶¹ Energy modeling indicates that maximum peak demand reduction generally occurs during summer months, when cooling loads are highest. Minimum peak demand reduction generally occurs during shoulder seasons, when HVAC usage is relatively low. The largest demand reductions were observed in Pacific Gas & Electric (PG&E) and Southern California Edison (SCE) service territories, with smaller impacts in the San Diego Gas & Electric (SDG&E) service territory.

8.1.3 Resilience

Buildings equipped with CRAWS technologies are better suited to accommodate load shifting events, as internal temperatures remain more stable and within a comfortable range for a longer period after the HVAC is set back or turned off in response to a demand-response signal or grid emergency. CalMTA performed energy modeling to assess the impact of improved commercial windows on interior space temperatures compared to buildings with SPC glass during a three-day power outage that coincided with extreme heat and cold events.⁶² We found that CRAWS technologies delay the passing of major internal temperature thresholds (e.g., 85°F, 90°F) by 15-

⁶² For this analysis, actual meteorological year (AMY) weather files were used: 2024 was chosen to represent a heat wave in Riverside (Sept. 9-15, 2024), and 2019 was chosen to represent cold in Lake Tahoe (March 1-11, 2019).

25 hours during a heat wave and delay the passing of major internal temperature thresholds (e.g., 60°F, 50°F) by 5-20 hours during a cold event.

8.1.4 Field installation

At the time of writing, CalMTA has a field installation of CSWs underway at Madison Elementary School in Madera, California. Classrooms at the school are the same size, with similar window and door configurations. Each classroom at the school is accessed from outside and is served by a packaged single-zone air conditioner with natural gas furnace. CalMTA installed CSWs on all windows in four classrooms and selected four classrooms to serve as a control group without CSWs.

Data collection started in September 2025 and will last for a year. CalMTA performed blower door testing on all eight classrooms and equipped each with air quality sensors that detect temperature, humidity, carbon dioxide (CO₂), volatile organic compounds (VOC), and particulate matter (PM). CalMTA also added door opening sensors and thermistors on the interior and exterior surfaces of windows and interior surfaces of CSWs. Energy data is also collected from the RTUs serving the classrooms, as well as supply and return air temperatures.

Preliminary blower door tests indicate that CSWs reduce infiltration rates in classrooms by roughly 8%-12%. Preliminary cooling season data observed during the month of September 2025 indicate that CSWs reduced HVAC cooling run time by 24% for classrooms with CSWs, while maintaining similar temperatures. During the month of January 2026, HVAC heating run time was reduced by 29% for classrooms with CSWs. CalMTA will share further data from the field study as it progresses.

8.2 Bill impacts

CalMTA used energy modeling to estimate the average annual total facility energy cost savings from adopting CRAWs technologies. We compared savings to a scenario where no action is taken, which was represented in this analysis using the SPC windows scenario. Annual utility cost savings were approximately 9% for each IOU as a weighted average of building type and climate zone.

Results summarized in Table 7 represent the total bill impacts for each modeled scenario. Negative values indicate bill savings. (All scenarios modeled resulted in bill savings.) Results are presented as a percentage reduction in the dollar amount of estimated customer bills on a whole-building basis. Since whole-building energy consumption includes lighting, water heating, plug loads, and miscellaneous loads, the percentages are lower than they would be if calculated solely for HVAC energy use.



Table 7. Average annual whole-building cost savings, by fuel type and utility

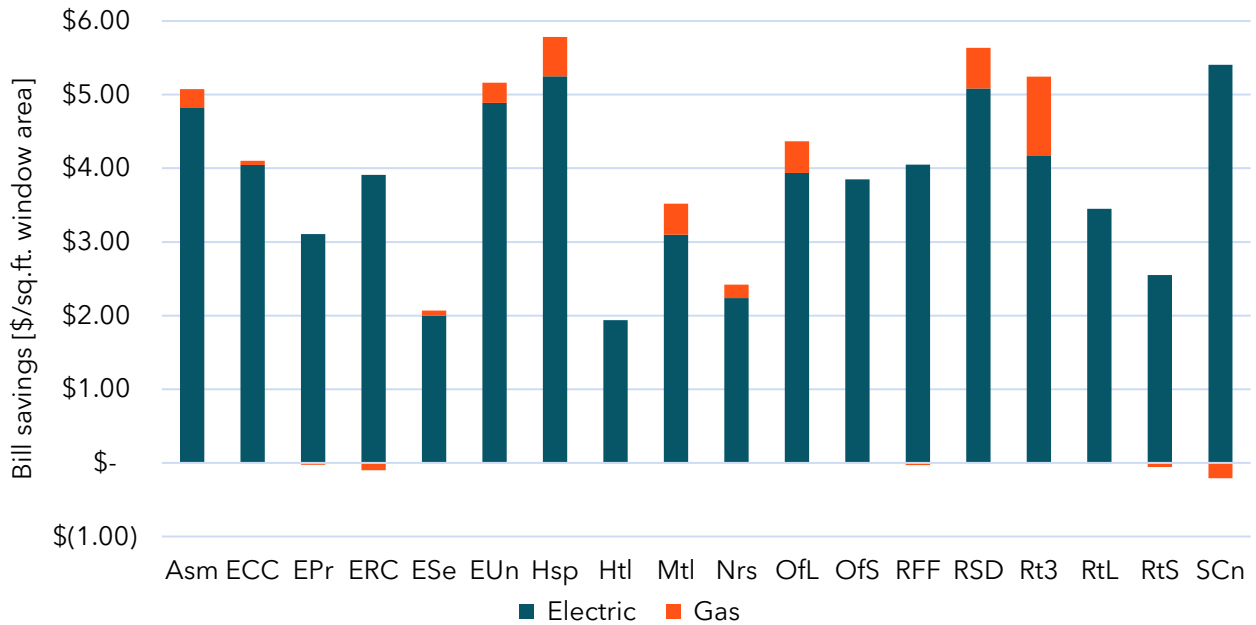
Case	Electric			Gas			Total		
	PG&E	SCE/SCG	SDG&E	PG&E	SCE/SCG	SDG&E	PG&E	SCE/SCG	SDG&E
CSW	-9%	-9%	-9%	-20%	-17%	-16%	-9%	-9%	-9%

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 (Figure 3). For each energy model, the electric and gas bills were calculated using the mainstream commercial tariffs available in each model's particular climate zone.⁶³ Commercial gas utility rates are constant annually for SCG and SDG&E but vary by month for PG&E. 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 a calendar year (1/1/2025-12/31/2025).

⁶³ Nine electric rates and ten gas rates were used for this analysis. The electric rate IDs are as follows: USCA-PGPG-0600-0000, USCA-PGPG-0800-0000, USCA-PGPG-1100-0000, USCA-PGPG-1400-0000, USCA-SCSC-0800-0000, USCA-SCSC-1800-0000, USCA-SCSC-2400-0000, USCA-SDSD-1010-0000, USCA-SDSD-1020-0000. The gas rate IDs are as follows: PGE-GNR-1 Tier I, PGE-GNR-1 Tier II, PGE-GNR-2 Tier I, PGE-GNR-2 Tier II, SCE-GN10 Tier I, SCE-GN10 Tier II, SCE-GN10 Tier III, SDGE-GN03 Tier I, SDGE-GN03 Tier II, SDGE-GN03 Tier III.

Figure 3. Average annual bill savings by building type



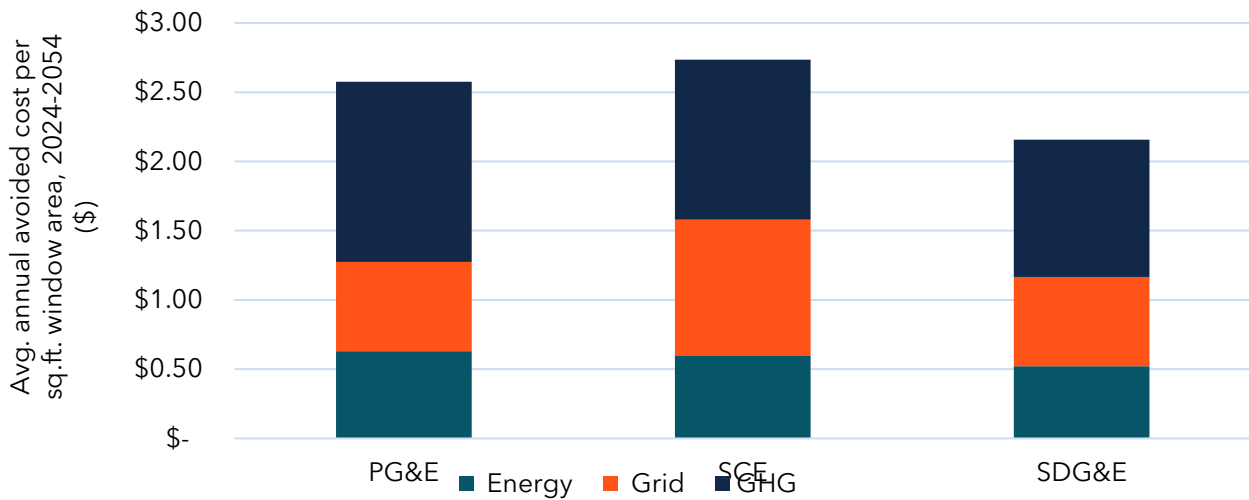
Annual heating loads for commercial buildings in California are relatively low. Peak load reductions result in outsized bill reductions due to TOU rates and demand charges. Demand charges, which are driven primarily by cooling energy consumption, make up a large percentage of electricity bills for California commercial customers.

8.3 Avoided costs

CalMTA used CPUC's Avoided Cost Calculator (ACC), which provides a robust framework for evaluating the impact of fuel substitution and energy efficiency measures. The ACC estimates system-level utility costs of providing electric or gas on an hourly basis in \$/kWh and \$/therm. The avoided cost factors were multiplied by the modeled hourly unit energy savings (UES) outputs to develop annual avoided costs for each measure. The avoided costs were batched into three categories: energy benefits, grid benefits, and GHG benefits, which are the categories that are used for TSB reporting in the MTI Plan.

The avoided cost benefit for CSWs was calculated based on a start date of 2024 and extending through the estimated useful life of the product. The avoided cost benefit is shown in Figure 4, broken down by energy, grid, and GHG benefits.

Figure 4. Annual average avoided cost per sq.ft. window area by IOU service territory, 2024-2054



9 Product plan

9.1 Objectives

The CRAWs MTI aims to enhance availability, raise awareness, and establish consumer funding mechanisms for CRAWs technologies. The technical barriers for both CSWs and VIG for SPR primarily stem from low awareness, a lack of product performance data, performance ratings and reliability data, and an immature supply chain. VIG for SPR also faces technical barriers in effectively and reliably reducing infiltration, and the formation of condensation on poorly insulating existing window frames. While effective CSWs are already available, the supply chain for distributing and installing them in California is relatively immature. VIG technology performs well, but the scale of manufacturing and distribution is small and currently focuses on the new construction market. The lack of awareness within the building industry regarding VIG is reflected in the absence of test methods to evaluate and rate the performance of VIG for SPR when installed in existing window framing systems. Additionally, the lack of awareness is evident in the absence of ratings from programs like ENERGY STAR to inform consumer purchases of CSWs.

On the other hand, the past several years have seen advancements in readying the market to be able to adopt CRAWs technologies more widely. CalMTA aims to extend the momentum built by organizations such as the national laboratories, GSA, CEC, regional energy efficiency organizations (REEOs), and utilities that have actively tested and promoted window solutions.



9.1.1 Short-term objectives

In the short term (1-2 years), the MTI will seek to achieve the following objectives:

- ESCOs and utility energy efficiency program administrators are aware of the potential energy savings and NEBs of VIG for SPR and CSWs.
- AERC or a similar industry organization commits to developing a method for rating VIG for SPR.

9.1.2 Medium-term objectives

In the medium-term (3-5 years), the MTI will seek to achieve the following objectives:

- Municipalities will increasingly incorporate CRAWs technologies into their climate and energy action plans, recognizing them as a means to reduce emissions associated with operating their building stock.
- Utility energy efficiency programs increasingly provide incentives for CRAWs projects.
- Architects, design firms, ESCOs, CBOs, and HVAC installers increasingly evaluate and recommend CRAWs technologies as an upgrade option for consumers.
- AERC, or a similar industry organization, publishes a method for rating VIG for SPR, allowing an increasing number of VIG manufacturers and products to be rated by AERC.
- CRAWs technology is increasingly adopted by the CRE market, the MUSH market (municipalities, universities, schools, and hospitals), and by ESCO project portfolio.

9.1.3 Long-term objectives

In the long-term (6-10+ years), the MTI will seek to achieve the following objectives:

- The majority of commercial building owners in both ESJ and non-ESJ communities with SPC and DPC windows will recognize CRAWs technologies as an effective means to enhance building efficiency. During (or prior to) HVAC system upgrades, HVAC designers and installers will consider the potential of incorporating CRAWs technologies to reduce HVAC system sizing as part of standard practice, and by 2045, 50% of HVAC replacements or upgrades will include envelope evaluation.
- CalMTA will collaborate with ENERGY STAR to commence certification of CSWs, building off ENERGY STAR's certification program for residential storm windows.



9.2 Product plan actions

9.2.1 Field demonstration projects

Short- to long-term action (1-10+ years)

In-field demonstration projects, such as the one currently underway at Madison Elementary School in Madera, California, aim to raise awareness about the energy and non-energy benefits that CRAWs technologies can provide to buildings in California. Building on its current field demonstration, the CRAWs MTI will expand its field study sites to encompass a wider range of building types and climate zones. To achieve this, it will collaborate with other MTIs conducting field demonstrations, such as the CRTUs MTI. This collaboration will enhance efficiency and facilitate the assessment of the synergistic effects of CalMTA's MTIs. For instance, it will demonstrate how HVAC designers can utilize CRAWs technology to improve building envelope efficiency, thereby enabling them to downsize replacement systems.

In-field demonstration projects collect and share performance data, including energy performance and quantification of NEBs like thermal comfort, noise, and air quality. CalMTA will publish data from field demonstrations, including energy consumption, NEBs, and best practices to demonstrate the value proposition of CRAWs technologies and build upon lessons learned, with the aim of supporting ESCOs in evaluating or recommending CRAWs technologies as upgrade options for consumers.

Medium-term action (3-5 years)

Using case studies developed from field demonstrations to illustrate the business case for CRAWs technologies, CalMTA 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.

9.2.2 Stakeholder and industry collaboration

Short-term actions (1-2 years)

CalMTA will evaluate the need for expanded options for operable CSWs and will work with manufacturers and national labs to document the conditions that promote condensation and identify best practices for prevention and remediation. We will work with manufacturers to encourage them to submit products to AERC for rating.

Short- to long-term action (1-10+ years)

As outlined in the preceding section, CalMTA will collaborate with industry stakeholders, including the DOE, national laboratories, extra-regional energy efficiency organizations, and collaborative organizations, by establishing partnerships and sharing data from analysis and field installations. This initiative aims to enhance activity in the supply chain by encouraging HVAC



designers to routinely consider the potential of CRAWs technologies in reducing HVAC system sizing during system upgrades, making it a standard practice.

Medium-term action (3-5 years)

CRAWs will collaborate with the DOE to expand the functionality of an existing CSW savings calculator to ensure applicability for California climate zones and building stock.

To further expand the VIG supply chain, CRAWs will collaborate with national laboratories, such as NLR, that are conducting research on VIG, to ensure that the latest research data informs industry standards as they are developed. For instance, NLR is leading studies to assess energy losses through existing window frames. This data can be used in part to design a system for rating the performance of VIG for SPR.

9.2.3 Certifying organization collaboration

Long-term action (6-10+ years)

VIG for SPR lacks a methodology for rating its performance in commercial applications. The CEC is currently developing a rating system for replacing SPC glass in residential applications. The CRAWs MTI will build off this momentum and serve as a catalyst to establish a rating system for commercial applications. 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 an increasing number of VIG manufacturers and products to be rated by AERC.

CalMTA will collaborate with ENERGY STAR to certify CSWs, building off the precedent they established with their certification of residential storm windows. Uncertainty around future DOE funding for ENERGY STAR poses a risk that its ability to cover a new category of products would be limited. Additionally, there is a possibility that AERC may lack the capacity to develop a rating method for a new product type, given their significant commitments to other window attachment products.





Commercial Replacement and Attachment Window Solutions

Market Characterization Report

June 26, 2026





REPORT # MR26-011

Commercial Replacement & Attachment Window Solutions

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List of Abbreviations

Abbreviation	Definition
AERC	Attachments Energy Rating Council
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	Advancing Standards Transforming Markets International
BPS	Building Performance Standards
CalMTA	California Market Transformation Administrator
CATI	Computer-Assisted Telephone Interviewing
CBECs	Commercial Buildings Energy Consumption Survey
CEC	California Energy Commission
CEUS	California Commercial End-Use Survey
CRAWS	Commercial Replacement and Attachment Window Solutions (program)
CSW	Commercial secondary window
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EPIC	Electric Program Investment Charge
ESCO	Energy service company
GDP	Gross domestic product
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
LEED	Leadership in Energy and Environmental Design
Low-E	Low-Emissivity
MTI	Market transformation initiative
NEEA	Northwest Energy Efficiency Alliance
NFRC	National Fenestration Rating Council
NLR	National Laboratory of the Rockies
NREL ¹	National Renewable Energy Laboratory
PG&E	Pacific Gas and Electric Company
PV	Photovoltaics
ROI	Return on investment
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric Company
SHGC	Solar heat gain coefficient
VIG	Vacuum-insulated glass
WWR	Window-to-wall ratio

¹ The National Renewable Energy Laboratory (NREL) was renamed to The National Laboratory of the Rockies (NLR) on December 1, 2025.

1 Executive summary

This market characterization report is an output of the Phase II research for the Commercial Replacement and Attachment Window Solutions (CRAWS) Advancement Plan, finalized in September 2024.² CRAWS in this report specifically refers to *vacuum insulated glass* (VIG) and *commercial secondary windows* (CSW). CSW and VIG are retrofit products and are referred to as *advanced window solutions* throughout this report. Although still emerging, the CRAWS market shows strong potential, as these solutions enhance the energy efficiency and performance of existing windows without the need for full replacement.³ The CRAWS market transformation initiative (MTI) offers a substantial opportunity to improve building envelope thermal performance; reduce heating, ventilation, and air conditioning (HVAC) loads; and enable downsizing of HVAC systems in need of replacement. VIG and CSW technologies can enable an “envelope first” approach that helps building owners maximize the efficiency of their decarbonization efforts (such as installing a downsized HVAC for the updated windows), while saving money by eliminating the need for full window replacement. 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.⁴

This report discusses the California market for CSW and VIG, highlighting key barriers, opportunities, and impacts by examining demand- and supply-side dynamics, awareness of secondary windows, and the regulatory framework.

1.1 Objectives and methods

This market characterization report provides an overview of the commercial market for CRAWS in California. It characterizes the current saturation and market shares of CSW and VIG; assesses demand-side factors such as awareness, perceptions, and adoption barriers among market actors; identifies the costs and benefits associated with CSW and VIG; and reviews the relevant regulatory landscape. To accomplish the above objectives, the California Market Transformation Administrator (CalMTA) conducted primary and secondary research, including a literature review, interviews, and a survey, as summarized in Table 1.

² CalMTA. 2024. *Commercial Replacement & Attachment Window Solutions Advancement Plan*. September 17, 2024. <https://calmta.org/resourcereport/commercial-replacement-attachment-window-solutions-advancement-plan/>

³ U.S. Department of Energy. 2019. *Foundational Design Research. Building Technologies Office*. https://www.energy.gov/sites/prod/files/2019/12/f69/2019-bto-peer-review-report_0.pdf

⁴ BetterBricks. 2025. *Secondary Windows Rejuvenate Aging Office Building*. https://betterbricks.com/wp-content/uploads/2025/03/915Broadway_SecondaryWindows_CaseStudy.pdf



Table 1. Summary of Research Activities

Audience or Task	Research Description	No. Completed
Secondary Research and Literature Review	Secondary data review and analysis; literature review of evaluation and market reports	14 articles/reports/presentations; 3 data sets
Manufacturers, Energy Service Companies (ESCOs), and Installers ⁵	In-depth interviews	13
Commercial Tenants	In-depth interviews	6
Building Owners and Property Managers	In-depth interviews	8
	Quantitative survey	114

1.2 Key findings and conclusions

1.2.1 Finding 1: Window performance has a strong influence on a building's energy use

Buildings account for nearly 40% of the total U.S. energy use and about 75% of the country's electricity use, with much of that energy spent on maintaining comfortable indoor conditions.⁶ According to a study by the Northwest Energy Efficiency Alliance (NEEA), windows represent roughly 15% of a building's exterior surface but account for about 40% of HVAC-related energy losses, equivalent to approximately 12% of total building energy use.⁷

Properly installed and well-performing windows can offer benefits, including peak load reduction, noise reduction, thermal comfort, visual aesthetics, and resilience to extreme weather conditions. However, investment in window and façade upgrades in general continues to be overlooked in favor of HVAC solutions.⁸ The reality is that windows can play a notable role in a building's energy

⁵ CalMTA team was able to interview only two installers. Due to the small sample size, the installer insights are not reported.

⁶ National Laboratory of the Rockies. 2023. *NREL Researchers Reveal How Buildings Across the United States Do—and Could—Use Energy*. September 14, 2023. <https://www.nlr.gov/news/detail/features/2023/nrel-researchers-reveal-how-buildings-across-the-united-states-do-and-could-use-energy>.

⁷ Northwest Energy Efficiency Alliance (NEEA). 2023. *Commercial Secondary Windows Field Test*. Retrieved December 18, 2023. <https://neea.org/resource/commercial-secondary-windows-field-test/>.

⁸ Façade Tectonics Institute. 2024. *High-Performance Façades: Barriers to Widespread Adoption in Non-Residential and Multi-Family Buildings and Strategies to Overcome Them*. Prepared for the U.S. Department of Energy. <https://www.facadetectonics.org/publications/collection/publications#entry:58756@1:url>.

savings by reducing peak load and stress on an HVAC system.⁹ Windows also provide additional non-energy benefits such as increased comfort and reduction of noise and glare.¹⁰

1.2.2 Finding 2: Market actors see meaningful benefits from window solutions adoption

Although familiarity with advanced window technologies remains low, market actors such as ESCOs recognize the potential non-energy benefits of CSW and VIG (see Table 2). While secondary windows have long been associated with helping preserve historic buildings (given that they do not require major renovations to frames or to the exterior of a building), they can also be applied to non-historic buildings to offer both energy savings as well as non-energy benefits.

Non-energy benefits

Non-energy benefits cited by CalMTA interviewees as well as in relevant literature include aesthetics, comfort, soundproofing, occupant safety, and long warranties. As shown in Table 2, manufacturers emphasize that CSW solutions tend to be less expensive and provide ease of installation compared to window replacement; however, these are not widely recognized benefits among other market actors. CalMTA interviews with ESCOs, manufacturers, and owners and managers highlighted that CSWs deliver occupant comfort benefits beyond energy performance. Participants consistently reported improved thermal comfort, with several interviewees emphasizing enhanced sound proofing. One university administrator (who was not very familiar with CSW) mentioned that they believed occupant safety was a benefit, a finding echoed by Evergreen Economics in the secondary window market characterization they developed for NEEA, noting that CSWs effectively reduced exterior noise.¹¹

Table 2. Non-Energy Benefits of Advanced Window Solutions

Customer Benefit	Sources
Aesthetics	Manufacturer interviews, CalNEXT Commercial Windows Market Study ^a
Comfort	Manufacturer interviews, ESCO interviews, CalNEXT Commercial Windows Market Study, NEEA Secondary Window Market Characterization ^b
Soundproofing	Manufacturer interviews, ESCO interviews, CalNEXT Commercial Windows Market Study, NEEA Secondary Window Market Characterization
Long warranties	Manufacturer interviews

⁹ National Renewable Energy Laboratory (NREL). 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. Prepared for the U.S. Department of Energy. April 2022. <https://research-ub.nrel.gov/en/publications/pathway-to-zero-energy-windows-advancing-technologies-and-market-adoption>

¹⁰ Navigant Consulting. 2018. *Commercial Windows Attachment (SGS) Initiative*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/commercial-window-attachments-sgs-phase-1-research.pdf>

¹¹ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>

Customer Benefit	Sources
Cost effectiveness (CSW only)	Manufacturer interviews, NEEA Secondary Window Market Characterization
Ease of installation	Manufacturer interviews
Safety and security	Building owner interviews, NEEA Secondary Window Market Characterization

^a Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. Prepared for CalNEXT.

^b Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA.

Energy benefits

Secondary windows offer energy benefits. The Attachment Energy Rating Council highlighted several BetterBricks case studies that illustrate the performance of secondary windows. In one case study, an aerospace manufacturer that was experiencing thermal comfort complaints decided to retrofit its single-pane window inventory with secondary windows and achieved a 12% reduction in total building energy cost, resulting in \$4,066 annual energy cost savings and representing a product payback period of 10.7 years.¹² The labor time needed to complete the installation of 331 window attachments was 3.5 days. Another study involving a 66,000 square-foot Montana University building achieved a 5.9 decibel reduction in noise level from outside noise and an 11% decrease in air leakage, along with improved thermal comfort.¹³ Yet another study at a legal office in Portland, Oregon, showed a 13.4% reduction in air leakage in a 15,741 square-foot building built in 1925. Installation averaged 20 minutes per window.¹⁴

LuxWall, a manufacturer of VIG, commissioned a study comparing the company's Enthermal glass product against both an existing single-pane glass and a high-performance double-pane full replacement and found that its VIG product outperformed the competition on U-value, interior glass surface temperature, and energy and carbon emission savings. Compared to the existing single-pane glass, Enthermal glass had a 60% reduction in solar heat gain, 45% improvement in heat loss, and a 43% lower HVAC peak load. Enthermal glass also represented a two to three times higher return on investment (ROI) compared to high-performance double-pane full replacement.¹⁵

¹² BetterBricks. 2025. *Secondary Windows Bring Stellar Savings for Aerospace Firm*. https://betterbricks.com/wp-content/uploads/2025/03/SecondaryWindows_Crane_CaseStudy_Ir.pdf.

¹³ BetterBricks. 2023a. *Secondary Windows Help Lead the Way to LEED Certification*. https://betterbricks.com/wp-content/uploads/2022/09/RomneyHall_Windows-Case-Study.pdf.

¹⁴ BetterBricks. 2023b. *Road Noise Disturbs the Peace at Portland Law Firm*. https://betterbricks.com/wp-content/uploads/2025/03/SecondaryWindows_SBH-Law-Office.pdf.

¹⁵ LuxWall. 2025. Enthermal™ product data sheet [PDF]. LuxWall. https://www.luxwall.com/wp-content/uploads/Enthermal-R18-Product-Data-Sheet_050725_LW00041.3.pdf.



1.2.3 Finding 3: Current incentives and building codes are insufficient to drive widespread adoption

Currently, there are only a few available incentive programs that help building owners offset the costs of secondary windows through tax benefits and credits. The 179 D Energy-Efficient Commercial Building Deduction offers a federal tax benefit for energy-efficient upgrades to lighting, HVAC, and building envelopes in both new and existing buildings that meet specific energy savings thresholds. Additional federal and state rehabilitation tax credits are available for qualifying properties. These programs are designed for broad energy efficiency improvements and not specifically for CSW, making them inadequate drivers of CSW adoption. Secondary windows, while improving thermal performance, often do not generate enough measurable energy savings to qualify for the full deduction. Additional non-tax-based program incentives are available through the California Energy Commission and state investor-owned utilities (IOU) (see Section 5.4, California programs, pilots, and incentives).

A recent market analysis found that incentives covering 40% to 50% of the incremental cost of secondary windows could substantially impact market adoption.¹⁶ Further, the report suggested that disadvantaged communities should be awarded 150% above the prescribed incentive for any high-performance window solution project.¹⁷ While advanced energy codes like California's Title 24 and New York City's Local Law 97 may influence demand, most manufacturers interviewed by CalMTA did not report actively tracking code changes.

1.2.4 Finding 4: Cost is a primary barrier to window improvements

High costs associated with traditional window replacements, often exceeding \$150 per square foot, remain a major deterrent for building owners. Despite their lower price points and faster installation timelines, market adoption of VIG and CSW continues to be hindered by the high cost of window upgrades.

General window investment

Most commercial buildings continue to rely on single-pane windows, a major source of energy loss, yet less than 1% of windows are replaced annually.¹⁸ Efforts to replace these windows are often hindered by persistent barriers—primarily, perceptions regarding costs, tenant disruption from installation, and extended project timelines.¹⁹ U.S. Energy Information Administration (EIA)

¹⁶ Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf.

¹⁷ Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf.

¹⁸ SPR Consulting. 2023. *Innovative and Cost-Effective Solutions to Improve Building Envelope Performance*.

¹⁹ NLR. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. <https://doi.org/10.2172/1866581>.

2012 data show that window replacements occur at less than half the rate of HVAC and roof replacements, and at only a slightly higher rate than insulation.²⁰ One reason for this disparity is that HVAC engineers are involved early in renovation planning, providing free modeling and influencing design decisions, whereas window and façade designers are typically consulted later, limiting their impact on early-stage project decisions.

In interviews conducted by CalMTA with market actors (manufacturers, building owners and managers, tenants, and ESCOs), owners and tenants cited a perception of high upfront prices, uncertain ROI, and competing upgrade priorities (such as HVAC or roofing) as reasons for delaying or avoiding window improvements in general.

CSW and VIG retrofits

Retrofitting with technologies like VIG and CSW offers faster, less disruptive, and more affordable upgrades compared with full replacements. Many emerging energy efficiency technologies tend to be more expensive than incumbent solutions, creating cost-related barriers to adoption. In contrast, advanced window technologies, specifically CSWs and VIG, have proven to be more cost-effective alternatives compared to traditional full window replacements. Traditional full replacement projects typically cost \$150 to \$200 per square foot of window area and may take up to 48 months to complete, since they often require new framing and additional repairs beyond the glass itself.²¹ In contrast, VIG installations are estimated at \$80 to \$120 per square foot, with timelines reduced to under 12 months. Importantly, VIG does not require frame replacement and minimizes tenant disruption, directly addressing some of the key concerns raised by building owners and operators. Similarly, CSWs require substantially less time than full replacements or VIG (60%–70% faster), with average costs of \$38.15 per square foot.²² Despite these advantages compared to traditional window solutions, market actor perceptions of the high cost for window upgrade persist, hindering market adoption.

Even when interest exists in CSW or VIG, competing capital needs often take precedence. CalMTA ESCO interviews reinforced this finding: cost was identified as a central barrier by multiple respondents. One noted that “windows typically do not sell unless the out-of-pocket expense is low,” emphasizing that utility incentives or state subsidies are often critical to make projects financially viable. Across discussions with ESCOs, building owners, manufacturers, and tenants, the consensus was clear: upfront costs, limited financing options, and opportunity costs remain the most substantial obstacles to adoption.

²⁰ NLR. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. docs.nrel.gov/docs/fy22osti/80171.pdf.

²¹ SPR Consulting. 2023. *Innovative and Cost-Effective Solutions to Improve Building Envelope Performance*.

²² Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf.



Additional market barriers include limited product availability and the inability of market actors to differentiate among window technologies.²³

Several factors have prevented market actors from embracing and seeking window solutions. Many barriers stem from a lack of awareness or knowledge regarding one or more aspects of window solutions or the installation process.

1.2.5 Finding 5: Persistent barriers inhibit the adoption of window solutions such as CSW and VIG

In addition to cost perception barriers, adoption of CSW and VIG technologies is slowed by low market awareness, supply chain limitations, inconsistent marketing, and misperceptions about performance and applicability, especially among key decision makers and midstream actors.

Low awareness

A common theme across literature is low levels of awareness of window solutions among key market actors. A 2021 report surveyed market actors about CSW and found that architects, glazing contractors, and property managers were all largely unaware of CSW products.²⁴ While architects and glazers expressed some level of awareness of CSW products, they associated them almost exclusively with historical buildings. Property managers who managed non-historical buildings had almost no exposure to CSW solutions. Other research found that architects, contractors, and consultants possessed a limited understanding of CSW nuances, including installation costs and processes relative to full window replacements, technical specifications and performance characteristics, and building code implications—that is, whether “secondary windows would meet build[ing] code requirements when code-related upgrades are triggered by larger renovations.”²⁵

CalMTA’s survey of commercial building owners and managers revealed that the main factor preventing selection of CSW or VIG as a window replacement or upgrade solution was a lack of information (64% of respondents), followed by concerns about performance (43% of respondents). Only 7% of surveyed commercial building owners and managers reported cost as a

²³ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>.

²⁴ Cadeo Group. 2021. *Commercial Secondary Window Program Development Research*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/High-Performance-Windows-Market-Characterization-Study.pdf>.

²⁵ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>.

factor that would prevent them from selecting CSW or VIG, suggesting that awareness of these technologies and their benefits is a key barrier in selecting them as a solution.²⁶

CalMTA survey data among commercial building owners/managers shows relatively high familiarity with CSW (51% familiar, 34% very familiar) but very low familiarity with VIG (19% familiar, only 4% very familiar). Interviews, however, tell a different story, as most owners, managers, and tenants reported little to no awareness of either technology, while manufacturers rated their own familiarity high but saw limited knowledge among other market participants (building owners, etc.). The high level of reported familiarity with CSW may be explained, at least partially, by the lack of distinct product differentiation documented in prior studies.²⁷

Supply chain constraints

While cost remains a critical challenge, supply chain constraints further complicate adoption—particularly for VIG. Although the CSW supply chain is well established, CalMTA interviews revealed that the VIG supply chain in the United States is still emerging. Manufacturers and ESCOs expressed concerns about tariffs, import dependencies, and rising lead times. These issues add risk and unpredictability to already expensive projects, exacerbating financial and logistical barriers to implementation. Additional challenges include a lack of product availability and the inability of market actors to differentiate between products.

Supply chain bypass

Research indicates that manufacturers tend to advertise secondary windows directly to end users since most orders for these products are custom, resulting in a very simple supply chain that bypasses distributors, wholesalers, and retailers.²⁸ However, this can cause a knowledge gap among midstream actors, perpetuating low awareness and knowledge and creating a barrier to adoption. Market actors expressed uncertainty about the commercial scale availability of secondary windows, with one architect commenting that they were familiar with only a “limited number of products that are

“Currently [we sell] D2C [direct to customer] mostly, especially in residential and small commercial markets.

- CSW Manufacturer

²⁶ CalMTA CRAWs Building Owner and Property Manager Survey Q F1: “What factors, if any, would prevent you from selecting CSW or VIG as a replacement or upgrade solution to your window needs? Please rank up to three factors, where #1 is the most important and #3 is the third-most important.” (n=114). Results rounded to the nearest percentage.

²⁷ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>.

²⁸ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>.



mostly aimed at the residential market. Most of these manufacturers are not geared to provide quantity or schedule for commercial application.”²⁹

Limited marketing

Secondary windows are often undermarketed, with limited emphasis on their distinct value and differentiation from other window solutions. In fact, a recent market characterization report found that secondary windows are often presented as one product and referred to with various terms such as “storm windows, secondary windows, window insulation, and window systems,” regardless of whether they are technically low-emissivity (low-E) storm windows or secondary glazing systems.³⁰ The authors of the report recommended that NEEA identify and use consistent terms to describe secondary windows in efforts to market and communicate the benefits of the technology.

Project bundling

Interviews with ESCOs indicated that CSW and VIG are rarely pursued as standalone projects; instead, they are bundled with HVAC, lighting, or envelope upgrades to improve ROI and minimize disruption. This suggests that adoption of secondary window technologies is largely dependent on integration with broader retrofit activities, with which incremental costs can be more easily justified.

Window lifespan

Commercial windows are often “set-and-forget” products, with lifespans ranging from 40 to 70 years. Unless failures such as water or air intrusion occur, replacements are rare and typically fall well beyond the 10-year warranty period.³¹ Consequently, the market for window upgrades is stronger in new construction than in existing buildings, as owners often prioritize higher-maintenance systems like HVAC. Supply chain challenges and low awareness of product differentiation further reduce the urgency to pursue window replacements.³² Since windows are a relatively low-maintenance product, they are often overlooked or disregarded in favor of other building upgrades, such as HVAC. The higher rate of replacement for HVAC over windows is partly due to the tendency for HVAC engineers and designers to be included early in building renovation planning phases compared to window or façade designers, who are generally

²⁹ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>

³⁰ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>

³¹ Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. Commercial Windows Market Study. Prepared for CalNEXT. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf

³² NREL. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. <https://docs.nrel.gov/docs/fy22osti/80171.pdf>



consulted during later phases. HVAC consultants typically provide modeling free of charge in the initial planning phase.³³ While window and façade designers may also provide free modeling services, they are typically consulted much later in the construction process than HVAC consultants, who have an opportunity to influence the early stages of project design and specification.

Misperceptions and disconnects

In the interviews with CalMTA, manufacturers highlighted affordability and ease of installation as benefits of CSW. In contrast, ESCOs frequently cite cost and complexity of window replacement or upgrade projects as barriers to adoption. This indicates a disconnect between the supply and demand sides of the market and merits additional research. ESCOs and building owners noted in the interviews that most window upgrades are a result of region-specific weather conditions and customers' desire to save energy.

Although previous studies indicate that awareness and knowledge are generally low among key market actors, there are several misperceptions that contribute to barriers to the adoption of window solutions. Customers and policymakers do not always view windows as an important source of a building's energy savings and believe that the costs for materials are expensive and prohibitive.³⁴ Other common misperceptions are that secondary window installations are time-consuming, invasive, and disruptive to tenants; that installations require workers with specialized skills; and that CSWs are a niche product, specific to historic building preservation.³⁵

Most prevalent barriers to adoption

Table 3 highlights some of the common barriers uncovered in the CalMTA literature review.

³³ Façade Tectonics Institute. 2024. *High-Performance Facades*.

<https://www.facadetectonics.org/publications/collection/publications>

³⁴ Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. Prepared for CalNEXT. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf

³⁵ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf>

Table 3. Barriers to the Adoption of Secondary Window Solutions

Barrier	Description	Source
Disproportionate Focus on Solutions that Require Frame Alteration	Technology advancements have tended to focus on glass rather than promoting solutions such as CSW and VIG that do not require alteration of frames for installation, which provide additional benefits related to cost, time, and effort to update window stock.	Commercial Windows Market Study and Measure Package Development. 2024. https://etcc-ca.com/reports/commercial-windows-market-study-and-measure-package-development
Lack of Awareness	According to secondary literature, there is a general lack of awareness of CRAWs products, their benefits, and range of applications.	Commercial Window Attachments: Secondary Window Market Characterization. 2020. https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Window-Program-Development-Research.pdf
Lack of Product Differentiation	Secondary window providers do not consistently distinguish between low-E storm windows and secondary glazing system products.	Commercial Window Attachments: Secondary Window Market Characterization. 2020. https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Window-Program-Development-Research.pdf
Lack of Available Information, Resources/Training	Many glaziers (i.e., installers or contractors) had concerns regarding the cleaning requirements, time on task, and whether the process required any special training. Although installation of CSW is relatively quick and easy, few options for learning and gathering information exist, aside from manufacturer demonstrations. This perpetuates the general lack of awareness regarding CSW.	Commercial Secondary Window Program Development Research. 2021. https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Window-Program-Development-Research.pdf
Uncertainty of EUL/Performance	Questions persist regarding the service life of VIG, including durability in various climates and the equipment needed to evaluate and test their performance; concerns about condensation also persist.	Lawrence Berkeley National Laboratory. 2023. "VIG Summit." https://drive.google.com/file/d/1ukXOH8bnzaF6kRiqm292weYReF9sxKEa/view
First Cost/Low Risk	New products—those in early stages of product maturity or those that are less common—often come with a level of uncertainty; decision makers often avoid uncertainty and risk in favor of a business-as-usual approach.	High-Performance Façades. 2024. https://www.facadetectonics.org/download/cudfdakogthxeaxihcsztdmahfstvmuuzcnp

Barrier	Description	Source
HVAC Design Focus	Most projects are driven by HVAC designers and advocates who play a larger and more pronounced role earlier in the planning process than façade/window designers who tend to be consulted at later phases of a project.	High-Performance Façades. 2024. https://www.facadetectonics.org/download/cudfdakogthxeaxihcsztdmahfstvmuuzcnp
Flexible Building Codes	Old building codes allow for buildings' performance targets to be addressed through various means (e.g., lighting, HVAC) with no enforcement of window performance specifically. New codes in CA (Title 24) have attempted to address this; however, implementation may take some time.	Commercial Windows Market Study and Measure Package Development. 2024. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf
Lack of Incentives	Expanding incentive programs, in addition to promoting the benefits of secondary windows, could increase market interest, but few programs currently exist to help building owners offset costs.	Commercial Windows Market Study and Measure Package Development. 2024. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf

2 Introduction and target market

VIG is a type of insulated glass that consists of two glass panes separated by a vacuum-sealed space. Unlike standard double-glazed windows, which use air or inert gases between panes, the vacuum barrier in VIG reduces heat transfer, providing much higher thermal insulation—up to five times that of conventional double glazing. This design substantially improves energy efficiency and indoor comfort. VIG's slim profile makes it versatile for a wide range of architectural applications. VIG also minimizes condensation, prevents moisture buildup, and provides better soundproofing compared to standard double-glazed units.

CSWs offer a cost-effective solution for commercial buildings with outdated or inefficient windows. Instead of full window replacement, secondary windows provide a simpler upgrade that can reduce heating and cooling energy use by up to 20%. Depending on the product and application, they can cost up to 90% less than replacing the entire window system.

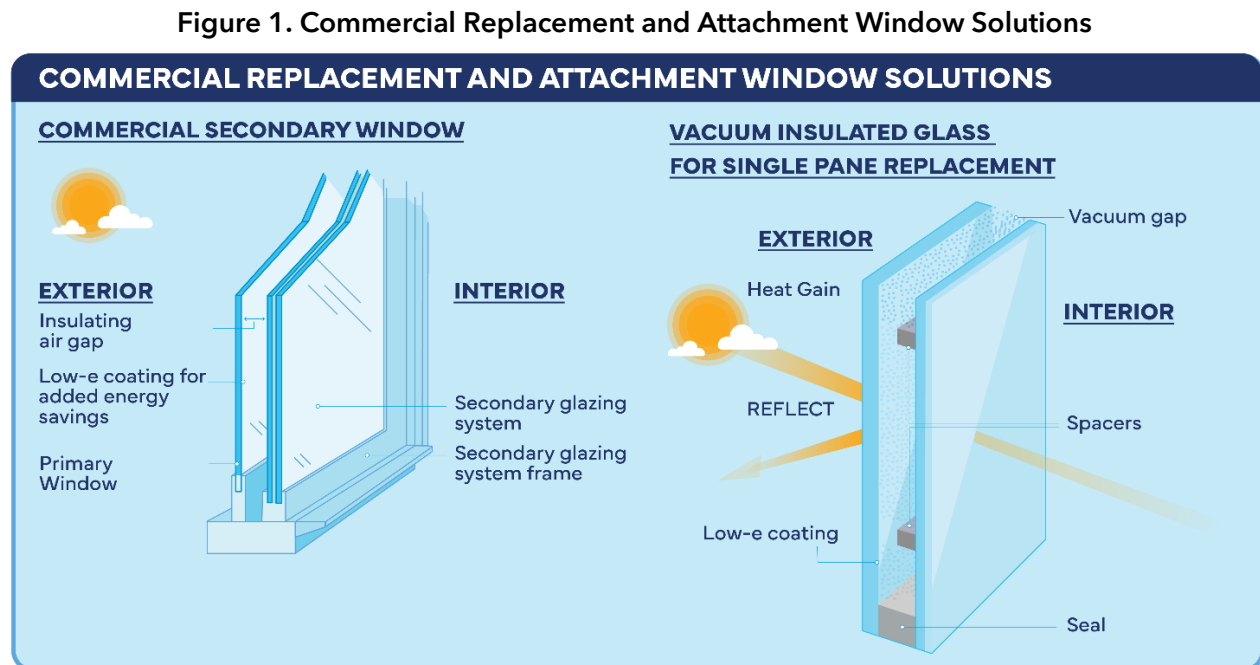
2.1 Product definitions

The product definitions from the advancement plan for this MTI have remained unchanged:



- **Commercial Secondary Windows (CSW)** in this context are attached to the interior or exterior of an existing window, creating an insulating air pocket between the new and existing panes. CSW can have one or more panes and low-E coatings; multiple panes can have insulating gases or a vacuum between the two CSW panes, creating additional insulating value.
- **Vacuum-Insulated Glass (VIG)** units replace existing single-pane windows while retaining use of the existing frame. The units are composed of two glass panes separated by spacers and hermetically sealed around the edges. Vacuum drawn on the void space between glass panes results in an R-10 to R-15 insulating value of the glass unit (R-5 to R-10 for the complete installed assembly).

Figure 1. Commercial Replacement and Attachment Window Solutions shows a simplified rendering of CSW and VIG.



Source: CalMTA, 2025.

2.2 Target market

The target market for this MTI is commercial buildings constructed before 2000 that still have single-pane windows or double-pane clear windows. Since the State of California did not

mandate double-pane windows until 2000, many of these buildings retain single-pane windows, which are a key target for decarbonization efforts.³⁶

In this research, CalMTA focused on specific segments of the commercial market. The team made this decision because owner-occupied buildings tend to have a longer ownership horizon and a stronger business case for efficient window investments than do commercial real estate properties where occupants or renters generally pay for utilities. As a result, CalMTA identified the municipal, university, school, and healthcare markets as the first likely target.^{37,38} The team also included hospitality and historic buildings in the research because VIG and CSWs offer these buildings substantial non-energy benefits, such as soundproofing and comfort improvements.

3 Methodology

3.1 Secondary research and literature review sources

CalMTA completed a literature review of published research and analyzed available secondary data pertaining to baseline and advanced window technology. Specifically, the team utilized the U.S. Census and the United States Energy Information Agency's (EIA) CBECS 2018,³⁹ the National Laboratory of the Rockies's (NLR), formerly known as the National Renewable Energy Laboratory (NREL), ComStock tool,⁴⁰ and the California Energy Commission's (CEC) CEUS to gain insights into window saturation levels, building stock characteristics, and other insights relevant to commercial buildings in California.⁴¹

CalMTA also reviewed publicly available technical market research documents and conducted searches using tools such as Google Scholar, Semantic Scholar, and Science.gov on window technologies, adoption rates, manufacturer priorities, and end-user behavior.

³⁶ Eley, C. and B. Pennington. 2002. *Requiring High Performance Windows in California*. Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy. https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel4_Paper09.pdf

³⁷ CBECS 2018 was used as one of the data sources. municipal buildings are categorized under offices in CBECS segmentation. Municipal buildings are a part of this analysis but are segmented under offices because of the above data classification issue.

³⁸ During the research phase, CalMTA found that the EIA's Commercial Buildings Energy Consumption Survey (CBECS) categorizes municipal buildings as "offices." Since this data serves as the primary source for estimating square footage and building energy characteristics in California, CalMTA included municipal buildings within the "offices" market segment in this report

³⁹ U.S. Energy Information Administration. 2022. 2018 Commercial Buildings Energy Consumption Survey: Building Characteristics. <https://www.eia.gov/consumption/commercial/data/2018/>

⁴⁰ National Renewable Energy Laboratory. 2024. ComStock. <https://comstock.nrel.gov/>

⁴¹ California Energy Commission. 2022. California Commercial End-Use Survey. <https://www.energy.ca.gov/data-reports/surveys/california-commercial-end-use-survey>

3.1.1 NLR ComStock (2018)

ComStock was the primary dataset for this analysis (baseline year 2018), based on the bottom-up model that uses multiple data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual energy consumption of the commercial building stock across the United States. ComStock's baseline represents the U.S. commercial building stock as it existed in 2018. This dataset is particularly valuable for its detail, including approximately 40,000 building models created specifically for California.

A key consideration when using ComStock is that it represents around 75% of the commercial floor space and does not include some key building types such as grocery stores and colleges/universities, among others.⁴²

For the baseline building configurations, ComStock utilizes four key input properties to define the windows: the number of panes (single, double, or triple), the glazing type (clear, tinted, or reflective), the frame material (wood, aluminum, or thermally broken aluminum),⁴³ and the presence or absence of a low-E coating. These properties are important because of their influence on window energy performance and the availability of data for modeling.

In addition to these descriptive characteristics, ComStock provides simulated output data that quantifies the energy-related performance of the windows. These simulated metrics include the average window solar heat gain coefficient (SHGC), which measures how much of the sun's heat is transmitted through the window (0 to 1; lower SHGC is better for reducing heat gain); the average window U-value, which indicates the rate of heat transfer through the window (measured in Btu per square foot per degree Fahrenheit per hour [Btu/sq ft/°F/hr]; lower U-value means better insulation); and the average window visible light transmittance, which represents how much visible light passes through the window (0 to 1; higher transmittance means more natural light). These simulated values offer insights into the thermal and optical performance of the modeled window systems.

3.1.2 EIA 2018 commercial building energy consumption survey (CBECS)

CBECS is a national sample survey that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures).⁴⁴ CBECS serves as a primary data source for building types and

⁴² National Renewable Energy Laboratory. 2024. ComStock Reference Documentation. <https://docs.nrel.gov/docs/fy25osti/92766.pdf>

⁴³ Thermal break technology involves inserting non-conductive materials between conductive elements within a window frame. While materials like aluminum are commonly used in windows for their strength and sleek appearance, they also conduct heat very efficiently. In conventional window frames, this allows heat to pass through easily, resulting in substantial energy loss. Please see for detail [Window Types and Technologies | Department of Energy](#)

⁴⁴ U.S. Bureau of Economic Analysis. 2024. GDP by State: <https://www.bea.gov/data/gdp/gdp-state>.

characteristics that are not fully represented in the ComStock dataset. CalMTA leveraged data from CBECS to estimate the commercial floor space in California.

CalMTA did not use CBECS as the sole primary dataset for assessing the entire California commercial sector for this study for two main reasons. First, the published data is typically representative at the broader Pacific Census Division level, which includes Alaska, California, Hawaii, Oregon, and Washington. Although California represents approximately 75% of this division in terms of both GDP and population, the data is not exclusively focused on California. Second, the sample size for the Pacific Census Division in the 2018 CBECS is relatively small, consisting of 828 observations.

CBECS collects information primarily through surveys and provides a different set of window characteristics than those in ComStock. Based on survey responses, CBECS includes variables such as window glass type (which relates to the number of panes and is categorized as single-layer glass, multilayer glass, combination of both, or no windows), whether the building has tinted window glass (yes/no), and whether it has reflective window glass (yes/no). CBECS also captures information on the window-to-wall ratio (WWR) by asking respondents to select a range that best describes the "percentage of the exterior wall surface of this building that is covered with window glass or glass doors." CBECS does not provide metrics for thermal and optical performance (such as U-value or SHGC). This distinction is important to note when utilizing the datasets for detailed analysis of window performance and its impact on energy use.

3.1.3 California commercial end use survey (CEUS) California Energy Commission 2022

The 2022 California CEUS provided the most recent data used in this report. The survey collected data from over 24,000 commercial facilities in California, primarily through rigorous on-site surveys and inspections. Based on the survey instrumentation and data collection methodology, the level of detail captured by CEUS is considerably greater than that available in CBECS. Furthermore, the sampling strategy employed for CEUS allows representative analysis at the service territory level for the five largest electric utilities in California, offering valuable localized insights.

Conducted in 2022, CEUS provides a more up-to-date snapshot of the commercial building stock and energy use in California than the 2018 ComStock and CBECS data. However, the full dataset is not publicly accessible; only summary statistics are available. Additionally, detailed information specifically pertaining to windows from the 2022 CEUS has not yet been publicly released. Nevertheless, this analysis includes a summary of floor space information from CEUS to provide a point of comparison, highlight differences between ComStock and CEUS, and engender discussion about the suitability of modifying ComStock data to match CEUS.

3.2 Stakeholder and market actor interviews

To gain a comprehensive understanding of the CSW and VIG market, CalMTA conducted in-depth interviews with a diverse group of stakeholders, including manufacturers, installers, ESCOs, building owners and managers, and tenants.



3.2.1 Manufacturer, ESCO, and installer interviews

CalMTA conducted interviews with CSW and VIG manufacturers, as well as ESCOs who work with CSW and VIG, to understand market trends, costs and benefits, and perceptions of market barriers and opportunities. The team gathered contact information via personal relationships and knowledge, as well as secondary internet research and consultation with CalMTA's Equity Sounding Board. The Equity Sounding Board consists of a group of eight professionals who work with or in environmental and social justice communities and provide insight regarding market transformation initiatives. Between April and June 2025, CalMTA conducted in-depth interviews with six manufacturers, two installers, and five ESCOs. The interview guides are included in Attachment C.

CalMTA interviewed employees from six manufacturers of CSW and VIG technologies. Table 4 lists key firmographic indicators for the firms interviewed.

Five of six manufacturers were engaged in research and development and conducted market assessment and marketing activities. Four of six manufacturers engaged with technology deployment activities, including the manufacturer that did not conduct either research and development or market assessment.

Table 4. Manufacturer Firmographics

Interviewee Title	Solutions Manufactured	Location of Manufacturing Facilities	Number of Employees
Founder & CEO	CSW	Portland, OR	35
Founder & CEO	VIG	Detroit, MI	1 (plus 2 contractors)
President	CSW	Lewisville, CO and Pittsburgh, PA	200
Founder & CEO	VIG	Waukesha, WI ^a	6
President	CSW	Houston, TX	10
Vice President	CSW	Cincinnati, OH	45

Source: CalMTA Manufacturer Interviews (n=6)

^a: This manufacturer has a laboratory facility in Waukesha. They are in the process of building a production facility elsewhere in Wisconsin, though they declined to give a specific location.

CalMTA interviewed representatives of five ESCOs. Table 5 lists key firmographic indicators for the firms interviewed.

ESCOs interviewed serve a diverse pool of clients in the industrial, municipal, commercial, education, and healthcare sectors. This pattern held regardless of company size, with both small and large ESCOs working across a wide variety of building types.

Table 5. ESCO Firmographics

Interviewee Title	Sector(s) Served	Locations Served	Number of Employees
President & Founder	Industrial, municipal, commercial, education, healthcare	CA, NV, AZ	60
Co-Founder & CEO	Commercial, industrial, education, healthcare	Nationwide; heavy presence in NY	1,200
COO	Education, municipal, healthcare, commercial	WA	2,100
Senior Project Manager	Education, municipal, healthcare	Nationwide; heavy presence in the Northwest and East Coast	2,000
Senior VP	Commercial, industrial, residential	Nationwide/international	55

Source: ESCO interviews (n = 5)

CalMTA interviewed owners of two commercial window installers representing the construction and window industries in California, as summarized in Table 6. Both businesses operated in the Bay Area within PG&E's service territory. Given the small sample size, insights from installer interviews are not reported.

Table 6. Installer Firmographics

Interviewee Title	Sector(s) Served	Location of Installations	Number of Employees
Owner	Commercial, Residential	Bay Area, CA	2; hires additional contractors for large jobs
Owner	Commercial	Bay Area, CA	35

3.2.2 Building owner and manager interviews

CalMTA conducted interviews with owners, property managers, and facilities managers of commercial buildings, with a focus on municipalities, universities, schools, and hospitals. The goal of these interviews was to understand the priorities and behaviors of decision makers regarding the window stock in their buildings, their knowledge and perceptions of CSW and VIG technologies, any tools or resources they use when planning window replacements or upgrades, and their knowledge of and participation in incentive programs meant to defray the cost of conducting window replacements or upgrades. Between February and June 2025, CalMTA completed eight in-depth interviews with owners and property managers of commercial buildings in the university, primary/secondary school, and healthcare sectors.

The research team conducted multiple rounds of outreach to municipal building managers. However, response rates were low. Additionally, it was difficult to identify individuals with the appropriate knowledge and authority to speak about plans for building envelope upgrades in municipal buildings.

Table 7 lists key firmographic indicators for these respondents.

Table 7. Building Owners and Managers Firmographics

Interviewee Title	Industry	Number of Buildings	Age of Building (estimated)	Sq Ft (estimated range)	Percentage Single Pane
Director of Facilities Management	Hospital	5	Don't know	3,000-18,000	10%*
Executive Director	Office	2	2000 and 2020	50,000 and 80,000	0%*
CEO	Hospital	3	1970-1980	Don't know	Don't know
Project Manager, Social Impact	Hospital	75	1970s and 2000s	Don't know	50%
Facilities Director	University	3	1950s	13,000-24,000	100%
Executive Director	Schools	6	2000	Don't know	100%
Director of Safety and Transportation	University	20	1920s, 1940s, new construction	Don't know	75%
Energy and Sustainability Manager	Schools	72	Don't know	Don't know	100%

Source: CalMTA Building Owner/Manager interviews (n=8).

Data provided for age of building, square footage, and percentage of single-pane windows are estimates.

*Indicates that buildings have recently undergone window replacement.

3.2.3 Commercial tenant interviews

CalMTA conducted interviews with tenants of commercial buildings to understand how (if at all) they engage with the window replacement or upgrade decision-making process, their familiarity with CSW and VIG technologies, and the level of influence they have on window replacement or upgrade decisions. Between April and June 2025, CalMTA conducted six in-depth interviews with tenants of commercial buildings. Table 8 lists key firmographic indicators for these tenants.

Commercial tenant demographics and characteristics varied across industries, roles, and business sizes. Interviewed tenants were in predominantly older, multi-tenant buildings constructed between the 1880s and 1980s. Tenants reported annual revenues for their businesses that range from \$300,000 to \$3 million, with most tenants occupying leadership roles such as owner, executive director, or manager. All interviewees shared their buildings with other businesses.

Table 8. Commercial Tenant Firmographics

Interviewee Title	Industry	Annual Revenue	Age of Building	Owns Building?	Number of Employees
Manager	Education	Don't know	10 to 20 years old	No	5
Owner/dance instructor	Fitness	Don't know	1880	No	6



CRAWS Market Characterization Report

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

Owner	Health and Wellness	\$300,000	1980s	No	3
Director of HR and Operations	Staffing	\$3 million	1970s	No	11
Executive Director	Fitness	\$600,000	1980	No	14
Executive Director	Nonprofit	\$2 million	1960s	No	20

Source: CalMTA commercial tenant interviews (n=6)

3.3 Building owner/manager survey

CalMTA surveyed a sample of building owners and property managers representing the targeted segments in California to gain an understanding of the factors that influence window upgrade decision making, awareness of and willingness to switch to efficient window solutions, and barriers that inhibit widespread adoption of efficient window solutions in the state. The survey instrument is included in Attachment C.

3.3.1 Survey Sampling Plan

CalMTA fielded the survey from May 19, 2025, to June 23, 2025, targeting owners and facility managers of commercial buildings in the targeted segments in California that met at least one of the following criteria:

- Building built before the year 2000
- Contains single-pane windows
- Contains double-pane windows without a low-E coating

CalMTA terminated the survey for building owners representing buildings that did not meet any of the above criteria.

The survey team used Qualtrics' sample services to recruit participants, drawing from a network of over 20 online panel providers. Respondents were randomly invited to participate based on screening criteria designed to ensure alignment with the study's target population. Qualtrics applied standard data quality protocols, including exclusions based on participation frequency and respondent category eligibility, to minimize response bias and ensure data integrity.

The team recruited participants using Computer-Assisted Telephone Interviewing (CATI) and completed the survey by phone. Interviewers screened respondents to ensure that they met the qualification criteria and then administered the full survey during the same call. This approach helped ensure high response quality and allowed for clarification of any complex or technical questions during the interview process. Qualtrics provided incentives to respondents upon completion.



The team completed a total of 114 surveys. To ensure representation across key commercial building types, the team applied quotas across five building types: office, healthcare, non-university school, college, and lodging. In addition to the 114 completed surveys by building type, the team also conducted surveys across “other” building types and ensured representation within the sample for all electric utility providers, including Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric Company (SDG&E).

The team designed the sampling plan to achieve 85% confidence with $\pm 15\%$ precision at the stratum level (by building type and utility, excluding “other”).

3.3.2 Survey weighting approach

CalMTA developed the survey sample frame focusing on specific building segments, including college/university, healthcare, lodging, offices,⁴⁵ and schools (non-college/university). The building types the team excluded from detailed analysis represent approximately 63% of the state’s total commercial floor space. For example, the analysis excluded warehouses.⁴⁶ Table 9 shows that the five included building types account for approximately 3,284 million sq ft of commercial floor space.⁴⁷

Table 9 California Commercial Floor Space

Building Type	Sq ft (in Millions)
College/university	174 ⁴⁸
Healthcare	427
Lodging	342

⁴⁵ CBEC was used as one of the data sources. Municipal buildings are categorized under offices in CBEC segmentation. Municipal buildings are a part of this analysis but are segmented under offices because of the above data classification issue. <https://www.eia.gov/consumption/commercial/building-type-definitions.php#Office>

⁴⁶ Warehouses (both conditioned and unconditioned) were excluded from the market characterization and target market due to the low window area and low potential for energy savings. The window to wall ratio for warehouses is very low, thus minimizing the potential energy impact of window improvements compared to the opaque building envelope. Accurate information on the exact window to wall ratio for warehouses, but the DOE prototype model has a window to wall ratio of 0.7% [NR Report] representing an estimate of national building stock. In addition, warehouses only represent 0.7% of the commercial building window stock by area in California, [Market Study] making it a less substantial market segment for our window MTI. The low energy use intensity of warehouses also limits the potential energy savings. Storage (0.9 kWh/ft²), unconditioned warehouse (2.6 kWh/ft²), and conditioned warehouses (4.9 kWh/ft²), represent the lowest energy use intensity of all of the building types in the California Commercial Saturation Survey, [Commercial saturation study] compared to an average of 10.2 kWh/ft².

⁴⁷ U.S. Energy Information Administration. 2024. *Commercial Buildings Energy Consumption Survey: Building Type Definitions*. <https://www.eia.gov/consumption/commercial/building-type-definitions.php#Office>

⁴⁸ We used college/university and others category from CBEC 2018 to fill data gaps in this analysis. Therefore, numbers in Tables 4 and 5 will not align by simple calculation.

Office	1,314
School (non-College/university)	1,028
Subtotal	3,284
Other ⁴⁹	5,681
Total floor space	8,965

Note: Primary source is NLR ComStock 2024. For College/university we used CBECS 2018 scaled by 75% to match the GDP of California in the Pacific West. Results rounded to the nearest percentage.

To account for differences in targeted population square footage by commercial building types, the team weighted survey results using a targeted population total over sample total approach, deriving sample totals from the survey data. The targeted population only includes the building types that are outlined in Table 9. The survey results are normalized to the targeted population of market segments by building type in California's building stock. This weighting approach ensured that findings accurately reflected the perspectives of decision makers responsible for smaller properties within a sample building type as well as targeted population building types comprising a larger share of total square footage. The survey responses represent the square footage of the buildings owned or managed by the respondents. The sample approach (summarized in Tables 10, 11, and 12) ensured that each analysis aligned with the intended unit of measurement and yielded meaningful insights by building type, attributable to the target population and across the broader market. Details about the weighting methodology are provided in 0.

Table 10. Achieved Sample by Utility and Building Type

Building Type	PG&E	SDG&E	SCE	Others	Total
College	5	3	12	4	24
Healthcare	2	3	16	2	23
Lodging	12	2	4	5	23
Office	11	3	4	3	21
School	13	1	5	4	23
Total	43	12	41	18	114

Source: CalMTA CRAWs Building Owner and Property Manager Survey Q A8 "Which electric utility provides your power at the buildings you own/manage?" and Q B1 "Which of the following types of buildings do you currently own or manage? Please select all that apply." (n=114)

Table 11. Achieved Sample by Role and Building Size (in sq ft)

Square Footage	Property/Facility Manager	Building Owner	Total
0 - 10,000	3		3

⁴⁹ Weighting excluded the 'Other' category.

Square Footage	Property/Facility Manager	Building Owner	Total
10,001 - 25,000	12	12	24
25,001 - 50,000	38	8	46
Over 50,000	39	2	41
Total	92	22	114

Source: CalMTA CRAWs Building Owner and Property Manager Survey Q A2 "What is the most appropriate description of your role? Select all that apply." Q B2 "What is the approximate total square footage of your [TYPE] buildings?" (n=114)

Table 12. Achieved Sample by Region and ESJ Status

ESJ Status	Coastal	Inland	Total
ESJ	3	16	19
Non-ESJ	57	38	95
Total	60	54	114

Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B2 "Please list the ZIP codes where your [TYPE] buildings are located." (n=114)

4 California window characteristics

CalMTA conducted an analysis using data from primary and secondary sources to characterize the California market for windows, as well as the current saturation and market shares of CSW and VIG. This section presents the analysis of findings.

4.1 Total commercial floor space in California

To estimate the market saturation of windows, CalMTA first developed an estimate of the total commercial floor space in California using three primary data sources: the 2018 CBECS, NLR's ComStock 2024, and the 2022 California CEUS. Table 13 presents a summary of the estimated floor space by building type group and specific building type. Table 13 also identifies building types not covered by the ComStock model.

Table 13. Total Commercial Floor Space in California by Data Source (Million Sq ft)

Building Type Group	Building Type	ComStock	2018 CBECS	2022 CEUS
Education	Schools	1,028	861	686
	College	Not covered	174	384
Retail	Food/Grocery	Not covered	88	242
Healthcare	Healthcare	427	461	480
Lodging	Hotels	342	466	472
	Dorms and Other Lodging	Not covered	157	NA
Office	Office	1,314	1,574	2,093



Building Type Group	Building Type	ComStock	2018 CBECS	2022 CEUS
Food Service	Food Service	162	146	224
Retail	Strip and Standalone Malls	984	818	1,126
	Enclosed Malls	Not covered	77	-
Warehouse	Warehouse	2,220	2,220	1,398
Survey Sample Total*	Covered in sample	3,110	3,284 ⁵⁰	
Others	Others	Not covered	1,993 ⁵¹	1,704
Total		6,477	9,033	8,809

Source: NLR ComStock 2018, EIA CBECS 2018, CA CEUS

Note: The "others" category includes laboratories, nursing homes, post offices, vacant buildings, and public order buildings for CBECS, and miscellaneous buildings for CEUS. CBECS data is available for Pacific Census division, which includes states of Alaska, Hawaii, Oregon, Washington, and California. We have scaled the data by 75% to more closely approximate CA data. The CBEC microdata was weighted using the weights provided in the microdata. ComStock figures were also weighted using their own weights provided in the microdata. CEUS numbers reported in the above table represents aggregates that were weighted.

*Subtotal reflects the sum of building types included in the survey sample and aligned across ComStock, CBECS, and CEUS for comparability. "Others" categories are excluded from the subtotal.

As shown in Table 13, there are considerable differences in the estimated floor space of building types across the three datasets. Offices and warehouses exhibited the largest discrepancies in reported floor space between ComStock and CEUS data. For office buildings, ComStock reports 1,314 million sq ft, while CEUS estimates a substantially larger 2,093 million sq ft, a difference of approximately 779 million sq ft. Conversely, for warehouses, ComStock shows 2,220 million sq ft, whereas CEUS reports 1,398 million sq ft, a difference of about 822 million sq ft.

A portion of these substantial differences can be attributed to variations in the sampling strategies and data collection methodologies employed by each survey. For instance, ComStock's reference documentation states, "Warehouses, representing distribution centers, light manufacturing, showroom and truck terminal spaces, encompass a large number of functions including office spaces. However, ComStock does not disambiguate these spaces."⁵² This suggests that a single building classified as a "warehouse" in ComStock may include substantial office areas that are not separately categorized. On the other hand, CEUS seeks to identify the function of mixed-use spaces by asking respondents to specify the percentage of the building allocated to different

⁵⁰ This was the total used for sample weighting (3,110+174=3,284). Please see Table 9 for details.

⁵¹ For CBECS, the key sub-categories included in 'Others' are Public Assembly (686 million sq ft), Religious buildings (397 million sq ft), Vehicle Servicing and Storage (373 million sq ft) and Vacant buildings (135 million sq ft).

⁵² National Renewable Energy Laboratory. 2025. ComStock Reference Documentation: 2024 Release 2

functions. Given this variance, we leverage publicly available data sources to develop a comprehensive understanding of the California market and address existing data gaps.

4.2 Commercial floor space by window type

This section provides a detailed characterization of commercial floor space in California based on key window attributes. CalMTA examined the distribution of floor space by the number of panes per glazing unit, comparing findings from the review of ComStock and CBECS data. Next, CalMTA reviewed the types of window frames prevalent in the commercial sector, highlighting their correlation with pane configurations and analyzing the presence and absence of low-E coatings across the window stock. The team also surveyed owners and managers of commercial buildings in California. The sample was representative of the segments identified in the target market. For further details on survey firmographics, see Section 3, Methodology, of this report.

4.2.1 Number of panes

To evaluate the consistency and coverage of window characteristics across datasets, Table 14 compares total commercial floor space by windowpane and glass type for building types common to both ComStock and CBECS. This approach enabled direct assessment of the window characteristics captured by each source, while minimizing any differences arising from variations in building type coverage.

As shown in Table 14, a comparison of matching building types in ComStock and CBECS shows discernible differences in the reported distribution of windowpane characteristics, which also reflects the distinct methodologies of the two data sources. The ComStock data, derived from detailed building energy models informed by various data sources, categorizes windows primarily by number of panes: single, double, and a small percentage of triple. The filtered subset of matching building types shows that single-pane windows account for the largest share of floor space at 52%, followed closely by double-pane windows at 48%. Triple-pane windows represent a marginal proportion of windows, rounding to 0%.

The filtered CBECS data shows a different distribution of glass type. Multilayer glass is the largest category at 46% of the filtered floor space, aligning closely with the combined proportion of double-pane windows in ComStock (48%). However, the distribution of single-layer glazing differs more substantially. Single-layer glass accounts for 27% of the filtered CBECS floor space (compared to 52% in ComStock); however, unlike ComStock, CBECS contains a notable additional category: "Combination of both," representing 20% (1,307 million sq ft). This category likely captures buildings in which both single-layer and multilayer windows are present, a condition that might arise from partial window upgrades in buildings originally constructed with single-pane windows.

Table 14. Comparison of Commercial Floor space by Windowpane/Glass Type California

Glass Type	ComStock		2018 CBECS	
	Million Sq ft	Proportion	Million Sq ft	Proportion
Single-Pane/Single-Layer	3,355	52%	1,786	27%



Glass Type	ComStock		2018 CBECS	
	Million Sq ft	Proportion	Million Sq ft	Proportion
Double-Pane/Multilayer - No Low-E Coating	1,374	48%	3,032	46%
Double-Pane/Multilayer - Low-E Coating	1,735			
Triple-Pane/Multilayer	13	0%	N/A	N/A
Combination of Both	N/A	N/A	1,307	20%
No Windows	N/A	N/A	419	6%
Total	6,477	100%	6,545	100%

Source: NLR ComStock 2018 (filtered), EIA CBECS 2018 (filtered to only consider building types covered in ComStock).

Note: ComStock data distinguishes by the number of panes based on modeled inputs. CBECS uses survey categories for glass types based on respondent reports and does not distinguish between double-pane/multilayer clear and low-E coating glass types. The total floor space for which glass type data is available for matching building types in CBECS is 7,037 million sq ft, which is the sum of the pane distribution counts for the filtered building types. This is slightly less than the total floor space reported for these types (7,240 million sq ft) in the original source data, indicating some floor space with an unreported glass type.

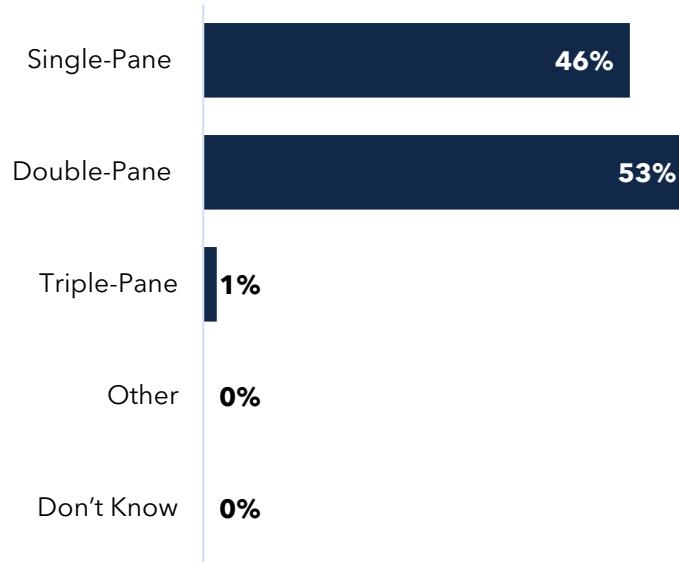
Note: Percentages may not sum to 100% due to rounding.

These variations underscore that while both datasets provide valuable insights into California's commercial window stock, the nature and precision of the information available for detailed analysis differ due to the distinct methodologies of modeled inputs versus surveyed responses regarding building characteristics.

CalMTA's survey also asked respondents about the distribution of different windows currently installed in all the buildings they own or manage, to characterize the baseline saturation of windows in California. As shown in Figure 2, respondents reported that 46% of the windows across their buildings are single-pane and 53% are double-pane. Triple-pane windows account for only 1% of windows, while other types account for approximately 0%. These proportions are consistent with those calculated using ComStock data (Table 14).



Figure 2. Average Distribution of Window Types Reported by Respondents



Source: CalMTA CRAWs Building Owner and Property Manager Survey QB3: "Please estimate the percentage of each type of window that is installed across all the buildings you own or manage. Each row should sum to 100%." (n=114). Results rounded to the nearest percentage.

4.2.2 Frame type and low-E coatings

CalMTA examined the distribution of windowpane types by frame material and the presence of low-E coatings to further characterize ComStock's window stock data.

Table 15 provides the distribution of floor space by windowpane type and frame material. A substantial portion of single-pane windows, comprising 2,604 million sq ft, have aluminum frames, while wood frames are exclusively associated with single-pane windows (751 million sq ft). Double-pane windows are more diverse and are associated with both aluminum (1,661 million sq ft) and thermally broken aluminum frames (1,449 million sq ft). From an energy performance perspective, thermally broken aluminum frames offer superior insulation properties compared to standard aluminum frames by reducing heat transfer through the frame material itself.

Table 15. ComStock Floor Space by Windowpane and Frame Material (million sq ft), California

	Single	Double	Triple	Total
Aluminum	2,604	1,661	-	4,264
Thermally Broken Aluminum	-	1,449	13	1,461
Wood	751	-	-	751
Total	3,355	3,110	13	6,476

Source: ComStock (2018)

Note: Some totals may vary slightly due to rounding or inherent dataset aggregation.



Low-E windows utilize a transparent coating that blocks infrared radiation, helping to keep heat outside during warm weather and inside during cold weather. The market penetration of these energy-efficient technologies has grown substantially. For instance, in the United States, windows incorporating low-E coatings had achieved greater than 80% market share in the residential sector and more than 50% in the commercial sector by 2017.⁵³

CalMTA's analysis of ComStock data shows that windows with low-E coatings are exclusively multi-pane; approximately 56% (1,735 million sq ft of floorspace) of double-pane windows are equipped with a low-E coating. All single-pane windows, totaling 3,355 million sq ft of floor space, do not have low-E coating.

Table 16. Commercial Floorspace by Number of Panes and Low-E Coating, California

	Single	Double	Triple	Total
Low-E Coating	-	1,735	13	1,748
No Low-E Coating	3,355	1,374	-	4,729
Total	3,335	3,109	13	6,477

Source: ComStock (2018)

Note: Some totals may vary slightly due to rounding or inherent dataset aggregation.

4.2.3 Window characteristics by building vintage

CalMTA's analysis of the ComStock dataset highlights substantial changes in window characteristics across building vintages, reflecting evolving construction practices and growing emphasis on energy efficiency over time. Table 17 presents the window characteristics for commercial buildings according to ComStock, disaggregated by construction vintage. Specifically, the percentages within each row illustrate the proportion of that vintage's total commercial floor space that features a given number of panes, type of frame material, or the presence of a low-E coating. The final column indicates total commercial floor space for each building vintage, which serves as the basis for these percentage distributions. Approximately 56% of the floor space in the ComStock dataset is more than 45 years old (representing buildings constructed before 1980).

⁵³ U.S. Department of Energy. 2015. EERE Success Story—Energy-Efficient Smart Windows are Lowering Energy Costs. <https://www.energy.gov/eere/success-stories/articles/eere-success-story-energy-efficient-smart-windows-are-lowering-energy>

Table 17. ComStock Window Characteristics Across Building Vintage as a Percentage of Building Floor Space

Building Vintage	Number Of Panes		Frame Material			Low-E Coating		Total Million sq ft
	Single	Double & Triple	Aluminum	Thermally Broken Aluminum	Wood	Low-E	No Low-E	
Before 1980	58%	42%	71%	16%	13%	18%	82%	3,619
1980-2000	53%	47%	73%	15%	12%	24%	76%	2,145
After 2000	14%	86%	20%	77%	3%	80%	20%	712

Source: ComStock (2018)

Window characteristics, frames, and coating are further detailed below:

- Number of panes:** The data suggests a clear trend towards more thermally efficient multi-pane windows in newer commercial buildings. For structures built before 1980, most of the floor space (58%) has single-pane windows, while 42% has double- or triple-pane. This proportion shifts substantially in more recent construction. Buildings from 1980 to 2000 have a 53% share with single-pane and 47% with double- or triple-pane windows. The most striking difference occurs in buildings constructed after 2000, for which single-pane windows account for only 14% of the floor space, while double- and triple-pane windows represent 86%.
- Frame material:** A distinct evolution can be seen in the types of window frame materials used across building vintages. In older commercial buildings constructed before 1980, aluminum frames are most prevalent, accounting for 71% of the commercial floor space, followed by thermally broken aluminum at 16% and wood frames at 13%. The 1980 to 2000 vintage shows a similar distribution, with 73% aluminum, 15% thermally broken aluminum, and 12% wood. However, a substantial shift occurs in buildings constructed after 2000. For these newer structures, thermally broken aluminum frames dominate 77% of commercial floor space, while standard aluminum frames drop drastically to 20%, and wood frames comprise only 3%. This trend highlights the increasing adoption of more advanced and energy-efficient frame materials in modern building practices.
- Low-E coatings:** The penetration of low-E coatings also varies with building age. For commercial buildings constructed before 1980, only 18% of the floor space features low-E coated windows, with the vast majority (82%) lacking this technology.⁵⁴ Adoption rates rise substantially in the subsequent vintage, with 24% of floor space in 1980 to 2000 buildings having windows with low-E coatings, while 76% do not. For buildings constructed after 2000, 80% of the floor space includes windows with low-E coatings, and 20% does not. This overall

⁵⁴ Please note that this analysis reflects percentages of the total commercial building stock in California, including segments outside of the target market for this CalMTA report.

trend demonstrates a substantial increase in the incorporation of low-E technology into window systems in newer constructions compared to older ones, reflecting a growing awareness of and regulatory push towards improved thermal performance.

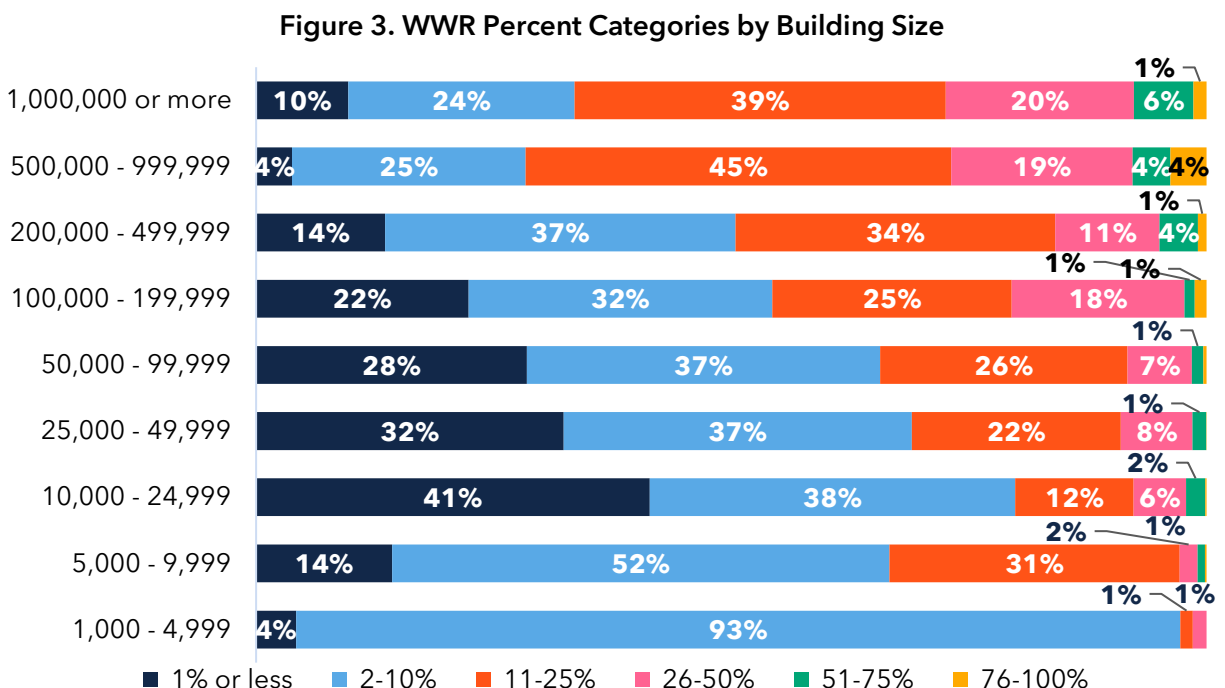
4.3 Window-to-wall ratio by building characteristic

This section provides a detailed characterization of the WWR in California based on key building attributes. The analysis includes the distribution of floor space by the WWR from ComStock data, followed by the relationship between WWR building vintage and building type.

4.3.1 Number of panes

Figure 3 presents a comparison of the WWR percentage bins by commercial floor space, binned into size categories presented in the ComStock dataset. Each bar represents 100% of the buildings in that size range; each colored block represents the proportion of buildings in that range with a given percentage of WWR.

WWR tends to decrease with building size. Approximately one-third of the largest buildings, those with over 500,000 sq ft, have WWRs of 10% or less. Among buildings between 100,000 and 500,000 sq ft, roughly half have WWRs of 10% or less. Whereas roughly two-thirds of buildings between 5,000 and 100,000 sq ft have WWRs of 10% or less. Buildings in the 10,000 to 25,000 sq ft range have the greatest share of buildings with WWRs of 1% or less, at approximately 40%. Among the smallest buildings, 97% have WWRs of 10% or less.



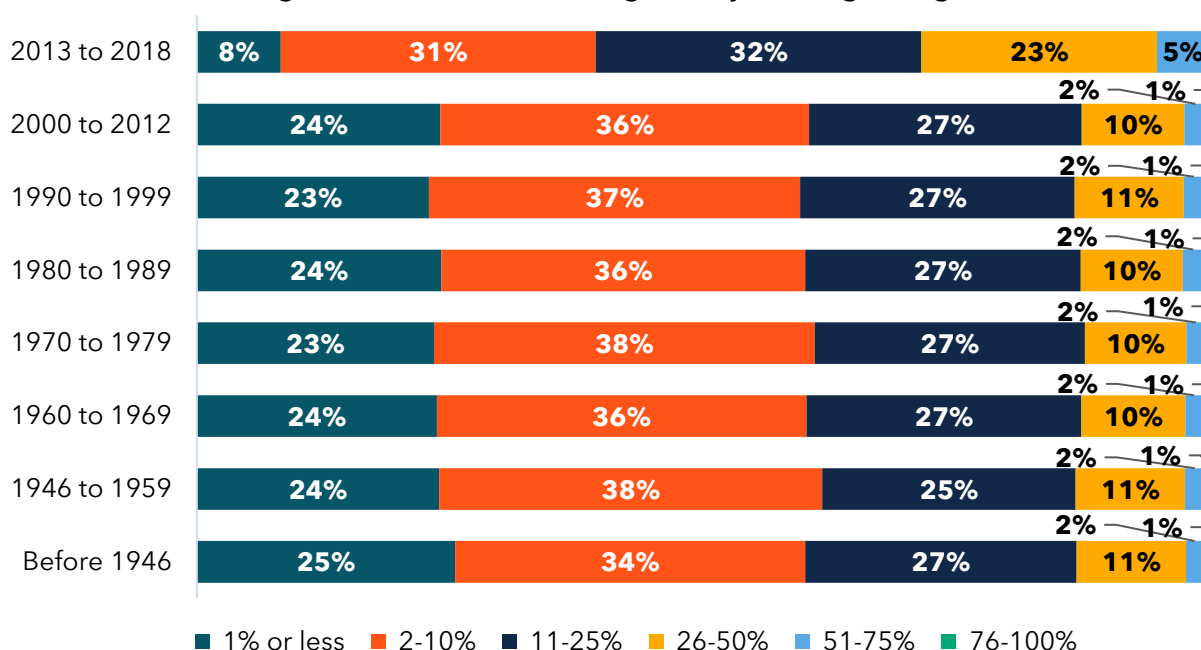
Source: ComStock 2018. Results rounded to the nearest percentage.



Figure 4 compares WWR percentage thresholds by building vintage, arranged into building vintage categories as presented in the ComStock dataset.

WWR distributions are similar across building vintages, with approximately 60% of buildings having WWRs of 10% or less. Only buildings constructed after 2013 show a clear difference, with just 40% having WWRs of 10% or less and a higher proportion falling into the 26% - 50% and 51% - 75% WWR ranges. Existing research indicates the reason for a shift to higher proportions of greater WWR percent ranges could be due to several factors, including design innovation for reduced energy consumption, improved indoor air quality, the rise of green building design to achieve certification, resiliency strategy to prevent premature structural aging, and occupant comfort - which can lead to improved productivity and overall well-being.⁵⁵

Figure 4. WWR Percent Categories by Building Vintage



Source: ComStock 2018. Results rounded to the nearest percentage.

Figure 5 compares WWR percentage bins by building type.

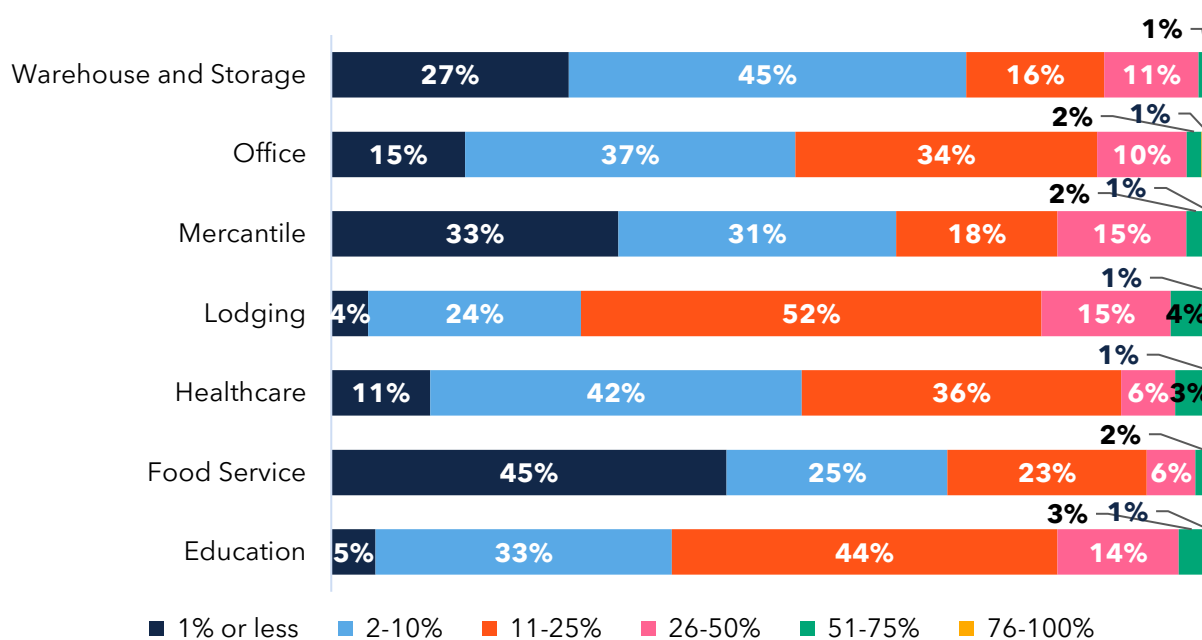
Warehouse and food service buildings have the highest proportion of structures with WWRs of 10% or less. Office and healthcare buildings show similar WWR distributions, with approximately half of the buildings in each category having WWRs of 10% or less. Nearly half of food service and one-third of mercantile buildings have a WWR of just 1%, the highest share among all building

⁵⁵ Fernandes, L., Harris, C., and Praprost, M., et. al. 2025. *Energy Impacts of Nationwide Window Upgrades in Commercial Buildings*. Lawrence Berkeley National Laboratory.
[Commercial window market report v2.05c luis fernandes 0.pdf](#)

types. In contrast, lodging and education buildings have the largest share of buildings with WWRs between 11% and 25% (but represent only about 1% of the overall building stock).

Warehouse and storage WWRs may skew high because ComStock data are not disambiguated for floor space within buildings with mixed use, particularly mixed office and warehouse buildings, as noted in the discussion in Section 4.1, Total commercial floor space in California.

Figure 5. WWR Percent Categories by Building Type Group



Source: ComStock 2018. Results rounded to the nearest percentage.

4.3.2 Window area by pane type

This section presents a comparison of window areas in California by windowpane type and building type group. The analysis looked at the distribution of floor space by pane type from ComStock data and the distribution of floor space by WWR and building type. Table 18 presents the distribution of single, double, and triple pane windows by building type.

Across all building types, slightly more than half of commercial floor space has single pane windows, with the remaining having double pane windows. Education and office buildings have the lowest share of single-pane windows, at 50% and 51%, respectively. Triple-pane windows represent a very small share of commercial floor space, with all categories of building having proportions of triple-pane windows that round to 0%.

Table 18. Percent of California Commercial Floor Space by Building Type and Number of Panes

Building Type	Single	Double	Triple	Total
Education	50%	50%	0%	100%
Retail	54%	46%	0%	100%
Healthcare	56%	44%	0%	100%
Lodging	54%	46%	0%	100%
Office	51%	49%	0%	100%

Source: NLR ComStock 2018.

Table 19 presents commercial floor space with single-, double-, and triple-pane windows by building type in millions of sq ft. Across all building types, single pane windows account for the largest share (130 million sq ft), followed by double pane windows,

Table 19. California Commercial Window Area (millions of sq ft) by Building Types and Number of Panes

Building Type	Single	Double	Triple	Total
Education	14	14	0	28
Retail	30	26	0	56
Healthcare	11	10	0	21
Lodging	11	8	0	19
Office	64	62	0	127
Total	130	120	0	251

Source: NLR ComStock 2018. Note: Values are rounded to the nearest million square feet. Totals may not sum exactly due to rounding.

Table 20 shows the annual HVAC energy use per square foot by building type and windowpane type.

HVAC energy intensity (expressed as kBtu/sq ft/year) generally decreases among most building types as the number of panes increases. The mean energy intensity for retail and healthcare buildings are exceptions, though the median energy intensity follows the same trend, suggesting some outlier buildings with high energy intensities.

Table 20. California Mean and Median HVAC Energy Intensity (KBTU/sq ft/year) by Commercial Building Type and Number of Panes

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Education	73.66	60.09	69.66	58.03	44.90	44.90	71.69	59.05
Retail	64.76	60.44	61.71	57.63	65.34	54.41	63.37	59.11
Healthcare	36.68	30.55	33.62	29.32	38.31	22.67	35.23	29.87
Lodging	13.84	10.10	13.58	10.04	6.21	6.21	13.71	10.05
Office	37.70	33.21	34.55	30.72	31.77	30.31	36.20	32.06
Food Service	132.23	118.24	131.10	118.58	117.31	95.48	131.65	118.49

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Warehouse	5.38	3.24	5.23	3.03	5.12	3.66	5.30	3.13
Overall	44.21	36.71	41.99	33.83	38.86	29.03	43.16	35.30

Source: NLR ComStock 2018

Further analysis of ComStock data (Table 21 and Table 22) separates results for windows with and without low-E coatings. CalMTA reviewed median energy intensity values for double pane windows between building types. The median HVAC energy intensity for double-pane windows in healthcare facilities without low-E coating was 30.80 kBtu/sq ft/year, compared to 28.13 kBtu/sq ft/year for facilities with low-E. The data indicates that pane count alone does not consistently reduce energy use: some double-pane windows without low-E coatings perform even worse than single-pane windows. In contrast, the addition of low-E glazing generally lowers energy use intensity across building types.

Table 21. California Mean and Median HVAC Energy Consumption Intensity (kBtu/sq ft/year) by Commercial Building Type and Number of Panes (No Low-E)

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Education	73.66	60.09	72.30	60.70	-	-	73.28	60.28
Retail	64.76	60.44	130.60	118.59	-	-	64.54	60.16
Healthcare	36.68	30.55	35.06	30.80	-	-	36.22	30.68
Lodging	13.84	10.10	13.47	11.19	-	-	13.73	10.39
Office	37.70	33.21	63.94	59.22	-	-	37.43	33.07
Food Service	132.23	118.24	36.73	32.57	-	-	131.76	118.40
Warehouse	5.38	3.24	5.26	3.04	-	-	5.34	3.17
Others	-	-	-	34.88	-	-	-	-
Overall	44.21	36.71	42.75	60.70	-	-	43.79	36.19

Source: NLR ComStock 2018

Table 22. California Mean and Median HVAC Energy Consumption Intensity (kBtu/sq ft/year) by Commercial Building Type and Number of Panes (With Low-E)

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Education	-	-	67.70	56.12	44.90	44.90	67.54	55.69
Retail	-	-	131.45	118.56	117.31	95.48	59.90	56.08
Healthcare	-	-	32.49	28.13	38.31	22.67	32.53	28.10
Lodging	-	-	13.67	9.39	6.21	6.21	13.63	9.36
Office	-	-	59.86	56.08	65.34	54.41	32.88	29.47



Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Food Service	-	-	32.89	29.47	31.77	30.31	131.36	118.54
Warehouse	-	-	5.20	3.02	5.12	3.66	5.20	3.03
Others	-	-	41.37	33.01	38.86	29.03	-	-
Overall	-	-	67.70	56.12	44.90	44.90	41.35	32.96

Source: NLR ComStock 2018

4.4 CSW market size

CalMTA obtained 2023 and 2024 sales data from three national CSW manufacturers (Table 23). One CalMTA market expert believes these sales may represent approximately 60-70% of the overall secondary window market, but CalMTA was unable to identify another source to substantiate this estimate. The data provided covers only the commercial sector.

The products sold by these manufacturers fall under the CSW category but are marketed under various names and brands. For confidentiality and clarity, the data is reported in total square footage. CalMTA analysis indicates that roughly 18% of sales from these manufacturers occurred in California. Data from secondary sources such as CBECS (2018) and CEUS (2022) indicate that California accounts for 9% of the total commercial floor area in the United States^{56,57} - implying that these CSW manufacturers sell more product in California relative to the total square footage of commercial buildings.

⁵⁶ U.S. Energy Information Administration (EIA). 2021. Commercial Buildings Energy Consumption Survey (CBECS) Table B1: Summary table: total and means of floorspace, number of workers, and hours of operation, 2018. September 2021 (revised December 2022). PDF available at:

<https://www.eia.gov/consumption/commercial/data/2018/bc/pdf/b1.pdf>

⁵⁷ Baroiant, S., Mort, D., Alereza, T., and Dohrmann, D. 2023. 2022 California Commercial End-Use Survey (CEUS): Final Report. Prepared by ADM Associates, Inc. for the California Energy Commission. Publication Number: CEC-200-2023-017. February 2024. Available

from https://www.energy.ca.gov/sites/default/files/2024-02/2022%20CEUS%20Final%20Report_ada.pdf



CRAWS Market Characterization Report

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

Table 23. Manufacturer Reported California and Total U.S. Average Annual CSW Sales (2023 and 2024)

	Square Footage	Dollars
California ⁵⁸	20,136	\$ 765,168 ⁵⁹
Total U.S.	110,597	\$ 4,202,686
Estimated California Share of U.S. Sales		18%

Source: Sales data provided by individual manufacturers of CSW. (CalMTA 2025).

To put these sales estimates in context, CalMTA used secondary data sources to estimate the size of California’s commercial window market. One industry report projects the total U.S. commercial window market at \$3.11 billion in 2024.⁶⁰ Based on this data, we estimate California’s commercial window market at approximately \$280 million, including retrofit and new construction.⁶¹ CalMTA is unable to estimate the size of the retrofit market alone and therefore unable to quantify the market share of CSW sales. However, CalMTA believes that CSW currently represents a very small proportion of the commercial retrofit market.

4.5 Market conditions for advanced window solutions: manufacturer, ESCO, and building owner perspectives

4.5.1 Manufacturers

Three of the four CSW manufacturer employees interviewed by CalMTA self-reported an estimated number of units sold nationwide in 2024. Their estimates were inconsistent with the 2023 and 2024 national sales data CalMTA obtained directly from manufacturers reported in the previous section, which were separate from the employee interviews. One of the CSW manufacturers interviewed reported producing only custom units and could not provide an average annual estimate, as the quantity produced changes drastically from year to year. Both VIG manufacturers interviewed reported producing either very few units or prototypes only.

4.5.2 ESCOs

To assess market conditions from the ESCO perspective, CalMTA asked respondents to discuss the typical profile of their projects, the percentage of projects that include building envelope or

⁵⁸ Sales were reported by zip code; CalMTA mapped zip codes to estimate California Sales

⁵⁹ Based on estimated square price per square foot of \$38, as shown in Table 28.

⁶⁰ Grand View Research. 2024. U.S. Commercial Windows Market Size, Share & Trends Analysis Report by Mechanism (Swinging, Sliding), by Frame Material (Vinyl, Wood, Metal), by End Use (New Commercial), by State, and Segment Forecasts, 2025-2030. December 5, 2024. <https://www.grandviewresearch.com/industry-analysis/us-commercial-windows-market>

⁶¹ Using data from CEUS and CBECS, we estimate that California represents roughly 9% of the total U.S. commercial window market, which corresponds to approximately \$280 million (based on \$3.11 billion × 0.09).

window upgrades, current demand trends, the level of competition respondents experience, and the tools they use to model their projects.

All five ESCOs reported working on commercial buildings. Projects were most frequently completed in college/university, healthcare, and office facilities (three responses each), followed by non-college/university schools (two responses).

ESCOs reported wide variation in project sizes and window areas. One cited working on buildings from 100,000 to two million sq ft, including a past project with 292 windows and an upcoming one with 6,000. Another noted that entire buildings are often upgraded, with 10% to 100% of windows replaced. Others described projects ranging from 10,000 to over 1 million sq ft. One mentioned a Northern California project with 80,000 sq ft of glazing.

On average, 49% of projects included envelope upgrades, while only 18% included window upgrades. Envelope upgrades were more common across all respondents, with one reporting that 100% of projects involve envelope upgrades. In contrast, window upgrades were less common, reported in just 10% to 25% of projects.

Most ESCOs interviewed reported that window upgrades were included in only a small share of their projects in 2024. One estimated that windows were included in about 25% of projects, while another estimated they were included in 10% of projects, typically when clients had larger budgets. One noted that window upgrades are often avoided due to poor payback and another mentioned concerns regarding complexity.

ESCOs shared mixed views on demand for window solutions, though several common themes emerged, such as limited demand due to a lack of education, weak utility incentives, and minimal program support. One respondent described demand as reactive, driven by visible damage or broader renovations. While some noted growing interest as clients become more informed, affordability⁶² and logistical challenges remain key barriers. Two respondents mentioned that windows add the most value when integrated with major remodels.

Respondents generally agreed that the window solutions market is competitive, though perspectives varied as to why this is the case. One noted that products like double-pane windows are difficult to differentiate. While several ESCOs indicated they do not compete directly with window contractors, they face intense competition for clients, making business development challenging. One respondent emphasized that limited funding, rather than competition, is the main barrier to securing projects.

⁶² Affordability contextualized within the interviews was noted in broad generalized context, rather than incorporating specific criteria. The term was used subjectively by respondents, based on non-specific perceptions of the overall window market.

Respondents shared mixed experiences with projects aimed at reducing energy use or greenhouse gas (GHG) emissions. One reported that every project they undertake includes these goals, while another noted that such targets are less common and typically pursued as part of broader performance upgrades. A third respondent highlighted the challenge of balancing emissions goals with financial constraints, explaining that clients often seek GHG reductions that can be achieved within a five-year payback period.

4.5.3 Building owners and managers

To assess market conditions from the building owner and manager perspective, CalMTA asked about respondents' views on current window solutions, including performance and upgrade experiences. These interviews were additional to the surveys conducted with this segment. CalMTA also asked about respondents' motivation for pursuing upgrades, and whether they receive comfort-related complaints or face challenges regulating indoor temperatures.

Building owners and managers communicated broad awareness that replacing or upgrading windows is important for optimal building function. Two of eight respondents had already upgraded their single-pane windows with double-pane windows; of the remaining six, one had concrete plans to make the same upgrade and four expressed varying degrees of interest in a comprehensive window upgrade. Five of six respondents who had not yet made upgrades to their buildings' windows said that their primary motivator to do so was internal comfort; this was also the main reason given by both respondents who had completed window upgrades. Two respondents said they were not considering window upgrades at all. In all cases, respondents indicated that they had not pursued window upgrades due to the cost and logistical difficulty of completing these projects. More information about these motivators can be found in Section 6.11.

Among buildings that had not undergone window upgrades, respondents commonly reported issues with thermal comfort (six of six), noise infiltration (five of six), and impaired window functionality (four of six). They also said that most existing windows (75% to 100%) are single pane.

5 Policies and programs

5.1 Key findings

- Stringent building codes, such as New York City's LL97 and California's Title 24, are key factors advancing window technologies, as traditional double-pane windows often are unable to meet emissions or efficiency targets.⁶³

⁶³ California Energy Commission. 2022. 2022 Building Energy Efficiency Standards (Title 24, Part 6). Sacramento, CA <https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency>

- Most manufacturers do not actively track code developments, relying instead on informal updates, while ESCOs depend on dedicated engineering teams to stay compliant.
- Permitting requirements for window projects vary widely by region. Manufacturers interviewed by CalMTA largely dismissed permitting as a barrier. However, hospital facilities managers described the permitting process as a major obstacle.
 - ESCOs view building codes as a double-edged sword—sometimes driving upgrades but often adding complexity, cost, and risk to retrofit projects, leading customers to favor simpler improvements that avoid triggering additional code-compliance requirements.
 - Building owner familiarity with building performance standards varies by role, but those aware emphasized that code compliance is essential for accessing public funding. However, many decision makers delegate permitting and regulatory responsibilities to staff or consultants.

Primary windows must comply with state regulations such as California Title 24, Part 6 (Building Energy Efficiency Standards).⁶⁴ The federal ENERGY STAR program does not cover secondary windows; eligibility for tax credit or rebates (e.g., under the Inflation Reduction Act)⁶⁵ requires ENERGY STAR-certified performance, which sets standards for energy efficiency based on climate zones. Voluntary programs such as utility-based programs promote the adoption of secondary windows by providing financial incentives or financing. Industry associations and other organizations also develop standards and performance ratings.

5.2 State regulations

As federal standards do not cover fenestration, states are free to set their own window efficiency requirements. In California, these are outlined in the state's energy code, and fenestration is governed by Title 24, Part 6, with the 2025 update.

5.2.1 Title 24

Title 24, Part 6 of the California Code of Regulations, also known as the Building Energy Efficiency Standards, sets mandatory requirements for the energy performance of windows (also called fenestration) in both residential and nonresidential buildings. The Title 24 requirement for windows applies to all new construction and projects that require permits. In the case of retrofits (alterations), the standards apply if the area of the windows that are being changed are more than

⁶⁴ California Energy Commission. 2025. *Building Energy Efficiency Standards*. Sacramento, CA.

⁶⁵ U.S. Congress, *Inflation Reduction Act of 2022*, H.R. 5376, 117th Congress, <https://www.congress.gov/bill/117th-congress/house-bill/5376>

a total of 150 sq ft.⁶⁶ These standards are designed to reduce energy consumption related to heating, cooling, and lighting.

Windows must meet specific performance metrics such as U-factor, SHGC, and visible transmittance, which vary by climate zone. The 2025 update to Title 24 introduces a mandatory fenestration backstop of a 0.47 U-factor for vertical glazing in new construction, additions, and alterations, alongside specific U-factor and relative SHGC limits for alterations. Compliance is typically verified through National Fenestration Rating Council (NFRC)-certified ratings and is required for new construction, additions, and certain retrofit projects. Title 24 also limits the percentage of window area relative to wall area (WWR) and includes daylighting and control requirements for some commercial applications. These regulations are updated every three years: the 2022 version is currently in effect since Jan 1, 2023; and the 2025 standards, which are already adopted, go into effect Jan 1, 2026. It is worth noting that these requirements apply only to VIGs, and not to CSWs, since Title 24 does not currently regulate attachment products other than window film.

5.2.2 Industry Associations, Standards, and Ratings

There are several organizations in the window and fenestration industry that support professionals involved in the design, manufacturing, installation, and specification of windows. These groups collaborate to develop industry standards, conduct and share research, provide professional education, advocate for energy efficiency policies, and offer networking opportunities across various roles (e.g., manufacturers, contractors, architects, and consultants).

Some notable national organizations include the following:

- **National Fenestration Rating Council (NFRC).** Labeling is the primary method for certifying and comparing the energy performance of residential and commercial windows, doors, and skylights in the U.S. and is mandatory for ENERGY STAR qualification. It is voluntary in general building product labeling but widely adopted across the industry.
- **Attachments Energy Rating Council (AERC).** The primary organization responsible for developing standardized rating and certification procedures for window attachment products, including secondary glazing systems such as CSWs. The AERC label provides independently verified data on thermal and optical performance, allowing comparison of attachment products based on metrics such as energy savings and comfort. Participation in AERC's rating program is voluntary but increasingly recognized across the industry as a credible means of demonstrating energy performance and supporting utility incentive eligibility.

⁶⁶ California Energy Commission. 2025. 2025 Building Energy Efficiency Standards for Residential and Nonresidential Buildings: Title 24, Part 6, and Associated Administrative Regulations in Part 1. Sacramento, CA. Publication Number CEC-400-2025-010. <https://www.energy.ca.gov/publications/2025/2025-building-energy-efficiency-standards-residential-and-nonresidential>

- **Advancing Standards Transforming Markets International (ASTM)** develops standardized testing methods widely used to evaluate the performance and safety of windows.
- **Leadership in Energy and Environmental Design (LEED).** While not a labeling system for windows, LEED projects can earn credits in the Energy and Atmosphere category by incorporating high-performance fenestration.
- **Window & Door Manufacturers Association.** Represents manufacturers and suppliers of windows, doors, and skylights. The association publishes performance standards and engages in federal and state policy advocacy.
- **Fenestration and Glazing Industry Alliance (formerly AAMA and IGMA).** Provides product performance standards, certification programs, technical documents, and market research for residential and commercial fenestration products.

5.3 Potential regulations that impact CRAWs market

In addition to compliance with California's Title 24 energy code, other policies and regulatory frameworks are under development that could materially influence the state's fenestration market. Building performance standards are one such policy that will likely affect the CRAWs market.

5.3.1 Building performance standards

Building Performance Standards (BPS) are policies that mandate existing commercial and large multifamily buildings to achieve and sustain specified energy efficiency and emissions performance thresholds aligned with clean energy adoption and greenhouse gas mitigation objectives. These standards are designed with inherent flexibility, allowing state and local jurisdictions to tailor implementation strategies to their specific building stock, climate conditions, and policy priorities, while ensuring compliance with measurable performance benchmarks within defined compliance periods.

In 2021, the federal government committed to supporting building performance standards aimed at achieving zero-emission requirements by providing funding programs and technical assistance from agencies, such as the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency, to local and state governments that commit to implementing them. California now has state-level momentum toward a statewide BPS strategy. Many cities and counties are actively developing or adopting local BPS-type rules (examples in California include Chula Vista as an early adopter and many big cities exploring or near-adopting BPS policies).⁶⁷ Looking ahead, potential statewide BPS in California (expected around 2029 to 2030) and the eventual codification of low U-factors as prescriptive baselines could accelerate adoption, especially if cost-effectiveness thresholds are met in future code cycles.

⁶⁷ Local Energy Codes. 2024. Building Performance Standards Issue. June.
<https://localenergycodes.com/content/june-2024?>

The policy landscape is also shaped by advanced building standards such as New York City's LL97, which mandate high levels of efficiency for major retrofits that are often achievable only by including advanced window solutions. The U.S. DOE has made funding available for advanced glazing, including VIG manufacturing expansion,⁶⁸ and in 2024 launched an initiative offering a \$2 million prize pool to spur the development of energy-efficient commercial glazing systems. These investments contribute to the adoption of advanced window solutions, although changing priorities at the federal level may negatively impact their likelihood of success.⁶⁹

While improving window performance has traditionally been a higher priority in colder climates, California's high solar heat gains, especially during peak load periods, highlight the need for better-performing windows to support the state's aggressive decarbonization goals.

While these prescriptive and mandatory requirements do not yet demand the very low U-factors VIG can achieve, the performance-based compliance path—which most builders use—strongly favors high-performance glazing, positioning VIG as a strategic compliance measure. While there are no federal mandatory fenestration standards, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1 and International Energy Conservation Code model codes provide incremental U-factor improvements in certain climate zones, and the NFRC, International Organization for Standardization, and ASTM are advancing VIG-specific performance and durability standards.

Barriers remain, particularly in the lack of an NFRC rating method for VIG in single-pane replacement applications, uncertainty about long-term performance degradation, and the use of default ratings that understate actual performance.

The CEC has initiated efforts to advance fenestration technologies and promote secondary window solutions to enhance building energy efficiency and has conducted multiple studies on façade solutions as a part of Electric Program Investment Charge (EPIC).⁷⁰ These research efforts have become a driving force for policy change.

5.4 California programs, pilots, and incentives

CalMTA reviewed existing programs, pilots, and incentives supporting the installation of advanced window solutions in California (Table 24). Few programs specific to advanced window solutions are currently available in the state. Most of these opportunities provide funding or

⁶⁸ U.S. Department of Energy. 2024. DOE's Building Technologies Office Awards 15 Small Business Grants to Develop Promising Building Technologies. July. [DOE's Building Technologies Office Awards 15 Small Business Grants to Develop Promising Building Technologies | Department of Energy](#)

⁶⁹ U.S. Department of Energy. 2024. CX-029985: Building Envelope Innovation Prize Secondary Glazing Systems. February. <https://www.energy.gov/nepa/articles/cx-029985-building-envelope-innovation-prize-secondary-glazing-systems>

⁷⁰ California Energy Commission. 2020. High-Performance Integrated Window and Façade Solutions. CEC-500-2020-001, <https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-001.pdf>

rebates for energy-efficient technologies in general and measure compliance using whole-building energy use models, such as Normalized Metered Energy Consumption, rather than specifically incentivizing advanced window solutions.

Table 24. Programs, Pilots, and Incentives Supporting Installation of Advanced Window Solutions in California

Program/Initiative	Type	Applicability to Advanced Window Solutions	Source
CEC GFO-22-501	Grant program	Supports high-performance window retrofits in existing commercial buildings	California Grants Portal
SDG&E Normalized Metered Energy Consumption	Pay for performance via model	Incentivizes efficiency-enhancing retrofits, including window replacements	Savings at the Meter - SD Energy Edge for SDG&E Customers
SoCalGas Customized Incentives	Investor-owned utility (IOU) incentives	Incentivizes efficiency-enhancing retrofits, including window replacements	Business Equipment Rebates SoCalGas
SCE Window Incentives	IOU incentives	Incentives are available for efficient window retrofits and window film	32nd Ed SolutionsDirectory2021Feb Draft 5 review.pdf
179D Commercial Buildings Deduction (Federal)	Federal tax deduction	Provides up to \$5.65 per square foot deduction for envelope energy savings, including windows	Energy-efficient commercial buildings deduction Internal Revenue Service

5.4.1 Perceptions about regulatory landscape

CalMTA interviewed manufacturers, ESCOs, building managers, and owners to gather their perspectives on the regulatory environment influencing business operations in California. When relevant, the team specifically asked about the impact of existing building codes on manufacturing and sales processes, including how these codes influence decisions about the types of equipment produced. The team probed whether any regulations particularly encourage or discourage the manufacturing and sale of CSW or VIG. Respondents were asked about permit requirements for installing their equipment and how often they obtain permits versus completing installations without them. CalMTA tailored interview questions to each respondent group: manufacturers, ESCOs, building managers, and owners. See Attachment C for details. CalMTA also surveyed building owners and managers to assess their awareness of available programs that support window upgrades.

Perception and awareness among manufacturers

CalMTA asked manufacturers of VIG and CSW technologies for information about any regulations or policies that affect their business (positively or negatively). Three of six manufacturers said that existing building codes have little to no impact on their business, while three mentioned the



beneficial influence of high-efficiency standards in certain cities, especially New York City, with its extremely stringent Local Law 97 (LL97), which sets efficiency standards and GHG emissions reduction targets for most buildings above 25,000 sq ft.

One manufacturer also mentioned Boston, Seattle, Denver, and San Francisco as cities with above-baseline efficiency standards and said that they have “doubled down on sales activity” in these cities due to their strict building codes.

A VIG manufacturer mentioned that California code is already “tuned to high-performance double-pane windows,” meaning that their products are well positioned to fulfill stringent regulatory requirements.

Five of six manufacturers reported that they do not make any special effort to stay up to date on building codes, as they do not consider it important to their business. The sixth manufacturer said that they keep informed by conducting regular activities such as reading trade publications and news wires.

Four of six manufacturers do not predict any substantial changes to building codes moving forward, while the other two expect to see increasingly stringent energy-efficiency standards as more technology becomes available and affordable.

When asked whether their products typically require permits to install, four stated they do not, while two said they don’t know or that it depends on where the project occurs. The consensus among manufacturers is that permitting is not a serious obstacle to most CSW and VIG projects. However, a facilities manager for a large hospital network disagreed, describing an extremely onerous approval, design, and permitting process for any retrofit affecting hospital buildings in California. Neither of the interviewed hospital administrators had pursued or conducted any kind of window upgrades due to the perceived extreme difficulty of getting approvals. According to the California Department of Healthcare Access and Information, window glazing replacement (such as with CSW) does not trigger a review or permitting process, whereas a full window and frame replacement (such as with VIG) would trigger a field review and permitting process.⁷¹ This suggests that healthcare decision makers might be more likely to pursue CSW projects if they were aware that they do not trigger a field review.

ESCOs

CalMTA asked ESCOs about any building codes or policies affecting their businesses. Respondents agreed that building codes can notably impact retrofit projects, often acting as a constraint. One noted that exceeding certain thresholds can trigger added requirements and costs, reducing ROI and sometimes causing projects to be canceled. This one respondent further

⁷¹ California Department of Health Care Access and Information. 2025. “FREER Manual.” August 14, 2025.
[Microsoft Word - FREER Manual Revised 08-13-2025-FINAL](#)

explained that to avoid this, many customers opt for simpler, maintenance-focused improvements that do not require full code compliance. Two respondents pointed to the challenge of meeting strict regional codes.

Experience varied regarding the impact of building codes on window upgrades. One respondent identified California's Title 24 as a deterrent due to its high stringency. Another explained that code requirements can be triggered when renovations exceed a certain percentage of the building's floor area, which can indirectly necessitate window or envelope upgrades. However, not all respondents considered codes to be a factor, with one reporting no awareness of any code provisions influencing window upgrades in their projects.

Several respondents also noted that recent code changes have increased regulatory complexity and added costs, particularly for retrofits. One cited a major shift in 2013, when performance-based requirements were introduced, leading to stricter window and envelope standards that made retrofits harder to finance. Others pointed to state and local policies that are raising compliance expectations.

All respondents reported that their engineering teams are primarily responsible for staying current with building code changes by engaging with municipal officials; attending conferences and webinars; and maintaining regular contact with industry peers, investors, and manufacturers

Looking ahead, all respondents expect building codes to continue evolving, with one respondent anticipating that cities will push for stricter energy and performance standards. Another noted that changes occur every two years and often introduce complexity and costs that discourage compliance, especially when compliance is loosely enforced or lacks clear financial returns for building owners. Another predicted a stronger focus on decarbonization and electrification, though they noted windows may only play an indirect role in meeting those goals. Finally, one respondent mentioned they expect cities to lead future code tightening in the absence of strong federal action.

In terms of permitting, respondents generally agreed that permits are required for many, but not all, equipment installations. Requirements vary depending on the equipment type and project scope. For example, certain retrofits or projects that exceed a threshold value or floor area percentage can trigger permitting needs, while smaller upgrades may not. Two respondents reported that permits are always required and consistently secured for their projects, reflecting a strong culture of compliance. Another emphasized that permitting needs vary by jurisdiction and project details. Overall, permit adherence appears to be standard practice, though the specific triggers depend on local regulations and project characteristics.

Building owners and managers

CalMTA asked decision makers about their familiarity with BPS and the impact that regulatory policies have on their motivations to address building performance, as well as their



understanding of the permitting process required to undertake major building projects in California.

Three of the eight respondents were familiar with BPS, two were somewhat familiar, and the other three had little to no awareness of BPS. Of the five who had some level of familiarity with BPS, they all mentioned the important role that BPS and other regulations play in their decision-making regarding alterations to their buildings. They all stressed the need to stay compliant with all required policies and codes because the availability of public funding is contingent on it. Two respondents who said they were somewhat familiar with BPS stated that they adhere to compliance regulations just enough, so they meet the requirements, but do nothing “above and beyond to improve the quality of their (university) buildings. Two respondents with no general functional knowledge of BPS or building codes said that they were not concerned with that information and delegated such responsibilities to others (both operated hospital buildings, including a CEO).

“They make a big impact. Our funding and financing are contingent upon being up to code and in line with regulations.”

-Hospital facilities manager

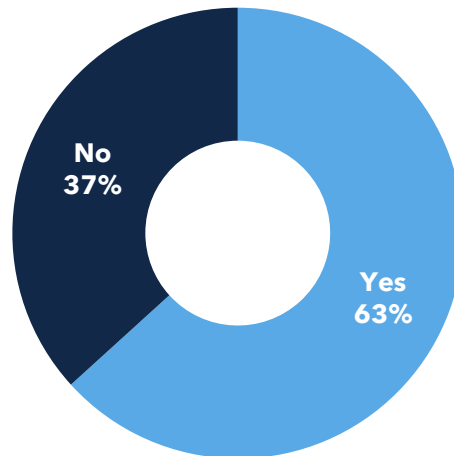
The lack of knowledge regarding codes and regulations appears to vary based on the role of the decision maker, as it is possible that a CEO could have the ultimate say on building upgrades, little awareness of regulations, and thus rely on others to stay abreast of certain details when necessary.

Understanding and awareness of the permitting process associated with window upgrades was generally low. Most respondents had not even considered window replacements, thus never considered the permitting process. Two were familiar with HVAC permits and questioned whether the process for windows was similar.

CalMTA also gauged the awareness of regulatory policy related to energy efficiency and windows among managers and building owners in the survey. As shown in Figure 6, CalMTA found that 63% of commercial building owners and managers are aware of current or potential regulatory policies that might affect them.



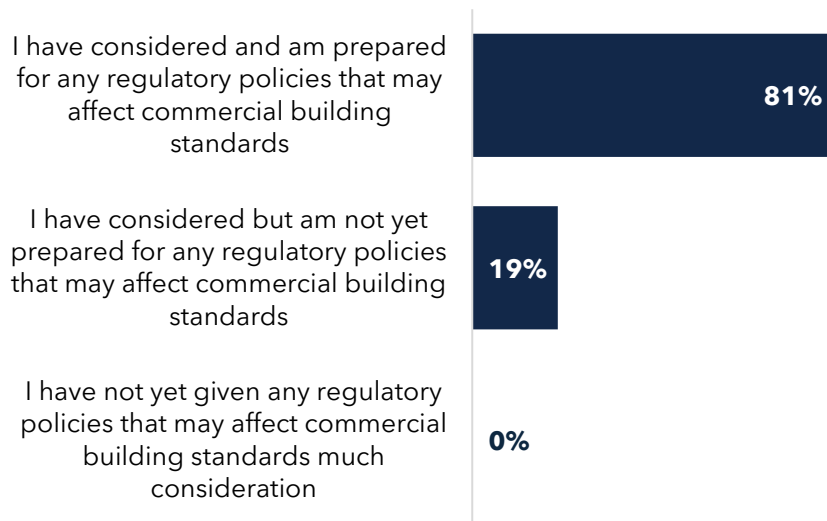
Figure 6. Regulatory Policy Awareness



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q G5: "Are you aware of any current or potential regulatory policies that may affect the way you operate your business in California, particularly how you make decisions regarding building upgrades?" (n=114). Results rounded to the nearest percentage.

To assess awareness and preparedness related to regulatory policies, the survey asked respondents to describe their level of consideration regarding performance standards for commercial buildings in California (Figure 7). Among commercial building owners and managers who were aware of the current or future regulatory policies, 81% have considered and are prepared for their impact.

Figure 7. Regulatory Policy Awareness and Preparedness

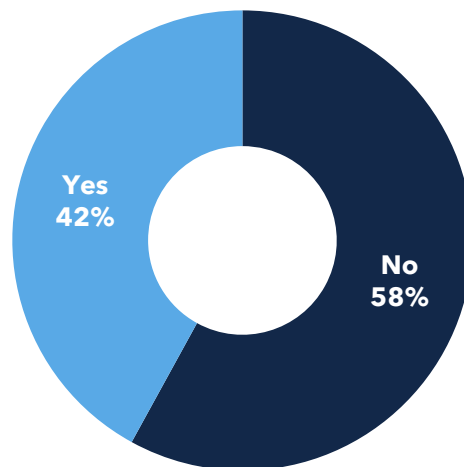


Source: CalMTA CRAWs Building Owner and Property Manager Survey Q G7: “Which of the following statements best describes your level of consideration and preparation regarding regulatory policies that may affect performance standards for commercial buildings in California” (n=85). Results rounded to the nearest percentage.

5.4.2 Awareness of the available incentive programs

The survey also assessed awareness of available incentive programs supporting window upgrades. CalMTA found that 42% of commercial building owners and managers are aware of energy efficiency or decarbonization programs (Figure 8).

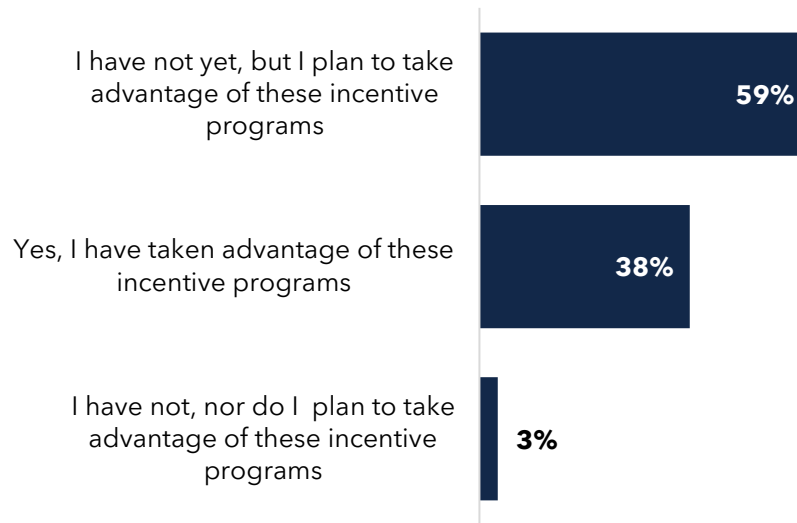
Figure 8. Awareness of Window Solutions Incentive Programs



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q G1: “Do you know of any energy efficiency or decarbonization programs that provide financial support, incentives, or tax rebates for window solutions to buildings in California?” (n=114). Results rounded to the nearest percentage.

The survey asked respondents who reported they were aware of incentive programs whether they had participated in programs offering financial support, incentives, or tax rebates for window solutions. As shown in Figure 9, of the 42% of commercial building owners and managers aware of energy efficiency or decarbonization programs, 38% have taken advantage of these incentive programs, while 59% said they plan on taking advantage of these programs.

Figure 9. Incentive Program Usage among Building Owners and Property Managers who are Aware of them



Source: CalMTA CRAWs Building Owner and Property Manager Q G2: "Have you or do you plan to take advantage of any of these programs that provide financial support, incentives, or tax rebates for window solutions?" (n=56). This question was asked of respondents who indicated in G1 that they are aware of energy efficiency or decarbonization programs providing financial support, incentives, or tax rebates for window solutions in California.

6 Demand side characteristics

6.1 Key findings

- Most buildings owned and managed by survey respondents were large, with 76% exceeding 25,000 sq ft. The most common size range was 25,001-50,000 (40% of buildings in the sample), followed by buildings over 50,000 sq ft (36%).⁷²
- In the decision-making process pertaining to renovations, owners have a primary role.

⁷² These percentages represent unweighted counts of survey respondents since they describe sample characteristics rather than population-level estimates.

- Forty-seven percent of commercial building owners and managers reported that tenants have 'no or very little influence,' 50% reported 'some influence,' while only 3% said that tenants have 'a lot of influence.'⁷³
- Apart from manufacturers, awareness of VIG technologies is low across market actors. ESCOs, building owners, and tenants consistently reported limited familiarity. Even where awareness exists, customers often lack understanding of benefits, costs, or installation processes.
- Eighty-five percent of surveyed commercial building owners and managers reported familiarity with CSW. Fifty-one percent said that they were 'familiar' and 34% said they were 'very familiar.'⁷⁴
- Manufacturers and ESCOs most frequently cite cost as the primary barrier to adopting both CSW and VIG, emphasizing that high upfront costs and uncertain ROI deter projects, particularly when competing with other capital improvements like HVAC or roofing.
- When asked what factors would prevent them from selecting CSW or VIG as a window replacement or upgrade solution, building owners cited limited information about CSW and VIG and concerns about performance, durability, and maintenance as the primary adoption barriers.
- Manufacturers cited a wide range of CSW benefits, such as soundproofing, improved comfort, easy installation, and minimal installation disruption. They also acknowledged drawbacks, including condensation, aesthetic concerns, and incompatibility with structurally unsound existing windows.
- Manufacturers and ESCOs described VIG as having superior technical performance compared to CSW but note that VIG adoption remains limited due to supply chain immaturity, high costs, and skepticism from the market.
- Building owners reported that improving comfort and reducing noise are primary motivations for pursuing upgrades, but decision-making is often delayed due to concerns over project costs, disruptions to operations (especially in healthcare settings), and a lack of information about available alternatives.

CalMTA surveyed decision makers (i.e., building owners and managers) and interviewed manufacturers, commercial tenants, building managers, and ESCOs. Additionally, the team conducted secondary research to gain a better understanding of the factors influencing window purchases, the willingness to adopt CSW or VIG, and the key barriers limiting broader adoption of

⁷³ CalMTA Building Owner/Manager Survey Q B17 "How much influence, if any, do tenants in the [TYPE] buildings you own or manage have in terms of selecting the types of renovations or upgrades to buildings? (e.g., HVAC, windows, lighting, insulation, etc.)" (n=114)

⁷⁴ CalMTA Building Owner/Manager Survey Q D1 "Prior to this survey, how familiar were you with CSW?" (n=114).

these efficient technologies in California. The following sections present detailed findings from the survey and interviews related to demand side market characteristics.

6.2 Commercial building market decision making

Decision-making about building renovations is a complex process involving many market actors.⁷⁵ Factors such as occupancy status (leased/rented versus owned), tenure of the tenant/owner, and overall economy influence renovation decisions around energy efficiency. A study by NEEA found that renovations involve multiple decision makers and various factors interacting with each other.⁷⁶ The study indicated that while owners hold ultimate authority over large strategic initiatives, property managers often act as tenant advocates to owners.

CalMTA reviewed both secondary and primary data to better understand the decision-making process behind window renovations. The team surveyed building owners and managers, asking them specifically if they were decision makers. Table 25 shows the breakdown of survey respondents by owners and managers. The distribution aligns with the NEEA study cited above, which found similar patterns in decision-making. An overwhelming majority (86%) of building owners said they alone make the decision, whereas only 1% of building managers said the same.⁷⁷

Table 25. Distribution of Building Managers and Owners

Role	I make the decision	Notable influence	Total
Building Owner	19	3	22
Building Manager	1	91	92
Total	20	94	114

Source: CalMTA CRAWs Building Owner and Property Manager Survey Q A1 "How much influence do you have on decisions regarding major renovations or retrofit projects to the buildings you own or manage?" (n=114) and Q A2 "What is the most appropriate description of your role?" Select all that apply. (n=114)

6.3 Building characteristics and occupancy dynamics

To characterize building use and estimate square footage, CalMTA asked respondents about the types of buildings they owned or managed, their estimated size, and their primary use.

Table 26 shows that most buildings in the CRAWs sample were large, with 76% exceeding 25,000 sq ft.⁷⁸ The most common size range was 25,001-50,000 (40% of buildings in the sample), followed by buildings over 50,000 sq ft (36%). Only 3% of buildings were smaller than 10,000 sq ft. College and healthcare buildings were the largest, with all college-affiliated buildings reported

⁷⁵ Stanitsa, A., Hallett, S.H., and Jude, S. 2022. *Investigating Key Factors Influencing Decision-Making in the Design of Buildings and Places: A Survey of Stakeholders' Perception*. Architecture, Structures and Construction, 2, 381-401. <https://doi.org/10.1007/s44150-022-00058-5>.

⁷⁶ Ethnos Inside, LLC. 2024. *Better Bricks Commercial Building Decision Making Study* [Better Bricks Study](#)

⁷⁷ Results are unweighted since they describe sample characteristics rather than population-level estimates.

⁷⁸ Results are unweighted since they describe sample characteristics rather than population-level estimates.

at over 25,000 sq ft. and 74% of healthcare buildings over 50,000 square feet. Schools (non-college/university) buildings also skewed large, with 83% above 25,000 sq ft.

This distribution of building sizes is generally consistent with secondary data sources, such as ComStock.

Table 26. Building Size (sq ft)

Building Type	0 - 10,000	10,001 - 25,000	25,001 - 50,000	Over 50,000	Total
College	-	-	9	15	24
Healthcare	-	1	5	17	23
Lodging	1	6	9	7	23
Office	2	13	6	-	21
School	-	4	17	2	23
Total	3	24	46	41	114

Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B1: "Which of the following types of buildings do you currently own or manage? Please select all that apply." (n=114); and Q B2 "What is the approximate total square footage of your [TYPE] buildings?" (n=114) Note: this table reflects unweighted data from the sample.

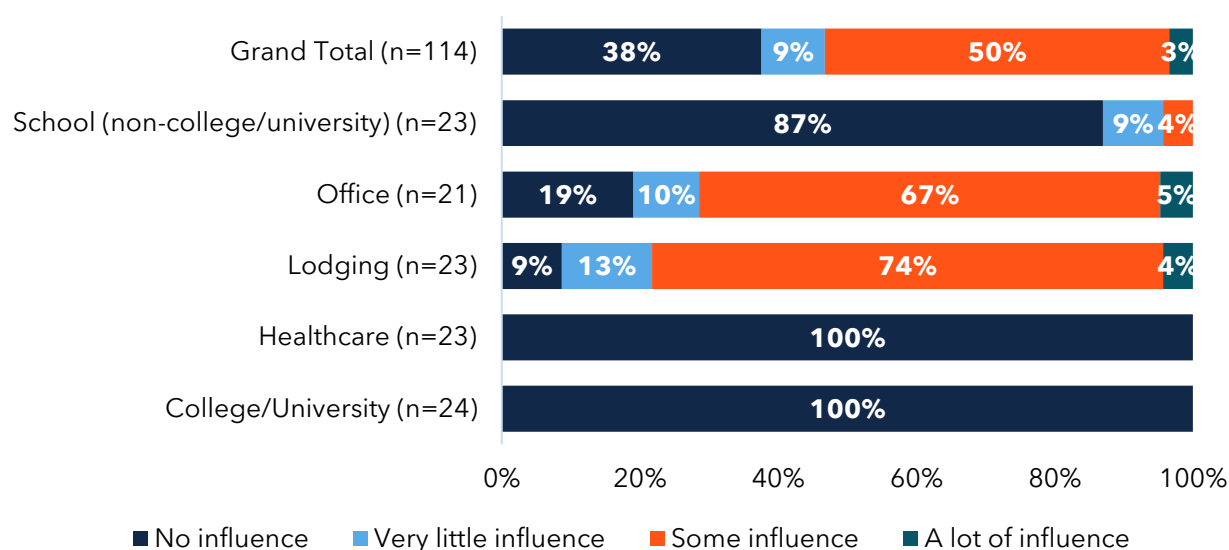
6.4 Occupancy and tenant responsibility

The survey asked commercial building owners/managers about the extent to which tenants influence decisions related to building renovations or upgrades (e.g., HVAC, windows, lighting, and insulation). Figure 10 summarizes responses by building type. Overall, 47% of commercial building owners/managers reported that tenants have no or very little influence over renovation or upgrade decisions, while 50% reported some influence. Only 3% of commercial building owners/managers indicated that tenants have a lot of influence.

Tenant influence over renovation and upgrade decisions was highest among lodging and office building owners/managers. Seventy-four percent of lodging building owners/managers and 67% of office building owners/managers reported that tenants have some influence over renovation and upgrade decisions. One hundred percent of college/university and healthcare building owners/managers reported no tenant influence over renovation and upgrade decisions, while tenant influence was minimal in schools (87% of school building owners/managers reported no influence).



Figure 10. Tenant Influence on Renovation and Upgrade Decisions by Building Type

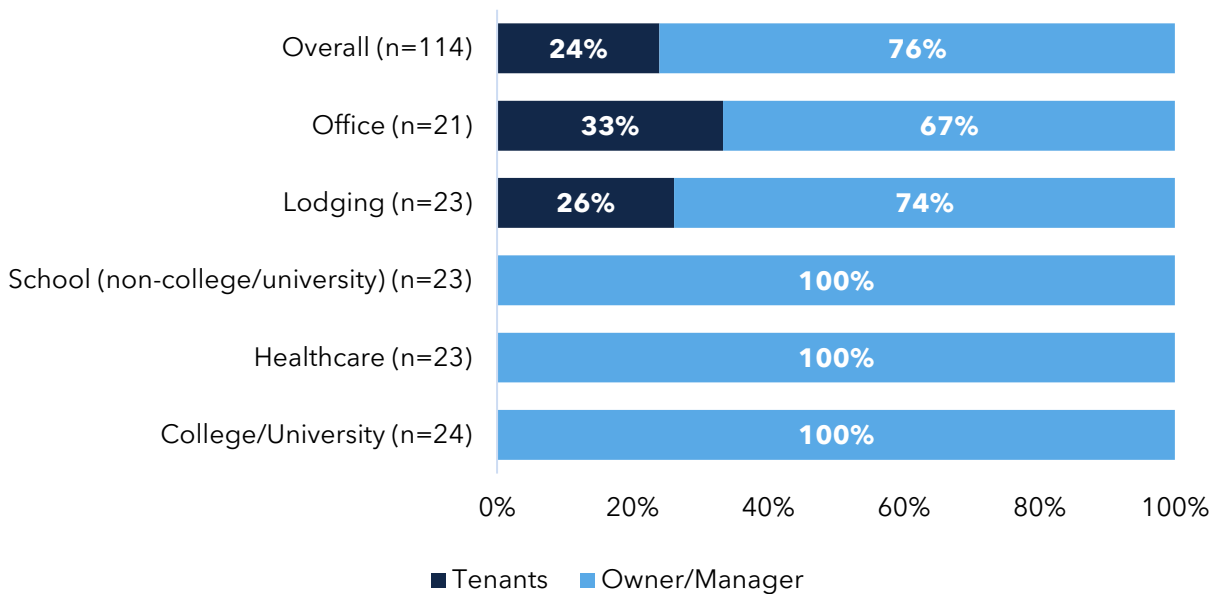


Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B17: “How much influence, if any, do tenants in the [TYPE] buildings you own or manage have in terms of selecting the types of renovations or upgrades to buildings? (e.g., HVAC, windows, lighting, insulation, etc.)” (n=114). Results rounded to the nearest percentage. Percentages may not sum to 100% due to rounding. A single “lodging” respondent indicated that their tenants have a lot of influence over these decisions; applying weights caused this to round to 0%.

The survey asked commercial building owners/managers about who typically pays the utility bills in the buildings they own or manage. Figure 11 summarizes utility bill payment responsibility by building type. Overall, 76% of commercial building owners/managers said they pay the utility bills themselves, while 24% reported that tenants are responsible. This finding suggests that owner-paid utilities in the selected segment present a clear opportunity for energy-efficiency upgrades.

Utility payment responsibility varies by building type. School, healthcare, and college/university building owners/managers all reported that utilities are paid entirely by the owner or manager (100% of represented square footage). Seventy-four percent of lodging and 67% of office building owners/managers reported that owners/managers paid utilities.

Figure 11. Responsibility for Paying Utility Bills by Building Type



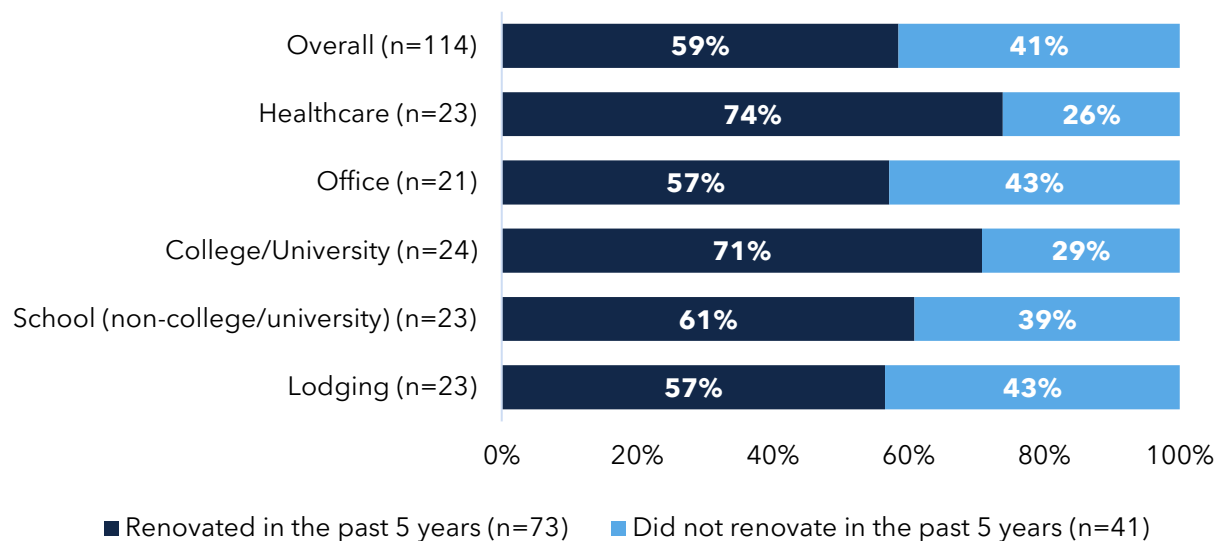
Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B18: “Who pays the utility bills in the [TYPE] buildings you own or manage?” (n=114). Results rounded to the nearest percentage. The “owner/manager” portion of the Overall responses comprises answers from building owners who reported that they pay the utility bills and answers from building managers who reported that the owner pays the bills.

6.5 Renovation history

The survey asked commercial building owners/managers about major renovations during the last five years, defined as projects affecting more than 50% of the square footage of a given building that they own/manage. Generally, renovations are a prime opportunity for upgrades. As displayed in Figure 12, 59% of commercial building owners/managers reported a major renovation or large retrofit on at least one of their buildings within the past five years. Note that these data do not indicate the proportion of square footage that has undergone major renovation, but rather the proportion of building owners/managers (weighted by building type) who reported that at least one building under their purview has undergone a major renovation.

Renovation activity varies by building type. Healthcare and college/university building owners/managers reported the highest rates of recent renovations, at 74% and 71%, respectively. Sixty-one percent of school building owners/managers reported recent renovations while 57% of office and lodging building owners/managers reported recent renovations.

Figure 12. Major Renovation on One or More Building in the Past 5 Years, by Building Type

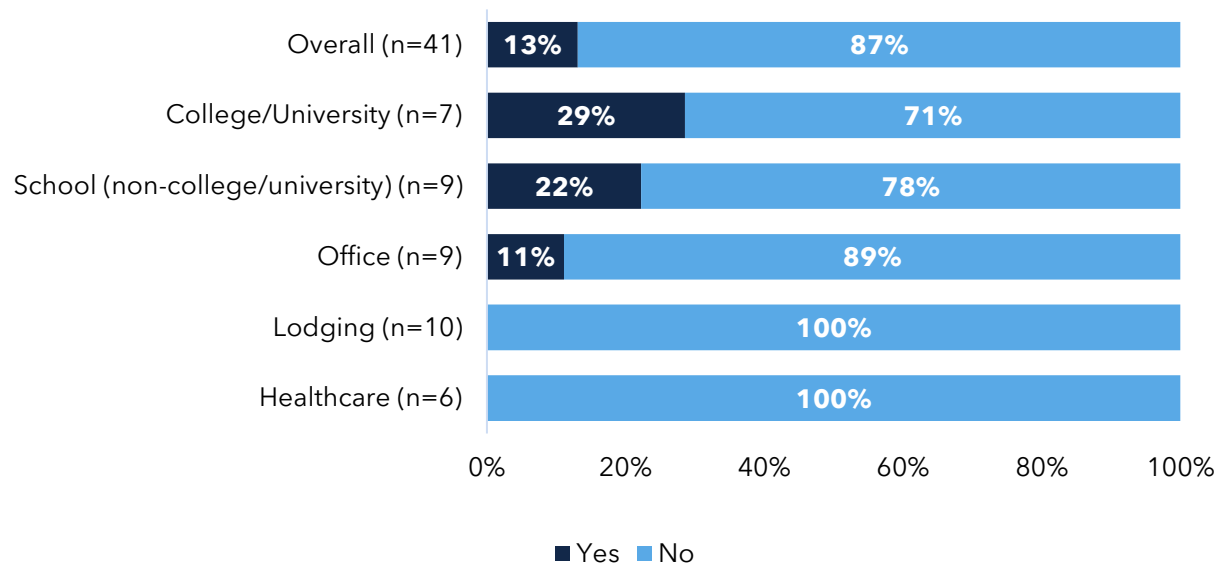


Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B6: "How many of your [TYPE] buildings have undergone major renovations or large retrofit projects within the past 5 years? For the purposes of this survey, a major renovation or large retrofit is a project affecting more than half the square footage of the building." (n=114). Results rounded to the nearest percentage. Respondents who reported that none of their buildings were renovated in the past five years are shown as "Did not renovate in the past 5 years." While those who reported that one or more of their buildings were renovated are shown as "Renovated in the past 5 years."

6.6 Future renovation plans

The survey asked building owners/managers about their renovation and retrofitting plans for the next five years. Owners/managers who responded that the building(s) under their purview had not undergone any major renovations or retrofits within the past five years were then asked about their future renovation/retrofit plans during the next five years. Figure 13 summarizes building owner/manager renovation plans by building type. Overall, 13% of commercial building owners/managers reported plans to renovate or retrofit at least one of the buildings they own or manage in the next five years, whereas 87% reported no plans. College/university building owners/managers were the most likely to report planned renovations (29%), followed by school building owners/managers (22%) and office building owners/managers (11%). None of the respondents who own or manage healthcare or lodging buildings reported any planned renovation.

Figure 13. Future Renovation Plans for One or More Buildings by Building Type



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B11: "Are you (owner or manager) planning for any of your building(s) to undergo major renovations or large retrofits within the next 5 years?" (n=41). This was a follow-up question asked only of respondents who, in Q B6, indicated that their buildings have not undergone a major renovation or large retrofit. Results rounded to the nearest percentage.

6.7 Purchase drivers and window upgrade behaviors and strategies

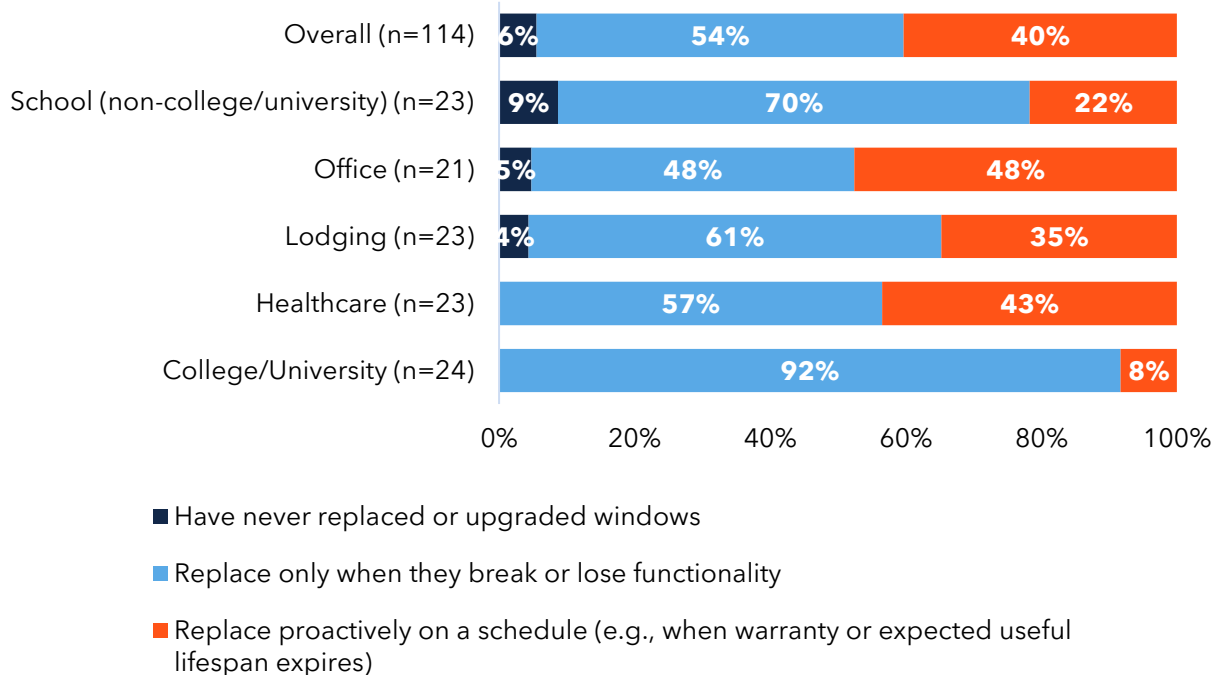
6.7.1 Window upgrade strategies

To better understand how and when window upgrades occur, the survey asked commercial building owners/managers about their replacement strategies. The findings suggest that window replacements are often more reactive than planned. Figure 14 shows that 54% of commercial building owners/managers replace windows only when they break or lose functionality. A smaller share (40%) replaces windows proactively on schedule, while 6% of commercial building owners/managers said they have never replaced or upgraded windows. Existing research indicates that only a small portion of the single-pane window stock is replaced each year. In a study by Energy Solutions on behalf of CalNEXT, one market actor interviewed stated that "about 40 percent of all commercial buildings still have the original single pane glass with aluminum

frames.”⁷⁹ In the same study, one survey respondent noted that “less than one percent of [commercial] windows get replaced per year.”⁸⁰

According to CalMTA survey respondents, 48% of office building owners/managers,⁸¹ 43% of healthcare building owners/managers, and 35% of lodging building owners/managers replace windows proactively on schedule. In contrast, school building owners/managers (22%) and especially college/university building owners/managers (8%) are the least likely to do so. Nearly all college/university building owners/managers (92%) reported replacing windows only upon failure.

Figure 14. Window Replacement Strategies by Business Type



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B19: “Thinking specifically about windows, what is the most common approach you take to replacing or upgrading the windows in your buildings?” (n=114). Results rounded to the nearest percentage. Percentages may not sum to 100% due to rounding.

⁷⁹ Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. Prepared for CalNEXT. [Commercial Windows Market Study and Measure Package Development](#). One explanation for low adoption levels is the lifespan of a commercial window. Among CalNEXT survey respondents, the life of a commercial window was estimated to be from 40 to 70 years, depending on upkeep and frame material.

⁸⁰ While there are some who placed the average closer to 25 to 30 years, the reality is that unless there is a window failure, such as water or air intrusions, window replacements are rare. (pg. 21).

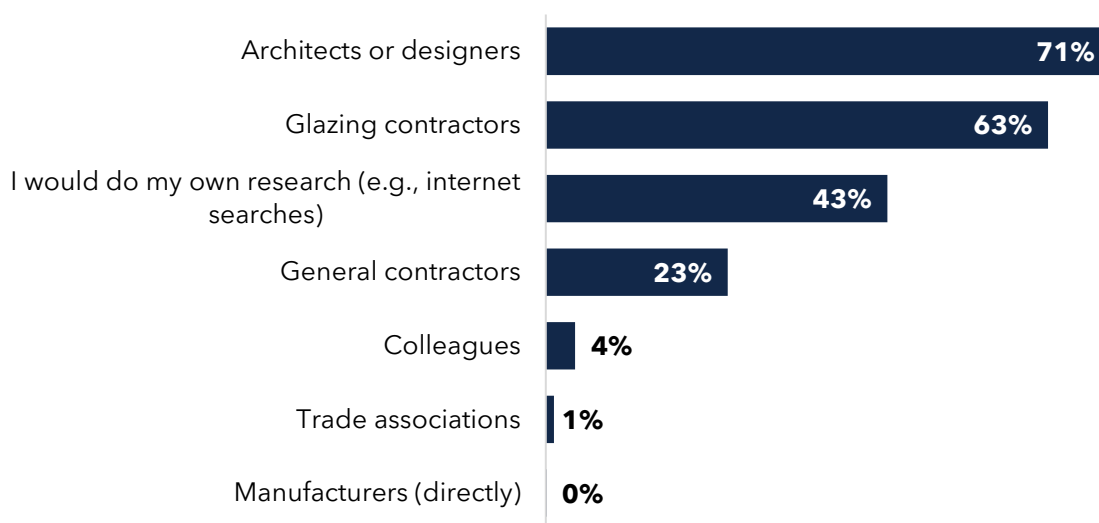
⁸¹ CalMTA did not screen for recent renovations during the interview screen.

6.7.2 Information sources

The survey also examined where decision makers turn for information and guidance during the window replacement process. Understanding these information channels will help identify key influences and potential market leverage points. Figure 15. Information Sources for Window Replacement or Upgrade Considerations

illustrates that 71% of commercial building owners/managers rely on architects or designers, while 63% rely on glazing contractors when considering window replacements or upgrades. Forty-three percent of building owners/managers reported conducting independent research, such as internet searches. Only 23% of commercial building owners/managers reported consulting general contractors, while only 4% reported consulting colleagues.

Figure 15. Information Sources for Window Replacement or Upgrade Considerations

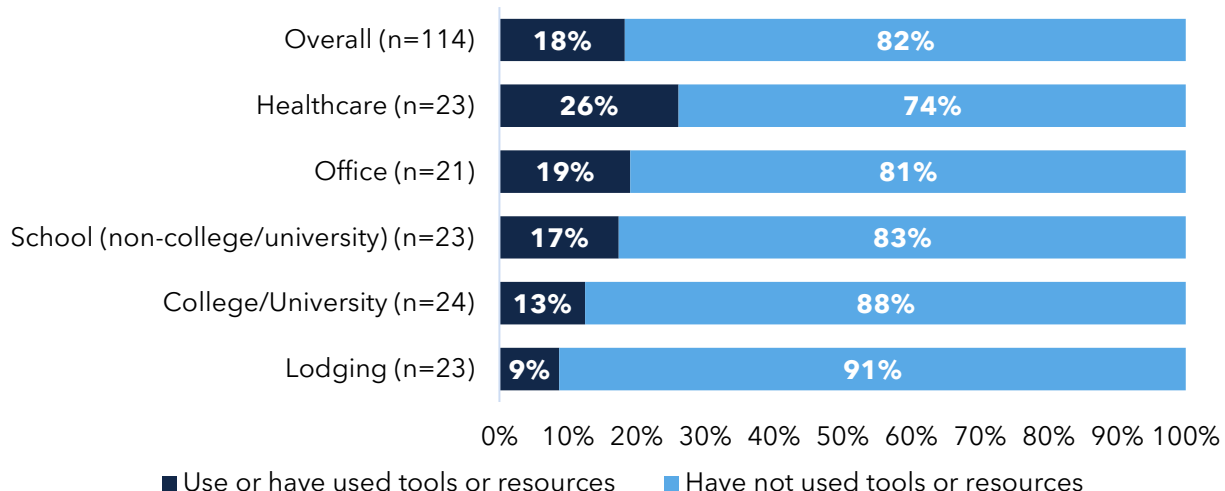


Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B20: "If you were to upgrade or replace your windows, which source(s) would you consult to get information? Please select all that apply." (n=114) Results rounded to the nearest percentage.

The survey and interviews probed the use of tools, models, and calculators in the window upgrade or replacement decision-making process. Figure 16 shows that 82% of surveyed commercial building owners/managers have not used tools, models, calculators, or other resources to determine whether to install high-efficiency window solutions, where 18% had used these tools or resources. Healthcare building owners/managers reported the highest use (26%), followed by office building owners/managers (19%). Lodging building owners/managers reported the lowest usage rates (9%). Healthcare and office respondents who reported using tools mentioned specific modeling software packages, such as EnergyPlus, BEopt, EnergyPro, eQUEST, COMFEN, and Revit. Respondents noted they had adopted these tools between 2005 and 2024, typically as part of broader energy modeling or building design processes. Suggestions for improvement focused on enhanced speed, usability, integration with BIM tools

like Revit, and features to support more complex window geometries or compare multiple design options side by side.

Figure 16. Use of Tools or Resources to Evaluate High-Efficiency Window Solutions



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q B21: “Do you use or have you used any tools, models, calculators, or other resources to determine whether to install high-efficiency window solutions?” (n=114) Results rounded to the nearest percentage.

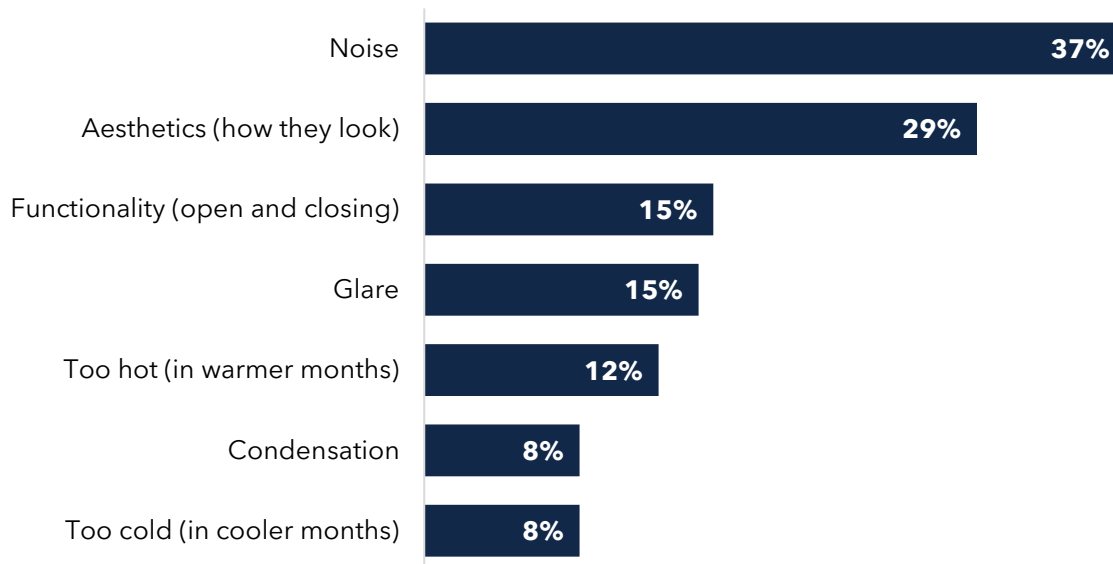
ESCO interview respondents also reported using modeling tools to evaluate window solutions, often before making proposals. Common tools included eQUEST, Trane, Energy Toolbase, and custom Excel-based models tailored to specific needs. Firms with large engineering teams cited decades of experience and active collaboration with software providers to refine these tools. However, one respondent noted the lack of a standardized methodology, pointing out that many tools do not fully account for factors like altitude, pressure, or location-specific conditions.

6.8 Satisfaction with current window inventory

6.8.1 Tenant feedback and complaints

The survey asked building owners and property managers which aspects of window performance they receive negative feedback or complaints about. As Figure 17 summarizes, the four most frequent topics of window-related complaints received by building owners and managers were noise (37%), aesthetics (29%), and functionality and glare (both 15%).

Figure 17. Topics of Window-Related Complaints

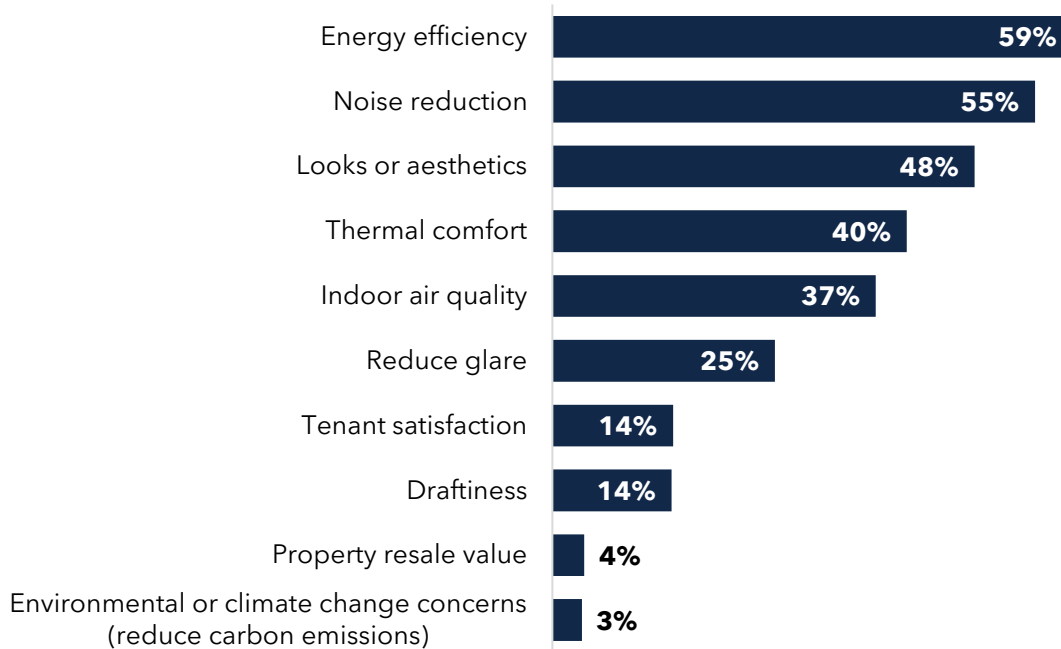


Source: CalMTA CRAWs Building Owner and Property Manager Survey Q C2: "Which aspects of window performance do you receive negative feedback or complaints about? Select all that apply" (n=39). Results rounded to the nearest percentage.

6.8.2 Motivations to upgrade

Surveyed building owners/managers were asked to rank their top reasons (up to three) for why they would consider upgrading or replacing windows in their buildings. Figure 18 summarizes the most selected motivators. Overall, 59% of commercial building owners/managers identified energy efficiency among the top motivating factors, followed by noise reduction (55%), and looks or aesthetics (48%).

Figure 18. Top Motivators to Upgrade



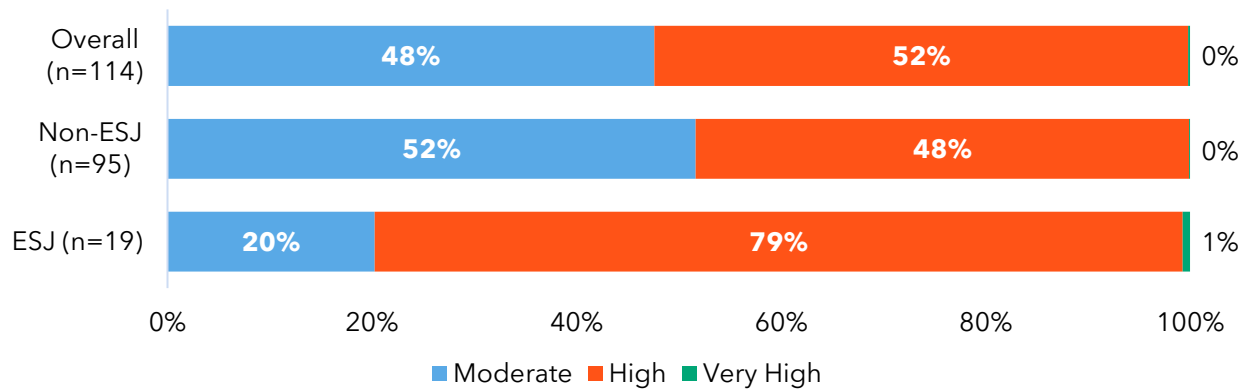
Source: CalMTA CRAWs Building Owner and Property Manager Survey Q C3: "If you were to upgrade or replace any of the windows in your building(s), what would you say are the most important reasons that you would consider doing so? Please rank up to three reasons, where #1 is the most important and #3 is the third-most important." (n=114) Results rounded to the nearest percentage.

6.8.3 Perceived importance of efficient windows

When asked to rate the importance of efficient windows in reducing energy costs in their buildings, 52% of owners/managers rated the importance of efficient windows as important (Figure 19). Very few building owners or managers reported it was of *very high importance*, while none rated it as *very low importance*. The survey found that building owners/managers with buildings in ESJ communities rated the importance of efficient windows higher than those with buildings in non-ESJ communities: 80% of building owners/managers in ESJ communities rated the importance of efficient windows highly, compared to only 48% of those in non-ESJ communities.⁸²

⁸² ESJ sample size was small (n=19). Therefore, this finding should be considered directional.

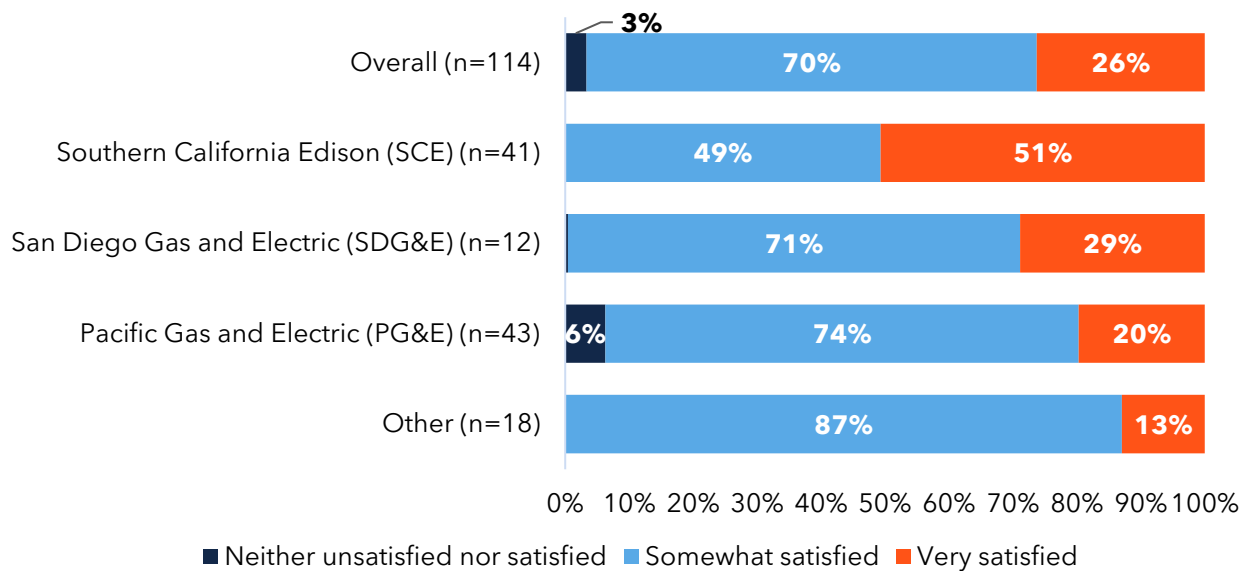
Figure 19. Importance of Efficient Windows



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q C4: "How would you rate the importance of efficient windows to reducing energy costs in your buildings?" (n=114). Results rounded to the nearest percentage. Note: Results are for directional purposes only, given the small n-value of ESJ responses (n=19).

Surveyed building owners/managers also rated their satisfaction with their current windows. As shown in Figure 20, 96% of commercial building owners/managers said they were *somewhat* or *very satisfied* with the performance of the windows in their buildings.

Figure 20. Satisfaction with Window Performance



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q C5: "Overall, how satisfied are you with the performance of the windows in your building(s)?" (n=114). Results rounded to the nearest percentage. Note: "Somewhat unsatisfied" and "Very unsatisfied" were response options, but no respondents selected them.

6.9 Awareness and perceptions of efficient window solutions

6.9.1 Familiarity with CSW and VIG

During the literature review, CalMTA found that CSW and VIG are referred to by different names in the market. Table 27 provides a list of secondary window manufacturers identified in a recent market report and VIG manufacturers identified by a consulting firm.⁸³ To highlight the fact that secondary windows are often referred to by different terms, the table provides the product description according to the manufacturer.

Table 27. Manufacturers of Secondary Windows and VIG

Manufacturer	Product description	Type	Market (Residential or Commercial)
Allied Window	Storm Windows	Secondary Window	Both
Alpen	Secondary Window	Secondary Window	Both
Chosen	Insulating Pane	Secondary Window	Both
Cityproof	Interior Windows	Secondary Window	Commercial
Climate Seal	Storm Windows	Secondary Window	Both
Innerglass	Interior and Exterior Storm Windows	Secondary Window	Both
Inovues	Glazing Retrofit System	Secondary Window	Commercial
Larson	Interior and Exterior Storm Windows	Secondary Window	Both
Indow	Storm Window Inserts	Secondary Window	Both
Magnetite	Interior Secondary Glazing Panel	Secondary Window	Both
Maine Glass	Interior Insulating Windows	Secondary Window	Commercial
QuantaPanel	Storm Window	Secondary Window	Both
Renovate by Berkowitz	Window Retrofit	Secondary Window	Commercial
Thermolite	Secondary Interior Window Systems	Secondary Window	Commercial

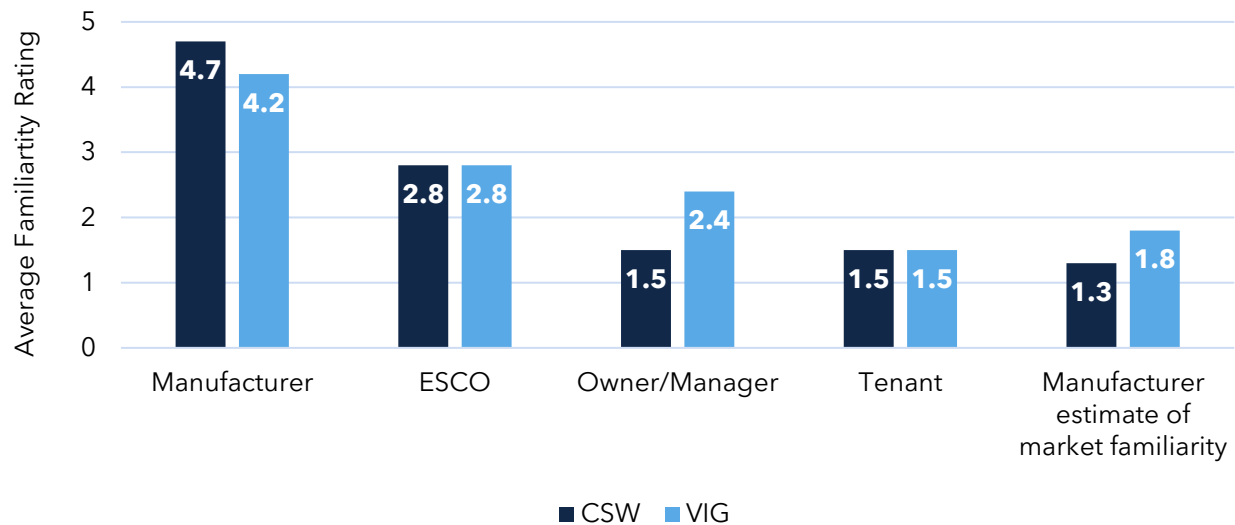
⁸³ Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA.

Manufacturer	Product description	Type	Market (Residential or Commercial)
Wausau Window	Interior Accessory Windows	Secondary Window	Commercial
Wex Energy	Windowskins	Secondary Window	Both
FINEO by AGC	Vaccum insulating glazing	VIG	
LandGlass	Vacuum glass	VIG	Both
LuxWall	Enthermal	VIG	Both
Nippon Sheet Glass (NSG)	Insulight Therm/Architectural glazing	VIG	Both
Vitro Architectural Glass	VacuMax Vacuum Insulating Glass	VIG	Both

To gauge familiarity with CSW and VIG, CalMTA asked questions about awareness in the survey with building owners and managers and in interviews with manufacturers and ESCOs.

Manufacturers demonstrated the highest level of familiarity with both CSW and VIG technologies, followed by energy service companies (ESCOs). On a scale of 1 to 5, where 1 is *not at all familiar* and 5 is *very familiar*, manufacturers reported high familiarity with CSW, averaging 4.7. Their familiarity with VIG was slightly lower, averaging 4.2. ESCOs, building owners/managers, and tenants all reported lower familiarity with CSW and VIG technology, as shown in Figure 21. Manufacturers uniformly reported that awareness among end users and distributors of CSW and VIG technologies is limited. Figure 21 shows self-reported familiarity with each technology by market actor type, alongside manufacturer-estimated familiarity for the market as a whole.

Figure 21. Self-Reported Familiarity with CSW and VIG by Market Actor Type

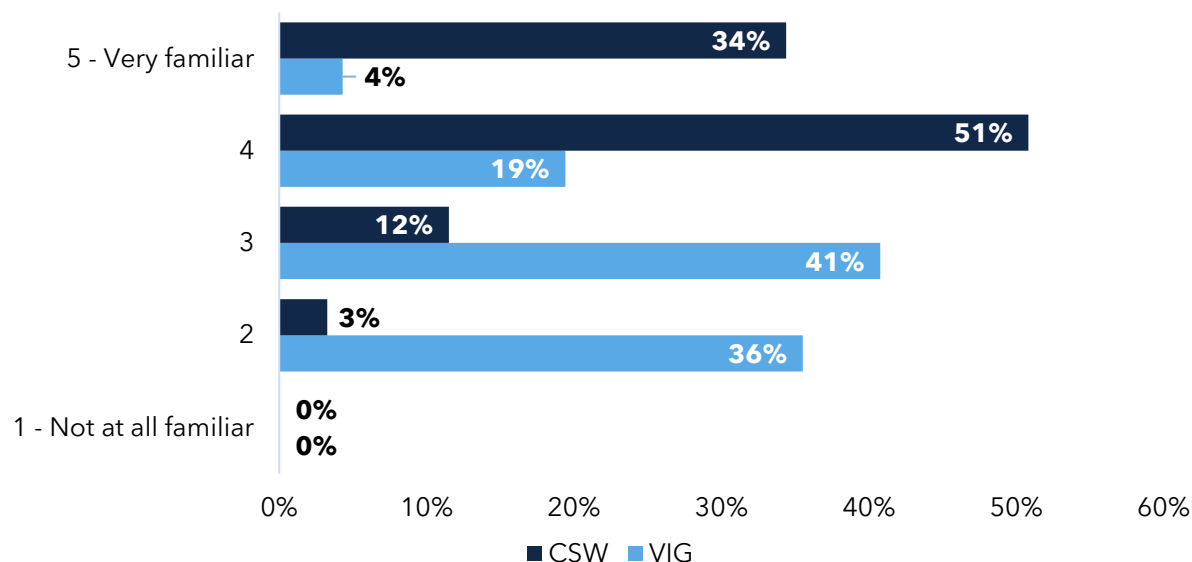


Source: CalMTA Manufacturer interviews (n = 6), ESCO interviews (n = 5), owner/manager interviews (n = 8, and tenant interviews (n = 6). "On a scale from 1 to 5 where 1 is not familiar at all and 5 is very familiar, how would you describe your level of familiarity with Commercial Secondary Window (CSW) technology?" and "On a scale from 1 to 5 where 1 is not familiar at all and 5 is very familiar, how would you describe your level of familiarity with Vacuum Insulated Glass (VIG) technology?"

The survey of building owners/managers provided a description of CSW and VIG and asked respondents if they were familiar with the technology. Eighty-five percent of commercial building owners/managers said they were at least somewhat familiar with CSW (a rating of 4 or 5, with 5 being *very familiar*).

Building owners/managers were far less familiar with VIG; only 23% responded that they were somewhat or very familiar with the technology. As shown in Figure 22, just 4% of commercial building owners/managers reported being very familiar with VIG prior to the survey. Forty-one percent of building owners/managers rated their familiarity a "3" and 36% rated it a "2" on a 5-point scale, where 1 meant *not at all familiar* and 5 meant *very familiar*. No respondents reported *not at all familiar* with CSW or VIG.

Figure 22. Familiarity with CSW and VIG Among Commercial Building Owners and Managers



Source: CalMTA CRAWs Building Owner and Property Manager Survey D1: "Prior to this survey, how familiar were you with CSW?" (n=114) and D11: "Prior to this survey, how familiar were you with VIG?" (n=114)

In the in-depth interviews CalMTA conducted with building owners and property managers, familiarity with the potential benefits, drawbacks, and installation processes for both CSW and VIG was generally low. Five of the eight interviewed respondents had never heard of CSW, and only two stated they had any level of familiarity. Of the two that had some level of familiarity, one said they had heard that CSW could help improve safety and internal comfort, while the other said the installation process was quick, and labor was less expensive than full window replacement.

Specifically, for VIG, five respondents said they had little to no awareness. One respondent was very familiar with VIG because they had installed the technology and praised its abilities to combat glare, reduce noise, and increase thermal comfort. Further, the respondent noted that if they had known about VIG prior to upgrading their hospital buildings, they would have elected to use VIG rather than double-pane window replacement. The lack of awareness is evident in the fact that the two respondents who had undergone window replacements regretted that their contractors did not provide alternative options to double pane, with one stating, "I have not heard anything about either CSW or VIG. They were not presented or mentioned by our third-party contractor."

Additionally, both commercial-tenant building owners interviewed reported no familiarity with CSW; however, both were familiar with VIG, one had installed it in the building where they operate their business and the other had it installed in their home. Both highlighted the ease of installation and emphasized that the benefits of VIG justified the cost.

To assess ESCO perspectives on demand, CalMTA asked ESCOs how they perceived their clients' awareness of the value proposition of CSW and VIG, as well as any barriers to adoption of these

technologies. Interview respondents rated both market and end-user familiarity with CSW as very low, with three out of four ESCOs rating their familiarity at 1 or 2 on a 5-point scale, and one estimating awareness among specialized trades as slightly higher at 2 or 3. All four respondents characterized awareness as limited. One noted that many installation contractors default to simpler solutions like window film, despite their lower performance benefits compared to CSW.

Interview respondents also emphasized that most building owners and customers are unaware of CSW as an alternative to full window replacement. One interviewee observed that architects and suppliers tend to promote full replacements, which discourages owners from pursuing a window upgrade project due to cost and complexity. Another noted that contractors often fail to educate end users about these technologies. In total, three respondents cited factors that contribute to low awareness, highlighting the need for broader education and outreach to increase CSW adoption.⁸⁴

6.9.2 Perceptions of CSW and VIG

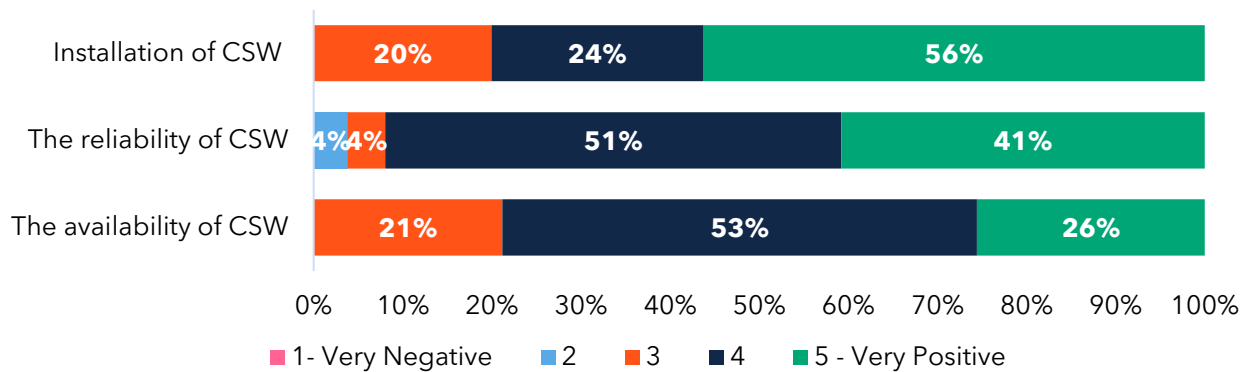
To assess manufacturer perspectives on demand, CalMTA asked respondents to discuss their familiarity with CSW and VIG, how they perceived their customers' awareness of the value proposition of these technologies, and any barriers to adoption they saw.

When asked about the benefits of CSW, all manufacturers interviewed cited its high energy efficiency, soundproofing, increased comfort, and the ease and non-disruptive nature of installation. When asked the same question about VIG, all manufacturers cited its high energy efficiency; two cited the lightness of the glass.

To assess market readiness for advanced window technologies, the survey asked building owners and managers about their perception of CSW and VIG solutions (Figure 23). Commercial building owners/managers who reported being familiar with CSW (a rating of 4 or 5) reported a positive impression of the availability (79%), reliability (92%), and installation (80%) of CSW.

⁸⁴ Interview responses were mixed on installer familiarity with CSW. Both installer respondents (n=2) rated their familiarity as *high* or *very high* (a 4 or 5 on a 5-point scale), while one installer mentioned that CSW building owners and property managers are well versed in technology.

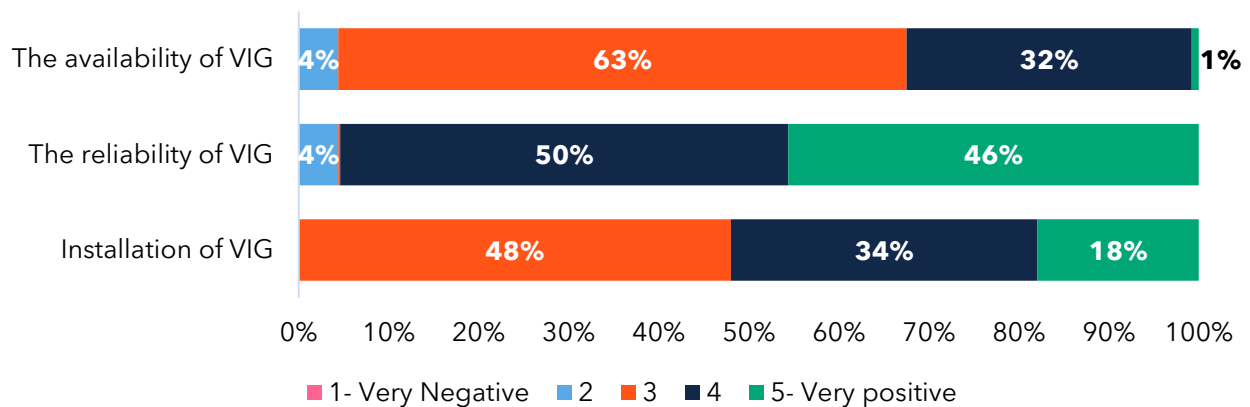
Figure 23. Building Owner and Property Manager Perceptions of CSW



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q D4: "How would you rate your impression of each of the following:" (n=104). This was a follow-up question asked only of respondents who reported being familiar with CSW. Results rounded to the nearest percentage. Results may not sum to 100 due to rounding.

As shown in Figure 24, building owners/managers' perceptions of VIG were less positive than their perceptions of CSW in terms of installation (52% rating positive or very positive) and availability (33% rating positive or very positive). However, perceptions of VIG reliability were similar to CSW (96% rating "positive or very positive").

Figure 24. Building Owner and Property Manager Perceptions of VIG



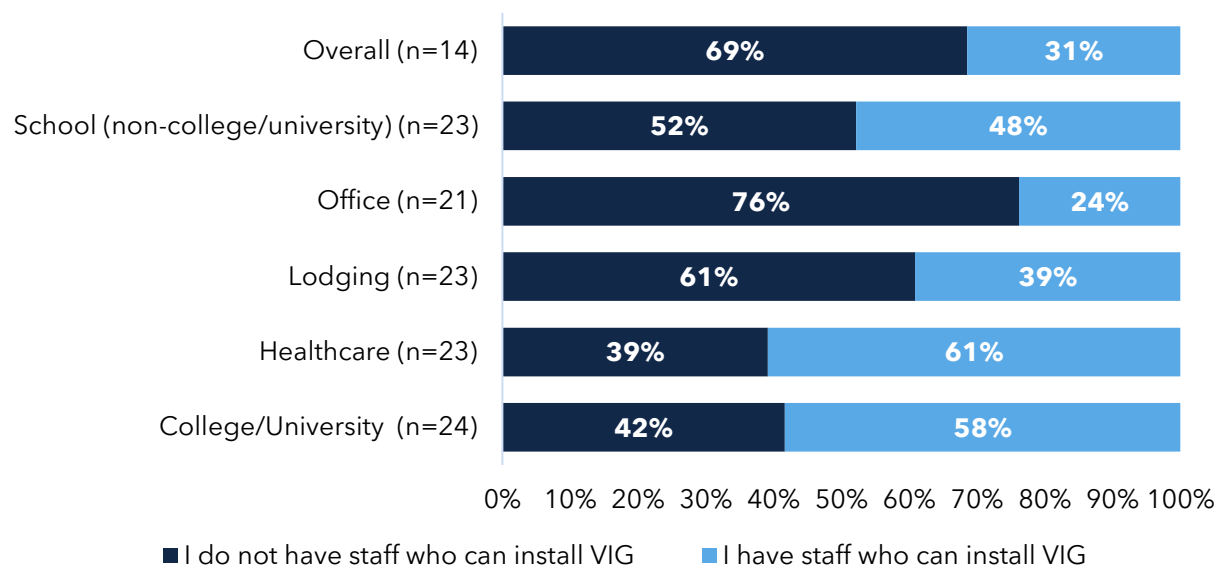
Source: CalMTA CRAWs Building Owner and Property Manager Survey Q D14: "How would you rate your impression of each of the following:" (n=24). This was a follow-up question asked only of respondents who reported being familiar with VIG. Results may not sum to 100% due to rounding.

6.9.3 Workforce capacity

To better understand workforce capacity and the availability of skilled staff, the survey asked commercial building owners/managers whether they employ personnel qualified to install CSW

solutions.⁸⁵ Overall, 31% of commercial building owners/managers reported having on-site staff capable of installing CSW (Figure 25). However, in the university and healthcare segments, 58% and 61% of building owners/managers, respectively, indicated they have qualified installation staff.

Figure 25. Ability to Install CSW by Building Type

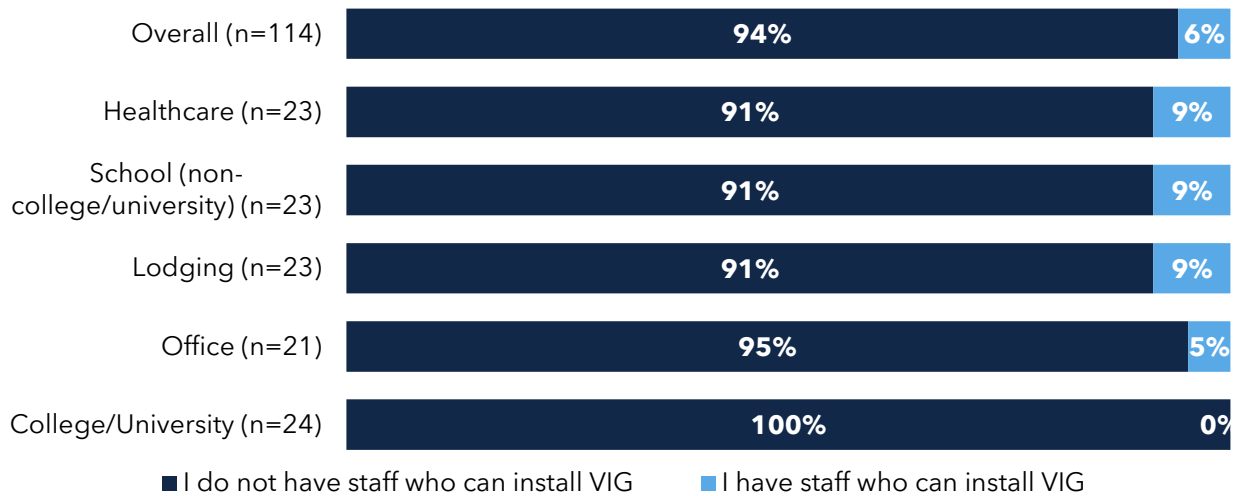


Source: CalMTA CRAWs Building Owner and Property Manager Survey Q D2: "Do the buildings you own or manage employ any staff who are able to install CSW?" (n=114). Results may not sum to 100 due to rounding.

In contrast to CSW, only 6% of commercial building owners/managers reported having staff capable of installing VIG (Figure 26). Across building types, VIG installation capability was virtually minimal or nonexistent. Only 9% of healthcare, lodging, and school building owners/managers reported having staff capable of installing VIG.

⁸⁵ The survey did not describe the qualifications required to install CSW solutions.

Figure 26. Ability to Install VIG by Building Type



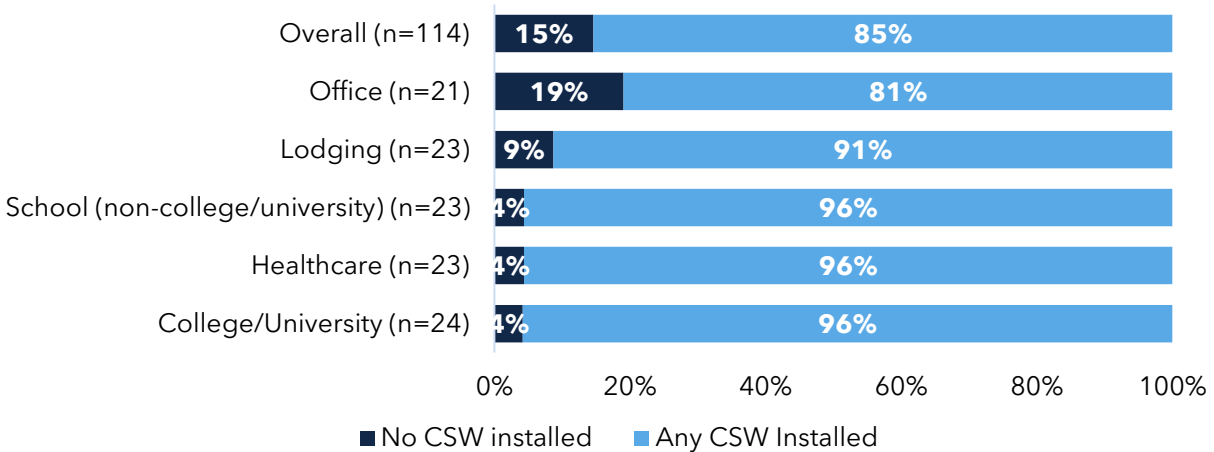
Source: CalMTA CRAWs Building Owner and Property Manager Survey Q D12: "Do the buildings you own or manage employ any staff who are able to install VIG?" (n=114). Results rounded to the nearest percentage.

6.9.4 Prevalence of CSW and VIG

The survey examined the presence of CSW and VIG across commercial building owners/managers. Eighty-five percent of commercial building owners/managers indicated having one or more CSW installed in at least one of their buildings (Figure 27). The proportion of respondents who reported having one or more CSW installed was especially high (96%) in the healthcare, school, and college building segments. However, the reported prevalence of CSW should be interpreted cautiously.

Prior to being asked about the presence of CSW and VIG windows in their buildings, respondents were provided with descriptions of the technologies and asked about their level of familiarity with the technology. Although familiarity was high, these findings are not consistent with findings from qualitative interviews or secondary research, which suggest that awareness and prevalence of CSW and VIG are quite low. Thus, actual awareness and prevalence levels are likely lower than reported by survey respondents. This could be due to participant misunderstanding stemming from the fact that CSW are often confused with storm windows.

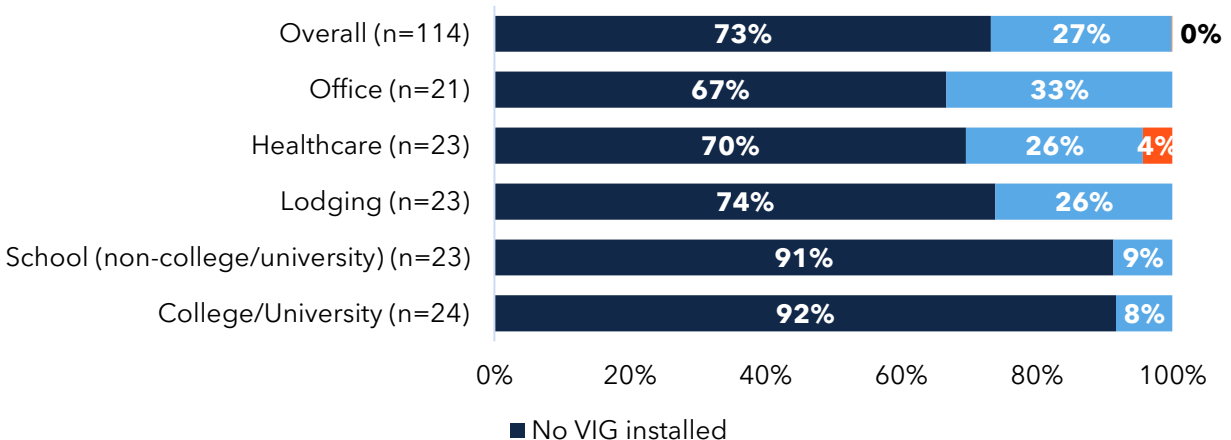
Figure 27. Building Owners and Managers Reporting One or More CSW Installed, by Building Type



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q D6: "To your knowledge, are any CSW installed in any of your buildings?" (n=114). Results rounded to the nearest percentage.⁸⁶

As shown in Figure 28, while commercial building owners/managers reported that CSW has been installed in at least some buildings across all market segments, VIG remains far less common. Only 27% of commercial building owners/managers reported any VIG installations. These numbers should also be interpreted with caution, given the limited number of estimated VIG installations to date.

Figure 28. Building Owners and Managers Reporting One or More VIG Installed, by Building Type



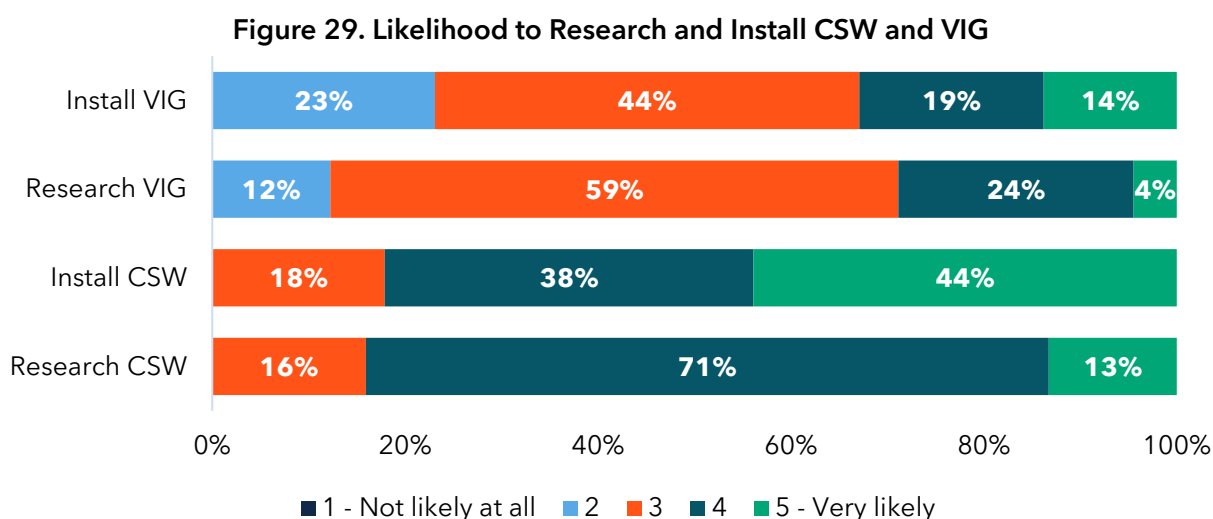
Source: CalMTA CRAWs Building Owner and Property Manager Survey Q D16: "To your knowledge, are any VIG installed in any of your buildings?" (n=114). Results rounded to the nearest percentage.

⁸⁶ CalMTA cannot report the percentage of actual square footage of buildings with CSW installed. The survey respondents reported the presence of CSW and VIG, but not the installed square footage.

6.10 Likelihood of adoption

6.10.1 Likelihood to research and install CSW or VIG in the future

The survey asked commercial building owners and managers how likely they would be to research and install CSW or VIG for future window upgrades or replacements. As shown in Figure 29, respondents were more likely to install and research CSW than VIG. Eighty-four percent of commercial building owners/managers responded that they were *likely* or *very likely* to research CSW, while 82% of commercial building owners/managers responded they were *likely* or *very likely* to install CSW. In contrast, only 29% of commercial building owners/managers responded that they are *likely* or *very likely* to research VIG (this figure differs slightly from the values shown in the chart due to rounding), while 33% responded that they are *likely* or *very likely* to install VIG.



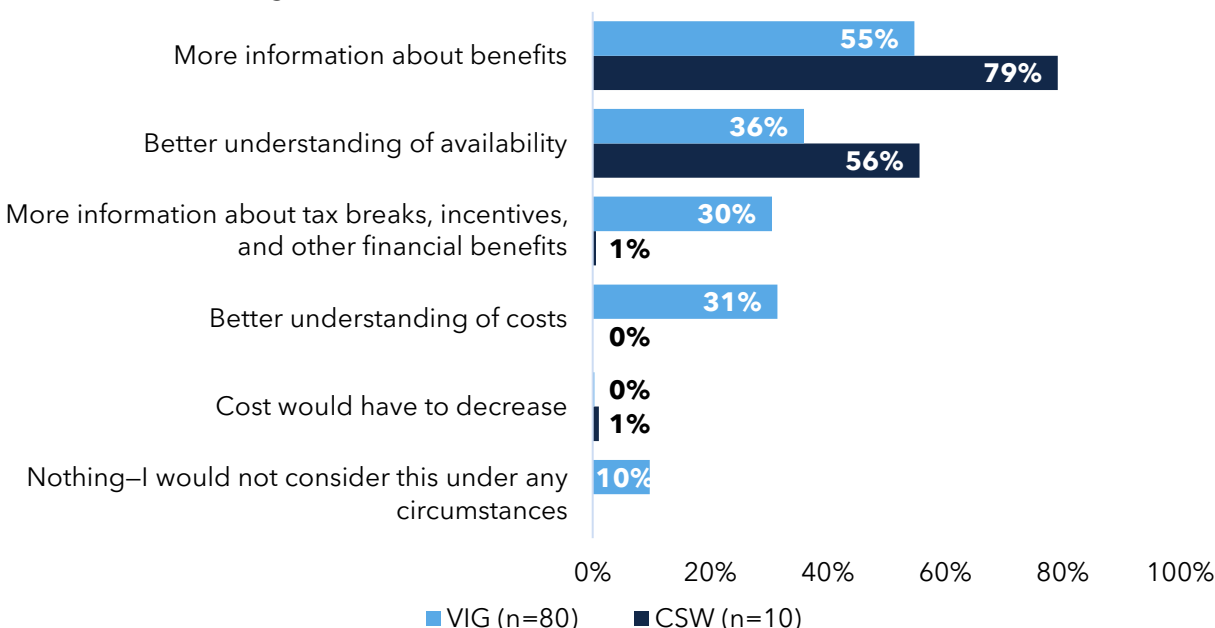
Source: CalMTA CRAWs Building Owner and Property Manager Survey Q E1: "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to research CSW on a scale of 1-5, where 1 is "Not at all likely" and 5 is "very likely"?" (n=114) & Q E2: "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to install CSW (with the level of understanding you have now)?" (n=114) & Q E3: "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to research VIG on a scale of 1-5, where 1 is "Not at all likely" and 5 is "very likely"?" (n=114) & Q E4 "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to install VIG (with the level of understanding you have now)?" (n=114). Results rounded to the nearest percentage. Results may not sum to 100% due to rounding.

6.10.2 Preferences and motivators in selecting window alternatives

To understand preferences for alternative window solutions, commercial building owners/managers who indicated a low likelihood of researching CSW or VIG (ratings of 1 to 3 on a scale of 1 to 5, where 1 is *not at all likely* and 5 is *very likely*) were asked which type of windows they might choose instead of CSW or VIG. All (100%) commercial building owners/managers within this subset stated that they would install double-pane windows instead of CSW, and 97% would install double-pane windows instead of VIG. This finding was consistent for all building types.

To explore potential drivers of adoption, commercial building owners/managers within the subset indicating low likelihood of installing CSW or VIG were asked what factors might motivate them to consider installing CSW or VIG in their buildings. As shown in Figure 30, 55% of commercial building owners/managers responded that learning more about the benefits of VIG would be the top motivation, while 79% of commercial building owners/managers said the same for CSW. This was followed by motivation through a better understanding of VIG availability (36%) and costs (31%), while owners/managers considering CSW were more likely to be motivated by having a better understanding of availability (56%).

Figure 30. Motivators of Future CSW and VIG Installation



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q E6: "What would motivate you to consider **installing** CSW in your building(s)? Select all that apply" (n=10) & Q E8: "What would motivate you to consider installing VIG in your building(s)? Select all that apply" (n=80). This question was asked only of respondents who indicated low likelihood of **installing** CSW or VIG (1-3 on a scale of 1 to 5, where 1 is "not at all likely" and 5 is "very likely"). Results rounded to the nearest percentage. N-values are unweighted.

6.11 Barriers to adoption

CalMTA identified barriers to CSW and VIG adoption through a combination of primary and secondary research.

A literature review identified several factors that have hindered market actors from embracing and pursuing secondary window solutions. Many barriers to adoption stem from a lack of awareness or knowledge regarding one or more aspects of CSW or VIG window solutions or the

installation process.⁸⁷ Capacity constraints and limited training opportunities for installers raise concerns about installation time and required expertise. Uncertainties remain around the service life and performance of VIG, especially regarding durability and condensation issues. Additionally, the high initial cost and perceived risks of newer or less familiar products often lead decision makers towards conventional alternatives.

6.11.1 Building owners and managers survey – barriers to CSW or VIG upgrade selection

The survey asked commercial building owners and managers to rank the top factors (up to three) that would prevent them from selecting CSW or VIG for window upgrade projects. As shown in Figure 31, 64% of commercial building owners/managers ranked a lack of information as the most important barrier preventing them from selecting CSW or VIG for window upgrade projects. Concerns about performance (43%) and concerns about durability or maintenance (39%) were also cited as major barriers.

⁸⁷ Energy Solutions. 2024. Commercial Windows Market Study and Measure Package Development. Prepared for CalNEXT.

⁸⁷ Evergreen Economics. 2020. Commercial Window Attachments: Secondary Window Market Characterization. Prepared for NEEA.

⁸⁷ NREL. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. Prepared for the U.S. Department of Energy. April 2022. <https://research-hub.nrel.gov/en/publications/pathway-to-zero-energy-windows-advancing-technologies-and-market-/>

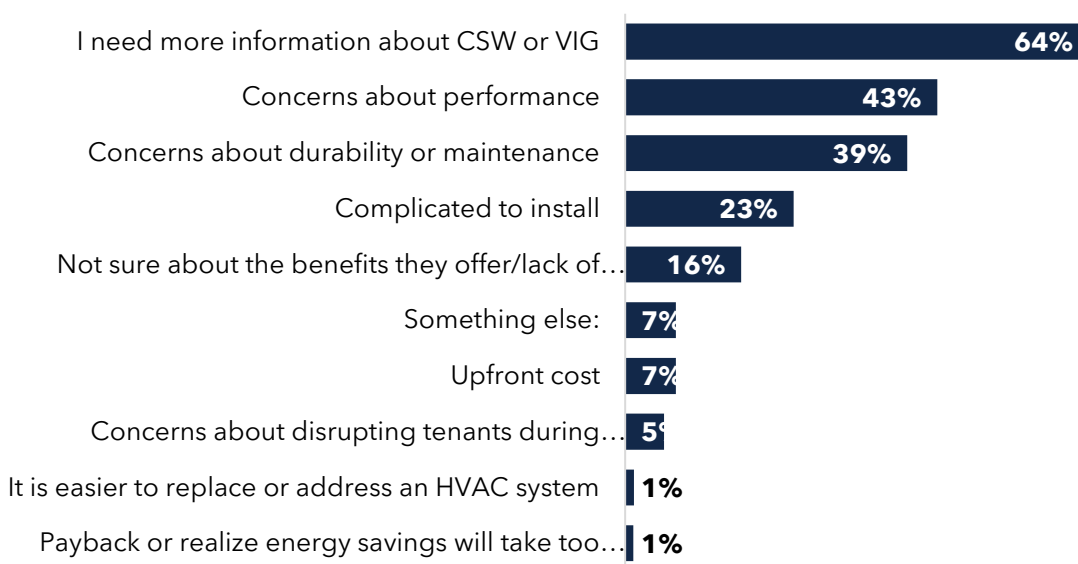
⁸⁷ Navigant Consulting. 2018. Commercial Windows Attachment (SGS) Initiative. Prepared for NEEA.

⁸⁷ SPR Consulting. 2023. Innovative and Cost-Effective Solutions to Improve Building Envelope Performance.

⁸⁷ Navigant Consulting. 2018. Commercial Windows Attachment (SGS) Initiative. Prepared for NEEA. <https://neea.org/wp-content/uploads/2025/03/commercial-window-attachments-sgs-phase-1-research.pdf>

⁸⁷ Energy 350. 2023. Commercial Secondary Windows Field Observations and Decision-Maker Interviews Report. Prepared for NEEA.

Figure 31. Top-Ranked Barriers to VIG or CSW Replacement or Upgrade



Source: CalMTA CRAWs Building Owner and Property Manager Survey Q F1: "What factors, if any, would prevent you from selecting CSW or VIG as a replacement or upgrade solution to your window needs? Please rank up to three factors, where #1 is the most important and #3 is the third-most important." (n=114). Results rounded to the nearest percentage.

6.11.2 Manufacturer interviews - barriers to CSW and VIG manufacturing and sales

CalMTA interviewed five manufacturers and asked about barriers negatively affecting the manufacturing and sale of these technologies for either CSW or VIG. One said that VIG faces difficulties due to the immaturity of U.S. manufacturing capacity. Interestingly, five of six manufacturers said that tariffs and economic uncertainty are negatively affecting their business but did not associate this disruption with a negative impact on manufacturing or sales capacity. One said that tariffs will slow the North American adoption of VIG manufactured in China, while three indicated tariffs are likely to increase the cost of raw materials.

When asked why a customer might decide not to buy CSW, manufacturers responded with a variety of reasons, including economic uncertainty, inability of the technology to meet a customer's needs, potential cost perceptions, and the presence of competing initiatives vying for retrofit funds. When asked the same question about VIG, all six manufacturers mentioned cost as a reason customers might decide not to purchase.

When asked how these barriers to adoption could be mitigated, two manufacturers mentioned government incentives. One said that an interior solution that does not change building aesthetics could allay some customer concerns.

6.11.3 ESCOs interviews - barriers to CSW and VIG sales

In CalMTA's interviews with ESCOs, cost was a key barrier, cited by two respondents. One noted that windows typically do not sell unless the out-of-pocket expense is low, and that utility incentives or state subsidies are often essential to make projects financially feasible. Another respondent pointed to broader market trends, stating that since 2023, permit applications for new buildings have declined by over one-third in many California cities. This respondent tied window retrofit activity to necessity, code compliance, and available financing.

ESCOs consistently cited cost as the primary barrier to VIG adoption. All four respondents indicated that budget limitations often prevent customers from moving forward with VIG projects. Two respondents noted that windows are usually considered a lower-priority upgrade, especially when there are competing renovation needs (e.g., roofing and HVAC). Unless there is a visible failure (e.g., leaks) or an insurance-driven replacement, VIG is often deprioritized in tight budgets. One respondent mentioned that even when customers understand the benefits, operational impacts and budget trade-offs can still derail the decision to move forward. Three out of four respondents reported positive or neutral perceptions of CSW and VIG reliability, especially when the products are installed by reputable contractors. One respondent had only received positive feedback, while another said that reliability concerns are rarely mentioned. One expressed skepticism, citing broader issues, such as maintenance costs and insufficient program funding, rather than problems with the products themselves.

When discussing efficient window solutions more broadly, cost again emerged as the most cited barrier (two of four respondents), particularly when projects require substantial out-of-pocket spending or lack access to long-term financing. Two respondents also mentioned operational and scheduling constraints, especially for sites like schools, where installation timelines are limited. One respondent raised concerns about product lead times and sourcing delays, while another emphasized the lack of consistent incentives and the need for more prescriptive rebate structures rather than custom ones.

Finally, one respondent highlighted the lack of customer education pertaining to CSW and VIG technologies, describing them as poorly understood and often perceived as a luxury. Additional concerns included the perception of tenant disruption during installation and skepticism about ROI claims due to limited or unclear market data.

6.11.4 Building owners and managers interviews - barriers to CSW and VIG adoption

Building owners and managers mentioned that the primary barriers inhibiting decision makers from pursuing window upgrades are cost related. Cost concerns, including both initial costs (labor, materials, and installation), and the opportunity cost of replacing windows for the energy savings they might experience, were explicitly mentioned by four of the six who had not addressed their window inventory. Another barrier mentioned by two respondents who operate medical centers was the time and disruption that come with major building upgrades, which is magnified in hospital settings where patients are treated. The one commercial-tenant business

owner who had VIG installed in their home stated that they would consider VIG for the commercial building if the cost was reasonable.

6.11.5 Tenants interviews - barriers to CSW and VIG sales

When asked about any barriers they perceived to the adoption of CSW and VIG, interviewed tenants highlighted the issue of decision-making authority. None of the tenants own the buildings where their businesses operate and therefore cannot independently implement upgrades. While some tenants can submit requests to landlords, the final decision typically lies with the property owner. This limits tenants' ability to pursue energy efficiency improvements, even if they are interested.

Other potential barriers emerged from these interviews regarding concerns around the cost of the products and installation. One tenant noted that both product and labor costs must be factored into the decision-making process. Additionally, the needs of businesses play a role in adopting these technologies. One tenant stated that window upgrades were not necessary for their building, suggesting that awareness of the benefits or urgency of such improvements may vary across tenants.

These insights suggest that ownership, financial considerations, awareness of benefits, and the needs of the business are tenant-perceived factors that influence the adoption of advanced window technologies in commercial settings.

Among surveyed commercial building owners/managers, lack of information was the top-ranked barrier (64%) to selecting CSW and VIG for a retrofit project, followed by concerns about performance (43%).

Manufacturers also highlighted limited customer awareness, particularly around the benefits and applications of CSW and VIG, as well as operational disruptions and scheduling constraints tied to installation. Tenants raised issues around decision-making authority, noting that even when they are interested in energy upgrades, the final decisions rest with property owners.

7 Supply-side characteristics

7.1 Key findings

- Interview responses from across groups (manufacturers, building owners and managers, and ESCOs) described a fragmented but interconnected network of market actors, with architects, contractors, glaziers, and general contractors commonly mentioned as influential in decision-making and delivery.
- Distribution channels for CSW and VIG products are diverse. Manufacturers distribute products directly to end users, as well as via contractors, glaziers, ESCOs, and manufacturer rep groups.

- A central, unifying theme is widespread concern over supply chain instability—tariffs on Chinese imports, geopolitical conflicts, and unpredictable lead times were repeatedly cited as major risks by manufacturers and ESCOs. These challenges complicate project planning and inflate costs, with some respondents noting extreme delays for imported products.
- Respondents expressed cautious optimism about emerging product trends such as electrochromic glass, solar-integrated windows, aerogels, and smart window technologies, though most of these remain costly or technically unproven for large-scale adoption.
- Window upgrades, particularly CSW and VIG, are rarely pursued as standalone projects. ESCOs consistently package these with other upgrades (HVAC, lighting, solar) to improve ROI and project feasibility.

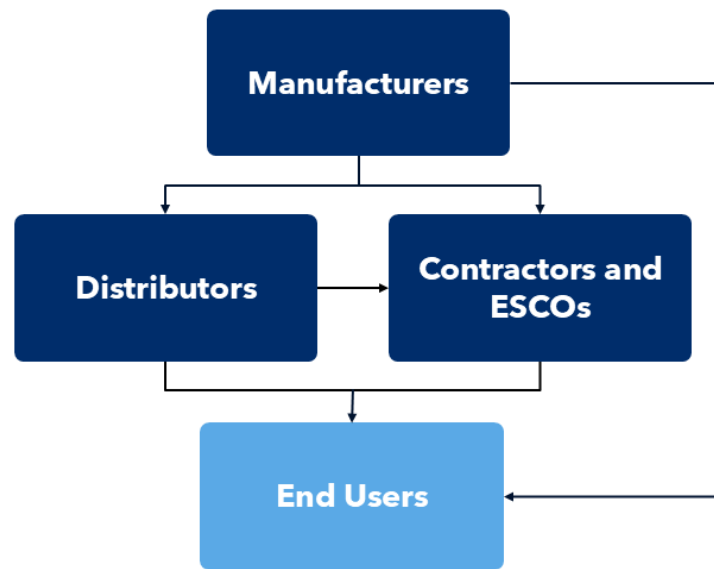
7.2 Supply chain map

Based on CalMTA’s interviews with CSW and VIG manufacturers, the supply chain for these technologies can vary substantially from project to project depending on size, end-user familiarity, and existing connections between the manufacturer, distributor, ESCO, and contractor or decision maker.

End users can take many paths to purchase a window. If an established line of communication and trust exists between a manufacturer and a building owner, manufacturers may provide windows directly. Otherwise, the manufacturer will provide windows via one or more intermediaries, which may include distributors, ESCOs, or installation contractors.

Figure 32 maps the CSW supply chain, which is well-established. In contrast, CalMTA’s interviews with manufacturers found that the VIG supply chain is still nascent in the U.S.

Figure 32. Commercial Secondary Window Supply Chain



7.3 Supply chain market actors and market channels

The NEEA study defined market actors as having either primary or secondary roles. The primary actors include the following:⁸⁸

- **Manufacturers** are primary actors; they manufacture and provide customized and standard solutions for windows. It is not uncommon for customers to interact directly with manufacturers. This helps in identifying the individual project needs.
- **Architects** often consult with general contractors but may recommend secondary windows.
- **Installers** are usually general contractors or glazers who work with all market actors in the building retrofit or window upgrade process.
- **Building owners and managers** are the individuals or groups who make decisions on projects for the buildings they own or manage.

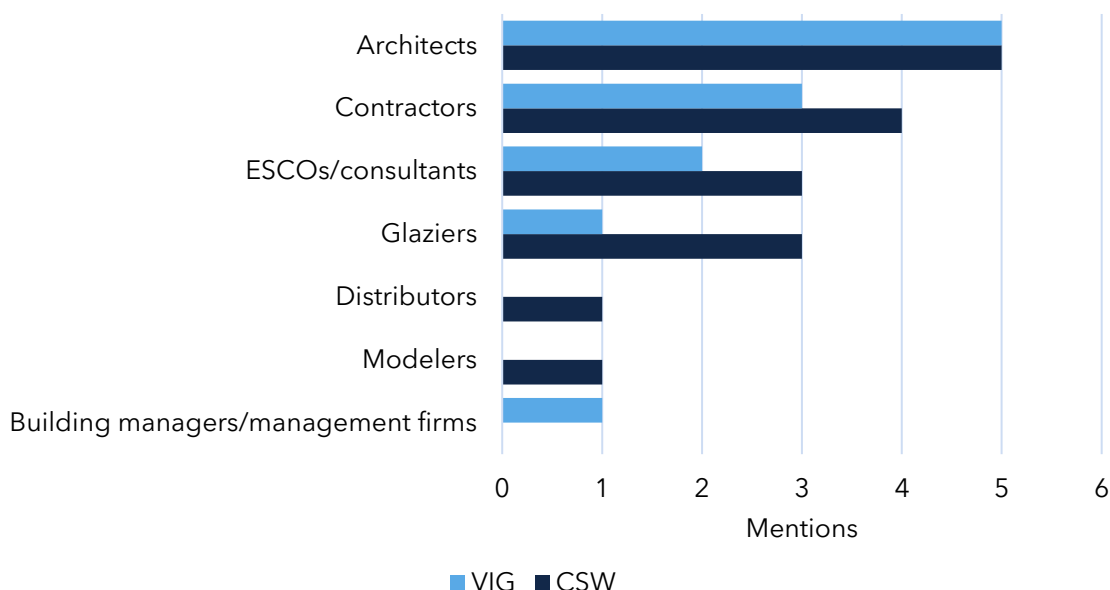
Secondary market actors provide support for the primary market actors:

- **Distributors** may offer different products. The NEEA study indicates that large manufacturers generally tend to engage distributors/dealers.
- **ESCOs** identify, specify, and manage energy efficiency projects that enable buildings to save energy and costs.

⁸⁸ Evergreen Economics. 2020. Commercial Window Attachments: Secondary Window Market Characterization. Prepared for NEEA.

In interviews, CalMTA gathered manufacturers' perspectives on the supply side of the market, asking them to identify key market actors and distribution channels they view as most influential in the window solutions market (Figure 33). Every manufacturer who responded to this question mentioned architects; no manufacturers considered modelers or distributors to be influential actors in the VIG market.

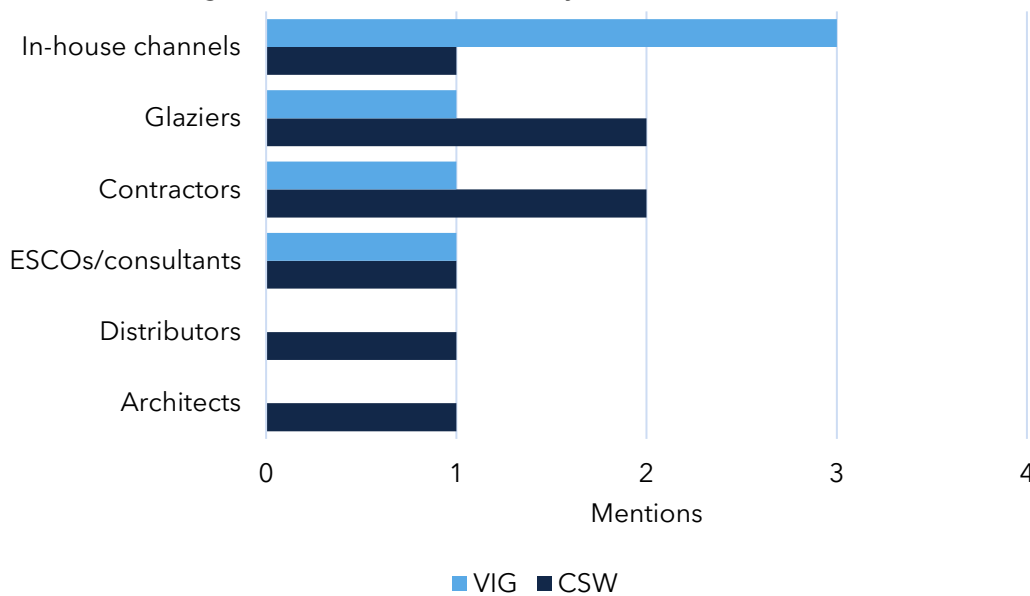
Figure 33. Manufacturers of VIG or CSW Identification of Key Market Actors



Source: CalMTA Manufacturer interviews Q D2: "Who are the key market actors that contribute to the sale, distribution, and installation of CSW solutions?" and Q D5: "Who are the key market actors that contribute to the sale, distribution, and installation of VIG solutions?" (n = 5)

Manufacturers also described the distribution channels commonly used for CSW and VIG products (Figure 34). They cited a variety of channels for CSW products, with glaziers and contractors each mentioned twice, and other channels mentioned once each. For VIG, three of five interviewees said that large manufacturers typically maintain in-house distribution channels.

Figure 34. Identification of Key Distribution Channels



Source: Manufacturer interviews Q D3: "What are the primary distribution channels for CSW equipment?" and Q D6: "What are the primary distribution channels for VIG equipment?" (n = 5)

ESCOs described a diverse network of actors in the window solutions market, including contractors, glazing subcontractors (mentioned as responsible for installation), design-build contractors, architects, and other ESCOs (mentioned as influencing decisions during early project phases). They explained that equipment selection is guided by technical, financial, and legal factors. One respondent outlined a detailed vetting they use to assess manufacturers—including reviewing their history, warranties, service coverage, and verifying they have a U.S.-based presence. Others described a collaborative approach with engineers, installers, and architects to evaluate technical fit and constructability. ROI remains central, with one noting that decisions are "almost always ROI based." ESCOs select installers based on a mix of trusted relationships and competitive bidding. One firm relies on a general contractor they regularly work with, rather than selecting window installers directly. Others prioritize past performance and proven reliability. Two respondents use RFPs or bidding processes, evaluating price, availability, and capacity. One respondent also mentioned a commitment to engaging diverse businesses.

ESCO projects involving CSW or VIG technologies are usually part of larger building upgrade packages. All three ESCO respondents who addressed this question cited HVAC and lighting as standard components, while two noted that adding controls, roofing, and envelope improvements is a common way to boost overall performance. Two respondents also mentioned pairing projects with renewable technologies such as solar panels, battery storage, and EV chargers, while one highlighted mechanical upgrades like motor replacements and variable-speed drives. Another mentioned solar film as a less disruptive, more cost-effective alternative to full window replacement.

7.4 Supply chain challenges

In interviews with manufacturers and ESCOs, supply chain challenges emerged as a continuing theme. When asked about trends affecting the supply chain for efficient window solutions, three of six manufacturers identified tariffs or the implications of escalating conflicts between the U.S. and China in current tariff negotiations. One explained that interest in high-efficiency technology is rising in the European Union and that their relationships with stakeholders there is moving much faster than those with U.S. firms because they are more supportive of energy-efficient technology and have higher efficiency standards in general than the U.S. Another said that construction is slowing down, causing contractors to diversify their project pipelines, typically by refocusing on the retrofit market; this manufacturer also mentioned that utilities and contractors are increasingly emphasizing the benefits of envelope retrofits and secondary windows, driving up demand for their products. Finally, a manufacturer of custom CSW solutions for historic buildings reported observing increased interest in adaptive reuse (i.e., conversion of office spaces to housing) and in historic preservation.

All respondents mentioned that supply chain challenges are a concern, reflecting broader issues across the building materials sector. Tariffs, especially on materials from China and Mexico, were cited by all four ESCOs who answered this question. Respondents described tariffs as chaotic and unpredictable, with some taking effect just hours before the interview. One respondent also mentioned logistical issues, such as high shipping costs and long lead times, which led to project delays or reductions in scope when materials were unavailable. One firm has tried to manage risk by buying in bulk and negotiating with vendors.

7.5 Lead times

The team asked manufacturers to estimate the lead times for their products and received a wide range of answers, from two to four weeks at the shortest to twelve to fourteen weeks at the longest (for a custom CSW manufacturer). Median lead time is five weeks for the lower bounds provided by interviewees and seven weeks using the upper bounds.

7.6 Emerging Technologies

CalMTA asked manufacturers about emerging technologies that were exciting or worrying and received a wide array of responses with no overlap. The only emerging technology that was mentioned as *exciting* more than once was windows that harvest energy via photovoltaics (PV). Manufacturers also discussed aerogel insulation, the application of a low-E coating that also produces heat, innovations in applied film products, and smart windows. One manufacturer said that VIG itself was an exciting emerging technology. When asked about *worrying* emerging technologies, four manufacturers had no response. One expressed worry at the lack of research and development

“Any solution that’s not taking both performance and weight into account is worrying. Adding additional weight to a façade just amplifies the complexity of the project.”

–CSW Manufacturer

funding (not technology, but rather the lack of exploration into new technologies), and one said that they were worried about any technology that does not take both performance and weight into account. This manufacturer also expressed worry over the longevity of VIG products, especially their steel components.

Respondents representing ESCOs expressed cautious optimism about emerging technologies. Two ESCO interviewees highlighted interest in electrochromic glass, including VIEWGLASS,[®] which offers on-demand tinting, but noted its high cost and the need for full lifecycle evaluation before broader adoption. Another respondent was most excited about the shift toward electrification and decarbonization, particularly the move from fossil fuel systems to electric HVAC solutions. One respondent did not have specific technologies they were excited about. Instead, they focused on upgrading legacy systems with improved versions of existing technologies like lighting, HVAC, solar, and batteries.

8 Costs and benefits

8.1 Key findings

- Among the three CSW manufacturers who provided price points for their products, two were less expensive per square foot than the average low-E double-pane window.
- VIG manufacturers were only able to provide speculative price points, but both agreed that once manufacturing capability is mature, VIG will have a similar price point to standard double-pane windows.
- Three of six ESCOs asserted that CSW and VIG projects are more expensive than traditional window replacements, with one calling the difference “outrageous,” though one noted the potential long-term value if paired with energy savings and lifecycle performance. This opinion contrasts starkly with the affordable market price and supposed ease of installation of CSW technology highlighted by manufacturers and indicates an informational asymmetry between manufacturers and ESCOs regarding costs.
- While non-energy benefits such as thermal comfort and noise reduction were appealing to building owners, several emphasized that these benefits alone were insufficient to justify a window upgrade. Projects had to demonstrate tangible energy cost savings and good ROI to be considered viable.
- Tenants who could speak to benefits cited aesthetics, noise reduction, and leak prevention. However, most declined to discuss the issues related to cost and financing knowledge and recommend that we speak with property owners or window installers, underscoring their limited role in capital improvement decisions.

8.2 Price points

CSW and VIG products are highly customized, which makes reliable price data limited and often inconsistent across available sources. To estimate price ranges, CalMTA relied on information from field studies, case studies, pilot projects, industry experts, and public retail pricing when available. CalMTA was unable to secure reliable cost data for standard commercial windows.

For CSW, we found an average installed cost of approximately \$40 per square foot.^{89,90,91,92} CalMTA's interview with an industry expert, along with pilot study data, indicates VIG prices range from \$25 to \$100 per square foot. Table 28 provides average costs per square foot for VIG and CSW.

Table 28. Average Installed Cost of CSW and VIG

Category	Average Installed Cost	Notes
Typical CSW	\$32 - \$44/ sq ft ⁹³	The average cost is based on various sources, including manufacturer retail prices, industry reports, and a California school case study, and represents a range.
Typical VIG	\$25-\$100/ sq ft ⁹⁴	The VIG average cost is an estimate based on a market expert interview.

Sources: CSW Cost: AERC (2023); Indow (2025); NEEA (2023); CalMTA, Madison Elementary Field Test (2025). VIG: CalMTA personal interview, Nov. 6, 2025.

8.3 ESCO perspective on CSW and VIG

CalMTA asked ESCOs about the costs of advanced window solution projects compared to traditional window replacements. All three respondents who answered this question indicated that installation costs of CSW and VIG technologies are greater than traditional window replacements. One respondent acknowledged the premium but emphasized potential long-term value through better lifecycle performance and energy savings. Still, the perceived high upfront cost remains a major obstacle, especially without stronger incentives. This conflicts with statements from some manufacturers that CSW are roughly as affordable as standard double-

⁸⁹ Attachments Energy Rating Council. 2023. CSW Technical Factsheet. May

2023. <https://aercenergyrating.org/wp-content/uploads/2023/05/CSW-Technical-Factsheet.pdf>

⁹⁰ Indow Windows. (n.d.). Commercial window inserts. <https://indowwindows.com/products/commercial-window-inserts>

⁹¹ Field study site at Madison Elementary in the Madera Unified School District CalMTA (2025)

⁹² Northwest Energy Efficiency Alliance. 2023. Commercial Secondary Windows field test (Report No. E23-341). Energy 350. December 18, 2023. <https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Windows-Field-Study.pdf>

⁹³ We have provided a range for the CSW costs. Some sources include installation and unit costs, while other sources available offer solely unit costs. For example, AERC mentions CSW installed cost being as "little as" \$32/sq ft including material and installation, Indow quotes unit cost at \$44/sq ft (\$40/sq ft for bulk pricing), and a NEEA field study cites an average installed cost of \$38.57/sq ft across six installation projects.

⁹⁴ CalMTA personal interview November 6, 2025.

pane windows and indicates a disconnect between perceived and actual cost of CSW among manufacturers and ESCOs. This may reflect the following issues:

- Lack of awareness or transparency around actual pricing
- Mistrust or outdated assumptions among purchasers
- Additional costs related to installation or supply chain that are not accounted for by manufacturers

8.4 Building owners and managers' perspectives on CSW and VIG

CalMTA asked decision makers about the cost considerations that would impact their decisions to upgrade their buildings, specifically their windows. None of the respondents know how much CSW or VIG might cost, but most (five out of eight) stated that access to public funding (such as utility rebates or federal tax incentives) was essential to any project. In the absence of public funding, window upgrades, which are already generally viewed as a lower priority compared to other needs, become an afterthought. Other avenues to funding include donations and private financing. One respondent noted that while they relied on some donations for retrofit projects, they only covered a fraction of the cost. Four respondents said that they would seek private financing through loans or company capital funds, but only if public financing was unavailable, and usually only in emergency situations.

“Often these types of projects are not the highest priority. Unless something is broken or we are forced to replace it, these projects get pushed aside.”

-School building manager

Respondents in the interview identified several non-energy benefits as primary motivating factors to seek out window upgrades, including increased thermal comfort, noise reduction, and improved air quality. However, several respondents noted that while non-energy benefits are good, they ultimately only matter if their performance can be quantified by energy cost savings. One university administrator noted that “non-energy benefits are more of a luxury, or secondary, to how much money we will save.” Additionally, one commercial building owner noted that limited availability of VIG products could influence decision-making, as window replacements are often time-sensitive and need to be completed quickly.

8.5 Commercial tenant perspective on CSW and VIG

CalMTA asked commercial tenants if they had any awareness of the cost and benefit considerations that would impact the likelihood of their buildings undergoing window upgrades. Due to low familiarity with the specified technology and inability to make building upgrade decisions, most tenants were unable to provide detailed input on cost or benefit considerations.

No tenants provided answers about the benefits of CSW. One tenant mentioned that VIG helped with noise reduction, leak prevention, and improved aesthetics.



When asked more generally about the benefits of efficient windows, two tenants had a clear understanding that installing advanced window technologies would likely reduce operational expenses. One tenant noted that better insulation and energy efficiency would help lower costs and have even encouraged the building owner to pursue upgrades. Another tenant confidently stated that operational costs would “go down, no question,” and believed installation would not extensively disrupt business operations, estimating a one-day installation period.

These responses suggest that while some tenants recognize the long-term financial benefits of building upgrades, there is limited awareness or discussion around specific technologies. This reflects the broader trend of tenants not being primary decision makers for capital improvements.

8.6 Financing

This section summarizes interview insights on financing for window upgrades. Manufacturers generally reported low awareness of or involvement with financing, noting that customers usually secure funding independently. ESCOs observed that financing is limited but gradually improving through state programs and green lenders. While improving, ESCOs noted that available financing typically supports only those projects with strong returns. Building owners emphasized that public incentives like rebates and tax credits are essential to build momentum in the market.

8.6.1 Financing insights from market actor interviews

Manufacturers

CalMTA asked manufacturers for information about financing mechanisms utilized by their customers. Four of six manufacturers said they were not aware of any financing mechanisms that their customers use for CSW, and all six stated they were not aware of any for VIG. Of the two that were familiar with such mechanisms for CSW projects, one mentioned traditional equipment leasing, construction loans, and “energy as a service” or “pay-for-performance” contracts where customers pay for retrofits in installments rather than up front; the other mentioned commercial property assessed clean energy programs and equipment lenders.

“Our assumption is that a sophisticated commercial building owner has their own line of credit.”

-CSW Manufacturer

When asked whether they have any concerns about financing for CSW projects, five of six stated they had none. The remaining manufacturers indicated their concerns include low occupancy rates reducing available capital, the value of real estate assets, and the ability of commercial building owners to secure loans (a concern which is exacerbated for commercial building owners in ESJ areas).

ESCOs

CalMTA asked ESCOs about their experiences with helping customers finance advanced window solution projects. Respondents indicated that financing for window upgrades is limited but beginning to improve. One noted that none of the 600-plus projects they had completed annually



since 2007 used third-party energy financing. However, they highlighted a new state-subsidized program that includes windows and stated they had two projects that might use it. Others reported offering flexible internal financing solutions, with one firm noting that it can act as the bank by delaying invoices and applying a finance charge. Another respondent described working with green banks, utility incentives, and lenders to help finance retrofits, demonstrating that public-private financing partnerships are a viable pathway.

Still, financing remains rarely used by most customers and is typically limited to nonprofits or budget-constrained organizations. One respondent asserted grants and incentives are more commonly used, with low-cost financing mainly appealing to clients lacking capital.

Views on financing concerns varied. One ESCO respondent mentioned the topic arises “every day,” highlighting capital access as a frequent barrier. Another noted that it is rarely discussed, as their clients seldom use financing. A third explained that financing can improve strong projects but will not justify those with poor ROI. Overall, ESCOs discussed financing as a tool to support viable projects rather than a solution for uneconomic ones.



Attachment A: Weighting Methodology

To ensure that survey results accurately represent the building stock in California, weights were developed at building type level using population data from publicly available sources (ComStock/CBECS).⁹⁵ Each building type is assigned a single, unique weight that is applied uniformly across all respondents within a given building type, treating each respondent equally within building types.

$$\text{Weight for Building Type}_b = \frac{\text{Population Square Footage of Building Type}_b}{\sum \text{Buildings}_{bi} \times \text{Square Footage}_{bi}}$$

Where:

Population Square Footage of Building Type_b = Total Population square footage of the building type owned or managed by respondent_i

Buildings_{bi} = Number of buildings owned or managed by respondent_i

Square Footage_{bi} = Average Square Footage of Buildings Owned or managed by Respondent_i of Building Type_b

Post stratification weighting is applied so that the survey responses are normalized to the targeted population, which CalMTA defined as specific building types in California's building stock, reflecting the relative share of the building types in the targeted population rather than the distribution in the sample.⁹⁶ This was necessary because the raw survey data overrepresents building types that make up a smaller percentage of the population share of the California building stock (colleges/schools) and underrepresents building types that account for a larger share (offices, non-college schools).

⁹⁵ CBECS and Comstock were used to develop the square footage for population

⁹⁶ The building segmentation is described in Section 2.2, Target market, and includes College/University, Healthcare, Lodging, Office, School (non-College/University)

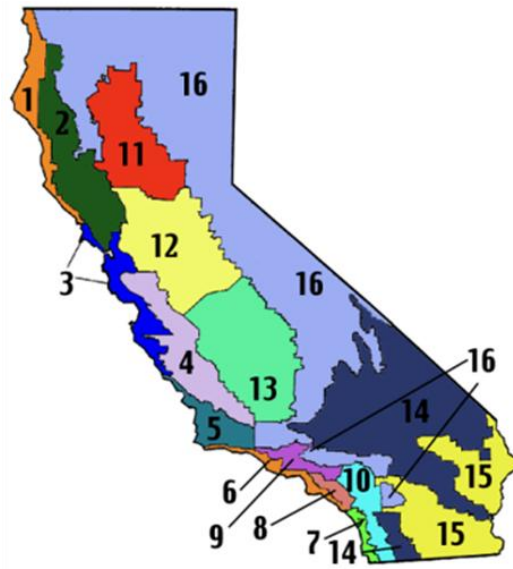
Attachment B: Zip Code and Climate Zone Mapping

CalMTA classified survey respondents by climate zone and regions. To identify the climate zone for the survey sample, we applied the California Energy Commission (CEC) mapping of zip code to California Building Climate Zones.⁹⁷

CalMTA then developed broader definitions of climate regions for the survey sample by mapping the CEC climate zones to regions, as identified by the CPUC Impact Evaluation of Water Heating Measures report.⁹⁸ These climate regions include the following (also depicted in Figure 35):

1. Coastal Climate Region: Includes CEC climate zones 1, 2, 3, 4, 5, 6, 7, and 16.
2. Inland Climate Region: Includes climate zones 8, 9, 10, 11, 12, 13, 14, and 15.

Figure 35. CEC Climate Zones



Source: DNV. 2019. *Impact Evaluation of Water Heating Measures*. Retrieved from https://www.calmac.org/publications/CPUC_Group_A_Report_Water_Heating_PY_2019_Final_CALMAC.pdf

⁹⁷ <https://www.energy.ca.gov/media/3560>

⁹⁸ DNV. 2019. *Impact Evaluation of Water Heating Measures*. Retrieved from https://www.calmac.org/publications/CPUC_Group_A_Report_Water_Heating_PY_2019_Final_CALMAC.pdf

Attachment C: Research Instruments

[CalMTA CRAWs Building Owner/Manager Online Survey](#)

CalMTA CRAWs Interview Guides:

- [CRAWs Tenant + Business Owner Interview Guide](#)
- [CRAWs ESCO Guide](#)
- [CRAWs Installer Guide](#)
- [CRAWs Manufacturer Guide](#)
- [CRAWs MUSH Interview Guide](#)



CRAWs Market Characterization Report

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Commercial Replacement and Attachment Window Solutions Market Transformation Initiative

Appendix E: External Program Alignment & Coordination

June 26, 2026

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Appendix E: External Program Alignment & Coordination for CRAWs

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List of Abbreviations¹

Abbreviation	Definition
C&S	Codes and Standards
CEC	California Energy Commission
CEDA	California Energy Design Assistance
CEE	Consortium for Energy Efficiency
CPUC	California Public Utilities Commission
CRAWS	Commercial Replacement and Attachment Window Solutions
EPIC	Electric Program Investment Charge
EPRI	Electric Power Research Institute
ESJ	Environmental and Social Justice
HVAC	Heating, Ventilation, and Air Conditioning
LADWP	Los Angeles Department of Water and Power
LBNL	Lawrence Berkeley National Laboratory
MT	Market Transformation
MTAB	Market Transformation Advisory Board
MTI	Market Transformation Initiative
MUSH	Municipal, University, School, Hospital
NEB	Non-Energy Benefit
NEEA	Northwest Energy Efficiency Alliance
OBFC	On-Bill Financing
PA	Program Administrator
PG&E	Pacific Gas and Electric Company
PNNL	Pacific Northwest National Laboratory
RA	Resource Acquisition
REN	Regional Energy Network
RFI	Request for Ideas
RFP	Request for Proposals
SCE	Southern California Edison
SEM	Strategic Energy Management
SoCalGas	Southern California Gas Company
SoCalREN	Southern California Regional Energy Network
USGBC-CA	U.S. Green Building Council California
WE&T	Workforce Education and Training

¹ Acronyms for organizations and programs referenced only once in this Appendix are not included in this list.



Appendix E: External Program Alignment & Coordination for CRAWS

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1 Introduction

This document describes CalMTA's approach to engaging with external programs and efforts throughout development of the Commercial Replacement and Attachment Window Solutions (CRAWS) Market Transformation Initiative (MTI) as well as plans for future coordination with these entities during MTI implementation.

The Market Transformation (MT) Framework attached to the California Public Utilities Commission (CPUC) D.19-12-021, which established CalMTA, called for MT ideas that are developed to "carefully consider" potential impacts on resource acquisition (RA) program(s) and codes and standards (C&S) implementation. The framework recognizes the value of collaboration within a target market, noting that CalMTA and "any impacted [program administrator(s)] [PAs], 3P implementers (3PIs) of RA programs, and C&S teams each have a role in charting a course that enhances the efficiency outcomes [...] of the proposed MTI as well as of RA and C&S programs. Each may also have a role in eliminating or minimizing and mitigating any conflict between the MTIs and RA/C&S programs. The parties should work collaboratively toward these objectives as much as possible."²

CalMTA built on this guidance and proactively engaged external program stakeholders at each stage of our MTI development process to leverage and align with other programs and efforts in a mutually beneficial way. Market transformation views the presence of other programs working in a target market as leverage – the type of "positive overlaps" described in D.19-12-021.³ Traditional RA or incentive programs serve as a point of leverage the MTI will use to drive increased adoption and sustained market change; the strategic market-level interventions identified for the MTI will in turn complement and add value to existing energy efficiency efforts in the state for the mutual benefit of each program. CPUC Decision 25-11-023, which approved CalMTA's first MTIs for market deployment, affirmed this, stating: "Our thinking is most aligned with the comments of the Northwest Energy Efficiency Alliance (NEEA), where they point out that MTIs and resource acquisition programs that are coordinated can achieve synergies and deeper savings than either approach may be able to accomplish on its own."

As such, CalMTA's coordination with external programs seeks to identify "points of alignment" that explain how an MTI will work synergistically with an existing program and will be critical to successful MT implementation in order to: 1) limit consumer and market confusion, 2) enhance the ability of programs to achieve their goals, 3) overcome barriers to a program serving a unique market segment, and 4) ensure effective use of program and CalMTA resources by aligning activities. Because the MT ideas under development vary, their relationship and need for alignment with established or emerging programs in the energy efficiency portfolio vary. However, our approach and process for minimizing overlap of these MTIs with existing efforts and

² See D.19-12-021, p. 133.



optimizing alignment for the benefit of both the MTI and the established program are consistent across all MTIs in development.

The sections below describe the engagement completed to date as well as plans for formalizing the ways in which the CRAWs MTI and current programs will align in Phase III: Market Deployment to maximize leverage and enhance outcomes.

2 Alignment in each development phase

CalMTA conducts engagement activities for each MTI throughout our [three-phase development process](#). Recognizing that Phase III activities will commence after the MTI Plan is approved by the CPUC, we have described the activities we will pursue at that time in Section 2.3. While Phase I activities and preliminary outreach on Phase II activities were completed prior to the filing of this plan, ongoing engagement will take place to further evolve collaborative relationships and better understand points of alignment between the MTI and external programs prior to market deployment.

At every phase, coordination activities seek 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 the scalability and efficiency with which desired results are achieved by leveraging existing work.

2.1 RFI to Phase I MT Idea Selection (Aug. 2023 – Sept. 2024)

CalMTA identified the CRAWs idea through a Request for Ideas conducted by CalMTA during the summer of 2023. Staff officially prioritized this idea in collaboration with the Market Transformation Advisory Board (MTAB) through threshold review, two stages of scoring, and official approval to move forward to Phase I in Jan. 2024.

During Phase I, CalMTA identified a preliminary set of local, state, and national programs for future coordination and summarized in Section 6 of the [CRAWs Advancement Plan](#) that concluded Phase I development. We finalized that Advancement Plan in Sept. 2024.

Channels to engage directly with these and other interested parties during the development and review of the Advancement Plan included direct collaborative meetings that allowed for an exchange of information, as well as formal opportunities to provide feedback on the plan through public meetings and public comment through the CPUC Energy Division's Public Document Area (PDA). These engagements sought to identify additional programs or activities to consider for coordination as well as to assess the extent of potential overlap between the MT idea and current energy efficiency or related programs. Specifically, CalMTA's external engagement activities included the following:



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- **MTAB meetings**, which are open to the public, allow CalMTA to share information and receive feedback about developing MT ideas. MTAB members can ask questions and make comments; public attendees can also do so at a designated time and through an online form.
- CalMTA offered **official opportunities to comment** on the CRAWs Advancement Plan via the CPUC's PDA site from June 19 – July 11, 2024. We received a total of 22 comments from eight submitters, including energy efficiency program implementers, manufacturers, and MTAB members. CalMTA provided [a formal response to these comments](#) and integrated feedback into the final Advancement Plan when applicable.
- We held **regular meetings with the IOU Codes & Standards working group**, which includes representatives of the Statewide Codes and Standards Advocacy Program and related subprograms. These meetings allow CalMTA to identify relevant codes/standards activities that can be leveraged in each market, ensure alignment and consistency when engaging with market actors, and share key findings from each team's product research and testing.
- **Regular coordination calls with California's electric Emerging Technology Program (CalNEXT)** inform participation in CalMTA's request for ideas (RFI) and public comment processes and seek to enable collaboration related to CalNEXT's Technology Priority Maps and focused pilot scoping.

2.2 Phase II Advancement Plan research to MTI Plan finalization

Throughout Phase II, the activities described in Section 2.1 continued but expanded to yield deeper knowledge about other program/research efforts and how they related to the developing MTI. These activities included the following:

- **Expanded research.** We further developed our list of potentially overlapping external programs through additional research and discovery. Identified programs and related organizations reflected those that are currently active in the target market for this MTI and offer opportunities for potential leverage, alignment, or co-creation/partnership. Related programs with potential alignment needs are described in Section 3 of this Appendix.
- **Market characterization work.** Structured interviews with key stakeholders and subject matter experts, including program administrators and implementers, helped inform CalMTA's understanding of the current market as summarized in Appendix D: Market Characterization Report.
- **Direct engagement.** In addition to ongoing meetings with the IOUs' C&S programs and energy efficiency portfolio directors, CalMTA's MTI research and development efforts in 2025 were supported by individual and small groups of stakeholders working in this market. Because envelope measures like CRAWs are not yet a significant component of traditional energy efficiency incentive programs in California, direct engagement prioritized market transformation, research, and emerging technology efforts from organizations and programs



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that include the California Energy Design Assistance Program, the CEC Electric Program Investment Charge (EPIC) program, the Electric Power Research Institute (EPRI), Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory (PNNL), Self-Help Enterprises, and the U.S. Green Building Council California (USGBC-CA).

- **Idea to Initiative Educational Campaign.** To help educate MTAB members, program representatives, and other interested parties about the CRAWs MTI Plan, CalMTA deployed an educational campaign with a series of presentations to share vital aspects of the plan. Individual sessions focused on the MTI theory and logic model, product assessment, market characterization research, market progress indicators, market forecasts, cost-effectiveness analysis, and other vital components. Information delivered through the Idea to Initiative educational campaign can be found at <http://www.calmta.org/idea-to-initiative>.
- **MTAB and public review of draft MTI Plan.** The Draft MTI Plan was posted for review and comment by MTAB members and the public via the CPUC Energy Division's PDA site in May 2026. Appendix I of this MTI Plan provides a summary of CalMTA responses to comments from MTAB members and the public.

2.3 Planning for collaboration in Phase III: Market Deployment

Prior to moving the CRAWs MTI into Phase III implementation, CalMTA will continue to engage external programs and entities promoting this technology to stay current on the changing mix of program offerings, continue to strengthen relationships, and ensure the MTI adds value to the market while avoiding duplication of efforts. Because the MTI is unlikely to enter the market deployment phase until mid-2027, we anticipate that new programs will have launched and that current programs may ramp down or evolve by then. Our ongoing engagement will help us refine our coordination strategy as needed upon CPUC approval of this MTI.

Planned activities in this stage include the following:

- **Coordination agreements with external programs.** CalMTA recognizes the need for formal documentation, developed jointly with PAs working in markets that have potential overlap with the CRAWs MTI, describing the coordination approach used 1) eliminate duplication or redundancy in market activities, 2) ensure that each 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 CalMTA and PA offerings achieve their respective goals. The resulting memos will document identified areas of alignment between the MTI and relevant PAs' portfolios, as well as the agreed-upon approach to mitigating overlap between our respective work. Memos will be updated annually or as needed and will guide the cadence and intensity of coordination efforts based on potential for overlap.
- **Ongoing monitoring and tracking.** As previously mentioned, CalMTA understands that the statewide and national energy efficiency market will evolve before this MTI moves into Phase III and will closely monitor planned future programs with potential alignment/overlap to



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supplement the list of currently identified programs found in Section 3. As new programs launch or existing programs re-launch, we will meet with PAs and implementation teams to ensure early alignment on implementation planning and coordinate related activities between that program and the MTI. This engagement may result in deeper collaboration that allows for co-creation or co-delivery of mutually beneficial activities, such as workforce development or product testing.

- **Request for Proposal (RFP) planning.** After CPUC approval of the CRAWs MTI Plan (expected in 2027), CalMTA will issue an RFP to solicit an implementation contractor. Leading up to that event, CalMTA will use regular meetings with key stakeholders to further develop details related to the points of alignment between the MTI and external programs. This coordination will surface and provide transparency on issues that may need to be addressed in the future.
- **MTI contracting and implementation.** In alignment with guidance in the CPUC MT Framework, the future RFP for CRAWs MTI implementation will include a distinct scope of work related to external program coordination and alignment. Describing their approach to this implementation area will require bidders to, as described in the CPUC Decision, “include a discussion of how their potential MTIs would dovetail with existing RA/C&S implementation effort(s).”³
- **Implementation collaboration.** After the MTI moves into market deployment, CalMTA will continue to monitor established points of alignment to ensure they address all potential overlaps between the MTI and existing external programs. We will report and discuss these efforts through regular meetings with IOUs and third-party implementers of related programs, especially for activities that involve end-use customers that may be solicited by or likely to participate in a statewide or local efficiency program. These milestones and ongoing touchpoints will help avoid market confusion, ensure points of alignment stay consistent, and provide an opportunity to adjust strategies, if needed.
- **Market progress evaluation.** As part of the MTI implementation, CalMTA will also contract with a third-party evaluator to review ongoing activities and measure progress toward MTI objectives. The resulting Market Progress Evaluation Reports are public documents and will be shared with external program teams and other interested parties. If a strategic intervention that impacts external programs does not result in the expected outcomes, the MTI may change course. In that case, CalMTA program managers will work with external teams to adjust as needed.

³ See D.19-12-021, p. 136.



Appendix E: External Program Alignment & Coordination for CRAWs

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3 Priority programs for alignment

Table 1 below summarizes the key areas for external program alignment and coordination identified by CalMTA during development of the CRAWs MTI Plan. 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 1. 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 U.S. Department of Energy/ENERGY STAR
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 U.S. Department of Energy (DOE) National Labs (e.g., LBNL or PNNL) and research universities California Energy Commission Energy Research and Development Division projects, particularly the Electric Program Investment Charge (EPIC) and Gas Research and Development Program
Statewide or regional incentive programs provide important 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.	California Energy Design Assistance (CEDA) Program major retrofit projects Southern California Edison (SCE) Commercial Energy Reduction Initiative (CERI) Program and Willdan's Comprehensive Commercial Program IOU Energy Savings Assistance (ESA) Multifamily Energy Savings Program (whole-building)



Appendix E: External Program Alignment & Coordination for CRAWs

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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 heating, ventilation, and air conditioning (HVAC) - Multifamily programs that include common area or envelope measures - Programs focused on the MTI's beachhead municipal, university, school, hospital (MUSH) market.	Southern California Regional Energy Network (SoCalREN) Multifamily Program Los Angeles Department of Water and Power (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 may opt 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 focused on a single measure but rather holistic energy performance.	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) 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

In addition to leveraging existing market activities and minimizing any potential duplicative efforts, CalMTA's coordination with these programs will allow us to share resources and deploy services that will enable external offerings to meet their goals more efficiently and effectively. Potential support for external programs through the CRAWs MTI may include:

- 1) CalMTA messaging research and subsequent marketing materials that can be shared with and customized for other parties to utilize



Appendix E: External Program Alignment & Coordination for CRAWs

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- 2) Increased product availability and product enhancements through CalMTA's market actor engagement
- 3) Data-sharing, including any data obtained by CalMTA through field testing or demonstration products, as well as sales data obtained through supply chain engagement.

More detailed information about these programs and their targeted impact on the CRAWs market can be found in Appendix D: Market Characterization Report.

4 Applying an equity lens

The Adopted MT Framework attached to D.19-12-021 establishes high-level principles that every MTI should aim to achieve, including a directive to "integrate strategies to maximize equity."⁴ To better understand opportunities to align potential MTIs with environmental and social justice (ESJ) community needs, CalMTA held a series of listening sessions with ESJ representatives in fall 2023. Cross-cutting insight from these sessions informed development of internal guides for integrating equity into MT research practices, logic model development, and intervention strategies, which are now in use across the MTI teams and were referenced throughout Phase II CRAWs activities. A [report summarizing key takeaways from the listening sessions](#) is available on CalMTA's website.

In 2025, formation of CalMTA's Equity Sounding Board enabled additional engagement that helped shape the CRAWs MTI Plan. Comprised of professionals who advocate for or work within ESJ communities, the Equity Sounding Board seeks to ensure that MTIs positively impact ESJ communities by guiding outreach activities, identifying actions that may cause unforeseen harm, and serving as a resource of equity-oriented feedback on CalMTA's work. In 2025, CalMTA coordinated two consulting sessions with the Equity Sounding Board to help shape logic model inputs for the CRAWs MTI, as well as the market progress indicators used to measure its success in achieving equitable outcomes. CalMTA also engaged Equity Sounding Board members in identifying connections to potential contacts for CRAWs market research focused on California clinics and hospitals.

These consultations yielded important insight into market barriers that need to be removed and the strategic interventions that should be deployed for the MTI to have its desired impact, with a focus on topics with particular relevance to ESJ communities, as well as how to best track the MTI's progress from an equity perspective. Specific feedback received and integrated into this MTI Plan includes:

- Efficient windows have traditionally faced greater barriers to adoption compared to other measures due to their cost and payback period. The CRAWs logic model's market-level interventions target medium-term outputs that will mitigate the upfront cost of these products

⁴ See D.19-12-021, p. 102.



through increased availability of incentives for CRAWs products and evaluating envelope as part of HVAC upgrades, Strategic intervention #3, which seeks to build an “envelope-first” business case for building retrofits, will also help clarify the overall return-on-investment for these products as a component of building energy performance.

- There is a significant need for CRAWs upgrades in schools located in high pollution areas and/or with high rates of childhood asthma, as well as other environmental impacts. In addition to informing CalMTA's decision to conduct our Phase II field study at a public school in a high-pollution area, with the location identified through an Equity Sounding Board member's organization, the CRAWs MTI will focus initially on the MUSH market, which will benefit schools like these. Strategic intervention #2, which focuses on in-field demonstrations, will build on this initial work to target ESJ communities with projects that can evaluate IAQ improvements and engage with diverse CBOs for workforce development.
- The need for more equitable and widely accessible financing surfaced repeatedly in conversations with ESJ community representatives. Strategic intervention #7 (*Demand-side marketing and support: awareness-building, education and financial tools*) is designed to prioritize financing models with the potential to reduce or eliminate upfront costs in ESJ communities, such as green banks, green bonds, C-PACE, California's GoGreen Financing Program, and on-bill financing. Monetizing the non-energy benefits (NEBs) of CRAWs technology and educating financing providers about their value will further bolster the financial support available to consumers who most need it.



Appendix E: External Program Alignment & Coordination for CRAWs

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Commercial Replacement Attachment Window Solutions (CRAWS) Market Transformation Initiative

Appendix F: Evaluation Plan

June 26, 2026

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List of Abbreviations

Abbreviation	Definition
AERC	Attachment energy rating council
BMA	Baseline market adoption
BOMA	Building Owners and Managers Association
BPS	Building performance standards
C/E	Cost Effectiveness
CA	California
CalMTA	California Market Transformation Administrator
CalSHAPE	California Schools Healthy Air, Plumbing, and Efficiency
CBEA	Commercial Building Efficiency Accelerator
CBO	Community based organization
CCA	Community choice aggregators
CEDARS	California Energy Data and Reporting System
C-PACE	Commercial Property Assessed Clean Energy
CPUC	California Public Utilities Commission
CRAWS	Commercial Replacement Attachment Window Solutions
CRE	Commercial real estate
CRTU	Commercial Rooftop Unit
CSW	Commercial Secondary Window
DAC	Disadvantaged Community
DOE	Department of energy
DPC	Double pane clear
EE	Energy efficiency
EM&V	Evaluation, measurement, and verification
ESA	Energy Savings Assistance
ESCO	Energy service companies
ESJ	Environmental and social justice
FGIA	Fenestration and Glazing Industry Alliance
HVAC	Heating, ventilation, and air conditioning
IFMA	International Facility Management Association
IOU	Investor-owned utility
LBNL	Laurence Berkely National Lab
Mfr	Manufacturer
MPI	Market Progress Indicator
MTI	Market Transformation Initiative
MUSH	Municipalities, universities, schools, and hospitals



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Abbreviation	Definition
NEB	Non-energy benefit
NFRC	National Fenestration Rating Council
NREL	National Renewable Energy Lab
PA	Program Administrator
PAWS	Partnership for Advanced Windows
PNNL	Pacific Northwest National Lab
PTLM	Program theory and logic model
REN	Regional energy networks
SEM	Strategic energy management
SHGC	Solar heat gain coefficient
SP	Single pane
TBD	To be determined
TBE	Theory based evaluation
TMA	Total market adoption
TRM	Technical reference manual
UEI	Unit energy impacts
VIG	Vacuum Insulating Glass



Appendix F: Evaluation Plan for Commercial Replacement & Attachment Window Solutions

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1 Introduction

The evaluation approach to the Commercial Replacement Attachment Window Solutions (CRAWS) Market Transformation Initiative (MTI) will follow the guidelines outlined in the [CalMTA Market Transformation Initiative Evaluation Framework](#) for assessing MTI performance and market progress. The CRAWS MTI envisions a long-term outcome of 14% of the existing commercial window square footage of addressable buildings to utilize Commercial Secondary Windows (CSW) by 2047.

Evaluation is essential to the development and successful management of market transformation programs. California Public Utilities Commission (CPUC) Decision 19-12-021 (the Decision), which authorized funding for and the creation of a statewide Market Transformation Administrator (CalMTA), includes guidance regarding evaluation of MTIs and the overall market transformation portfolio. It calls for setting clear savings goals and other MTI metrics at the time the CPUC initially approves the MTIs to ensure a high level of accountability and ongoing evaluation to reduce program performance risk.

CalMTA and the CPUC's Energy Division will oversee implementation of rigorous and strategically focused evaluation, measurement, and verification (EM&V) practices that will enable CalMTA management and stakeholders to gauge the performance of the MTIs, verify incremental impacts, and improve the design and success of future MTIs. The Decision calls for "real-time" market evaluation, which will provide MTI program managers and implementers with ongoing, timely feedback, enabling them to pivot strategies as needed to maximize the value delivered to California ratepayers. Tracking of proximate and longer-term market progress indicators (MPIs) that are tightly aligned with the MTI's market transformation theory will reduce MTI performance risk and support timely decisions regarding ongoing investment, or termination of investment, in MTIs.

This document describes CalMTA's preliminary plan for third-party evaluation of the CRAWS MTI, including:

- MPIs that demonstrate movement toward short-, medium- and long-term outcomes;
- Data sources and approaches to evaluate MPIs, milestones, equity (including assessment of CRAWS market access, adoption barriers, and benefit distribution in environmental and social justice [ESJ] communities);
- MTI causality (assessment of the extent to which observed market changes can be attributed to the MTI interventions vs other market forces); and
- The approach for validating incremental impacts and cost effectiveness.



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Per the MTI Evaluation Framework, CalMTA developed this preliminary evaluation plan with input from the Evaluation Advisory Group, a group of three independent evaluation experts; the CPUC CalMTA project manager; and the CalMTA market research and evaluation lead.

Final evaluation plans will be developed by an independent third-party evaluator to be selected via a competitive bidding process after the MTI advances to Phase III: Market Deployment. CalMTA expects that the third-party evaluator may recommend refinements to the approach and metrics described in this document. It is expected that for CRAWs, this competitive bid will occur in the second half of 2027, and that market progress evaluations will be completed by the third-party evaluator on an annual basis.

1.1 Overview

The approach described in this preliminary evaluation plan employs theory-based evaluation (TBE), which is widely accepted as a best practice for market transformation program evaluation. TBE relies upon the MTI to have a program theory that clearly identifies MTI strategic market interventions, their timing, and the specific market outcomes associated with the interventions. TBE also assesses causality between the market interventions and observed outcomes.

In addition to the proposed MPIs, this preliminary evaluation plan identifies data sources and evaluation approaches that the third-party evaluator can use to assess market progress, MTI causality, and CalMTA's estimates of MTI incremental impacts and cost effectiveness. This plan focuses on third-party evaluation activities over the first four years of Phase III (that is, through CalMTA's initial funding period). It does not describe ad hoc market research studies that CalMTA and/or the third-party evaluator will conduct to inform "real-time" strategy decisions.

1.2 Evaluation objectives

The third-party evaluator will employ a TBE approach to assess observed market outcomes in relation to what was anticipated in the CRAWs MTI Plan. It will use the MTI program theory as the point of reference, assessing market progress against the theorized short-, medium-, and long-term outcomes and corresponding MPIs and evaluating the extent to which the market interventions caused the outcomes theorized in the logic model. The evaluator will conduct ongoing market monitoring via secondary data analysis and primary research to evaluate market progress and causality and, importantly, to provide ongoing market insights that provide real-time information to inform MTI strategy and improve performance. The evaluation will address the following high-level objectives:

- Monitor market dynamics and characteristics; assess market developments
- Review and assess the MTI program theory and logic model (PTLM)
- Measure market progress, per the MPIs and milestones



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- Assess equity, per the MTI plan, and the previously identified equity metrics and equity research questions
- Assess MTI causality per the logic model through 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 baseline market adoption (BMA) and total market adoption (TMA) forecasts, unit energy savings, incremental net MTI impacts and co-created MTI impacts,¹ and cost-effectiveness inputs and assumptions

Figure 1 shows the evaluation approach. First, the evaluator will review the program theory/logic model and assess whether the logic model accurately captures the implemented MTI interventions and outputs. During this step, the evaluator will also identify any gaps in MPI baseline data and determine what data are needed to assess causality based on the MTI’s theory of market transformation. Next, the evaluator will conduct primary and secondary research to measure actual units of adoption and assess equity and other MPIs. Third, the evaluator will synthesize the evidence gathered through multiple lines of research to establish MTI causality and to identify opportunities to improve the MTI’s effectiveness. Lastly, the evaluator will review CalMTA’s models for calculating incremental impacts and cost effectiveness and make recommendations for improvement.

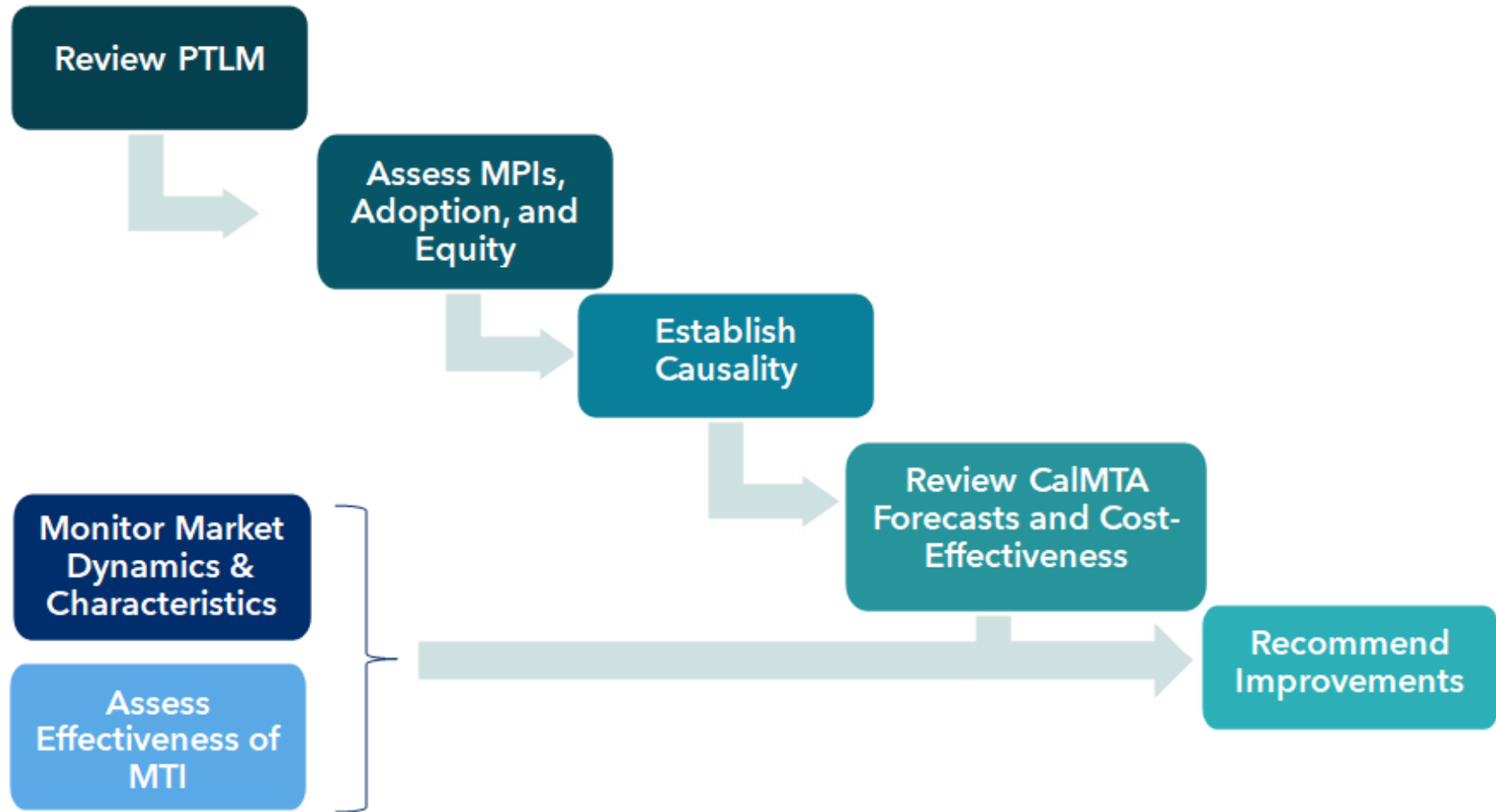
¹ Co-created impacts are the total impacts resulting from an MTI’s interventions, including those resulting from collaborations with resource acquisition programs.



Appendix F: Evaluation Plan for Commercial Replacement & Attachment Window Solutions

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Figure 1. Evaluation process



**Appendix F: Evaluation Plan for Commercial Replacement
& Attachment Window Solutions**

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1.3 Market progress indicators and milestones

During Phase II: Program Development, CalMTA team members drafted indicators and milestones for the MTI:

- The **CRAWS MTI strategy manager** created a program theory of market transformation and a logic model informed by product and market characterization research.
- The **CRAWS MTI evaluation lead** collaborated with the team and evaluation advisors to develop a set of MPIs against which market progress and MTI performance can be assessed, along with data sources that can be used to track progress against those MPIs.

Table 1 outlines the MPIs derived from the PTLM interventions (depicted and described in detail in Appendix A: Logic Model) and outcomes, along with associated milestones. The table also includes MPIs and associated milestones for several outputs because the timely completion of those outputs is critical to the MTI’s success. Equity-focused MPIs are denoted with an “EQ” to highlight their relevance to the ESJ goals of the MTI. The “Focus” column identifies the MTI’s focus associated with each MPI.² CalMTA also created a comprehensive evaluability map (see Table 5 in Section 5) that includes the MPIs and milestones shown in Table 1, along with the associated data sources the evaluator will use to assess the MPIs, milestones, and causality.

Table 1. CRAWS PTLM outcomes, MPIs, milestones, and current baseline

PTLM Outcome (or Output)	Focus	Market Progress Indicator (MPI)	Program Milestone/Expected Trend ³
Short-term (1-2 years)			
Awareness of problem, solutions, and business case grows among: • CRE owners/operators • BPS Hubs, accelerators • MUSH market • ESCOs • Architects, specifiers • Utility external programs • CBOs • HVAC installers	B, P	1. The % of each group of surveyed/interviewed market actors that understand the energy and non-energy problems associated with SP/DPC windows as well as CRAWS solutions	Increasing awareness/understanding in each targeted market actor group.
CRAWS included in TRMs	T	2. CSW and VIG included in TRM	Field study data collected; draft measure developed for TRM consideration by 2029.
Utility commercial EE programs include CRAWS technology in list of measures	P	3a. Number of external programs that include CRAWS technology 3b. Funding of external programs that include CRAWS technology	Increasing number of programs that list CRAWS technology as eligible measures.
Number of AERC-rated products increases	T	4. Number of AERC-rated CSW and VIG products	Increasing number of CRAWS technologies rated by AERC.
Manufacturers provide installer training and self-installation resources	B, S	5a. Number of installers who completed manufacturer training 5b. Number of manufacturers providing self-installation resources (videos, installation manuals, etc.)	At least two manufacturers have launched installer training programs and published self-installation resources per product line by 2029.

² Focus abbreviations: B=building professional market actors; F=financing entities; I=industry stakeholders; P=external programs; S=supply-chain; U=CRAWS units.

³ Program milestones are bolded.



PTLM Outcome (or Output)	Focus	Market Progress Indicator (MPI)	Program Milestone/Expected Trend ³
		5c. The % of trained installers reporting increased confidence or capability to install CRAWs products	
Market actor offerings reflect value proposition of NEBs in determining incentives and financing terms	B	6aEQ. The % of customers who are offered CRAWs (non-ESJ vs ESJ) 6bEQ. The % of customers who are offered CRAWs that include NEBs in the value proposition	At least 30% of customers offered CRAWs receive offerings that include NEBs in the value proposition by 2029.
Medium-term (3-5 years)			
Municipalities include CRAWs as part of climate/energy action plans	B	7. The % of municipalities that include CRAWs as part of climate/energy action plans	% of municipalities that include CRAWs as part of climate/energy action plans increases over time.
- External EE programs increasingly offer incentives for CRAWs products. - Incentives offered for evaluating envelope as part of HVAC updates	P	8a. Number of CA external programs that include CRAWs measures (also tracking budget) 8b. Number of CA external programs that offer incentives for evaluating envelope as part of HVAC updates	Increasing number of CA external programs that list CRAWs technologies as eligible measures; growth in the share of commercial HVAC programs that include envelope evaluation as a required or recommended step in HVAC upgrade.
CRAWs technologies increasingly recommended or evaluated by architects, design firms, ESCOs, CBOs, HVAC designers (i.e., specifier and influencer engagement increases)	B	9EQ. The % of market actors (such as specifier/influencers, ESCOs) recommending CRAWs solutions to non-ESJ and ESJ building owners and managers	30% of market actors recommending CRAWs solutions in appropriate circumstances (when building is retrofitted, to be compliant with BPS, when addressing comfort/noise/EE problems) by 2032.
Increase in number of manufacturers and products with AERC ratings	S, I	10a. AERC developed and published a VIG rating method 10b. Number of manufacturers and products rated by AERC	VIG rating method published by 2030. Five major CSW manufacturers have rated products by 2030; two major VIG manufacturers have rated products by 2032.
Increase in number of suppliers and installers selling CRAWs product	B, S	11a. The % of trained installers who have recommended CRAWs to at least one customer in the past 12 months 11b. Number of suppliers and installers (overall) selling CRAWs products 11bEQ. Number of suppliers and installers (ESJ-owned) selling CRAWs products	CRAWs products available through at least five suppliers by 2032. Five regional installation companies trained to install CRAWs products (ESJ and non-ESJ) by 2032.
Adoption of CRAWs technology grows in: - CRE market - MUSH market - ESCO project portfolios	U	12a. Square feet of CRAWs technology sold by market segment 12b. The % of ESCO projects incorporating CRAWs	1.3M sq-ft of CSW sales by 2032. 32M sq-ft of CSW sales by 2040. (long-term) 14% of the existing commercial building sector window sq-ft of addressable buildings that currently has SP or DPC windows adopts CSW by 2047. (long-term)
Market actors including funding/financing entities recognize monetary value of NEBs and provide mechanisms for ESJ financing	P, F	13. The number of program administrators and commercial financing pathways (e.g., PACE, green lending products, commercial appraisal) that factor NEBs (air quality, thermal comfort, noise, workforce, resilience) into asset value	Growth in the share of financing products that incorporate NEB value.
Long-term (6-10+ years)			

PTLM Outcome (or Output)	Focus	Market Progress Indicator (MPI)	Program Milestone/Expected Trend ³
Majority of market with SP and DPC windows view CSW and VIG as standard products for improving building comfort and energy efficiency and as a standard practice for optimal HVAC sizing	B	14. The % of installers and architects/engineering firms/specifiers who routinely recommend CSW/VIG during building envelope assessments or HVAC system sizing consultations	At least 60% of surveyed installers and architects/engineering firms/specifiers report routinely recommending CRAWs solutions by 2040.
By 2045, 50% of planned HVAC replacements or upgrades include envelope evaluation	B	15. The % of planned HVAC replacement/upgrades that include envelope assessment	25% of planned HVAC projects that are surveyed included envelope assessment using assumed CRAWs performance specifications as part of sizing analysis by 2040.
ENERGY STAR® agrees to include CSW	I	16a. ENERGY STAR includes CSW technology in ES list 16b. Number of CSW models that meet proposed ENERGY STAR criteria	Develop a specification for ES.
CA BPS (or similar policy) includes CRAWs in prescriptive and performance-based pathways as means to meet CA state efficiency and decarbonization goals	I	17. CA BPS or similar policy including CSW and VIG in a pathway	Growth in the number of policy processes that acknowledge CRAWs technologies.
Increasing number of funding and financing pathways for CRAWs, including ESJ solutions	F	18EQ. Number of financing pathways that fund CRAWs installation in ESJ communities	Growth in the number of pathways with explicit ESJ criteria.

1.4 Data collection and analysis activities

CalMTA identified primary and secondary data collection activities and analysis tasks that would allow the third-party evaluator to evaluate the CRAWs MTI. Table 2 lists the evaluation research objectives along with associated data collection and analysis activities, which are described in the text that follows. We look forward to seeing proposals that improve upon what is laid out here by identifying good sources of data and/or offering detailed descriptions of innovative methods that will be used.

Within six months of the evaluation initiation, the evaluator will identify data gaps and potential options for filling those gaps.

Table 2. Research objectives and evaluation activities

Research Objective	Secondary Data & Literature Review	Building Owners & Operators Survey	Building Professional Market Actor (installers, specifiers, ESCOs, etc.) Interviews & Surveys	Manufacturer & Supply-Chain Interviews	Sales Data Analysis	PA Interviews & Program Data Review	Financing Entities Interviews	Industry Stakeholder (national partners, trade orgs, etc.) Interviews	CalMTA Forecasting & C/E Model Reviews
Assess the theory of market change per the MTI logic model	X	X	X	X		X	X	X	
Monitor market dynamics and characteristics	X	X	X	X		X	X	X	
Track units of adoption	X	X	X	X	X	X			
Measure market progress, per MPIs and milestones	X	X	X	X	X	X	X	X	
Assess MTI equity	X	X	X	X	X	X	X		
Assess MTI causality	X	X	X	X		X	X	X	
Assess MTI implementation		X	X	X		X	X	X	
Assess incremental MTI impact		X	X	X	X	X			X

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2 Data sources

CalMTA conducted a Market Characterization study of the California CRAWs market between mid-2024 and October 2025 to broadly characterize the market conditions in California; however, as it was mostly completed prior to the CRAWs product being defined, many baseline MPI values still need to be established. For those MPIs, Year-1 evaluation data will serve as the reference point for tracking market progress – although market interventions will have begun, minimal market movement is expected this early in the initiative.

This preliminary evaluation plan includes data collection activities that build on the early research conducted in that study. CalMTA will seek recommendations for additional data sources and innovative methods as part of the third-party evaluator solicitation process.

2.1 MTI program data and materials

The evaluator will review CalMTA's program-tracking data to assess MPIs and milestones. These documents track CalMTA's activities and interventions. They provide evidence of what the MTI team did and when. This creates a record for the evaluator to assess causality between interventions and market outcomes. These include:

- MTI program documentation and implementation records
- Stakeholder and market actor communications logs
- Program agreements and data from market partners
- Market adoption and cost-effectiveness models with inputs, assumptions, and calculations
- MPIs tracking data (e.g., Salesforce)
- Strategic intervention activity records
- Marketing materials and program manual

The Market Characterization study included an extensive literature review drawing from various secondary data sources, including commercial stock assessment in California and market studies that provided insights into baseline analysis, market barriers, standard market practices, and decision making relevant to CRAWs supply chain actors. These existing datasets describe California's building stock and population characteristics and establish baseline conditions and market context that help the evaluator understand the size and characteristics of the target market. These include:

- Foundational market characterization studies
- Population and building characteristics data
- Technology and policy sources



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- Case studies and field data
- The evaluator will also use additional secondary sources to track the MTI MPIs, including:
- California Technical Reference Manual (TRM)
- Building performance standards (BPS) or similar policy documents
- ENERGY STAR documents
- Municipality climate action plans
- Published AERC documents

During the literature and secondary data review, and throughout the course of their work, the evaluator will also attempt to identify additional relevant data sources, including new evaluations or market studies.

2.2 Sales and shipment data

Sales and shipment data represent key metrics for tracking actual product movement in the marketplace and are critical for calculating the MTI's incremental impact on market adoption. CalMTA has already secured data-sharing agreements with the three major CSW manufacturers operating in California—Alpen, Indow, and QuantaPanel. These manufacturers have provided historical sales data and have committed to providing annual California sales data at the beginning of each calendar year, including ZIP code, sq-ft, model, U-factor, solar heat gain coefficient (SHGC) specs, etc. This ongoing data stream will enable the evaluator to track year-over-year adoption trends and establish a baseline against which to measure the MTI's influence.

2.3 Primary data collection

The evaluator will develop a sampling and research plan that allows for longitudinal tracking of key market characteristics to measure progress toward achieving MPIs and also supports process evaluation. The evaluator will clearly document data sources, the sampling strategy (targeting 90% confidence and 10% precision for quantitative research), and sample frame development process. For MPIs for which an established baseline value is not available, the first-year measurement will serve as a baseline for future year comparisons.

2.3.1 MTI staff and implementer interviews

The evaluator will conduct interviews with MTI staff and implementers covering a variety of topics, including but not limited to:

- Implementation status and challenges across strategic interventions
- Coordination with other CalMTA MTIs (Commercial Building Efficiency Accelerator [CBEA] and Commercial Rooftop Units [CRTUs])



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- Partnerships developed with program administrators, manufacturers, ESJ organizations, and industry stakeholders
- Resources and tools created, including business cases, case studies, and calculators
- Field demonstration activities and lessons learned
- Market feedback and strategy adjustments
- Progress toward key milestones, outcomes, and barriers encountered in advancing CRAWs market adoption

These interviews will inform other research activities, process evaluation, and program theory assessment.

2.3.2 Building professional market actor interviews and surveys

To effectively evaluate the progress of the CRAWs MTI, the evaluator will conduct comprehensive primary data collection activities across key market actor groups that work with building owners on upgrade and retrofit: including HVAC installers, window installers, architects and specifiers, design-build firms, and Energy Service Companies (ESCOs).⁴ These data collection efforts should employ both qualitative, in-depth interviews and quantitative surveys to track changes in awareness, perceptions, and behaviors over time. Critical topics to address include:

- Awareness and understanding of CSW and VIG, their applications, and performance benefits compared to traditional window solutions
- Familiarity with and ability to differentiate between various advanced window products and their appropriate use cases
- How market actors influence building owner decisions to invest in window upgrades using CRAWs technologies
- Frequency and context of recommending or specifying CSW and VIG to clients
- Understanding of envelope-HVAC interactions and how window performance affects thermal comfort
- Current practices regarding envelope evaluations during HVAC replacement projects

⁴ ESCOs are specialized firms that design, implement, and finance energy efficiency improvements for commercial and industrial building owners, offering comprehensive services spanning energy auditing, project development, equipment procurement, installation, and ongoing measurement and verification (M&V) of energy savings. A defining feature of many ESCO engagements is the performance contract model in which the ESCO guarantees a level of energy savings and is compensated from the realized cost savings over the contract term, allowing building owners to undertake upgrades with little or no upfront capital. ESCOs frequently intersect with utility energy efficiency programs as trade allies, bundling utility incentives into project financing to improve project economics and accelerate customer decision making.

- Attitudes toward an envelope-first approach and HVAC downsizing opportunities
- Changes in sales volumes, project pipeline, and market share of CSW and VIG
- Integration of advanced window solutions into standard practice, including incorporation into energy modeling tools, project proposals, and design specifications
- Perceived and actual barriers to adoption, including cost concerns, supply chain issues, installation complexity, and regulatory requirements
- Engagement with training, education, and technical resources related to CSW and VIG

Additionally, the evaluator should explore how these market actors position window retrofits relative to other competing building envelope and HVAC solutions, their role in project bundling decisions, and their awareness of available incentives and financing mechanisms. Baseline metrics should be systematically tracked to assess market transformation progress.

2.3.3 Utility and energy-related program administrator interviews

The evaluator will conduct in-depth interviews with representatives from key stakeholder groups:

- Program administrators (PAs), including investor-owned utilities (IOUs), community choice aggregators (CCAs), and regional energy networks (RENs)
- Commercial energy efficiency (EE) programs,
- Multifamily and Energy Savings Assistance (ESA) programs
- MUSH (municipal, university, school, and hospital)-focused programs (such as PG&E's Government and K-12 Comprehensive Program and CEC's CalSHAPE)
- ESJ advocacy organizations and community-based organizations (CBOs) active in commercial building energy efficiency, including those engaged in customer outreach, contractor workforce development, and building-owner decision making in ESJ and disadvantaged communities.

These interviews should explore several critical topics:

- Whether and how CSW and VIG have been incorporated into program measure lists and Technical Resource Manuals (TRM)
- The types and levels of incentives being offered for CRAWs technology installations
- How programs are communicating the value of an envelope-first approach to building owners, and what types of market actors are targeted
- How PAs are bundling window evaluations with HVAC replacement programs



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- Whether non-energy benefits (NEBs) like thermal comfort, noise reduction, and improved indoor air quality are being incorporated into cost-effectiveness screening and program design and whether their inclusion meaningfully affects measure eligibility or incentive levels
- What barriers PAs perceive to promoting CSW and VIG
- What marketing and outreach materials have been developed or adopted
- The extent to which PAs are reaching ESJ communities and tailoring financing mechanisms for these populations
- How PAs view CSW and VIG in the context of broader electrification and decarbonization goals, including their contribution to peak load reduction, load flexibility, and grid resilience
- Whether PAs are actively advocating for inclusion of CSW and VIG in Reach codes or California building energy codes and standards

2.3.4 Building owners and operators survey

To understand the MTI's impact on commercial building owners and operators, the evaluator will conduct surveys with decision makers across the target market segments – including MUSH facilities, commercial office buildings, lodging establishments, historic buildings, and commercial real estate (CRE) management firms – with particular attention to representation from ESJ communities. These surveys should track changes over time in several important areas, including:

- Awareness and familiarity with CSW and VIG
- Understanding of the energy and non-energy problems associated with SP and DPC windows
- Knowledge of available window solution alternatives beyond full replacement
- Perceptions of CRAWs technology performance characteristics including reliability, installation complexity, and availability
- Understanding of comparative costs between CRAWs technologies and traditional window replacement
- Awareness and utilization of available incentive programs and financing mechanisms
- Prevalence of CRAWs technology installations in respondents' building portfolios
- Likelihood to research and install these technologies in future renovation projects
- The extent to which building owners are evaluating envelope improvements as part of HVAC replacement or retrofit decisions, and whether an envelope-first approach is gaining traction in their decision-making process
- Motivators and barriers affecting adoption decisions
- Satisfaction with current window performance and frequency of tenant complaints



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- Whether respondents view CRAWs as a standard practice for improving building efficiency
- Who in the organization makes the decisions to adopt CRAWs

The survey should also capture firmographic data including building type, size, vintage, geographic location, ESJ status, ownership structure (owner-occupied versus leased), utility service territory, renovation history, and future renovation plans to enable segmented analysis and identify differential adoption patterns across market segments.

2.3.5 Manufacturers and supply-chain interviews

To assess the initiative's progress in supporting the CRAWs supply chain, the evaluator will conduct in-depth interviews with CRAWs technology manufacturers and distributors/suppliers to explore key areas, including:

- Product development activities such as feature enhancements (e.g., expanded operability options), condensation prevention improvements, and efforts to address performance concerns
- Participation in product rating and certification programs, including AERC submissions
- Cost-reduction strategies, including material sourcing, production efficiencies, and pricing trends over time
- Workforce development efforts such as installer training programs and development of self-installation resources
- Partnerships with CBOs for ESJ workforce development, pay equity, and transition strategies from direct manufacturer installation to utilizing local installer networks
- Go-to-market strategies and distribution channel development, including partnerships with ESCOs, architects, design firms, and building material suppliers
- Marketing and demand generation activities, including case study development, conference participation, and messaging strategies for different market segments
- Manufacturing capacity and supply chain challenges such as lead times, tariff impacts, and production scaling
- Sales data, including volume trends, geographic distribution, and penetration in target market segments (MUSH, commercial office, hospitality, historic buildings)
- Perceived market barriers and opportunities, including feedback on PA incentive programs, BPS policy development, and competitive positioning relative to traditional window replacement and alternative solutions
- Awareness and opinion of other programs for similar products outside of California



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2.3.6 Industry stakeholder interviews

To evaluate the initiative's progress in advancing industry standards and technical infrastructure, the evaluator will conduct interviews with key industry stakeholders, including Department of Energy's (DOE) Partnership for Advanced Windows (PAWS), ENERGY STAR program managers, national laboratory researchers (LBNL, PNNL, NREL), industry/trade organizations (AERC, National Fenestration Rating Council [NFRC], Window & Door Manufacturers Association [WDMA], Fenestration and Glazing Industry Alliance [FGIA], Building Owners and Managers Association [BOMA], and International Facility Management Association [IFMA]). Interview topics should cover:

- Progress on rating methodology and certification program development for CSW and VIG
- Advancement of technical tools and resources such as the CSW savings calculator adapted for California
- Implementation of DOE programs including the Building Envelope Innovation Prize
- Field and laboratory testing activities documenting product performance and durability
- Technical support provided to manufacturers, and coordination and data sharing with the MTI on demonstration projects
- Stakeholder perspectives on how standards development, testing protocols, and certification programs are influencing market adoption and addressing key barriers
- Member education regarding CSW and VIG, installation best practices, and code compliance
- Trade associations advocacy efforts supporting advanced window solutions in building codes and incentive programs
- Industry perspectives on Title 24 requirements, supply chain development, and CRAWs technology adoption barriers
- Industry feedback on current programs, policies, and what they need to address perceived gaps and/or resolve barriers to enhanced market adoption of CRAWs

2.3.7 Financing entities representative interviews

To assess the MTI's progress in expanding financing pathways for CRAWs projects, the evaluator will conduct interviews with representatives from financing entities including green banks, C-PACE programs, on-bill financing administrators, ESCOs, and programs like California's GoGreen Financing. Interview topics should explore:

- Awareness and integration of CSW and VIG into financing portfolios and loan products
- Approaches to valuing and monetizing NEBs in financing structures
- Development of ESJ-tailored low-interest financing mechanisms that reduce upfront costs



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- Financing terms and bundling strategies with other efficiency measures, and approaches to overcoming split-incentive barriers
- Barriers limiting financing availability for envelope improvements
- Case studies demonstrating successful CRAWs project financing and perceived market opportunities driven by BPS and decarbonization policies
- Any other issues they see as major hurdles/barriers and what CalMTA could do to improve outcomes

2.3.8 Timeline for data collection and analysis activities

Table 3 outlines the preliminary timing recommended for evaluation activities. MPIs correspond with MTI market interventions and associated activities and outputs, which occur at different times and result in logic model outcomes that are achieved over different time horizons. The timing and frequency of data collection and other evaluation activities will be planned accordingly to allow timely assessment of MPIs and to provide market insights that will support improvements to the MTI. This timeline will be updated to address any changes in MTI implementation or if MPIs need additional review or no longer need to be evaluated. The data collection activities in the first and second years will be critical for measuring baseline MPI values and for providing early, timely feedback to the MTI implementation team.

The third-party evaluator will produce reports annually documenting evaluation findings and progress toward market transformation goals. Reporting format may vary by year and could include a written report, memo, or slide deck, depending on the scope and nature of evaluation activities completed during that period.



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Table 3. Timeline for data collection activities

Data Collection Activities		Y1	Y2	Y3	Y4
Review CalMTA program data and materials review		X	X	X	X
Secondary data and literature review		X	X	X	X
Analyze sales and program data	Manufacturers/distributors data	X	X	X	X
	PA program data	X	X	X	X
Primary data collection: market actor data gathering	MTI staff interviews	X	X	X	X
	Building owner/operator surveys	X		X	
	Building professional market actor interviews/surveys *	X	x	X	x
	Manufacturers & supply-chain interviews	X		X	
	Program administrator interviews		X		X
	Financing entities interviews	X		X	
	Industry stakeholder interviews		X		X
Forecasting & C/E model review		X	X	X	X

* Interviews (X) may be conducted annually with a subsample of stakeholders to monitor market conditions, while surveys (x) are recommended biennially to track longer-term market changes.

3 Program theory and program implementation review

The evaluator will compare the MTI PTLM and MPis against the market interventions implemented by CalMTA and the resultant outputs. After conducting MTI staff interviews and reviewing program documents, the evaluator will make recommendations on how to improve the PTLM and MPis. The program theory should provide a feasible explanation of how the interventions will lead to incremental market adoption of CRAWs.

CalMTA will provide the evaluator with the following information (where available):

- PTLM
- Tools, fact sheets, and other MTI outputs
- Implementation and marketing plans
- List of key stakeholders and contact information
- List of MTI engagements and relevant Salesforce entries
- Written agreements/contracts with market actors and resulting data



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The evaluator will review this data to identify information needs to be addressed in primary and secondary research tasks. It is expected that the PTLM review will be thoroughly conducted in the first year of the evaluation to ensure clarity and alignment with program theory. The evaluator should revisit the PTLM annually thereafter, incorporating findings from the evaluation activities to assess the extent to which the PTLM accurately describes observed market dynamics and to identify any needed refinements to the program logic. This review should be included as part of the process evaluation activities detailed in Section 6.

4 Evaluating market progress

4.1 Market adoption tracking

Tracking the volume and characteristics of CRAWs installations is fundamental to assessing the market progress of this initiative. The third-party evaluator will systematically monitor CSW and VIG installations across California's commercial building sector. The tracking framework will allow CalMTA to measure both overall market growth, and growth by market channel and building type.

The evaluator will independently estimate market adoption of CSW and VIG in California through the following steps:

- 1) **Compile available sales data.** The evaluator will analyze data from CalMTA's negotiated data-sharing agreements with manufacturers and other market actors to establish a baseline estimate of CRAWs units sold in California.
- 2) **Conduct primary research to fill data gaps.** Comprehensive sales data may not be available from all market channels. To address gaps, the evaluator will conduct interviews and surveys with contractors, distributors, and manufacturers to estimate the share of CRAWs sales occurring through different market channels (e.g., direct sales, ESCO projects, contractor installations, retrofit programs). These market share estimates will be used to extrapolate from known sales to total statewide adoption.
- 3) **Calculate total market adoption.** The evaluator will combine sales data from Step 1 with market share estimates from Step 2 to calculate total annual CRAWs adoption in California. The evaluator will review these market adoption estimates and update them annually.

The evaluator will also track installations across the target building types (e.g., MUSH), building sizes, and building vintage through sales data and surveys of building owners/operators. Geographic and equity tracking will assess penetration across IOU service territories, coastal versus inland climate regions, and crucially, ESJ communities. Economic and financing characteristics provide another dimension of market progress by documenting total project costs,

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cost per square foot, and financing mechanisms employed. Additionally, the evaluator will assess changes in installation triggers (i.e., shifts from reactive to proactive replacement that could signal market maturation), and in technology specifications such as low-E coatings and performance metrics such as U-factor and SHGC values to understand which product configurations gain market traction.

4.2 Evaluating MPIs

CalMTA completed a baseline market characterization study in 2025 that provides foundational data for many of the MPIs. The evaluator will use this market characterization study as the primary source for baseline measurements where available. For MPIs not addressed in the baseline study, the evaluator will establish baseline measurements during the first year of the evaluation through targeted data collection activities. The evaluator will then track MPIs over time and note when measured MPIs do not follow expected trends, investigating potential causes for deviations and their implications for the MTI's theory of change.

4.3 Evaluating equity

Equity assessment is a cross-cutting evaluation priority that encompasses both market progress and process evaluation objectives. Market progress aspects include tracking adoption rates, awareness levels, and market penetration in ESJ communities. Process evaluation aspects (which should be addressed in conjunction with the broader process evaluation activities detailed in Section 6) include assessing CalMTA's outreach strategies, partnership effectiveness with CBOs, engagement with ESJ stakeholders, and ESJ consumer experience.

Primary identification of ESJ communities is based on the location of the installed CRAWs within California census tracts designated as disadvantaged communities (DAC) by CalEnviroScreen or otherwise classified as ESJ by the CPUC's definitions (e.g., tribal lands, low-income census tracts).

The evaluator will take a holistic approach to assessing equity. In addition to several equity-specific MPIs identified in Table 1, the evaluator will research the following questions:

- What is the baseline awareness and adoption of CRAWs in ESJ communities, and what specific barriers (e.g., access to financing, language barriers, contractor availability) may affect adoption in these communities?
- What is the experience of buyers in ESJ communities, including installation quality, information/education provided, customer service, technology performance over time, bill impacts, and unintended consequences?
- How much investment is made into CBO partners to provide training and awareness of CRAWs, job creation, and pay equity?
- What is the upfront cost and incentives for CRAWs?



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- How is the initiative addressing other concerns such as cultural and historical preservation considerations, managing potential risks for tenants such as rent increase due to improvement, split incentives, and language/cultural diversity?

For all the data collection, the evaluator will pay particular attention to whether CalMTA is reaching ESJ communities adequately, given baseline findings show higher interest in window efficiency among ESJ building owners (80% rating it important versus 48% in non-ESJ areas). This will include a sampling plan that sufficiently addresses ESJ coverage, questions appropriately worded with accessible language, non-English language option (if needed), and obtaining both quantitative and qualitative data that can provide contextual insights into ESJ community experiences.

4.4 Evaluating causality

Causality assessment in market transformation programs is required to link incremental adoption and other changes in the market to MTI interventions as firmly as possible. The PTLM includes theorized linkages between interventions and market outcomes. By conducting research to assess the MPIs, the evaluator will gather data to validate those linkages, assessing whether the program is influencing the market in the manner hypothesized and to establish causality between MTI activities and outcomes. The evaluator will assess causality for each MPI where practical, to support the overall causality assessment.

The evaluator will conduct the causality assessment based on a preponderance of evidence approach, which seeks to demonstrate influence across multiple metrics from multiple lines of evidence. Methods shall include document review and in-depth interviews and surveys with stakeholders, SMEs, market actors, and program partners. The approach will use empirical evidence to explain how changes in market adoption can be traced back to MTI interventions and non-MTI market drivers.

For example, to determine whether the MTI accelerated and increased market adoption of CRAWs in California commercial buildings, the evaluator would consider all available evidence that the MTI interventions led to the theorized outcomes – such as partner programs including a greater diversity of qualifying CRAWs products, increased installer confidence and capability with CRAWs technology, and decreased installed costs for high-performance window solutions – as well as evidence that those outcomes increased and accelerated market adoption. The evaluator will also consider alternative explanations and causes for the observed market outcomes, which is important to avoid confirmation bias.

Table 4 provides examples of some of the questions the evaluator may consider.



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Table 4. Causality assessment

Example Causality Question	Example Data Sources/Evidence
Did the MTI influence partner programs to offer different types of CRAWs product/offering? How?	• MTI Salesforce documentation of meetings and conversations with program partners • Program partner interviews • Program partner materials (e.g., comparisons of pre- and post-partnership CRAWs qualified product lists)
Did the MTI lead installers and contractors to believe there is a CRAWs solution suitable for the majority of their commercial customers?	• Installer surveys • Program partner and manufacturer interviews (e.g., questions addressing training and tools about product-to-building matching)
Did increased California program consistency strengthen the supply chain business case for high-performance commercial window products, as evidenced by larger annual CRAWs product shipments to the state and a greater variety of product types that better meet the needs of California's commercial building stock?	• Shipment data trends • Manufacturer interviews • SME and stakeholder interviews • Building owner/operator survey (increased interest/demand for CRAWs products corresponding with MTI interventions)
To what degree could the observed market changes have been caused by non-MTI alternative market dynamics or interventions? What market results could have occurred in the absence of the MTI?	• Review of observed market changes, including analysis of documentation, program materials, and timing of interventions • SME, stakeholder, and program partner interviews • Market actor interviews and surveys

5 Forecasting, impacts, and cost effectiveness review

This section describes the approach to evaluating the MTI's incremental energy impacts. CalMTA has developed forecasts for baseline market adoption (BMA) and total market adoption (TMA), along with estimates of unit energy impacts (UEI). CalMTA developed *ex ante* estimates of incremental MTI impacts using the formula below:

$$\text{Net Incremental MTI impacts} = [(TMA \text{ units} - BMA \text{ units}) * UEI] - \text{utility verified impacts}$$

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The evaluator will review CalMTA's market adoption and cost-effectiveness forecasting models, including inputs and assumptions, and make recommendations for improvement. Net incremental impacts will exclude savings associated with PA-verified adoption.

5.1 Total market adoption forecast

CalMTA will regularly update its TMA forecast, updating its forecasting model with actual sales or shipment data as it becomes available. The evaluator will review the TMA forecast, using the most recent data available.

5.2 Baseline market adoption forecast

In the first year, the evaluator will review CalMTA's process for developing the BMA, including inputs and assumptions, and make recommendations for improvements based on:

- Availability of new data
- Whether the causality assessment found adoption being driven by non-MTI market forces that are missing from the baseline
- Any other reasons given in the guidance in the evaluation framework

The BMA should only be revised when the evaluator has confidence that initial assumptions were incorrect and that the MTI did not significantly contribute to an observed change in market adoption. CalMTA identified three scenarios that warrant consideration of revising the BMA in the evaluation framework: an incorrect BMA assumption was discovered, an unanticipated exogenous event occurs, or an unanticipated product/technology advancement.

The evaluator will also provide recommendations to close any data gaps that were found in this review. CalMTA will request additional reviews in subsequent years as needed. Note that BMA includes adoption from established resource acquisition programs because they would have occurred absent the MTI, but excludes savings associated with collaborative efforts under the umbrella of the MTI.⁵

5.3 Unit energy impacts (UEI)

The methodology to develop UEI for CRAWs technologies is detailed in Appendix B: CRAWs Market Forecasting & Cost-Effectiveness Modeling Approach. The evaluator will review UEIs (including savings estimates, load shapes, and effective useful life [EUL]), and assumptions and methodology to make recommendations for improvements.

⁵ Per the CalMTA MTI Evaluation Framework, p. 11, footnote 15.



The evaluator will review net verified impacts attributable to the PAs based on claimed and verified data from CEDARS. These impacts will be subtracted from incremental adoption (TMA-BMA) as shown in the equation at the start of this section, ensuring no double-counting of impacts between CalMTA and other PAs.

5.4 Cost-effectiveness model

As part of the ongoing evaluation, the evaluator will review the cost-effectiveness model and the model inputs, assumptions, and data sources that CalMTA used to calculate cost effectiveness of the MTI. CalMTA's approach is fully documented in Appendix B of the MTI Plan.

Evaluating cost effectiveness involves outputs from the market-forecasting model as well as initiative costs, incremental measure cost, avoided cost, load shape, and UEs. This application of inputs considers the baseline installation conditions, baseline and efficient technologies, fuel types, target sector, and costs incurred by all stakeholders in the MTI implementation. Moreover, both the costs and benefits change over time due to factors such as EUL, regulatory policy, electricity and gas rates, and initiative funding.

During the first evaluation year, the evaluator will review the inputs, assumptions, and the model used by CalMTA that inform the cost-effectiveness forecast; during subsequent years, the evaluator will review any updates CalMTA has made to the models and will consider whether additional updates may be advisable. The review will include the following model inputs:

- **Incremental Adoption Forecast.** Incremental adoption will be forecasted as an input to the cost-effectiveness model. The evaluator will review this forecast and make recommendations for improvement.
- **Incremental Measure Costs.** Incremental measure costs reflect the difference in cost between the baseline windows installation case (no window retrofit) and installation of CRAWs technology. For the full discussion of how the incremental cost was forecasted see Appendix B. The evaluator will review the incremental costs and cost trends applied in the CalMTA cost-effectiveness model. The evaluator will determine, given recent market data and market conditions, if the cost assumptions are reasonable or need to be adjusted.



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5.5 Proposed MTI evaluability map

This is a proposed evaluability map. The evaluator is encouraged to make recommendations for improvement.

Table 5. MTI evaluability map

Market Progress Indicator (MPI)	Program Milestone	Current baseline condition	Data Source - MPI	Data Source - Causality
1. The % of each group of surveyed/interviewed market actors that understand the energy and non-energy problems associated with SP/DPC windows as well as CRAWs solutions		TBD by the first-year evaluation	Interviews of architects/specifiers, utility EE programs, CBOs, BPS Hubs Building owners/operators survey, ESCO survey	Interviews of architects/specifiers, utility EE programs, CBOs, BPS Hubs Building owners/operators survey, ESCO survey Salesforce contact log, program materials
2. CSW and VIG included in TRM	Field study data collected; draft measure developed for TRM consideration by 2029.	CSW/VIG not in TRM	CAL TF, eTRM, DEER, field study data	Interviews of utility program/stakeholders Salesforce contact log Program documentation
3a. Number of external programs that include CRAWs technology 3b. Funding of external programs that include CRAWs technology		TBD by the first-year evaluation	CA IOUs/Munis EE program portfolios, CAL TF, eTRM, DEER	Salesforce contact log, utility PA interview



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Market Progress Indicator (MPI)	Program Milestone	Current baseline condition	Data Source - MPI	Data Source - Causality
4. Number of AERC-rated CSW and VIG products		15 CSW products, 0 VIG product rated.	AERC workgroup's published meeting minutes, annual reports, or newsletters for announcements about commercial workgroup formation or VIG rating activities	Salesforce contact log
5a. Number of installers who completed manufacturer training 5b. Number of manufacturers providing self-installation resources (videos, installation manuals, etc.) 5c. The % of trained installers reporting increased confidence or capability to install CRAWs products	At least two manufacturers have launched installer training programs and published self-installation resources per product line by 2029.	TBD by the first-year evaluation	Interviews of manufacturers Review of self-installation resources	Salesforce contact log, MNF interview, review of self-installation resources
6aEQ. The % of customers who are offered CRAWs (non-ESJ vs ESJ) 6bEQ. The % of customers who are offered CRAWs that include NEBs in the value proposition	At least 30% of customers offered CRAWs receive offerings that include NEBs in the value proposition by 2029.	TBD by the first-year evaluation	Building owners/operators survey	Building owners/operators survey



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Market Progress Indicator (MPI)	Program Milestone	Current baseline condition	Data Source - MPI	Data Source - Causality
7. The % of municipalities include CRAWs as part of climate/energy action plans		TBD by the first-year evaluation	Data tracking of municipalities' climate/energy action plans in the list of municipalities affiliated with League of CA Cities	Salesforce contact log, municipality interview
8a. Number of CA external programs that include CRAWs measures (also tracking budget) 8b. Number of CA external programs that offer incentives for evaluating building envelope as part of HVAC updates		TBD by the first-year evaluation	eTRM, DEER, program website, utility PA interview	Salesforce contact log, utility PA interview
9EQ. The % of market actors (such as specifier/influencers, ESCOs) recommending CRAWs solutions to non-ESJ and ESJ building owners and managers	30% of market actors recommending CRAWs solutions in appropriate circumstances (when building is retrofitted, to be compliant with BPS, when addressing comfort/noise/EE problems) by 2032.	TBD by the first-year evaluation	Building owners/managers survey, ESCOs survey, installers survey, specifier/architects survey, CBOs survey	Building owners/managers survey, ESCOs survey, installers survey, specifier/architects survey, CBOs survey
10a. AERC developed and published a VIG rating method 10b. Number of manufacturers and products rated by AERC	VIG rating method published by 2030. Five major CSW manufacturers have rated products by 2030 and two major VIG manufacturers have rated products by 2032.	15 CSW products and more than three manuf. rated.	AERC website Interviews of manufacturers	Interview with AERC and MNFs, Salesforce contact log
11a. % of trained installers who have recommended CRAWs to at least one customer in the past 12	CRAWs products available through at least five suppliers by 2032.	TBD by the first-year evaluation	Survey of suppliers (distributors/wholesalers) and installers	Survey of suppliers (distributors/wholesalers) and installers



Appendix F: Evaluation Plan for Commercial Replacement & Attachment Window Solutions

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Market Progress Indicator (MPI)	Program Milestone	Current baseline condition	Data Source - MPI	Data Source - Causality
months 11b. Number of suppliers and installers (overall) selling CRAWs products 11bEQ. Number of suppliers and installers (ESJ-owned) selling CRAWs products	Five regional installation companies trained to install CRAWs products (ESJ and non-ESJ) by 2032.		Review of documentary evidence, such as website copy, sales brochures	
12a. Sq-ft of CRAWs technology sold by market segment 12b. % of ESCO projects incorporating CRAWs	1.3M sq-ft of CSW sales by 2032. 32M sq-ft of CSW sales by 2040. 14% of the existing commercial building sector window sq-ft addressable market that currently has SP or DPC windows adopts CSW by 2047.	Approx. 20,136 sq-ft of CSW were sold in California annually.	Manufacturer/distributor or sales data for CA commercial market Utility EE program data Building owners/managers (CRE, MUSH) survey, ESCOs survey	Manufacturer/distributor or sales data for CA commercial market Utility EE program data Building owners/managers (CRE, MUSH) survey, ESCOs survey
13. Number of program administrators and commercial financing pathways (e.g., PACE, green lending products, commercial appraisal) that factor NEBs (air quality, thermal comfort, noise, workforce, resilience) into asset value		No activity	ESCOs survey; interview with financing programs, CBOs, Equity sounding board	ESCOs survey; interview with financing programs, CBOs, Equity sounding board
14. % of installers, architects/engineering firms/specifiers who routinely recommend CSW/VIG during building envelope assessments or HVAC system sizing consultations	At least 60% of surveyed installers, architects/engineering firms/specifiers report routinely recommending CRAWs solutions by 2040.	TBD by the first-year evaluation	ESCOs survey, specifier/architects survey, CBOs survey	ESCOs survey, specifier/architects survey, CBOs survey



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Market Progress Indicator (MPI)	Program Milestone	Current baseline condition	Data Source - MPI	Data Source - Causality
15. % of planned HVAC replacement/upgrades that include envelope assessment	25% of planned HVAC projects that are surveyed included envelope assessment using assumed CRAWs performance specifications as part of sizing analysis by 2040.	TBD by the first-year evaluation	Building owners/managers (CRE, MUSH) survey, ESCOs survey	Building owners/managers (CRE, MUSH) survey, ESCOs survey
16a. ENERGY STAR includes CSW technology in ES list 16b. Number of CSW models that meet proposed ENERGY STAR criteria		No activity	ENERGY STAR documentation	ENERGY STAR documentation, ES administrator interview, Salesforce
17. CA BPS or similar policy including CSW and VIG in a pathway		No activity	BPS or Title 24 documentation	Interview of stakeholder organizations
18EQ. Number of financing pathways that fund CRAWs installation in ESJ communities		TBD by the first-year evaluation	ESCOs survey; interview with financing programs, CBOs, Equity sounding board	ESCOs survey; interview with financing programs



Appendix F: Evaluation Plan for Commercial Replacement & Attachment Window Solutions

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6 Process evaluation

The process evaluation component assesses how effectively CalMTA is implementing the CRAWs MTI and identifies opportunities to enhance delivery. While market progress evaluation focuses on *what* changes are occurring in the market, process evaluation examines *how* CalMTA activities are being executed and *why* they are or are not achieving intended results. This component is essential for continuous improvement throughout the initiative's lifespan, enabling mid-course corrections that can strengthen market impact.

The process evaluation serves three primary goals:

- **Assess implementation fidelity and quality:** Determine whether CalMTA activities are being executed as planned, with appropriate quality and reach to the target audiences. This includes evaluating whether educational programs, technical assistance, stakeholder engagement, and market intelligence activities are delivered effectively.
- **Identify implementation barriers and facilitators:** Understand what factors enable or constrain effective program delivery. This includes examining resource allocation, partnership dynamics, market actor engagement patterns, and operational challenges that affect CalMTA's ability to influence market transformation.
- **Generate actionable recommendations for improvement:** Provide specific, evidence-based guidance for enhancing initiative delivery. Process evaluation findings should directly inform CalMTA's ongoing strategy refinement, activity redesign, and resource reallocation decisions.

The process evaluation will be conducted iteratively throughout the initiative, with biannual assessments that enable responsive adaptation to emerging challenges and opportunities.

6.1 Key research objectives

The process evaluation will address research objectives organized across five critical domains.

6.1.1 Market actor engagement

The process evaluation will assess the extent to which CalMTA is successfully reaching and engaging the diverse market actor groups critical to CRAWs market transformation, including building owners/operators, architects/specifiers, ESCOs, window installers, and manufacturers/distributors. This assessment will identify which groups are well-engaged versus underrepresented. The evaluation will examine what motivates deep engagement with CalMTA, identify barriers preventing broader participation, and document geographic patterns to reveal

Appendix F: Evaluation Plan for Commercial Replacement

Attachment Window Solutions

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potential gaps across IOU service territories. Special attention will be paid to whether CalMTA is adequately reaching ESJ communities.

6.1.2 Awareness building and education

The evaluation will examine how effectively CalMTA's educational mechanisms – including trainings, webinars, demonstration projects and case studies, technical guides, and website content – are increasing market actors' knowledge of CSW and VIG. This includes assessing whether they demonstrate accurate understanding of key concepts of CSW and VIG, cost ranges, performance benefits, installation requirements, and business case fundamentals for different building types and ownership scenarios. The evaluation will determine how well CalMTA is addressing the information gaps that building owners identified as their primary adoption barrier, and whether CalMTA is successfully correcting misconceptions about CRAWs being niche products (such as for historic buildings only), installations being overly disruptive, and costs being prohibitively expensive.

6.1.3 Decision support tools and market resources

The process evaluation will assess the adoption and utilization of CalMTA's decision support tools and market resources, including cost calculators, energy modeling resources, and measure characterization templates. The evaluation will examine whether these tools are meeting market actors' needs and identify barriers preventing broader use. Key research questions include:

- Are building owners, ESCOs, PAs, and contractors aware of and using tools and resources created or supported by the MTI?
- What features or data would increase tool adoption?
- Are there technical or usability barriers limiting uptake?

The evaluation will also assess whether CalMTA is providing the specific data and information that market actors need for decision making, including credible local cost data, defensible savings estimates, field-verified performance information, and market opportunity assessments. For PAs specifically, the evaluation will examine how effectively CalMTA's resources support development of cost-effectiveness analyses and measure characterizations that meet CPUC regulatory requirements.

6.1.4 Supply chain and market enablement

The evaluation will assess CalMTA's efforts to strengthen the CRAWs supply chain and expand workforce capacity in California. Key areas of focus include:

- **Supply Chain Coordination.** The evaluation will examine how effectively CalMTA is facilitating connections among manufacturers, distributors, contractors, and end users.

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Particular attention will be paid to engaging midstream actors (distributors and contractors) who are often bypassed when manufacturers sell directly to building owners.

- **Installer Readiness and Participation.** Baseline findings indicate that a limited share of building owners report having internal staff capable of installing CSW, highlighting the importance of an enabled external installer market. This includes documenting:
 - The extent to which manufacturers and other market actors are offering installer training and installation resources
 - Whether trained installers and contractors are increasingly offering CRAWs technologies and services
 - Whether installer participation appears to be expanding across regions and market segments over time.
- The evaluation will assess whether CalMTA-supported enablement efforts – such as manufacturer training programs, development of installation guidance, and engagement through trade associations – are associated with increased availability of qualified installers offering CRAWs solutions.
- **Market Infrastructure.** The evaluation will determine whether manufacturers report that CalMTA activities are helping to stabilize or expand their California market presence, including increased product availability, reduced lead times, and stronger distribution networks.

6.1.5 Stakeholder collaboration and partnership management

The process evaluation will assess how effectively CalMTA facilitates collaboration among market actors and coordinates with key partners.

- **Multi-Stakeholder Engagement.** The evaluation will examine whether CalMTA's collaborative forums and engagement activities are facilitating productive connections, information exchange, and partnership formation among diverse market actors. This includes assessing how well CalMTA balances its role as a neutral market development entity while remaining responsive to diverse stakeholder interests.
- **PAs and Regulatory Coordination.** A major focus will be examining collaboration between CalMTA and PAs and the CPUC. Key questions include: How do PAs perceive CalMTA's role? What specific contributions has CalMTA made to PA program design and measure characterization? How effective is CalMTA's engagement with CPUC regulatory processes?
- **Regional and National Coordination.** The evaluation will examine how CalMTA coordinates with complimentary efforts, including NEEA's secondary window work, DOE research programs, and industry association activities. This assessment will determine whether CalMTA

Appendix F: Evaluation Plan for Commercial Replacement Attachment Window Solutions

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is successfully leveraging synergies, avoiding duplication, and positioning itself as a valued partner within the broader ecosystem of organizations advancing building envelope efficiency.

- **Equity and ESJ Community Engagement** (in conjunction with Section 4.3). The process evaluation will assess the effectiveness of CalMTA's outreach and engagement strategies in ESJ and DACs, including the accessibility of program resources, the strength of partnerships with CBOs, and whether engagement approaches are adequately reaching and serving the intended populations.

Appendix F: Evaluation Plan for Commercial Replacement

Attachment Window Solutions

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Commercial Replacement and Attachment Window Solutions Market Transformation Initiative

Appendix G: Risk Management Plan

June 26, 2026

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Introduction

This document details the potential risks that could negatively impact the Commercial Replacement and Attachment Window Solutions (CRAWS) Market Transformation Initiative (MTI) and CalMTA's plan to monitor and mitigate the risks. Additional information is included to establish the severity of the risk, likelihood of occurring, indicators that the risk is occurring, and assumptions around the possible mitigation approach. If the risk is designed with an “*”, then the risk is listed in Section 9 of the CRAWS MTI Plan as part of the summary of key risks that could impact this MTI.

Ongoing monitoring of market progress indicators (MPIs) and milestones will inform the team when risks are manifesting, to what degree, and which risk mitigation strategies should be undertaken.

To the extent reasonable, the risks are listed in the chronological order in which we expect them to become evident (assuming they occur), generally corresponding to the timing of CalMTA's planned strategic interventions.

For “Probability of Occurring” in the third 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 plan to mitigate.
- **Low:** The probability of this risk occurring is low based on what's known about the market to date. It could have some impact on the need for resources and timing, so the MTI needs to track it.

For “Severity” in the fourth column, CalMTA is defining:

- **High:** If this risk plays out and our mitigation approach is unfeasible, then the success of MTI may be in jeopardy.
- **Medium:** This may have an impact on the timing or overall success of the MTI, but a solid mitigation approach exists, and 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 level.

Appendix G: Risk Management Plan: Commercial Replacement and Attachment Window Solutions

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Table 1. Risk assessment



indicates possibility of greater impact
on Environmental and Social Justice (ESJ) communities.

#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
1	Unable to carry out combined HVAC/CRAWS pilots: Building owners do not agree to or see value in including CRAWS technology as part of HVAC upgrade/replacement resulting in lack of field data on combined benefits.	Low	Medium	Scheduled team meetings and engagement with building owners or HVAC designers during Commercial Rooftop Unit (CRTU) pilot design	Strategy Manager and Program Manager	In order to overcome the financial barrier to window inclusion in HVAC project scoping that building owners face, CalMTA can fund partial or whole window purchases. In lieu of real-world data from a combined HVAC/window pilot, we can utilize modeling approaches and existing savings calculators to estimate HVAC downsizing potential and operational savings. To ensure proportionate participation from ESJ communities, conduct early outreach in collaboration with Community Based Organizations (CBOs) and other ESJ advocacy organizations, similar to what was done for the Phase 2 pilot. The goal of this engagement would be to create awareness of pilot opportunities, identify potential demonstration sites, and build trust among ESJ decision makers.
2	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.	High	Medium	Data from pilot studies	Strategy Manager and Product Management	Demonstrate CRAWS’s substantial non-energy benefits (NEBs) including thermal comfort, noise reduction, resilience, and increased asset value.



Appendix G: Risk Management Plan: Commercial Replacement
and Attachment Window Solutions

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#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
						Negotiate bulk purchase or purchase commitments with manufacturers to drive down material costs. For commercial secondary windows (CSW), develop educated labor force to bring down installation costs. Demonstrate value of CRAWs technology in defining optimal pathways to meeting Building Performance Standards (BPS) targets.
3a	 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.	Low	Medium	Engagement with U.S. Department of Energy (DOE), national labs, utilities, and Program Administrators (PAs)	Strategy Manager and Market Research and Evaluation Lead	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.^{1,2,3} Where quantification cannot be achieved, we will utilize market actor interviews and surveys to develop qualitative estimates of NEBs. 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.

¹ California Energy Commission (CEC) Order Instituting an Informational Proceeding (OIIP) 24-OIIP-03, March 2024. <https://www.energy.ca.gov/proceeding/order-instituting-informational-proceeding-non-energy-impacts-nei>.

² Market Rate Equity Segment Non-Energy Benefits Research Plan, ILLUME Advising, LLC & Industrial Economics, Inc.; prepared for SoCalGas, July 2025. https://pda.energydataweb.com/api/view/4183/CA%20Market%20Rate%20Equity%20Segment%20NEBs%20Study%20Research%20Plan%20v20250701_clean.pdf.

³ Non-Energy Impacts Approaches and Values: an Examination of the Northeast, Mid-Atlantic, and Beyond, Northeast Energy Efficiency Partnerships, June 2017. <https://neep.org/sites/default/files/resources/NEI%20Final%20Report%20for%20NH%20updated%2010.4.17.pdf>.



#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
3b	 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.	Medium	Medium	Interviews with building owners and Energy Service Companies (ESCOs)	Strategy Manager and Market Research and Evaluation Lead	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 vacuum insulated glass (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.
4	Combined energy and NEBs are insufficient to establish compelling business case for beachhead markets: Modeling and measured savings from Northwest Energy Efficiency Alliance (NEEA) field studies indicate that energy savings alone, while significant, do not lead to return on investment (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.	Low	High	Building owner/operator interviews and surveys	Strategy Manager and Market Research and Evaluation Lead	Continue work with manufacturers to bring down material costs. Develop local workforce including DIY install programs to bring down installation costs. Leverage forthcoming BPS policy and work of Commercial Building Efficiency Accelerator (CBEA) MTI to highlight optimal compliance pathways that include window retrofits.
5	 Combined energy and NEBs are insufficient to establish compelling 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.	Medium	High	Building owner/operator interviews and surveys	Strategy Manager and Market Research and Evaluation Lead	Expand trusted messenger outreach to build awareness and to help us learn what makes for a compelling business case in ESJ communities. Continue work with manufacturers to bring down material costs.

#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
						Develop local workforce including DIY 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.
6	Unable to establish methodology for rating VIG for Single Pane Replacement (SPR) by Attachment Energy Rating Council (AERC) or National Fenestration Rating Council (NFRC). Without a rating, building designers and owners cannot receive full credit for the performance of VIG for SPR when demonstrating compliance with energy codes, and uncertainty surrounding performance limits the amount that utilities can allocate in incentives	Low	High	Engagement with DOE, AERC and/or NFRC	Product Manager	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., Environmental Protection Agency (EPA)). Engage with DOE and manufacturers to establish self-certification process with documented methodology and verification criteria.
7	Manufacturers don't submit products for AERC or NFRC rating. Ratings for CSW and VIG are necessary to give market actors confidence that CRAWs will deliver the expected energy savings and allow utilities to offer incentives.	Low	High	Engagement with manufacturers, AERC and NFRC	Strategy Manager and Product Manager	Inform manufacturers of higher incentives for rated products. Provide financial support to manufacturers to mitigate costs of AERC certification process. Preferentially promote AERC-rated products to PAs.
8	 California external energy efficiency and whole building decarbonization programs don't include CRAWs technologies in commercial and ESJ measures. Limited field data, low awareness of benefits, and uncertainty about	Medium	Medium	Engagement with PAs	Strategy Manager and Program Manager	Support program inclusion through field data and market support (e.g., manufacturers, BPS hubs, CalNEXT electronic Technical Reference Manual windows measure, CBOs, existing low-

#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
	cost-effectiveness may result in limited CRAWs inclusion in energy efficiency programs.					income program implementers, marketing support, etc.). Support programs through bulk purchase agreements in target regions to bring down material and labor costs for ESJ communities.
9	 California external energy efficiency programs don't offer incentives for envelope evaluation as part of HVAC upgrades. Limited field data, low awareness of benefits, and 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.	Medium	Medium	Engagement with PAs	Strategy Manager and Program Manager	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 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.).
10	 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.	Medium	High	Engagement with PAs	Strategy Manager and Program Manager	Same mitigation approach as risk #9.
11	Municipalities don't include CRAWs in climate action plans (CAPs). Municipalities update their CAPs infrequently, and on varying timelines, so getting CRAWs in within the timeframe of the MTI is out of our control. CAPs also may not stipulate specific measures for	High	Low	Engagement with municipal policy makers	Strategy Manager and Program Manager	Utilize data from field studies to demonstrate incremental energy savings delivered by combined HVAC/window upgrades. Support program inclusion through data and market support with manufacturers, BPS hubs,

#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
	reducing energy consumption, so getting CRAWs named in CAPs might be challenging.					CalNEXT windows measure, CBOs, and marketing support.
12	Unable to achieve viable ESCO/financier business model for financing window upgrades. Although CRAWs are significantly less expensive than a traditional full window replacement, the costs may often require external funding and financing. If ESCOs and other financing organizations don't see a pathway to ROIs that align with their business models, they will not offer the financing terms needed to enable CRAWs uptake in the market.	Medium	Medium	ESCO interviews	Strategy Manager and Market Research and Evaluation Lead	Engage with ESCOs and other green financiers to develop accommodating financing mechanisms using field test data and quantification of NEBs to better demonstrate the business opportunity and financier business case. Leverage interventions of CBEA and CRTU MTIs to engage with ESCOs and other financiers to build the business case for holistic building upgrades that bundle longer-term ROI measures such as windows with shorter-term ROI measures such as HVAC.
13	 Financing mechanisms like green banks, green leases, and Commercial Property Assessed Clean Energy (C-PACE) offer insufficient funding for window upgrades. Even if ESCOs and other financing organization offer financing packages and terms that work for them, the terms (e.g., interest rates, funding caps) may be insufficient to fully fund a CRAWs project leaving building owners to close the gap with internal capital.	Medium	Medium	Engagement, interviews with ESCOs and other financing market actors	Strategy Manager and Market Research and Evaluation Lead	The value stack for building owners includes energy savings, monetized NEBs, HVAC downsizing opportunities, and BPS compliance (fine avoidance). Where finance mechanisms recognize the value of only some of these benefits, we will emphasize the other value streams to reinforce the business case for owners to include windows in long-term capital planning. Develop strategies for staged window upgrades to spread the cost out over time. Engage with manufacturers and supply chain partners to bring down the capital cost and installation costs of windows. Develop DIY training programs for facilities staff to eliminate third party installation costs.

#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
						Leverage work of CBEA MTI to identify and expand access to ESJ-focused financial resources and funding mechanisms.
14	 Manufacturers slow to develop sales distribution and local installer networks, including ESJ businesses. Driving scale and reducing supply chain and installation costs requires developing local distribution and installer networks, eliminating dependence on expensive direct-to-consumer models.	Low	Medium	Manufacturer engagement and interviews	Product Manager, Strategy Manager, and Market Research and Evaluation Lead	Engage with manufacturers to identify potential sales/distribution partners and include them in field tests to demonstrate business opportunity. Provide incentives to regional sales/distribution partners for development of marketing plans and lead generation. Continue to work with ESJ training centers, technical schools, community colleges, and pre-apprenticeship trade programs to develop local installation workforce. CalMTA to fund workforce development and training programs for installers in collaboration with CBOs.
15*	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.	Medium	High	Market actor and building owner interviews and surveys	Strategy Manager and Market Research and Evaluation Lead	Conduct in-depth market actor interviews to better understand reservations and objections to utilizing CRAWWS 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).

#	Risk	Probability of occurring	Severity	How will we know the risk is occurring?	Responsible & tracking	Mitigation approach
						Leverage forthcoming BPS policies to supplement "carrot" of energy and NEBs.
16	Statewide BPS not implemented in California. A statewide BPS and the anticipated energy and emissions reductions would trigger the market to consider building upgrades that they might not otherwise consider or plan for. Absence of this "stick" would put more pressure on success of the carrots (energy and NEBs) to support the business case.	Low	Medium	California Energy Commission (CEC) engagement	Strategy Manager and Program Manager	Leverage <i>regional</i> BPS and municipal climate policies as the "stick" to accompany the "carrot" of energy savings and NEBs.
17	ENERGY STAR® does not create a category for CRAWs. ENERGY STAR is a well-recognized, respected, and influential program for both residential and commercial products. Having CSW included in ENERGY STAR would help overcome barriers associated with awareness and performance and support development of tiered incentives. Lack of an ENERGY STAR category and rating for CSW would put more pressure on other interventions to resolve the awareness and performance barriers.	Medium	Low	Engagement with EPA	Strategy Manager and Program Manager	Utilize data from field studies and develop market segment-specific case studies to build awareness and demonstrate product performance. Collaborate with AERC and NFRC to promote qualifying products. Develop tiered incentives based on AERC/NFRC ratings.
18	CRTU and/or CBEA MTIs do receive Phase III approval. Without CRTU and CBEA MTIs, CRAWs would be unable to leverage strategic interventions that are building the business case for holistic building upgrades and/or inclusion of envelope assessment during planned HVAC upgrades. This would place more pressure on the CRAWs-specific interventions to create that value proposition.	Medium	Low	MTI plans are not approved	Program Manager and Strategy Manager	CRAWs MTI to take lead on select strategic interventions identified in CBEA and CRTU MTIs. Utilize existing data from CBEA and CRTU Phase I and II research to adjust CRAWs interventions as dictated by market response. CRAWs to engage with BPS hubs, CEC, and regional policy makers to ensure windows are included in prescriptive and performance-based pathways.

The roles listed under the column "responsible & tracking" will be on point to track and identify if the risk is something that needs attention. The team will then work to deploy the appropriate mitigation strategy.



Appendix G: Risk Management Plan: Commercial Replacement and Attachment Window Solutions

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Commercial Replacement and Attachment Window Solutions (CRAWS) Market Transformation Initiative

Appendix H: Phase III Cost Estimate

June 26, 2026

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1 Introduction

The cost estimates contained in this appendix include only the estimated costs for Phase III: Market Deployment and do not include Phase II: Program Development costs. Market Transformation Initiative (MTI)-specific Phase II costs for conducting research, completing strategy pilots, and developing the MTI Plan were included in CalMTA's authorized start-up budget and reflected in the 2024 and 2025 Annual Budget Advice Letters. Phase II costs are included in the total MTI lifecycle costs that were modeled to determine cost-effectiveness, as described in Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach.

This estimate is based on the MTI logic model and program strategy and was further informed by the experience of CalMTA team members who have delivered market transformation programs in other states. The estimate will be further refined as Phase III activities are launched and as the program strategy evolves over the life of CalMTA's market development activities. CalMTA's activities will focus on filling gaps not currently addressed by other programs; therefore, cost estimates may also change based on ongoing and future collaboration. Annual cost estimates will be refined in consultation with CPUC staff and the Market Transformation Advisory Board (MTAB) as part of the annual operations planning process, which may include fund-shifting between and among activities, MTIs, and program years.

1.1 Budget activity definitions

The following definitions describe the types of actions included in the Phase III cost estimate. Detailed descriptions of proposed market interventions for the CRAWs MTI Plan are included in Section 2: Market Transformation Theory & Opportunity.

- **MTI oversight, strategy, and management:** Activities required to manage MTI core deliverables such as subcontractor identification, onboarding and management, strategy development, stakeholder outreach, and metric reporting.
- **Awareness-building:** Awareness-building activities associated with the MTI strategy, including campaign strategy design and production, and campaign advertisements as required to build demand.
- **Policy development/support:** Activities required to support and influence relevant policies and standards as called out in the MTI strategy, such as federal and voluntary appliance standards (i.e., data-sharing, expert participation, and commenting on draft regulations or standards).
- **Supply chain engagement:** Activities along the full supply chain as defined in the MTI strategy, including workforce education and training (e.g., workforce outreach and recruitment, training material development and implementation), manufacturer outreach and engagement to support the development of products to better reflect the needs of California



Appendix H: Phase III Cost Estimate for Commercial Replacement and Attachment Window Solutions (CRAWs)

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consumers, and retailer engagement on stocking practices, messaging, and program participation.

- **Market research:** Market research, as needed, to provide market insights that inform ongoing MTI strategy refinement and MTI effectiveness.
- **Data collection:** Continued collection of data over the course of the MTI to monitor the success of interventions as they progress and for future long-term monitoring and tracking.
- **Mid- or upstream incentives:** Manufacturer and retailer incentives to encourage product innovation and sufficient stocking practices.
- **Downstream incentives:** Consumer-facing incentives to encourage purchasing and adoption and create a meaningful market pull.
- **Evaluation:** Activities performed by the third-party evaluator as described in Appendix F: Evaluation Plan, including review of market adoption forecasts and cost-effectiveness, market progress evaluations, and long-term monitoring.



Appendix H: Phase III Cost Estimate for Commercial Replacement and Attachment Window Solutions (CRAWS)

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Table 1 contains annual cost estimates by major program activity for the first five years of implementation, representing costs incurred over the initial CalMTA funding period allocated in CPUC D.19-12-021. A more detailed breakdown of these costs by CalMTA labor, CalMTA non-labor, third party-contracted labor, and incentives is included in the Application five-year budget. Year 1 costs assume Phase III: Program Implementation beginning in July 2027.

Table 1. Year 1-5 cost estimate

Activity	Year 1 cost estimate	Year 2 cost estimate	Year 3 cost estimate	Year 4 cost estimate	Year 5 cost estimate	Five-year total
Program implementation						
MTI oversight, strategy, and management	\$443,000	\$909,000	\$933,000	\$958,000	\$983,000	\$4,226,000
Awareness-building/training	\$600,000	\$250,000	\$280,000	\$325,000	\$285,000	\$1,740,000
Policy development/support	\$105,000	\$105,000	\$125,000	\$125,000	\$125,000	\$585,000
Demonstration projects	\$570,000	\$845,000	\$355,000	\$100,000	\$0	\$1,870,000
Market research	\$150,000	\$350,000	\$350,000	\$500,000	\$350,000	\$1,700,000
Data collection	\$15,000	\$15,000	\$55,000	\$55,000	\$55,000	\$195,000
Incentives						
Mid-/upstream incentives	\$50,000	\$100,000	\$100,000	\$100,000	\$100,000	\$450,000
Downstream incentives	\$750,000	\$750,000	\$1,000,000	\$1,000,000	\$1,000,000	\$4,500,000
Evaluation						
Program evaluation	\$158,000	\$161,000	\$154,000	\$152,000	\$139,000	\$765,000
Total	\$2,841,000	\$3,485,000	\$3,352,000	\$3,315,000	\$3,037,000	\$16,031,000



**Appendix H: Phase III Cost Estimate for Commercial Replacement
and Attachment Window Solutions (CRAWS)**

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Table 2 contains annual cost estimates 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.

Table 2. Phase III cost estimate*

Activity	Years 1-5 cost estimate	Years 6-10 cost estimate	Years 11-15 cost estimate	Years 16-20 cost estimate	Total Phase III cost estimate
Program implementation					
MTI oversight, strategy, and management	\$4,226,000	\$4,768,000	\$2,141,000	\$424,000	\$11,560,000
Awareness-building/training	\$1,740,000	\$1,610,000	\$700,000	\$550,000	\$4,600,000
Policy development/support	\$585,000	\$125,000	\$40,000	\$0	\$750,000
Demonstration projects	\$1,870,000	\$0	\$0	\$0	\$1,870,000
Market research					
Market research	\$1,700,000	\$900,000	\$0	\$0	\$2,600,000
Data collection	\$195,000	\$415,000	\$475,000	\$380,000	\$1,465,000
Incentives					
Mid-/upstream incentives	\$450,000	\$300,000	\$0	\$0	\$750,000
Downstream incentives	\$4,500,000	\$9,000,000	\$1,750,000	\$0	\$15,250,000
Evaluation					
Program evaluation	\$765,000	\$828,000	\$248,000	\$61,000	\$1,901,000
Total	\$16,031,000	\$17,946,000	\$5,355,000	\$1,414,000	\$40,746,000

*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.

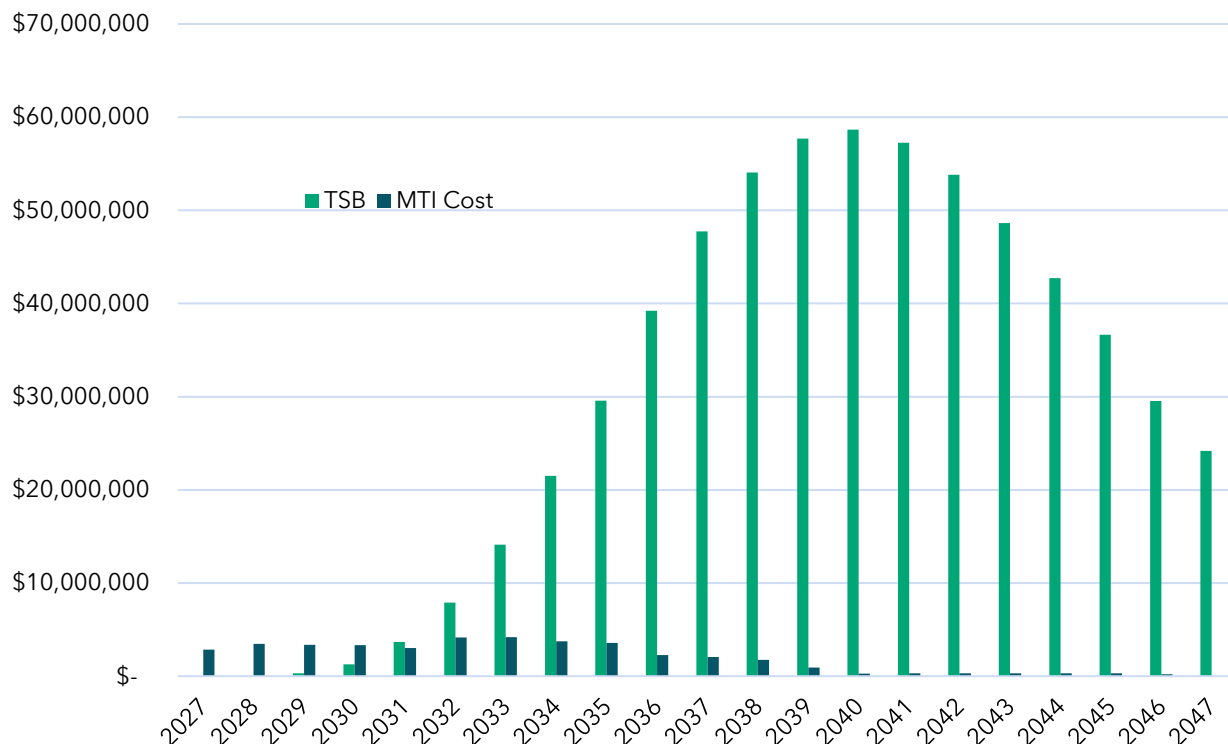


**Appendix H: Phase III Cost Estimate for Commercial Replacement
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Figure 1 contains Phase III cost estimates by year and estimated annual total system benefit (TSB). This illustrates the estimated spend over time, showing increased spending over the first ten years of market development activities followed by a taper-down of program spend over an estimated four years. This highlights the long-term impacts of market transformation initiatives, with significant long-term impacts occurring after program activities have ramped down. The total cost associated with the remaining six years includes only program evaluation costs, marketing costs, data acquisition costs, and program administration costs.

Figure 1. Phase III cost estimate and market impact by year



Appendix H: Phase III Cost estimate for Commercial Replacement and Attachment Window Solutions (CRAWS)

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Commercial Replacement and Attachment Window Solutions (CRAWS) Market Transformation Initiative

Appendix I: MTAB and Public Feedback

June 26, 2026

This appendix contains written comments and responses from the Market Transformation Advisory Board (MTAB) and the public, as well as links to the notes from the MTAB meetings where this content was discussed. There were no comments from the public.

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Appendix I: MTAB & Public Feedback for Commercial Replacement & Attachment Window Solutions

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1 Purpose

This document provides a comprehensive list of comments received from the Market Transformation Advisory Board (MTAB) on the draft Commercial Replacement and Attachment Window Solutions (CRAWS) Market Transformation Initiative (MTI) Plan. Content from the draft MTI Plan was shared with the MTAB via public meetings on [November 13, 2025](#), and [January 29, 2026](#). The MTI Plan was discussed with the MTAB via a public meeting on [May 6, 2026](#), and the full draft of the MTI Plan and Appendices was provided to the MTAB and the public from May 22, 2026, to June 9, 2026. We received no comments from the public on the CRAWS MTI Plan, which was posted to the CPUC Public Documents Area (PDA) website during those dates. Aside from minor grammatic corrections for added clarity, all feedback that appears in this document is presented verbatim as submitted, with no edits made by CalMTA.

2 MTAB feedback

#	Section	Page #	Source	MTAB Feedback Provided	CalMTA Response
1	1.1 Technology overview	9	Fred Gordon	First sentence, before tech review. Mentions carbon only, not energy efficiency. Is this deliberate?	Revised, thank you.
2	1.1 Technology overview	10	Jillian Rich	Might be helpful to define "clear glass". I interpret it as windows without a factory tint or after-market film applied like you often see in high-rises. Low-e coating is usually a clear-looking product as far as I know	A footnote has been added after the first mention of "clear" glass.
3	1.1 Technology overview	10	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Bundling window replacements with HVAC replacements is a critical sales point of the program. The report states that commercial replacement and attachment window solutions "...save about 9% annually in whole building energy costs..." Would reducing energy costs by 9% be enough to reduce the required size of a heat pump?	The 9% savings refers to bill savings, which are complex calculations involving various rate structures. In terms of reducing HVAC loads, multiple pilots within and beyond California have documented larger % energy savings resulting from installation of CRAWS (e.g., 20% electricity savings in the NEEA CSW project and 40% gas savings in CalMTA's Madison Elementary project). These savings are enough to support downsizing opportunities for HVAC systems.

Appendix I: MTAB & Public Feedback for Commercial Replacement & Attachment Window Solutions

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#	Section	Page #	Source	MTAB Feedback Provided	CalMTA Response
4	1.1 Technology overview	10	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	CRAWS ($U \leq 0.35$) generally meets or improves on baseline Title 24 levels, but does not meet the most stringent prescriptive requirements in certain climate zones or scenarios in Title 24.	Title 24 does not cover window retrofits. CRAWS represents an added benefit that can be implemented to complement other energy efficiency requirements. CalMTA selected the U value and SHGC value for the CRAWS products to optimize energy savings across all California climate zones, based on extensive energy modeling. The CalMTA team is aware of commercially available products that meet or improve upon our baseline product specifications and can be specified on a case-by-case basis.
5	1.2 Market overview	10	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	The biggest barrier may be the fact that there is no reason (mandate) for most building owners to consider adding replacement or attachment window solutions.	CalMTA agrees that there is currently no mandate for window retrofits. However, there are compelling reasons for building owners to adopt CRAWS now: improved thermal comfort and noise abatement, aided by energy savings and downsized HVAC potential (at time of replacement) that offer capital and ongoing operation cost savings. If/when BPS is adopted in CA, that will provide another driver for adoption, if not a mandate.
6	1.3 Vision	12	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	This proposal relies heavily on three primary drivers: (1) Non-Energy Benefits (NEBs), (2) policy mechanisms—particularly Building Performance Standards (BPS), and (3) measure bundling strategies. The principal risk lies in the long-term persistence of the market following CalMTA's exit, as the pathway to sustained adoption without these supporting factors is not yet fully demonstrated.	The lastingness mechanism is expected to increase awareness of the combined energy and non-energy benefits. Currently, awareness is nearly non-existent. BPS is a potential catalyst/driver that will aid with moving building owners off the 'do-nothing' decision and can amplify the other lastingness mechanisms. Bundling strategies are a financial opportunity to optimize the ROI and reduce financial barriers. The MTI aims to demonstrate that the value stack created by these and additional factors will drive the market to

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					sustained adoption. If the strategic interventions fail to drive the desired outcomes, as defined by the evaluation plan, the MTI will either adapt in consideration of observed outcomes or may sunset if no viable path forward can be identified (as is always the case with MTIs).
7	1.4 Strategic interventions for Phase III	12	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Consider the potential of leveraging the TECH Clean California incentive program.	Thank you. TECH Clean California is a residential and multifamily program driving adoption of heat pumps for space and water heating. CRAWs is a commercial market MTI. If TECH Clean California expands into commercial markets, then we would look to work together given envelope/HVAC interactions.
8	1.4 Strategic interventions for Phase III	12	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Market transformation expects "self-sustaining" markets, not ones that remain dependent on incentives. It seems that the intervention proposed is mainly focused on "incentives," not on how "self-sustaining" the market would be after the interventions.	There are seven strategic interventions described in the MTI Plan. Incentives play a role but are not the primary intervention. Self-sustained market activity is expected to be driven primarily by a diverse value stack including substantially increased awareness of energy and non-energy benefits, the corresponding value proposition, and business case.
9	1.5 Recommendations	13	Jillian Rich	Total nit, but the finance person in me always wants right-aligned financials for comparability.	Revised, thank you.
10	2.1 Theory of market transformation	14	Fred Gordon	The lost opportunity market due to HVAC systems being oversized seems valid but overstated. Prior installations have often been on "problem buildings" where there were thermal comfort, HVAC balancing, or other related problems. If there is high heat loss through the shell and a less than perfect air distribution system these problems may persist with the new HVAC system and a low efficiency shell.	Agreed that the problem may persist, but may be mitigated enough by the new/larger HVAC system that the net effect is the same: far less motivation to upgrade the envelope. In other words, if it's difficult to drive envelope upgrades with an aging HVAC system, it will be even more difficult/less likely to do so once a better (and oversized) HVAC is installed.

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#	Section	Page #	Source	MTAB Feedback Provided	CalMTA Response
11	2.1 Theory of market transformation	15	Jillian Rich	See comment in section 1.1. exec summary on "clear". My original assumption was wrong above - clarify in both sections?	Thank you. A footnote has been added after the first mention of "clear" glass in Section 1.
12	2.1 Theory of market transformation	16	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	The identified target market for VIG seems small and unpredictable. Consider pushing this product for new construction.	VIG for single-pane replacement and CSW are not seen as interchangeable products. Each has its own market segment where it is expected to be an optimal solution relative to the other. VIG for single-pane replacement is expected to be the preferred product for larger scale building renewal projects where the scope of retrofit activity and strategic goals of building renewal will favor a non-attachment solution. We agree that this is, currently, a small and emerging market - but not insignificant. We are currently not modeling VIG adoption, but Section 2.1.2 of the MTI plan goes into additional detail about the rationale for retaining VIG in the MTI at this time.
13	2.1 Theory of market transformation	17	Fred Gordon	Third point. I don't think CalMTA has been able to assess the importance or lack thereof of quantifying the value of NEBs. Hard numbers are always nice, but owners often make decisions about factors that influence occupancy rate, rent, productivity, or property value without hard numbers today. I am not convinced either way with the idea that owners need hard data to act. Owners always talk about ROI, but don't always want numbers for "soft" values and may not believe them.	There are multiple audiences that NEBs will impact. While it's true that building owners may take action based solely on the qualitative impact of the NEB, quantifying them to build a stronger business case would likely add value and increase confidence in making the investment. The quantification of NEBs is expected to be more important/valuable to financiers for a more robust business case/ROI analysis. Lastly, policy makers are already working to quantify NEBs (see CPUC and CEC projects in this area) to support policy making and better inform cost-effectiveness calculations. Other organizations are also actively working to quantify NEBs. Assuming success by others, the CalMTA team can utilize those data for our efforts.

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14	2.1 Theory of market transformation	17	Jillian Rich	First bullet, last sub-bullet - perhaps consider adding that there appears to be a lack of knowledge of cost especially as it relates to the tradeoff costs between CRAWs and HVAC over-sizing (both upfront and operational costs over time)	Revised, thank you.
15	2.1 Theory of market transformation	19	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Additional data potentially available from the California GTI Energy research grant could improve this section.	Agreed, thank you. CalMTA does participate on the TAC for the GTI project and will incorporate learnings as the pilot gets underway.
16	2.1 Theory of market transformation	21	Fred Gordon	Need to define "ESCOs" as used here. Were respondents primarily firms that bundle performance guarantees or pay for performance with financing and installation? Or did respondents include audit/install contractors who do not directly provide financing and guarantees. The extensive reliance on the term "ESCO" and scant mention of audit/install contractors makes me wonder if it's both.	The term "ESCO," as used throughout the MTI Plan (including this appendix), refers to firms that provide financing, which aligns with the industry and DOE definition: <i>"ESCOs are distinguished from other firms that offer energy-efficiency improvements in that they use the performance-based contracting methodology. When an ESCO implements a project, the company's compensation is directly linked to the actual energy cost savings."</i> Firms that were interviewed by CalMTA as part of the market characterization fit this definition.
17	2.1 Theory of market transformation	21	Fred Gordon	Instead of saying that ESJ markets will be brought along, is it accurate to say that they will be used as leading demonstration markets for this initiative, in part because they have significant opportunities and specialized programs that may provide leverage?	Both are true: The MTI aims to ensure ESJ communities are not left behind (due to financial burdens) AND also aims to utilize ESJ sites as early demonstration projects, given greater need/benefit and ESJ-specific programs, points of leverage, etc. The first bullet under section 2.1.8 was modified accordingly.

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18	2.1 Theory of market transformation	22	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	The CEC should be included among key decision makers who need to be informed.	Agreed, thank you.
19	2.1 Theory of market transformation	22	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	This report assumes that short- and medium-term utility incentives are available to include envelope evaluations as part of any HVAC upgrade or replacement which is a good idea. It would be useful to evaluate how the MTI would be impacted if an incentive program was not available to support the MTI.	Section 8 risks & mitigation describes mitigation steps if incentives for either envelope assessments or envelope retrofits fail to materialize or contribute to increased adoption (noting that incentives are only one of many drivers of adoption).
20	2.2 Strategic interventions	25	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	We agree that all HVAC incentive programs should require an envelope audit and analysis of whether window replacement (and insulation and air sealing) can lower the initial HVAC cost. The cost savings from the lower initial HVAC cost could cover the cost of the audit and a portion of the window replacement cost.	Agreed, thank you.
21	2.2 Strategic interventions	25	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	California BPS could be a huge driver for addressing windows. The other interventions may prove to be less impactful.	Possibly. The robustness of the CRAWs MTI is due in part to its outcomes being driven by a constellation of interventions and opportunities, such that the MTI is not dependent upon any one activity, policy, or market driver.
22	2.2 Strategic interventions	26	Jillian Rich	Not sure where this goes (maybe SI 6? Or back when you mentioned the calculator you'd build?) but do installers need any	No new physical tools are needed. We do mention the need to quantify NEBs for those situations where a more quantified benefit is needed to

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				additional physical tools for selling CSWs? For instance, they all mostly have infrared cameras and tools to show the customer a visual of heat gain, but the main selling point are NEBs. Anything there?	develop a value proposition, build a business case, etc. Typical energy audits or envelope evaluations would be a common first step in selling CRAWs technologies.
23	2.2 Strategic interventions	28	Fred Gordon	Opportunities may include renovation of office space to improve attractiveness and/or change use to improve occupancy.	Agreed. This is related to Opportunity #1, though not exclusively. Since the opportunities listed in this section are directly from the logic model, and this level of granularity is not expressed in the logic model, the CalMTA team is leaving this section unchanged.
24	2.2 Strategic interventions	32	Fred Gordon	Part of establishing the value proposition should be understanding how the building owner/manager assesses certain types of benefit- with average dollar numbers, anecdotal dollar numbers other numerical criteria, or subjective evidence.	Agreed. This sentiment is reflected in section 2.1.2 Target market where we note that the value proposition will vary by building type and ownership models. Understanding what the building owner values will necessarily include understanding how they calculate/define benefit.
25	2.2 Strategic interventions	40	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Another intervention we suggest is focused outreach toward historic building owners and historic preservation professionals. This was discussed in MTAB meetings and it would be useful to have that approach documented.	Agreed. Historic buildings are listed as one of the MTI's target markets where strategic interventions will be focused. Also, revised Strategic Intervention #4 in the MTI Plan to specifically call out historic preservationists.
26	2.2 Strategic interventions	41	Fred Gordon	Should there be a section on trade ally development and diversification? The workforce section seems to dart back and forth between workforce and trade allies. They overlap but might be best separated so it's clear you're working on both.	Good point. The CalMTA team added language to Strategic Intervention #4 and section 2.4 Workforce development.
27	2.2 Strategic interventions	43	Jillian Rich	Also not sure where this goes, but I didn't see anything about tying into local ESPM benchmarking ordinances like SF's. I think	Good suggestion. Some local/regional benchmarking programs do require periodic audits. Currently, the statewide benchmarking

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				they not only require the score but also a regular energy audit. Are CRAWs a standard option in an ASHRAE Level 1 or 2 audit?	program does not. The CalMTA Team added language to Strategic Intervention #4 and section 2.1.5 Market opportunities and key leverage points.
28	2.3 ESJ communities	45	Fred Gordon	Seems to start with strategic intervention 2. Is this misnumbering? The numbering also jumps from 4 to 6.	Section 2.3 ESJ communities only includes the strategic interventions with ESJ impacts, which are labelled with our ESJ icon that is defined in Strategic Intervention #2 (see footnote on page 28). Strategic Interventions #1 and #5 do not have a strong ESJ impact so they are omitted from section 2.3 (ESJ communities).
29	2.4 Workforce development	47	Fred Gordon	2.4.3 title. I suggest that whenever a title consists of two or more acronyms and no words, spell something out.	Revised, thank you.
30	2.5 Total system benefit & cost-effectiveness forecast	49	Fred Gordon	2.5.1. Thank you for explaining why you picked the particular curve. This is a small but valuable step in demystifying the B/C process. I rarely see this.	Thank you for your input.
31	2.5 Total system benefit & cost-effectiveness forecast	50	Fred Gordon	It would be useful to state what the end of forecast cumulative participation rate (%) is expected out of the MUSH and non-MUSH markets.	The CalMTA team added a statement that specifies the % of total incremental adoption forecasts to be non-MUSH (82%) with reference to Table 6 of Appendix B, which presents the window square footage detail.
32	2.6 Other benefits	52	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Another benefit of this technology is related to historic preservation. A construction team could upgrade the windows without changing the aesthetics of the building.	Agreed, thank you. Historic buildings are one of the target markets for this MTI and are specifically identified in section 2.1.2 Target market.
33	3.3 Product performance	60	Fred Gordon	Figure 4 needs a legend for building types.	Thank you for pointing out that the abbreviations are unclear to the reader. They are defined in a

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					table several pages earlier, so we've added a footnote to the title referring the reader to that table.
34	3.4 Product plan	62	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Consider also including professional conventions (architects, historic preservation, BOMA) and industry trade shows under 3.4.2.	Thank you for the suggestion. A sentence has been added in section 3.4.2 Stakeholder and industry collaboration stating that CalMTA will participate in professional conventions.
35	4.1 Current market state summary	63	Fred Gordon	Some of the emerging technologies have been emerging for 30 or 40 years without widespread commercial, success. E.G., aerogel and electrochromatic windows. They remain in the market in small niches. That might be worth mentioning. Not 'early stage' but each limited by persistent barriers, technical, reputational, or cost.	Edited section 4.1.2 Technology outlook to reflect this distinction.
36	4.3 Market actor and end-user insights	66	Fred Gordon	NEBS seem to be called "secondary considerations" in general. But if a building is difficult to occupy due to comfort, noise, or air quality, does this generalization hold? You are reporting accurately on what was said, but does the evidence in the field line up? If respondents have not been through a specific decision process, they sometimes lack the experience to provide a reliable answer, so they retreat to generalities.	Edited this paragraph to clarify and improve accuracy.
37	4.3 Market actor and end-user insights	66	Jillian Rich	4.3.1 - I'd bring up historical building NEB to retain external façade. Also, I think a lot of our building's pre-date CA building code for safety glass / tempered glass. You mention safety benefits of preventing glass	Edited paragraphs in Section 4.3.1 Non-energy benefits to clarify and improve accuracy.

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				from breaking, which is especially important with older, non-tempered glass.	
38	5.2 Related programs and potential alignment approach	69	Jillian Rich	Table 8 - Per comment above, local benchmarking ordinance programs? What about green business programs? LEED? All make energy recs.	Table 8 is intended to be representative of key types of programs and examples of active programs that the CRAWs MTI will seek to coordinate with and complement, rather than a comprehensive list of all programs that meet that description. It is also focused on programs offered by the California Program Administrators (PAs), rather than industry entities or policymakers. The CalMTA team added language clarifying this point and acknowledging the value of coordination with other non-PA entities working in this market.
39	5.2 Related programs and potential alignment approach	70	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	TECH Clean California, while primarily focused on single family homes, also offers rebates for new heat pumps in multifamily buildings. If a multifamily building is considering an HVAC replacements, then it might be a good opportunity to also consider commercial replacement windows which would potentially reduce the size and cost of the HVAC equipment. Therefore, it would be appropriate to align and consider synergies with TECH Clean California.	TECH Clean California, by design, only incentivizes clean space and water heating technologies and is not structured to offer incentives on CRAWs and other commercial products. The representative multifamily programs identified in Table 1 of Appendix E are those that include, or are structured in a way that could include, CRAWs products in common areas, which have limited impact on building-level HVAC sizing.
40	7.2 Market progress indicators	75	Jillian Rich	I know I said this in the last meeting, but I don't think tracking climate/energy action plans are at all correlated to success of this MTI. CAPs are meant to be long-term policy documents so they rarely mention specific technologies. They instead focus on outreach/implementation channels. I did a quick check of a handful of recent CAPs just to make sure my understanding from when	Following the most recent MTAB meeting, we modified Table 8 of the MTI Plan to state, "Local reach codes and Climate Action Plans" to describe broader opportunities (see row titled, "Programs and services that address whole building energy performance improvements or strategic energy management.")

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				I used to write these plans ages ago was still valid, and it is. See Strategy 1 (page 69) of the San Carlos Climate Action Plan or measure GHG-04 from the Sacramento County CAP, among others. You'll see nothing about lighting or HVAC or water heaters, let alone windows. They might mention the building envelope but no specific measures.	CAPs are evolving and do identify priority areas such as weatherization and commercial HVAC that drive development of local reach codes. CRAWs could be highlighted as a weatherization solution for commercial buildings, consistent with our intervention language. We acknowledge that CAPs are one example of policy levers available to drive CRAWs adoption, but we will not rely exclusively on CAPs.
41	8 Risks & mitigation	78	Jillian Rich	Cost/financial risk: Is it worth pointing out that utility incentives might be a benefit and a challenge? A benefit because it'll help boost manufacturer and installer awareness and capability, but a challenge because incentives almost always artificially inflate the cost of a technology and sometimes the higher cost persists even when incentives end. Something perhaps to consider.	Downstream utility incentives would drive participant awareness and offset capital costs. While CalMTA generally recognizes that downstream incentives can inflate product costs, it is unclear to what extent that has been documented. The program team will track product costs through evaluation and other data management activities and will modify strategies as needed if we see upward price pressure as a result of our incentives.
42	8 Risks & mitigation	80	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	We suggest that this risk has a high probability of occurring: "CA external EE programs don't offer incentives for building envelope evaluation as part of HVAC upgrades."	Thank you. Others have commented that they believe incentives for envelope evaluations are a good idea and some have suggested that they would be the preferred focus of incentives, vs. for product directly, as they would drive similar behavior without the risk of driving up product costs. Given that, and that changing it to "high" wouldn't alter the described mitigations, the CalMTA Team believes that "medium" is appropriate for the risk level.
43	9 Cost estimates	82	Mary Anderson on	Market and outreach costs may be overstated. Once a statewide BPS is	BPS alone is not expected to drive awareness of window solutions – only increase the need to

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			behalf of the California Investor-owned utilities (IOUs)	implemented, there will be considerably more awareness of the impact of poor performing windows.	research pathways to satisfy compliance. Extensive market characterization has documented the nearly non-existent awareness of retrofit solutions and significant confusion, even when respondents indicate familiarity. As such, we expect awareness, education, and outreach activities to be critical to the success of the MTI.
44	9 Cost estimates	82	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Midstream/upstream incentive budget estimates seem low, and there is some concern that the market may not strongly participate at that incentive level.	The \$750K for mid/upstream incentives are primarily for demonstration projects, aimed at ESCOs and HVAC designers to secure their involvement where they would otherwise not be motivated to engage. Additionally, there are some incentives set aside for manufacturers to submit secondary windows to AERC for rating. We feel these are adequate for the scope suggested but will monitor and adjust if needed.
45	Appendix A: Logic Model Packet	2	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Barriers / Opportunities include the lack of education around CSW, and benefits they provide.	Agreed. This is identified in barrier #1.
46	Appendix A: Logic Model Packet	2	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	"Awareness of problem, solutions and business case grows among:" The list leaves out general window installer contractors.	General window installers are not likely participants for CSW installation (and we are not currently modeling VIG adoption). CSW products compete with full window replacement, and the skill level to install CSW is much lower than for full window replacement. If conditions change as the MTI is deployed into the market, we will revise accordingly.
47	Appendix B: Market	18	Mary Anderson on	The baseline market adoption is also effected by the lack of CSW manufacturers.	Thank you for your comment.

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	Forecasting and Cost-Effectiveness Modeling Approach		behalf of the California Investor-owned utilities (IOUs)		
48	Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach	25	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Per square foot unit energy savings are not shown. This is a key input parameter that should be included.	We agree that this is a key input parameter. The energy savings are shown in section 8.1 of Appendix C; the CalMTA Team updated the document to include a reference to that information.
49	Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach	26	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	The MTI uses one per-unit savings value across all 16 climate zones. There is a measure package for commercial secondary windows that is almost approved by CPUC. Once approved, it would be beneficial for the MTI to adopt the per-unit savings from the measure package and utilize the 16 climate zones for CA.	The CalMTA Team included unique load shapes for all 16 climate zones; we did not use one savings value across all climate zones. We corrected a sentence in section 3.7 of Appendix B to clarify this. We also state in section 3.8 of Appendix B that we model a single installation case, which is true, but should not be confused with using a single savings value. The load shapes from each climate zone and building type were combined using weights from the TRM to create one final avoided cost value for each IOU as can be seen in the weighting Tables 35 and 36 in Attachment 2 of Appendix B.
50	Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach	32	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	A TRC of 1.31 seems very high compared to what we are seeing in the commercial measure package, which is approximately a 0.5 average TRC without admin. It would be helpful to understand the difference.	The TRC of 1.31 is higher than the average of all TRC values across all building types and climate zones. The primary reason for this is that we modeled adoption in part as a function of customer economics, so the resulting adoption is high in building types and climate zones with high savings and fast payback periods. This selection for cases where adoption "makes sense" leads to a higher TRC compared to the TRC for an average building:

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					the 0.5 average TRC includes many cases with low savings and long paybacks, whereas our result includes more of the higher savings cases and almost none of the low savings cases. This analysis also helps inform the MTI strategy by identifying target markets that are more likely to adopt the solution. If scaling results in cost declines, or NEBS support adoption in other markets, this analysis will be updated. The CRAWs MTI also recommends higher performance CSW with U-factor = 0.35 and SHGC = 0.25, which is comparable to the performance specifications used in our field study.
51	Appendix C: Product Assessment Report	15	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Are there modeling results for VIG?	A sentence has been added to section 4.2.4 of Appendix C explaining that because CSWs and VIG for SPR showed similar energy performance (within 1% on average), CalMTA used CSWs to represent all CRAWs technologies.
52	Appendix C: Product Assessment Report	16	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	It is unlikely that CSWs or VIGs could provide a one-measure solution toward BPS goals for any but the smallest percentage of buildings.	The NLR study was referenced as a demonstration that envelope measures such as windows can generally reduce HVAC costs in buildings. The CalMTA Team revised text in section 5.1.1 of Appendix C to remove specific dollar values, as they were not specific to CRAWs technologies or to commercial buildings.
53	Appendix C: Product Assessment Report	16	Mary Anderson on behalf of the California Investor-	It is unlikely that CSWs or VIGs could provide a one-measure solution toward BPS goals for any but the smallest percentage of buildings.	Agreed that the sentence as written could overstate the potential for CRAWs to enable compliance with BPS. The CalMTA revised text in section 5.1.2 of Appendix C to read, "Given the simplicity of installation and the substantial savings they provide,

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			owned utilities (IOUs)		CSWs and VIG for SPR could offer an effective pathway for compliance with whole-building energy and emissions reduction targets set by BPS."
54	Appendix C: Product Assessment Report	22	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	"VIG glazing units meeting the CRAWs product definition exceed the prescriptive energy code requirement for glazing units." The CA energy code only provides performance requirements for whole fenestration units, including framing. Please provide substantiation for this assertion.	The paragraph in section 6.1 of Appendix C has been restructured to reference the Title 24 requirement that replacement glazing must be at least equivalent to the original in performance.
55	Appendix C: Product Assessment Report	24	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	Please include analysis regarding IECC-Commercial code.	IECC-Commercial was not originally included in the analysis, given that it is not used as the basis of building energy codes in California and, in contrast with ASHRAE 2025, its most recent version has not raised new industry standards for glazing performance. Text in section 6.4.1 of Appendix C has been revised to describe the national influence that both ASHRAE standards and ICC model codes have on accelerating the adoption of high-performance glazing technologies.
56	Appendix D: Market Characterization Report	8	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	It is helpful that ESCOs recognize the non-energy benefits, but their contracts are based off of performance. The table associated also should include ESCO testimonials. "Although familiarity with advanced window technologies remains low, market actors such as ESCOs recognize the potential non-energy benefits of CSW and VIG (see Table 2). "	Thank you for this observation. Appendix D (Market characterization report) is a final deliverable produced by Cadmus (2025) and is not subject to revision by the CalMTA MTI team. Your comment has been noted and will inform the team's ongoing work.
57	Appendix D: Market Characterization Report	12	Mary Anderson on behalf of the California	1.2.5 "While architects and glazers expressed some level of awareness of CSW products, they associated them almost exclusively with historical buildings." We	Thank you for your input.

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			Investor-owned utilities (IOUs)	agree with this because of all the other savings associated with the project. This would include demo, cranes, and preserving the frame and look of the building.	
58	Appendix D: Market Characterization Report	69	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	"Manufacturers demonstrated the highest level of familiarity with both CSW and VIG technologies" What type of manufacturers were interviewed? Shouldn't this be closer to 100%? 6 interviewed, and 4.XX knew of the technology. Was this because of the nomenclature? Or what was the gap for a manufacturer not familiar with the technology? Depending on the explanation, this issue should be addressed in the logic model.	The sample (n=6) included both CSW and VIG manufacturers, and the gap reflects each being very familiar with their own product but less so with the adjacent technology. The 4.2 for VIG is CSW manufacturers rating their VIG familiarity lower (and vice versa), not a manufacturer unfamiliar with their own product.
59	Appendix F: Evaluation Plan	9	Mary Anderson on behalf of the California Investor-owned utilities (IOUs)	One of the market progress indicators is getting a commercial secondary windows measure package developed in the eTRM. This is an activity separate from the MTI that Energy Solutions is in the process of completing, so it should not be considered a measure of success for the MTI.	We agree that the market progress indicator is not intended as a measure of success for the MTI and will not be attributed to the MTI; however, it does represent a critical enabling condition for utility program adoption of CRAWs, so it remains important to track, regardless of who drives it.
60	Appendix F: Evaluation Plan	10	Jillian Rich	Same comment above about CAPs	Thank you, please refer to our Climate Action Plans (CAPs) response in row #40.
61	Appendix F: Evaluation Plan	15	Jillian Rich	Page 15 2.3.2 - Missing HVAC installers on list of key market actor groups? They're in the PTLM list but not here.	We added HVAC installers to the list in section 2.3.2 of Appendix F (Evaluation Plan). The complete plan for interviews will be finalized as part of the final Evaluation Plan developed with input from the MTI third-party evaluator selected for this MTI.
62	Appendix F: Evaluation Plan	n/a	Jillian Rich	General question - Do the evaluation plans usually specify how you'll find your contact lists for interviews and surveys similar to the	These details will be specified as part of the final Evaluation Plan, developed with input from the MTI third-party evaluator that is selected for this MTI.

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				section on how you'll obtain sales data? I wonder how you'll achieve a representative sample, especially for measuring awareness I think you need a fresh sample every year(?) We've found it extremely difficult in our recent process evaluations to pinpoint commercial customer decision makers and a representative mix of industry representatives.	
63	Appendix F: Evaluation Plan	n/a	Jillian Rich	Overall excellent job - I can tell RI and the evaluation subcommittee knows their stuff!	Thank you for your input!
64	Appendix G: Risk Management Plan	n/a	Jillian Rich	It may be helpful to document the risk of a severe economic disruption or public health event similar to COVID-19 that impacts the occupancy and ownership of commercial building spaces, even in the MUSH market. Such an event could delay progress by 3-5 years and would require downsizing the MTI market potential.	These types of 'black swan' events pose a risk to EE programs broadly and aren't necessarily an MTI-specific risk that the MTI team can mitigate.



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