Commercial Replacement & Attachment Window Solutions

Market Transformation Advancement Plan

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

Contents

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	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
LBNL	Lawrence Berkeley National Laboratory
MR	Market Research
MT	Market Transformation
MTAB	Market Transformation Advisory Board
MTI	Market Transformation Initiative
as	Municipal, University, School, and Hospital
NEB	Non-energy Benefit
NFRC	National Fenestration Rating Council
NREL	National Renewable Energy Laboratory
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
SPR	Single-Pane Replacement
TA	Technology Assessment
TSB	Total System Benefit
TMA	Total Market Adoption
TRC	Total Resource Cost
TRM	Technical Reference Model
UEI	Unit Energy Impacts
VIG	Vacuum Insulated Glass
WE&T	Workforce Education and Training

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Date:	September 17, 2024

1 Purpose

This Advancement Plan summarizes available information and essential research activities for the proposed Market Transformation Initiative (MTI) that CalMTA recommends advancing from Phase I: Concept Development into Phase II: Program Development. It represents the stage gate deliverable illustrated in Figure 1 that describes the scope of work for research, testing, and stakeholder engagement that will be needed during Phase II to develop a full MTI Plan for approval by the California Public Utilities Commission (CPUC) for Phase III: Market Deployment. The initial research efforts outlined in this Advancement Plan will inform the long-term potential of this technology before CalMTA recommends whether to advance this Market Transformation (MT) idea further. All MT Advancement Plans are reviewed by the Market Transformation Advisory Board (MTAB) and the public before they are finalized by CalMTA. This Advancement Plan contains:

1. Key characteristics of the MT idea (e.g., description, target market, initial MT theory, etc.).
2. Identified gaps in knowledge that need to be filled before an MTI Plan could be written for CPUC approval.
3. Estimated costs and work plan for activities in Phase II that will fill the knowledge gaps.

Figure 1: MTI Development Documents by Phase

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

2 Executive summary

This section summarizes the Market Transformation concept opportunity, the problem it is trying to solve, strategies that are likely to drive market change, and the sustained change in the market we are expecting to see.

As California moves towards electrification, Commercial Replacement and Attachment Window Solutions (CRAWS) offer a significant opportunity to improve building envelope thermal performance and downsize heating, ventilation, and air conditioning (HVAC) systems. The technologies of Vacuum Insulated Glass (VIG) and Commercial Secondary Windows (CSW) as defined in Section 3 below, offer substantial improvements over typical window replacements. Although windows on average comprise approximately 15% of a building's exterior surface, they are responsible for HVAC losses of approximately 40%, which equates to approximately 12% of a typical building's overall energy use.[1]

There is a growing recognition that replacing poor-performing, single-pane windows should be a prerequisite to decarbonization in existing commercial buildings. Statewide Building Performance Standards (BPS)[2] are in the early development phase in California, but the CalMTA team believes that BPS is coming, at least in major metropolitan areas, and this creates a sense of urgency to prepare the existing commercial building market to enable compliance.[3] 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. This MT idea will seek to address the many commercial buildings that still contain single-pane glass windows. The initial target market for this MT idea will be the municipal, university, school, and hospital buildings (MUSH) market with an emphasis on the installation of CSW to buildings in underserved communities. Over time, we plan to expand this to include the full commercial building market as conditions in the commercial real estate market improve.

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[1] Pratt, Jordan and Wynn, Sean. Commercial Secondary Windows Field Test. Northwest Energy Efficiency Alliance. December 18, 2023. https://neea.org/resources/commercial-secondary-windows-field-test.

[2] BPS are policies that require commercial and multifamily buildings to meet certain performance levels, typically for energy use or greenhouse gas emissions. Each local or state government that implements a BPS customizes the requirements to fit its needs, but in general, a BPS contains a performance target and a timeframe in which all buildings must meet this target. https://www.energystar.gov/buildings/resources-topic/what-are-building-performance-standards

[3] Maps and Comparisons. Institute for Market Transformation. Undated. https://imt.org/public-policy/maps-and-comparisons/.

The business benefits for consumers of VIG and CSW technologies include:

- Significantly improved thermal resistance (R-value) and insulating capacity (U-value) over single-pane glass.
- 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 decreased global warming potential (GWP) refrigerant usage from oversized HVAC systems needed in buildings with a poor building envelope.
- Non-energy benefits (NEBs) like increased thermal comfort, noise reduction, 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.[4]
- Compared to traditional full window replacement, both VIG and CSW installations are minimally disruptive to existing tenants, often requiring no tenant displacement.
- Compared to traditional full window replacement, and depending on the application, VIG can be 50% less expensive and CSW can be as much as 90% less expensive.[5]

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

Strategies to overcome these barriers and accelerate market adoption include:

- Build market momentum for BPS adoption and technical support for building owners and service providers (architects, ESCOs, engineering firms) likely to be impacted by BPS policies growing in California. This includes working to develop high performance building technical hubs[6] and engaging leading service providers to support and advocate

[4] To the building owner/tenants, it's greater comfort, coasting longer through DR events without seeing large temperature changes. To the utility, it's more curtailment because the AC can stay off longer before reaching temperatures where it has to be turned back on.

[5] Pratt, Jordan and Wynn, Sean. Commercial Secondary Windows Field Test. Northwest Energy Efficiency Alliance. December 18, 2023. https://neea.org/resources/commercial-secondary-windows-field-test.

[6] High Performance Building Hubs deliver customizable best-practice and educational resources to support BPS policy compliance. These hubs provide critical market and technical support for building owners and service providers as BPS policy goes into effect. https://imt.org/wp-content/uploads/2022/06/bpp_hubguidance.pdf.

an "envelope first"[7] approach for buildings with single-pane windows.

- Build a full business case including estimates on the monetization of NEBs and impacts on HVAC investment and modeling tools for California.
- Build marketing tools and resources that communicate the importance of taking an "envelope first" approach when working to improve existing commercial buildings with single-pane windows, especially for those in the MUSH market.
- Engage manufacturers and supply chain partners on innovations to drive down product and installation costs and create go-to market strategies especially for the MUSH market.
- Conduct in-field demonstrations in the MUSH market that document benefits including NEBs.
- Build awareness of benefits and business case of tackling poor performing windows through leveraged partnerships on both the demand and supply side like California chapters of the American Institute of Architects and the Building Owner and Management Association (BOMA).
- Build market awareness of and drive increased manufacturer engagement with CSW and VIG national energy rating mechanisms: The Attachments Energy Rating Council (AERC) for CSW and the National Fenestration Rating Council (NFRC) for VIG.

As envisioned by CalMTA, by 2045 over 25% of the existing commercial building sector square footage that currently have single-pane windows will utilize the window technologies of VIG or CSW, in line with California's decarbonization targets. 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 on the benefits of taking an "envelope first" strategy utilizing 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 the windows and California will permanently forfeit envelope-related Total System Benefits (TSB).

CalMTA's preliminary analysis for this MT idea during Stage 2 scoring, which only included VIG technology, estimated a TSB of $145 million over the 20-year lifecycle of the initiative. This Advancement Plan suggests broadening the scope of Phase II to include CSWs given the overlap in the supply chain as well as the similarity in business case benefits compared to full window replacement. Since CSW technology was a late addition to this proposed MT idea, its TSB analysis would need to be performed and added to this initiative in Phase II. Preliminary TSB estimates by

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[7] An "envelope-first" approach to improving building energy performance involves prioritizing enhancements to a building's envelope—the walls, windows, roof, and foundation. By focusing on creating a tight, well-insulated envelope a building can minimize thermal losses between the interior and exterior environments.

CalMTA for the combined MT idea of VIG and CSW indicate it could be nearly four times that of VIG alone with a substantially lower cost.

3 Product, service, or practice definition

This section describes the preliminary understanding of the initiative's technology, service, or practice, its benefits, and any existing codes, standards or policies that governs it. Some parts of this definition may not be fully known at this point and will be solidified through further research and studies outlined in the following sections.

The two products included in this MT idea target similar building applications and share a large degree of overlap in supply chain and market drivers:

- Vacuum Insulated Glass (VIG) for single-pane replacement (SPR)
- Commercial Secondary Windows (CSW)

VIG SPR: Commercial Vacuum-Insulated Glass units, designed to replace existing single-pane glass while retaining use of the existing frame, are comprised of two glass panes, separated by spacers and hermetically sealed around the edges. A vacuum is drawn on the void space between the glass panes resulting in a center-of-glass R-Value of R-10 to R-15 (not including frame effects, which can reduce the whole-window R-Value). 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 may include low-E coatings, insulating gases, thermal films and/or vacuum insulated glass units in their construction. CSWs may be permanently installed or removeable. Because CSW are installed over the existing window and because light-weight options are available for CSW, installation can be substantially easier, faster, and less expensive than VIG or full window replacement.

VIG are capable of achieving higher insulation values than CSW but have a higher product and installation costs. They are likely more attractive solutions for buildings undergoing deep retrofits given these costs. CSW, with lower product cost and significantly lower installation costs, are attractive solutions for any building that needs to address envelope performance and may not be undergoing a deep retrofit.

Compared to traditional full window replacement, and depending on the application, VIG can be 50% less expensive and CSW can be as much as 90% less expensive.

No federal or state codes govern VIG for single-pane replacement or CSW attachment products, though local building codes may be triggered for VIG depending on the magnitude of the retrofit.

4 Market Transformation theory and opportunity

4.1 Market context and opportunity

This section describes the market context, Market Transformation concept, and opportunity.

As California tries to meet their aggressive building decarbonization goals, existing commercial buildings, particularly those that still have single-pane windows, remain a significant problem to address. Although windows on average comprise only 15% of a building's exterior surface, they are responsible for HVAC losses of approximately 40%, which equates to 12% of a typical building's overall energy use.[8]

To meet this challenge, BPS and the market ecosystems of service providers and technology hubs they create, are a growing policy tool to push existing commercial building owners towards decarbonization investment. BPS policies aim to reduce buildings' carbon impact and have been implemented or are under development in over 20 states and jurisdictions. Statewide BPS is in its early development phase in California, but it is likely to move forward as the primary viable strategy to decarbonize existing commercial and multifamily building.[9]

To address these existing buildings there is a nascent but growing recognition by the Department of Energy (DOE), American Council for an Energy Efficient Economy, and others impacted by BPS such as the New York State Energy Research and Development Authority, that poor-performing, single-pane windows must be addressed as a prerequisite to decarbonization. Windows have historically taken a higher precedence in colder climates, but high solar heat gains in California, create a need for better window performance to meet the state's aggressive decarbonization goals. The current default strategy for decarbonization and BPS compliance is to upgrade the HVAC system with heat pumps. However, addressing building decarbonization with HVAC only solves a short-term problem and, in many cases, creates more problems as detailed below:

- **Oversized HVAC systems leading to increased costs and emissions:** Converting from natural gas heating to a heat pump only system may require oversizing to compensate for the reduction in heating capacity at lower temperatures. Peak load impacts are anticipated to be exacerbated by this approach along with excessive GWP refrigerant use due to the higher capacity system design. Window upgrades will enable efficient, correctly sized heat pump only systems to run properly. Yet failure to upgrade windows prior to HVAC upgrades will result in less resilient buildings and lower available demand response (DR)

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[8] Pratt, Jordan and Wynn, Sean. Commercial Secondary Windows Field Test. Northwest Energy Efficiency Alliance. December 18, 2023. https://neea.org/resources/commercial-secondary-windows-field-test.

[9] Building Performance Standards. Building Energy Codes Program. May 18, 2022. https://public.tableau.com/app/profile/doebecp/viz/BuildingPerformanceStandards/BuildingPerformanceStandards.

capacity. Moreover, it is highly unlikely that building owners will upgrade or replace windows after an HVAC upgrade. And even if building owners do elect to address inefficient windows after an HVAC upgrade, this results in an oversized HVAC system and reduces energy efficiency for the life of that system. Thus, waiting on window upgrades can result in forfeiting their benefits.

- **Exacerbate thermal discomfort:** For building owners, installing a more efficient HVAC system without first addressing single-pane windows may exacerbate thermal comfort problems at the building perimeter, due to slower rates of heating and cooling with heat pumps. This places greater burden on the HVAC system, compounding peak load impacts and pushes electric bills even higher.
- **Lost efficiency potential:** For the energy system as a whole, if we invest in heat pumps before addressing the building envelope, we permanently forfeit envelope-related TSB benefits including energy efficiency and peak load reduction.

It is not surprising that mitigating poor performing windows has not been considered a viable solution until recently. The default practice - full window replacements where the building facade is opened and the complete window (frame and glass) is removed and replaced - is very complex, disruptive to owners and tenants who are displaced during the lengthy process, requires skilled labor and is consequently very expensive. Return on investments (ROIs) for these traditional window replacements are in the 40 to 50-year range, resulting in a "do-nothing" decision in most cases.

In recent years, better solutions have entered the market, though awareness of these solutions remains low. CSW and VIG are market-ready solutions that deliver similar energy savings benefits of full window replacement, do not require opening the building facade, cost 50-90% less than full replacement and can be installed without tenant disruption. In jurisdictions with BPS currently, building envelope strategies are now working their way into BPS compliance paths for buildings with single-pane windows. CSWs play a prominent role in Con Edison's strategies for compliance with New York Local Law 97 (NY's BPS), and Puget Sound Energy is offering custom incentives as part of their Accelerator Program supporting compliance with Washington state's BPS.

The imperative to act now via this MT idea is to help prepare the market and ensure technology hubs push for an "envelope first" strategy utilizing CSW and VIG *before* BPS becomes a significant policy driver in California, thus preventing a situation where CA permanently forfeits envelope-related TSB benefits.

4.2 Target market

This section defines the sector(s) this product, service or practice is intended for. The target market may be adjusted based on the results of the research conducted in Phase II of the initiative.

The target market for this MT idea is existing commercial buildings built before 2000 that still have single-pane windows. The state did not mandate double-pane glass until 2000, so many buildings have inefficient, single-pane glass that needs replacement if they are to be efficiently decarbonized.

Initially, CalMTA will focus on a few submarkets within the commercial building market that are good candidates for VIG and CSW. Because owner-occupied buildings have a longer ownership horizon and a stronger business case for efficient window investments than commercial real estate owners whose occupants/renters generally pay for utilities, the MUSH market (municipal, universities, schools and healthcare) is a likely first target. VIG/CSW also offer historic and hospitality buildings significant NEBs like sound and comfort improvements so these submarkets will also be in the initial target. In addition, commercial buildings that are already considering major retrofits or in need of HVAC replacement are also prime targets for VIG given the potential for a reduced investment in HVAC if poor performing windows are improved.

For CSW specifically, this MT idea will target smaller commercial buildings in environmental and social justice (ESJ) communities. CSWs provide lower product and installation costs and are attractive solutions for smaller buildings that need to address envelope performance.

4.3 Key market barriers

This section captures a high-level overview of perceived barriers which limit adoption of the technology in this market. These barriers will be verified, during Phase II, through the work defined in Section 6 of this document.

The market for addressing poor performing windows with VIG and CSW products is slowly growing. This is driven in part by a growing awareness of the importance of dealing with poor performing windows to reach decarbonization mandates but also by the growth of more diverse and mature products in the market. Yet this technology still faces significant barriers.

- **Cost:** Compared to other energy efficiency improvements, improving windows is still expensive and paybacks are long if based only on short-term energy savings. This is the largest barrier to adoption and why we still see existing buildings with single-pane windows.
- **Understanding of the problem:** Many building owners are unaware of the positive impacts of high-performing window solutions on energy consumption, peak savings, HVAC downsizing, and occupant comfort. This lack of awareness is more acute in mild climates like CA.
- **Awareness of technical solution:** Even when supply-chain actors and building owners understand the problem, most are unfamiliar of VIG and CSW technologies as viable solutions. They quickly dismiss addressing single-pane windows, thinking this would involve full window replacement, the most expensive option. The supply chain for both

CSW and VIG installers is also in early development with not enough supply chain players like architects and ESCOs pushing these products.

- **Current HVAC contractor business models:** The business model for HVAC contractors typically focuses on specifying larger HVAC systems first because it is simpler, faster, and more profitable for them. Because owners are unaware of the benefits of improving the windows first and then sizing the HVAC after, this opportunity is largely missed.
- **VIG product and market maturity:** VIG specifically is an emerging technology with significant potential but, currently, there is limited product availability from a few specialized domestic manufacturers with most of the product currently being produced in Asia. There is also a lack of sufficient façade-level testing, certification, and documentation systems for VIG. These products require robust engineering capability that includes building energy modeling to define ROI, structural requirements, pricing estimates, and waterproofing guidelines to mitigate any water and air infiltration issues when a renovation occurs.
- **Estimation of NEBs**: Both CSW and VIG offer valuable NEBs such as improved thermal comfort around the perimeter of the building and noise reduction, both which may improve occupancy rates. Addressing poor performing windows with VIG and CSW also allows the building to maintain moderate internal temperatures during significant heat or cold climate events, offering significant climate resilience benefits. There is also a direct benefit to historic buildings, especially with CSW, as it allows the building owner to keep the original windows and add the CSW products. Quantifying these benefits is a challenge because of costs and the degree of variability between projects but this MTI will leverage existing research to create estimates of the financial benefits for CSW based upon modeling or pilot data acquired during the next phase. This is critical to building the business case and need to be considered in the entire ROI to encourage adoption by building owners and the supply chain.
- **Building Performance Standards (BPS) are not yet fully deployed across California**: The CalMTA team sees the adoption of BPS, where building owners are required to make improvements to their existing buildings, as the key driver for the adoption of CSW and VIG. At this time, BPS policies in CA are in early development, BPS has not yet been adopted statewide, and technology hubs to support BPS implementation are not yet in place. Not having a statewide BPS policy, along with the market infrastructure in place to support building owners in this transition, is a near-term barrier for this MT idea.
- **Overall challenges in commercial building market**: Commercial real estate continues to experience a downturn post Covid with changes in workforce patterns and impacts to office buildings. This may impact the ability of building owners to address poor performing windows and efficiency improvements overall. In some cases, however, this may be a driver for building retrofits including window solutions as building owners try to repurpose their buildings. This is less of a barrier with the MUSH market.

4.4 Possible Points of leverage and strategic interventions

The section describes the points of leverage and strategic interventions that are envisioned at this early stage that could be utilized to achieve the transformed market end state. The next research phase of this MT idea will help the team test and refine assumptions.

- **Build momentum for BPS:** BPS is a growing policy tool that could push existing commercial buildings owners to make improvements to their windows to reduce overall energy use. There are several large municipalities currently in California pursuing BPS that could be leveraged for this MT idea in the future. California does have a statewide commercial benchmarking mandate which is considered a steppingstone to a statewide BPS. Thus, a strategic intervention for this MT idea would be to collaborate with other organizations working to advocate for BPS and help prepare the market with field study results, tools, and resources targeting the importance of taking an “envelope first” approach when working to improve existing commercial buildings with singe-pane windows. This intervention might involve CalMTA taking an active role in helping build technology “High-Performance Building Hubs” that offer resources to building owners to assist them in meeting current and future BPS targets. These hubs have been important resources in other markets that have BPS policies in place (Washington State and New York City).
- **Build business case for "envelope first” and/or integrated program approach for deeper retrofits:** The business case for taking an envelope first approach with CSW or VIG needs to be built. It needs to bundle the holistic energy benefits (EE, HVAC downsizing, peak savings) with the extensive NEBs. In many cases, building owners may be trying to address comfort issues, and improved energy efficiency is a secondary driver. An intervention here will be to first quantify these benefits through field demonstrations and research and then partner with demand aggregators like American Institute of Architects, energy service companies (ESCOs), and BOMA to reach building owners and their influencers with the full business case for CSW and VIG. These would also be critical resources for supporting high-performance building hubs that would serve building owners as BPS policies become adopted. These hubs could be the central channel that the envelope first approach diffuses to building owners.
- **Engage manufacturers and other supply chain partners:** There is a group of leading CSW and VIG manufacturers investing in innovations to drive down product and installation costs. This work is being supported by the DOE, the Partnership for Advanced Window Solutions (PAWS), and national labs like the Lawrence Berkeley National Laboratory (LBNL). 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. The DOE work will catalyze manufacturers to reduce manufacturing and installation costs which can then serve as a leverage point for this MT idea. A CalMTA intervention would involve building on this manufacturer engagement coupled with helping to build demand amongst key submarkets, particularly in the MUSH

market. Both of these interventions would support long-term product installation cost declines and possible workforce development goals with window installers.

- **Build awareness and support of energy rating systems:** Rating organizations are in place but need market support. For CSW products there is the AERC and many products are already rated. AERC needs support from the energy efficiency community to build demand for energy-rated products. Through field studies and awareness building this MT idea will work to build demand for AERC-rated products. For VIG, a rating needs to be developed under the National Fenestration Rating Council (NFRC) and in partnership with other energy efficiency organizations and DOE. These organizations are instrumental to building the needed energy rating for these products and support manufacturer engagement.

4.5 Environmental & social justice approach

This section describes the initiative's targeted equity approach and summarizes the initiative's potential intervention strategies to advance Equity, Environmental and Social Justice as well as Workforce Development, Education, and Training.

The ESJ approach for CRAWS centers on primarily targeting ESJ buildings in the MUSH markets in ESJ communities with both CSW and VIG as they try to decarbonize. Because CSW are a more affordable product, CalMTA also sees a specific opportunity to target small commercial buildings, more commonly owned by ESJ community members with CSW. Through the interventions described in the section above (4.4) and in the conceptual logic model detailed in Section 4.9, we foresee several specific areas to target that would benefit ESJ communities.

- Target any in-field demonstrations to MUSH buildings that primarily serve ESJ communities, to document the benefits and savings created for the communities. These can be developed into case studies and support ESJ community building owners as they work to comply with BPS policies through an envelope first approach.
- Both CSW and VIG manufacturers are working to bring down installation costs with new models of on-site sizing and installation, the deployment of which will likely require workforce training and development. By working with manufacturers directly, CalMTA can help to prioritize workforce development opportunities in ESJ communities.
- Bundle CSW with other program's measures and ESJ-targeted finance mechanisms to drive down the overall project costs. Bundling of measures with financing will improve the ROI and enable building owners to target envelope measures before investments in HVAC improvements.
- Engage with community-based organizations (CBOs) and their local building owner clients to increase the awareness of CSW's business case which, in time, can generate increased community advocacy and adoption. CBOs could become advocates for CSW within the communities they serve.

- Engage local utility programs, Regional Energy Networks, and Community Choice Aggregators to offer incentives to lower product cost and increase accessibility to commercial/facilities buildings located in ESJ communities. This will direct resources towards an increased awareness/adoption of CSW/VIG.

4.6 Market vision/end-state

The section describes the vision of the end state for what the transformed market will look like because of the initiative's work.

To meet BPS targets, the business benefits of taking an "envelope first" approach are promoted by high-performance building technology hubs and valued by commercial building owners, who then invest in these products as a key strategy to fully decarbonize their buildings over the long term. In response, the supply chain for both CSW and VIG is mature to meet growing demand. By 2045 over 25% of the existing commercial building sector square footage that currently have single-pane windows utilizes the technologies in support of California's plans to achieve carbon neutrality by 2045.

4.7 Key market Assumptions

The section describes Key Market Assumptions for the State of California that are assumed when determining the Market Vision/End State.

- Energy costs in California continue to rise improving the ROI for both CSW and VIG.
- BPS as a policy tool grows in jurisdictions across California with a possible statewide BPS in place. These policies will include investments in high-performance building technology hubs to support the market as BPS policies take effect.
- California policies and programs continue to shift towards electrification and net zero buildings, serving as a driver for owners of existing commercial buildings to improve their poor performing windows.
- Undergoing full window replacement (i.e., replacing both the glass and frame) will remain more expensive than CSW or VIG.
- CSW and VIG product manufacturers continue to pursue relevant energy ratings through AERC and NFRC.

4.8 Diffusion and "lastingness" mechanism

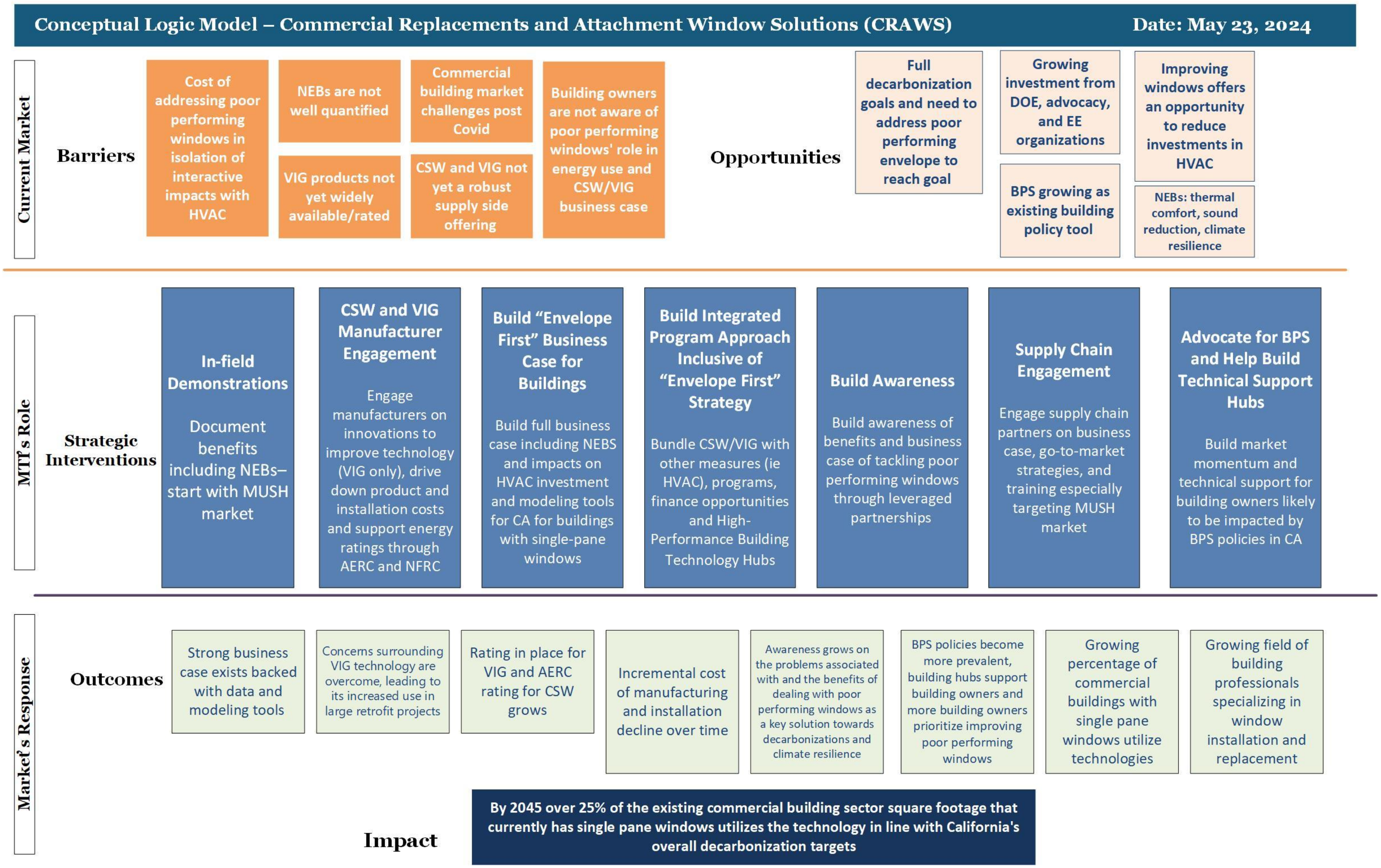
At some point, the market will continue to transform, even when the initiative's investments have ended. This section describes the market mechanism that will continue to move the technologies' transformation forward, after CalMTA's exit, to achieve the end state described above.

The CalMTA team foresees multiple long-term drivers coalescing that would create diffusion for this MT idea. Owners of commercial buildings will be faced with a growing need to decarbonize their buildings driven by state policies, BPS mandates, and challenges with a heat pump only approach. As awareness of CSW/VIG benefits grow, including the role they play in resilience and demand response, building owners and supply chain actors will be compelled to take a more integrated approach and invest in CSW and VIG as a primary step towards decarbonization and improving poor performing buildings with single-pane windows.

4.9 Conceptual logic model

Figure 2 on the following page features the conceptual logic model developed to provide a preliminary visualization of the MTI program theory. It includes high-level barriers and opportunities that inform the draft interventions, as well as expected outcomes and long-term impacts. The proposed market characterization, product assessment, and pilots conducted in Phase II will verify this logic model's assumptions and draft interventions. Once this work is completed in Phase II, CalMTA will develop a more refined and formal logic model for Phase III: Market Deployment.

Figure 2. Draft Phase I Conceptual MTI Logic Model



4.10 Measuring market outcomes

This section identifies a few preliminary Market Progress Indicators (MPIs) for the initiative. A more comprehensive set of MPI's and Equity Metrics will be established during the development of a more refined and formal logic model for Phase III: Market Deployment.

Table 1. Possible MTI Market Progress Indicators and data sources

Preliminary Outcome*	Possible Market Progress Indicator	Possible Data Sources
Strong business case for building owners exists, backed up with data and modeling tools	Availability of modeling tools that enable building owners and installers to estimate the benefits of VIG/CSW installations compared to current systems and alternatives like full window replacement	Interviews with technical SMEs, building owners and window installers.
Concerns surrounding VIG technology are overcome, leading to its increased use in large retrofit projects	Proportion of building owners and window installers who are aware of VIG, have fewer concerns about its use, and perceive VIG technology as more effective than traditional window replacement for large retrofit projects	Survey of building owners, window installers and rating organizations Interviews with technical SMEs at national labs and NFRC
Nationally recognized rating systems (NFRC for VIG and AERC for CSW) become more widely adopted by VIG and CSW manufacturers, increasing the availability of rated products in the market.	Number of NFRC and AERC certified products	AERC/NFRC database
Incremental cost of manufacturing and installation of technologies declines over time	Cost of VIG and CSW installations	Survey of building owners, ESCOs, and window installers Industry reports
Awareness grows on the problems associated with and the benefits of dealing with poor performing windows as a key solution towards decarbonization and climate resilience	Proportion of building owners and supply chain actors who are aware of the economic and environmental impacts of poor performing windows and recognize the potential benefits of window upgrades	Survey of building owners, ESCOs, and window installers

Preliminary Outcome*	Possible Market Progress Indicator	Possible Data Sources
As BPS policies become more prevalent, more building owners prioritize improving poor performing windows	Increased awareness of building performance standards among building owners Number of building permits issued for renovations that include window upgrades in areas with stricter building performance standards	Survey of building owners, ESCOs, and window installers Building permit data
Growing percentage of commercial buildings with single-pane windows utilize technologies	Number and percentage of existing buildings with single-pane windows retrofitted with VIG or CSW	Building audits Survey of building owners, ESCOs, and window installers Market research on VIG and CSW adoption trends
Growing field of trained professionals specializing in CSW and VIG window installation	Number of personnel – 3rd party installers and property manager staff – trained to install CSW Window, ESCO and service provider companies include training in VIG or CSW technology	Surveys with relevant companies

*See Figure 2. Draft Phase I Conceptual MTI Logic Model

Table 2. Possible MTI equity metrics and data sources

Preliminary Outcome*	Possible Equity Metric	Possible Data Sources
The percentage increase in MUSH market buildings serving ESJ communities (e.g., schools, libraries) with VIG/CSW installations should be at least proportionally equal to the increase in non-ESJ serving buildings	Percentage of MUSH market buildings with CSW/VIG installations in ESJ communities compared to same in non-ESJ communities	MUSH market inventory data, building upgrade project reports, installer surveys, customer surveys

Preliminary Outcome*	Possible Equity Metric	Possible Data Sources
Increased awareness of financing options for building owners, and the bundling of state incentives and rebates, utilized in ESJ communities	The percentage of building owners in ESJ communities who are aware of the financing options and incentives or rebates available for windows upgrades	Survey of building owners and window installers operating in ESJ markets
Increased access and awareness of VIG/CSW installation training opportunities in underserved communities	Number of VIG/CSW installation training programs offered in underserved communities	Interviews with SMEs as well as industry alliances like Fenestration and Glazing Industry Alliance (FIGA) and National Fenestration Rating Council (NFRC)
Improved awareness of VIG/CSW benefits among owners/management staff of buildings in ESJ Communities	Level of awareness of VIG/CSW technology and its benefits among building owners/management staff in ESJ communities	Building owner survey
Increase awareness and adoption of CSW/VIG among CBOs serving ESJ communities and their building owner clients	Level of awareness of VIG/CSW technology and its benefits among CBOs serving ESJ communities and their building owner clients	Survey of CBOs and their building owner clients operating in ESJ communities

*Section 4.5 Environmental & social justice approach

5 Gap analysis

This section describes the most critical data/information needs to be gathered through phase II to make sure the Market Transformation initiative is viable and to create the full MTI Plan. Section 6 will provide more information on how we are going to gather this data.

CalMTA has identified critical knowledge gaps surrounding the adoption of CSW and VIG. These gaps are crucial for informing the development of a successful MTI Plan to drive increased utilization of these energy-saving technologies. These gaps will be addressed through targeted data collection and analysis effort in Phase II. Section 6 details the technical and market research questions to be addressed in Phase II and the corresponding methods.

Interaction between envelope upgrades and HVAC system sizing and cost: A precise understanding of how CSW and VIG impact HVAC systems is essential to building the business case for this MT idea. This includes how these technologies can lead to downsized HVAC equipment needs, resulting in cost savings in both capital financing and ongoing operating expenses, increased energy efficiency, and reduced refrigerant use.

Regulatory/public policy landscape: A critical knowledge gap exists regarding the current policies and regulations impacting the adoption of advanced window technologies like CSW and

VIG. Research is required to understand how these technologies are influenced by building codes and energy efficiency regulations, BPS, and permitting processes. Specifically, we need to determine how current codes and standards support or hinder a holistic approach that combines HVAC and envelope upgrades, how BPS programs address window performance and recognize CSW/VIG as compliance measures for achieving energy targets, and the complexity of obtaining permits for installing these systems.

Comparative installation considerations: Currently, there is a lack of precise estimates regarding the comparative effort, time, and cost of VIG single-pane replacement compared to both full window replacement and CSW installation. Gathering data on these factors will allow for a more comprehensive cost-benefit analysis for building owners considering these technologies and will be included in the business case.

Uncertainties in forecasting VIG benefits: While VIG offers promising benefits in energy efficiency and thermal comfort, the precise quantification of these advantages for specific retrofit projects in existing commercial buildings remains a knowledge gap. A number of factors regarding the existing window frames including their geometry, material, and current condition are likely to significantly impact the performance of VIG retrofits. Unfortunately, current research lacks data that quantifies these variations in real world conditions, making it challenging to precisely forecast the benefits of VIG retrofits across diverse commercial building applications.

Financing considerations: A significant knowledge gap exists regarding financing mechanisms for CSW and VIG projects, particularly for buildings serving ESJ communities. For public sector buildings, such as schools and colleges, the primary source of funding for such projects typically comes from the state, county, and city budget. The team will investigate the budget allocation processes, funding cycles, and constraints within the budget that affect the adoption of improved envelopes in public buildings. There is also a gap in this MT idea's understanding on the potential role of ESCOs. ESCOs offer performance-based financing for energy efficiency upgrades. Understanding their business model for MUSH market buildings and payback criteria will be crucial for identifying building types most suitable for ESCO-financed CSW and VIG projects.

Market awareness and education: In addition to the technical aspects, this MT idea needs to understand more about the level of market awareness and education surrounding CSW and VIG technologies among key decision-makers, such as building owners, building managers, and architects including their understanding of the interactive effects poor performing windows can have on HVAC needs. Potential obstacles linked to building regulations and performance standards also need to be scrutinized.

Strategy for future BPS in California: While California currently has limited implementation of BPS, there is a knowledge gap regarding the effectiveness of existing municipal BPS policies in addressing the energy performance of commercial building envelopes. This includes understanding how current or upcoming BPS policies incorporate the performance of building components, such as windows, into overall building energy assessments. It is unclear whether BPS policies adequately consider the potential benefits of high-performance window technologies like CSW and VIG in achieving energy performance targets. Additionally, examining BPS policies from other states including New York City, Oregon, and Washington could provide valuable insights into best practices for BPS policy design and implementation and reveal potential roles for CalMTA in advancing BPS policies statewide. Another area to explore is how building owners and property managers strategize to meet BPS standards, particularly in terms of prioritizing envelope upgrades such as CSW and VIG.

By addressing these critical knowledge gaps through targeted data collection in Phase II, CalMTA can develop a more comprehensive and effective MTI Plan with targeted interventions to drive market transformation and accelerate the adoption of CSW and VIG technologies.

6 Research and program development plan

6.1 Technology assessment

This section describes any assessment that might be needed to prove the viability of the technology, service, or practice the initiative is targeting. Table 3 summarizes what and why the information is needed to complete the planning phase of the initiative and how the information will be collected. Table 4 summarizes the estimated cost per task and the time it will take to complete the task by the research team.

Technical Assessment Objectives: The CalMTA team will conduct technical assessments of VIG and CSWs currently on the market, including products that are in the early commercialization stage. These assessments will allow the CalMTA team to validate and refine assumptions about how the technology will be adopted and used, whether it will have the expected impact, and if there are any technical limitations that might reduce customer confidence or otherwise limit adoption and use that will need to be addressed during implementation of the MTI. Most studies or lab testing described in the methods column will address multiple objectives and research questions.

Note: Interviews and literature reviews will be conducted in conjunction with the Market Research described in Table 3. Initial cost estimates are included in Table 6 below.

The CalMTA team identified the following technology assessment (TA) activities to address critical knowledge gaps and to inform the MTI strategy. Interviews and literature reviews will be conducted with the Market Research described in Table 5.

TA 1. Quantify Energy and Non-Energy Impacts specific to CA Climates

a. For each target building type, quantify energy impacts and thermal comfort impacts of single-pane windows in CA relevant (mild) climate zone through energy modeling. Estimate temperature rise over time during simulated DR events.

Measure interior and exterior window surface temperatures under different solar exposure scenarios.

b. Evaluate ability of single-zone HVAC to maintain comfortable and safe temperatures across entire building footprint (e.g., building core, central building, building perimeter) by measuring temperature gradients under defined scenarios.
c. Determine what percentage of target building types would be unable to switch to heat pump HVAC technology without first upgrading building envelope by estimating building HVAC heating loads.

TA 2. Quantify Energy Benefits

a. Assess window/HVAC interactions (e.g., run time) and heating/cooling savings for VIG and range of CSW products.
b. Evaluate air leakage reduction for VIG and range of CSW products.
c. Assess potential for elimination of baseboard heating.
d. Determine energy savings associated with HVAC downsizing potential.
e. Evaluate energy savings potential and costs of competing solutions such as blinds, shades, film, and full window replacement.

TA 3. Identify the NEBs

a. Evaluate and quantify, when possible, the dollar-equivalent benefit of the following non-energy benefits: thermal comfort, noise reduction, and resiliency during extreme weather (both heating and cooling).

TA 4. Quantify Peak Electrical Load Impacts

a. Determine peak load reduction and shift associated with target products in each target building type and for most common HVAC types.

TA 5. Investigate Resiliency & Grid Flexibility

a. Evaluate temperature rise profile and HVAC operations during DR events with and without VIG or CSW across all target building types.

TA 6. Evaluate Product Performance & Durability

a. Condensation: collect field data from manufacturers from existing installations, evaluate to see if incremental field work is necessary.
b. Test installation of VIG and CSW as solutions for operable windows.
c. Assess the true system level U-factor for VIG when installed in existing frames.
d. Understand estimated VIG lifetime through review of durability studies.

TA 7. Product Ratings & Test Procedures

a. Identify relevant barriers and requirements to create ratings standards for VIG.

TA 8. Investigate Financial & Cost Factors

a. Determine typical purchase and installation cost ranges by product type.
b. Evaluate long-term cost-reduction potential.

c. Evaluate ESCO business model and payback criteria to determine what building types present ESCO-financed opportunities. Evaluate as a portfolio of measures to include HVAC and lighting.

Technology Assessment Methods: Technology assessment methods will include literature review, data analysis, discussions with SMEs and other key stakeholders, energy modeling, laboratory testing, product tear down, and field studies. An initial review will be performed to identify and inventory existing assessment data and any planned or in-progress product testing. We will identify where we can leverage existing work and where to prioritize research efforts to fill knowledge gaps.

The assessment effort will leverage ongoing work being performed by the DOE, California's Statewide Codes and Standards Enhancement (CASE) Team, LBNL, Pacific Northwest National Lab (PNNL), Oak Ridge National Lab, National Renewable Energy Lab (NREL), U.S. General Services Administration's Center for Emerging Building Technologies and Green Proving Grounds Program as well as research efforts being coordinated by DOE's PAWS, the California Energy Commission, CalNEXT, Northwest Energy Efficiency Alliance field study, and other energy efficiency organizations.

In addition to leveraging work currently underway, CalMTA will coordinate novel technology assessment activities as needed with a focus on real world case studies in California climate zones and California building stock that more clearly quantify the whole building and system-level energy benefits (HVAC down-sizing, lighting impacts and heat-pump readiness) and NEB market drivers such as thermal comfort, noise reduction, and climate resilience during weather events and historic preservation. The existing data along with new research will help inform the product specifications that the team determines provides the greatest value to target existing buildings in California. A product specification can leverage the AERC database of existing products to define a CSW performance level while the technology assessment work can guide the VIG performance for installation in existing frames. Creating a product specification will guide manufacturer engagement, BPS strategies, and inform financing strategies based upon projected energy savings and first costs.

Table 3. Summary of technology assessment activities

Technology Assessment (TA) Research Objective	Phase II Research Task					Deliverable(s) Informed by Research	Related Market Research
	Literature & Existing Data Review	Ongoing Expert Engagement	Energy Modeling & Engineering Calculations	Lab Testing or Product Tear Down	Field Study		
TA.1: Quantify Energy and Non-Energy Impacts specific to CA Climates	✓	✓	✓		✓	Product Plan, MTI Plan	MR.1 MR.5
TA.2: Quantify Energy Benefits	✓		✓		✓	Product Specifications, Product Plan, MTI Plan	MR.1
TA.3: Identify the NEBs	✓	✓	✓		✓	Product Specifications, Product Plan, MTI Plan	MR.2
TA.4: Quantify Peak Electrical Load Impacts	✓		✓		✓	Product Plan, MTI Plan	
TA.5: Investigate Resiliency & Grid Flexibility	✓		✓		✓	Product Plan, MTI Plan	
TA.6: Evaluate Product Performance & Durability			✓	✓	✓	Product Specifications, Product Plan	
TA.7: Product Ratings & Test Procedures		✓	✓	✓	✓	Product Specifications, Product Plan	MR. 5
TA.8: Investigate Financial & Cost Factors		✓	✓	✓	✓	Product Specifications, Product Plan	MR.4 MR.6

Table 4. Summary of technology assessment needs, cost, and estimated timeline

Technology Assessment Task	Schedule (Estimated Weeks)	Estimated Cost	Deliverables Informed by this Task
(1) Lit & Existing Data Review, Expert Engagement	Weeks 1 – 32	$75,000	Product Plan
(2) Product Tear-Down	Weeks 12 – 40	$75,000	Product Assessment, Product Plan, Impact and Cost-effectiveness (CE) Forecast
(3) Energy Modeling & Engineering Calculations	Weeks 16 - 60	$75,000	Product Assessment, Product Plan, Impact and CE Forecast
(4) Lab Testing	Weeks 24 – 60	$175,000	Product Assessment
(5) Field Study	Weeks 24 – 72	$400,000	Product Assessment, Product Plan, Impact and CE Forecast
(6) Test Method Development*	Weeks 1 – 72	$75,000	Product Assessment, Product Plan
Total Estimate:		**$875,000**	

*Test method development is a technical assessment task unique to this MTI. This task would combine expert engagement, engineering calculations, and lab testing in addition to stakeholder coordination on a technical committee.

6.2 Market research

This section describes the market research needed to inform the MTI planning. The objective of the proposed research, the methods by which the research is conducted and how the results of the research will be use are shown in Table 5. Table 6 summarizes the estimated cost per task by the research team.

Market Research Objectives: This market research (MR) aims to assess the potential adoption of CSW and VIG technologies within California's commercial buildings. By investigating both the demand and supply sides of the market, the research will assess the barriers and opportunities to adoption of the target technologies and inform the MTI planning. Additionally, the research will analyze the existing regulatory landscape to understand how it might impact the adoption of these technologies. This comprehensive analysis will establish a foundation for forecasting market adoption of CSW and VIG within California's commercial sector as well as opportunities for CalMTA intervention.

Specifically, the CalMTA team has identified the following market research (MR) objectives to fill critical knowledge gaps in the market and inform the MTI strategy.

MR 1. Characterize the Baseline Market Conditions

a. Windows inventory: Estimate the current distribution of window types (single-pane, double-pane, etc.) across different commercial building categories in California.
b. Planned replacements: Estimate the proportion of building owners considering window upgrades in the near future. What are the primary drivers for these planned replacements?
c. Utilize the energy audit data currently being collected in CA to identify buildings most likely to need an envelope upgrade in order to meet anticipated energy use intensity or greenhouse gas (GHG) emission targets and determine what the reductions are with and without windows. "With" reductions could be evaluated by identifying building retrofits where windows are being addressed, and the 'without' condition could be accomplished via energy modeling.

MR1a. Estimate Current Adoption of VIG and CSW:

a. Estimate current market saturation and market share of VIG and CSW in commercial sector in California through surveys, review of existing research, and analysis of sales or shipment data.

MR 2. Demand-side Market Characterization

a. Assess awareness among market players: Estimate the extent to which building owners and managers are aware of CSW and VIG technologies, their benefits, and ease of installation.
b. Assess perceptions and knowledge: How knowledgeable are key decision-makers regarding the value proposition of CSW and VIG compared to traditional window replacement or other energy-saving measures?
c. Window replacement versus HVAC upgrades: How do building owners and managers perceive the benefits and challenges of VIG/CSW installations relative to HVAC system retrofits, including heat pump replacements? What factors influence their decision-making process regarding these upgrades, considering energy efficiency, occupant comfort, aesthetics, cost, and the potential synergies between VIG/CSW and different HVAC systems? How do changes in the HVAC market, such as the increased adoption of electric heat pumps, influence building owner decisions regarding VIG/CSW installations, considering factors like energy costs, regulatory requirements, and occupant comfort?
d. Identify barriers: Identify and qualitatively rank the key obstacles hindering the adoption of CSW and VIG technologies? This could include factors like initial cost, installation challenges, maintenance concerns, lack of information, or perceived impact on building aesthetics. Are there misperceptions about the value proposition of these technologies in California's mild climate? Assess perceptions and priorities related to HVAC downsizing after CSW installation, including concerns about occupant comfort and the prioritization of envelope improvements versus HVAC upgrades.

d. Estimate NEBs: Evaluate and quantify NEBs from VIG and CSW: thermal comfort, noise reduction, and climate resiliency during extreme weather events.

MR 3. Supply-side Market Characterization

a. Identify market players: Who are the current or expected major suppliers and installers of CSW and VIG solutions in California? What are their product offerings and distribution channels? What are the emerging product trends and timelines?
b. Assess supply-chain challenges: Identify and rank the key obstacles related to manufacturing, logistics, and installation that could impact the availability and cost of CSW and VIG solutions.

MR 4. Costs and Benefits Characterization/Financing Options

a. Cost considerations: What are the typical cost ranges for CSW and VIG installations compared to full window replacements, considering both upfront purchase and installation costs, as well as on-going operating costs? What role can ESCOs play in financing VIG/CSW projects?
b. Non-energy benefit estimation: What are the potential NEBs associated with CSW and VIG installations (e.g., occupant thermal comfort and noise reduction)? How can these benefits be quantified or estimated to inform decision-making?
c. Financing mechanisms: How do building owners typically finance major building upgrade projects? What role can ESCOs play in facilitating CSW and VIG projects, particularly when combined with other upgrades?

MR 5. Regulatory/Public Policy Landscape

a. Building code impact: How do existing building codes and energy efficiency regulations in California influence the adoption of advanced window technologies like CSW and VIG? Are there specific requirements or incentives that encourage or hinder the use of these technologies?
b. BPS: How do existing BPS in California address the energy performance of building envelopes, specifically windows? Which California jurisdictions currently have BPS in place? What is the status and timing for both large metro area BPS polices and a statewide BPS? Are CSW or VIG panels included as approved measures for building owners to achieve compliance with energy performance targets? What role and strategic interventions could CalMTA undertake in encouraging BPS adoption?
c. Permitting process: What is the complexity of obtaining permits and approvals for installing CSW and VIG systems? Are there any safety or environmental considerations specific to these technologies?

MR 6. Develop Market Baseline Forecast for Commercial Replacement and Attachment Window Solutions

a. Generate a baseline forecast of market adoption of CSW/VIG among existing commercial buildings (baseline market adoption).
b. Generate an evaluation plan for incremental impact of CalMTA interventions.

Market Research Methods: The market research will depend upon a combination of (a) secondary data analysis, (b) qualitative interviews, (c) Delphi panel, and (d) a large-scale survey of building owners and managers. For qualitative interviews, the team will interview three broad categories of stakeholders. First, we will interview manufacturers and installers of CSW and VIG to gain insights into supply chain dynamics, costs, and installation challenges. The group will also include ESCOs. Second, we will conduct interviews with building owners and managers across various sectors (office, municipal, university, school, healthcare) to understand decision-making processes, perceived benefits/barriers, and the influence of building type on adoption. Finally, we will interview tenants, including small business owners and employees, to identify non-energy related benefits.

After the qualitative interviews, we will convene a Delphi panel of industry Subject Matter Experts (SMEs) to validate the key barriers and opportunities identified during interviews and create a baseline market adoption forecast for CSW and VIG in California's commercial buildings. Finally, we will develop and administer a survey to a broad range of building owners and property managers to gather quantitative data on adoption rates, decision-making factors, and the impact of various barriers.

Table 5. Market Research objectives, tasks, and final deliverables

Market Research (MR) Objective	Phase II Research Task						Deliverable(s) Informed by Research
	Secondary Research/ Sales Data Purchase	Interviews - Manufacturers & Installers	Interviews - Building Owners including MUSH	Interviews - Tenants & Business Owners	Delphi Panel	Survey of Building Owners/ Property Managers	
MR.1: Characterize the Baseline Market Conditions	✓	✓	✓			✓	Market Characterization, Baseline Market Adoption Forecast
MR.1a: Estimate current saturation and market share of VIG and CSW	✓					✓	Market Characterization
MR.2: Demand-side Market Characterization	✓	✓	✓	✓	✓	✓	MTI Plan, Evaluation and Data Collection Plans, Market Characterization, Baseline Market Forecast, Impact and Cost-Effectiveness Forecast
MR.3: Supply-side Market Characterization	✓	✓	✓		✓		MTI Plan, Evaluation and Data Collection Plans, Market Characterization, Baseline Market Forecast, Impact and Cost-Effectiveness Forecast
MR.4: Costs and Benefits Characterization/Financing Options	✓	✓	✓	✓		✓	MTI Plan, Evaluation and Data Collection Plans, Market Characterization, Baseline Market Forecast, Impact and Cost-Effectiveness Forecast
MR.5: Regulatory/Public Policy Landscape	✓	✓	✓				MTI Plan
MR.6: Develop Market Baseline Forecast for CRAWS					✓		Baseline Market Forecast

Table 6. Market Research task, estimated cost, and estimated timeline

Market Research Task	Schedule (Estimated Weeks)	Estimated Cost	Deliverables Informed by this Task
(1) Secondary Data Research/Sales Data Analysis	Weeks 1-20	$60,000	Market Characterization, BMA Forecast; Impact and CE Forecast, MTI Plan
(2) Interviews of manufacturers and installers including ESCOs	Weeks 8-24	$50,000	Market Characterization and MTI Plan
(3) Interview of building owners/property managers and MUSH.	Weeks 8-32	$65,000	Market Characterization and MTI Plan
(4) Interview of tenants including business owners	Weeks 15-40	$45,000	Market Characterization and MTI Plan
(5) Survey of building owners & property managers	Weeks 30-52	$125,000	Market Characterization and MTI Plan
(6) Delphi Panel	Weeks 42-60	$55,000	Baseline Market Adoption Forecast
Total Estimate:		**$400,000**	

The market research activities will conclude with an estimation of base year saturation and market share of the MTI technology.

The technology and market research activities described in this plan will inform an updated forecast of market adoption and development of Phase II TSB and cost-effectiveness estimates. These revised estimates will be developed upon the completion of the market characterization and will be submitted as part of the full MTI Plan. We will incorporate CSW into market adoption, TSB and cost-effectiveness analyses for Phase II and report the revised estimates in the MTI Plan.

6.3 Strategy pilots

This section describes any potential intervention strategies that need to be tested during the Phase II development of this initiative and how conducting the pilot can inform the MTI's business case.

The CalMTA team has concluded that this MTI needs further research before pilots can be identified. Below outlines a potential pilot and its research objectives, but the team will develop a full Strategy Pilot Test Plan at a later date after preliminary product and market research is conducted.

In addition, the team has submitted four proposals to CalNEXT's Q2 2024 Request for Ideas (RFI) that includes the following research objectives.[10] CalNEXT will not make a decision on which pilots they choose to move forward until late 2024. Once the team learns what CalNEXT includes in their research portfolio, the CalMTA team will have a better understanding what the scope of a strategy pilot CalMTA will need to invest in for this MTI.

The MT program theory asserts that, if a building owner is trying to fully decarbonize their building and they have single-pane windows, it is likely they will need to improve the windows to reach their goals. Although BPS is not yet in place throughout California, in anticipation of future BPS mandates and based on experience in jurisdictions that have BPS, it is expected that meeting energy and GHG reduction targets will necessitate addressing single-pane windows prior to HVAC updates. A pilot is needed to test the efficient bundling of CSW and VIG with a building owner's effort to decarbonize and downsize their HVAC system. This pilot could target two buildings: one targeting an appropriate application for VIG and one for CSW. In addition, this pilot would document energy and NEBs to build a complete business case for building owners and supply chain market actors like ESCO's and architects, to convince them on the viability of dealing with poor performing windows and their potential energy and business impacts.

Pilots that involve the improvement of fenestration typically are a longer-term proposition and need at least 1-1.5 years to complete. Given that, CalMTA is looking for buildings in the MUSH market that are already trying to either fully electrify or are needing to upgrade their HVAC systems, or both. If we can find a project in the early phases that has the right building characteristics, we can work to add VIG or CSW to the measure mix before HVAC investments are made. Draft research objectives of this pilot could include:

- Research Objective 1: Verify and document the role that improving poor performing windows plays in a building's journey towards full electrification.
- Research Objective 2: Document financial impacts of investment in VIG and/or CSW on HVAC investments needs and full project financing.
- Research Objective 3: Document and quantify, when possible, the NEBs accrued from the addition of VIG or CSW. This could include improved occupant comfort, noise reduction, and improved climate resilience during weather events.

[10] CalNEXT is a statewide initiative in California that identifies, tests, and grows electric technologies and delivery methods to support the state's decarbonized future. More information may be obtained at https://calnext.com/.

7 External program review and stakeholder engagement

This section identifies a few key program stakeholders CalMTA needs to coordinate with as we determine the MTI viability and develop the MTI Plan. This list is a subset of a larger list and more stakeholders will be identified to coordinate with during Phase II.

As is standard practice in Phase I of our MTI development process, CalMTA conducted initial analysis to identify areas of potential overlap and opportunities for collaboration between the CRAWS MT idea and existing programs or organizations focused on this market segment. While incentive programs and other investor-owned utility offerings may be an important point of leverage during the MTI's implementation, CalMTA will prioritize coordination with the following stakeholder groups as we conduct the activities identified in this Advancement Plan.

Table 8. Summary of key external stakeholders

Program – Organization/ Stakeholder Segment	Coordination Approach
CalNEXT	Review CalNEXT existing research findings, especially their recently completed Commercial Windows Market Study and Measure Package Development Report, and conduct 1:1 outreach to the team's SMEs to understand questions and areas of future research Maintain regular cadence of meetings to share research plans and explore for overlap and cost-sharing opportunities Submit to CalNEXT RFIs for identified research needs
Partnership for Advanced Window Solutions (PAWS)	Coordinate and share information to ensure that energy modeling and research efforts reflect the needs of California's building types and climate zones
Local municipalities who have plans or have already adopted BPS and their support for high-performance building hubs	Track and support efforts to adopt BPS at the city or county level as a potential point of leverage for CSW/VIG adoption Encourage incorporating envelope upgrades that include CSW/VIG as a component of city/county-wide building retrofits and support they give building owners through high performance building technology hubs
School-based and overall MUSH building energy efficiency, electrification, and resilience programs	Identify sites for strategy pilots and build the business case for CSW/VIG with whole building electrification efforts
Commercial sector energy efficiency programs	Encourage inclusion of CSW/VIG incentives in commercial programs

Program – Organization/ Stakeholder Segment	Coordination Approach
Statewide Codes & Standards Advocacy Programs as it pertains to Title 24 on major window renovations in commercial buildings (in some cases, VIG may be subject to Title 24 in large commercial projects)	Continue ongoing series of coordination meetings to understand partners' current work and/or upcoming activities related to this technology and market segment Provide relevant information and insight to support the standardization of product performance and efficiency metrics

As described in Section 4.4, CalMTA also sees multiple opportunities to coordinate with national energy rating and certification programs like the AERC and NFRC, the DOE and the DOE-funded national labs, all of which offer significant points of leverage in the market.

8 Potential risks & mitigation

Table 9 describes potential risks, the assumed severity, and how we plan to track and mitigate the risk if needed.

Table 9. Hypothesized MTI risk review

Initiative Risk	Severity	Mitigation Approach
Commercial office real estate is not conducive to large upgrades at this time given the post pandemic impacts to commercial buildings and changes in workforce patterns	High	Focus on other beachhead markets (i.e., MUSH, owner-occupied) and monitor commercial office real estate market
Challenges associated with developing a test methods/ratings for VIG with NFRC inhibits ability to model savings	High	Early in the program, work with NFRC and LBNL to identify VIG appropriate test methods and rating procedures
Inability to quantify the challenges with windows in mild climates leads to low interest from the market for window solutions	High	Significant early effort to quantify thermal comfort and energy-related negative impacts of single-pane glass in CA climate zones
Currently BPS is not yet a driver in the California's existing commercial market	Medium	In the near term prepare and help motivate the market by quantifying and including NEBs in the business case and/or value proposition. (i.e., focus on the "carrot"). When BPS policies come online, we will be able to use the possible BPS compliance "stick"
Challenges to quantifying NEBs	Medium	Investigate utilities/other programs that have successfully quantified NEBs Scan of other projects that have included these NEBs in business case and also conduct pilots in CA that work

Initiative Risk	Severity	Mitigation Approach
		to document NEBs as part of pilot design
HVAC upgrades precede window upgrades resulting in oversized HVAC systems that cost the building owner more than if they had taken an "envelope first" strategy	Medium	Awareness and education effort among architects, engineers and building owners/managers regarding incremental benefits of taking an envelope-first strategy
VIG market failing to mature limits domestic manufacturing scale and associated cost-reduction opportunities	Medium	Establish test methods and ratings for VIG SPR; demonstration projects and case studies to quantify benefits of SPR
Building owners and supply chain looks to alternative products (like shading) to mitigate window issues, thus do not reap the energy savings and benefits to reduced HVAC investments	Low	Use energy modeling to demonstrate/differentiate energy and NEBs performance for MTI product vs shading devices

9 Estimated costs, timing, and expected results

Table 10 summarizes the estimated costs to complete the Phase II technology assessment, market research, and strategy pilot described in Section 6.

Table 10. MT Advancement Plan estimated cost summary

Task	Estimated Cost
Technology Assessment	**$875,000**
(1) Lit Review, Market Actor Interviews (Weeks 1-32)	$75,000
(2) Product Tear-Down, Cost Analysis (Weeks 12-40)	$75,000
(3) Energy Modeling & Data Analysis (Weeks 16-60)	$75,000
(4) Laboratory Testing (Weeks 24-60)	$175,000
(5) Field Study and Measurements (Weeks 24-72)	$400,000
(6) Test Method Development (Weeks 1-72)	$75,000
Market Research	**$400,000**
(1) Secondary Data Research/Sales Data Analysis (Weeks 1-20)	$60,000
(2) Interviews of manufacturers and installers including ESCOs (Weeks 8-24)	$50,000
(3) Interview of building owners/property managers and MUSH (Weeks 8-32)	$65,000
(4) Interview of tenants including business owners (Weeks 15-40)	$45,000
(5) Survey of building owners & property managers (Weeks 30-52)	$125,000
(6) Delphi Panel (Weeks 42-60)	$55,000
Strategy Pilots	
Pilot 1 – To Be Determined*	$0

Task	Estimated Cost
Total	**$1,275,000**

*See Section 6.3 Strategy pilots

Figure 3 shows a rough timeline of this phase's activities to develop the MTI Plan.

Figure 3. Overall timeline/schedule of activities

Activity	Duration (Weeks)	Timeline (Months)																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Technology Assessment																			
(1) Lit Review, Market Actor Interviews	Weeks 1-32																		
(2) Product Tear-Down, Cost Analysis	Weeks 12-40																		
(3) Energy Modeling & Data Analysis	Weeks 16-60																		
(4) Laboratory Testing	Weeks 24-60																		
(5) Field Study and Measurements	Weeks 24-72																		
(6) Test Method Development	Weeks 1-72																		
Market Research																			
(1) Secondary Data Research / Sales Data Analysis	Weeks 1-20																		
(2) Interviews of manufacturers and installers	Weeks 8-24																		
(3) Interview of building owners/property managers and MUSH (also ESCOs)	Weeks 8-32																		
(4) Interview of Tenants included business owners	Weeks 15-40																		
(5) Survey of building owners & property managers	Weeks 30-52																		
(6) Delphi Panel	Weeks 42-60																		

Table 11 shows a rough estimate of the initiative's market deployment timeline and impacts should it advance to the market deployment phase.

Table 11. Initiative market deployment estimated cost & expected results

Initiative Cost ($)	>$25 million	VIG is an expensive and complicated technology with a large market to transform. Encouraging change will take significant investment.
Initiative Timeline (Years)	>10 years	Given the long-term investment of building envelope improvements, enacting change in the market will take time.
Expected Results	TSB: $145 million TSB Energy: $23.5 million TSB Grid: $50.4 million TSB GHG: $71 million	Preliminary analysis shows that a VIG MTI could result in substantial emissions reduction, in alignment with achieving state decarbonization goals. We expect this estimate to increase with the addition of CSW to the product mix. The team will conduct this analysis in the next phase. Preliminary TSB estimates for the combined MTI of VIG and CSW indicate it could be nearly 4 times that of VIG alone.

About CalMTA

CalMTA is a program of the California Public Utilities Commission and is administered by Resource Innovations. We work to deliver cost-effective energy efficiency and decarbonization benefits to Californians through a unique approach called market transformation. Market transformation is the strategic process of intervening in a market to create lasting change by removing market barriers or exploiting opportunities, accelerating the adoption of identified technologies or practices. CalMTA-developed market transformation initiatives also aim to advance state goals on demand flexibility, workforce development and equity. Learn more at www.calmta.org.

Appendix A: Market Forecasting Benefits and Cost-Effectiveness Estimation Approach

SINGLE-PANE RETROFIT WITH VACUUM-INSULATED GLASS

The information provided in this appendix summarizes the approach and methodologies used for the preliminary estimation of market adoption, total system benefit (TSB), and cost-effectiveness during stage 2 scoring. The target markets, product definition, or other criteria may have shifted during the development of the advancement plan. The information contained in this appendix will be updated at the end of Phase II as part of the MTI Plan development to ensure the estimates better reflect the most current MTI design.

Market transformation initiatives (MTIs) generate energy savings and related benefits by accelerating and increasing market adoption of energy-efficient technologies and practices. Estimating the energy impacts and cost-effectiveness of MTIs requires developing a market forecasting model that uses a set of inputs based on well-documented sources, methods, and assumptions.

This appendix provides an overview of the technology and market characteristics of the MT idea as originally conceived in Stage 2 involving single-pane retrofit with vacuum-insulated glass (VIG), followed by a summary of the inputs, sources, and methods used to develop the market forecasting and cost-effectiveness model. The summary of model outputs covers the estimates of the benefits and cost-effectiveness of the original MT idea.

In Phase II of the MTI lifecycle (end of Phase II), a TSB and cost-effectiveness analysis will be performed for the refined MTI, including Commercial Secondary Windows (CSWs). We also will refine and update our approach as we learn more about the market through additional Phase II research.

A.1 MTI Overview

The Stage 2 analysis focused only on VIG and did not include (CSWs). Table A1 summarizes the product definition and market characteristics of an MTI involving single-pane windows retrofit with VIG, which was the idea that advanced to Stage 2 scoring. MTIs typically evolve over time based on market research and experience.

Table A1. MT idea product definition and market characteristics

MTI Phase	Phase I Stage 2
Product Definition	Upgrade existing single-pane windows with VIG. While retaining use of the existing frame. VIG is comprised of two glass panes, separated by spacers and hermetically sealed around the edges. A vacuum is drawn on the void space between the glass panes resulting in improved energy performance.
Addressable Market Segments	Existing commercial buildings with single-pane windows.
Baseline Installation Conditions	Retrofitted with Title 24 2022 Retrofit Metal-Framed Window. Existing single-pane windows are tinted.

A.2 Adoption Forecasting Model

This section outlines our team's approach to forecast the adoption of VIG from 2025 to 2045 in the addressable market segments in California's commercial sector.[11] To begin, we projected the baseline market adoption (BMA) of the technology, which considers current and expected market trends, technological advancements, and regulatory factors, assuming no intervention by CalMTA. Next, we forecasted the total market adoption (TMA), which assumes the presence of market interventions by CalMTA to address market barriers. Finally, the incremental adoption (TMA minus BMA) is allocated to various scenarios based on baseline technologies being replaced by the MTI technology to estimate cost-effectiveness and TSB.

Inputs

Table A2 lists the key assumptions used to forecast the adoption of single-pane windows retrofit with VIG by the California commercial sector.

Table A2. Assumptions used in forecasting model

Category	Variable	Assumptions	Notes
Forecasts of Units of MTI technology	Effective Useful Life (EUL)	20 years	California Electronic Technical Reference Manual
	Proportion of repeat buyers at end of life (RPR)	75%	
Timing of MTI Initiation, Rollout, and Impact Realization	Start year for initiation of CalMTA MTI	2025	
	Number of years for design and finalization of CalMTA initiatives	2	

[11] This analysis assumes the start of CalMTA program design and intervention rollout in 2025 (Phase III of the project). However, actual MTI implementation will be contingent upon the MTI Plan development (Phase II) and approval by the CPUC. The forecast horizon will be revisited in Phase II analysis.

Category	Variable	Assumptions	Notes
Share of VIG as percent of total single-pane window upgrades by commercial buildings	2023	0.5%	
	2045	BMA: 10% TMA: 25%	

The following sections discuss the sources and methods used to estimate product saturation, market size, and market growth (with and without the MTI).

Base-Year Saturation

The team used the ComStock® dataset to estimate the distribution of windows in existing commercial buildings in California (Table A3).[12] The ComStock dataset was developed by the NREL with funding from the U.S. Department of Energy (Parker, Andrew, et al. 2023). ComStock is a granular, bottom-up model that uses multiple data sources, statistical sampling methods, and building energy simulations to estimate the annual sub-hourly energy consumption of the commercial building stock across the United States. For California, the model includes 39,391 building energy models (BEM) providing detailed information about a building's characteristics and energy systems. Together, the 39,391 BEMs in ComStock represent the commercial building stock as it existed in 2018 in California (Parker et al. 2023). The dataset provides the following information about windows in commercial buildings: window-to-wall ratio, number of panes, frame material, glazing type, low-E coating, gas fill, solar heat gain coefficient, and U-factor.

Table A3. NREL ComStock estimate of windows in commercial buildings in California in 2018

	Single-Pane Windows*	Double-Pane Windows*	Triple-Pane Windows*
Number of Commercial Buildings	94,225	82,565	198
Total Commercial Floorspace (Million Square-feet)+	3,220	2,823	14

*The MTI focuses on commercial buildings with single-pane windows only. Information about double-pane and triple-pane windows are provided for context only.
+The floor space represents the total gross floor area of commercial buildings. This does not account for the specific area within these buildings that are affected by windows. In Phase II, we will investigate the potential to adopt windows area rather than floorspace for analysis.

[12] https://comstock.nrel.gov/

For the Stage 2 preliminary forecasts, we assumed that the number of windows in commercial buildings in 2023 is consistent with the 2018 estimate in Table 3.[13]

Vintage of Single-Pane Windows

Table A4 summarizes the distribution of single-pane windows disaggregated by vintage. The vintage information is based on NREL's ComStock. The dataset does not track the age of the windows but does track the specific energy code standard that was adhered to during the most recent replacement of windows. For simplicity, we use that estimate as a proxy for the age of the window.

Table A4. Age distribution of single-pane windows in commercial buildings in California in 2018 by vintage category

Vintage Category of Current Single-Pane Window	Assumed Average Age in 2023	Floor Space (Million Sq-ft)	# of commercial buildings
1975	48 years	172	5,341
1980	43 years	1,058	32,373
1985	38 years	58	1,820
1992	31 years	1,406	40,305
2000	23 years	60	1,854
2004	19 years	97	2,551
2007	16 years	225	6,159
2010	13 years	63	1,962
2013	10 years	49	1,091
2016	7 years	32	770
Total		**3,220**	**94,225**

Source: NREL ComStock

Methodology

To develop the preliminary Stage 2 forecast of VIG, the team developed a transition schedule for existing single-pane windows based on their vintage and assumed operational lifespan. Upon reaching the transition point, building owners may replace existing single-pane glass and install VIGs using the existing frame. Alternatively, they may adopt baseline technologies, which involve either tinting the existing single-pane windows or retrofitting with Title-24 compliant metal framed new windows. In Phase II we will also consider a baseline condition that does not involve a single-pane windows upgrade. Throughout this section, the units of the forecast are in terms of commercial floorspace (square feet or sq. ft.) transitioning to this MTI technology.

[13] In Phase 2, we will refine this assumption by considering historical trends in turnover of commercial buildings and may also consider updated versions of the Comstock dataset.

Baseline Market Adoption Forecast

For the Phase I forecasting model, the following equation summarizes the team's approach to forecast adoption of VIG in any given year:

$$y_t = Transition_t^{BMA} \times \rho_t^{BMA} + y_{t-EUL} \times RPR$$

Where:

y_t	=	annual adoption in year t in terms of the MTI technology
$Transition_t^{BMA}$	=	existing commercial floorspace (sq. ft.) that transition their single-pane windows in year t in BMA
ρ_t^{BMA}	=	market share of the MTI technology in year t in BMA
RPR	=	repeat purchase rate of the MTI technology
EUL	=	effective useful life (EUL) of the MTI technology in years
y_{t-EUL}	=	MTIs adopted in year ($t - EUL$) and retired in year t

Transition of current single-pane windows ($\mathbf{Transition_t^{BMA}}$)

Instead of assuming that all single-pane windows of a given vintage are transitioned in a single year (see Table A5), we employed a statistical distribution to model window transition over a period of several years. This approach assigns each vintage a transition start year and a transition end year as shown in Table 5. Within this timeframe, we assumed a uniform statistical distribution for transitions,[14] where the probability of a window from a specific vintage transitioning is considered equal across each year between the start and end years. This statistical approach provides a more realistic representation of window transition patterns compared to a single-year assumption. It acknowledges the variability in window lifespans and avoids an unrealistic "cliff effect," where all units transition at once. Given average vintage as shown in Table A5, and assumed transition schedule, we computed the average age at transition for a given vintage.

Table A5. Assumptions for transition schedule of current single-pane windows

Vintage Category of Current Single-Pane Windows (Year Installed/Retrofitted)	BMA		
	Transition Start Year	Transition End Year	Avg age at Transition Completion (years)
2016	2046	2075	45
2013	2043	2072	45
2010	2040	2069	45
2007	2037	2066	45
2004	2034	2063	45
2000	2030	2059	45
1992	2023	2052	46
1985	2023	2042	48

[14] The team considered a Weibull statistical distribution to model equipment retirement/phase out to capture the nonlinear nature of failure rates over time. In Phase 2, we will revisit the approach used to model equipment failure rates.

Vintage Category of Current Single-Pane Windows (Year Installed/Retrofitted)	BMA		
	Transition Start Year	Transition End Year	Avg age at Transition Completion (years)
1980	2023	2037	50
1975	2023	2032	50

Market Share of VIG (ρ_t^{BMA})

Table A6 gives CalMTA assumptions about annual market share of VIG in the market for single-pane window retrofit by commercial buildings in California. The year 2023 is considered as the base year for market share data although the forecast period is 2025-2045. For the intervening years, CalMTA assumed a linear interpolation.

Table A6. Assumed share of single-pane windows

Year	Assumed Annual Market Share for BMA forecast
2023	0.5%
2045	10%

VIG is a relatively new technology in the commercial building space. Due to this, it is not currently captured explicitly in major resources like ComStock or the Energy Information Agency's Commercial Buildings Consumption Survey.[15] Given the newness of the technology and insufficient data available, we assumed a near zero market share in the base year 2023.[16]

Looking ahead to 2045, we anticipate that various market barriers will limit the growth of VIG's market share over the forecast period. These barriers include limited awareness of the technology and its benefits, restricted product availability, and an immature supply chain. In order to forecast the adoption of VIG, CalMTA examined the market trends of two other window technologies: triple-pane windows, which have maintained a steady 1% market share, and low-emissivity coatings, which experienced slow growth for the first decade after their introduction but then saw a significant surge over the subsequent decade. Drawing from these analogies, CalMTA predicts that the growth of VIG's market share will likely fall somewhere between these two trajectories.[17]

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[15] 2018 Commercial Buildings Energy Consumption Survey final results. Energy Information Administration. https://www.eia.gov/consumption/commercial/

[16] See Table 1 in Watts, Alliston et al. Guidelines and Specifications for Enhanced Durability Evaluation of Insulating Glass and Vacuum Insulating Glass Units. NREL. September 2022. https://www.nrel.gov/docs/fy22osti/83550.pdf

[17] See Figure ES-2 in Harris, Chioke. Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption. Department of Energy. April 2022. https://www.nrel.gov/docs/fy22osti/80171.pdf

Total Market Adoption Forecast

This section focuses on the Stage 2 adoption forecast for the MTI in California with targeted interventions to address market barriers and opportunities. While the specifics of these interventions remain undetermined, we considered the probable increase in adoption resulting from them. The forecasting methodology for TMA was consistent with the methodology used by the team to forecast BMA, and adoption in year t is written as:

$$y_t = Transition_t^{TMA} \times \rho_t^{TMA} + y_{t-EUL} \times RPR$$

Where:

y_t	=	annual adoption in year t of the MTI technology
$Transition_t^{TMA}$	=	existing commercial floorspace (sq-ft) that transition their single-pane windows in year t in TMA
ρ_t^{TMA}	=	market share of the MTI technology in year t in TMA

Other terms are as defined in the prior equation for BMA.

The TMA forecast applies assumptions that differ from BMA in two specific ways. First, we assume an accelerated transition schedule of current single-pane windows in commercial buildings (Table A7). Second, we assume that a higher proportion of commercial buildings will adopt VIG instead of tinting their existing single-pane windows or retrofitting with Title-24 compliant metal framed windows (
Table A8).

Transition of current single-pane windows ($\mathbf{Transition_t^{TMA}}$)

Given average vintage as shown in Table A7 and assumed transition schedule, we computed the average age at transition for a given vintage.

Table A7. Assumptions for transition schedule of current single-pane windows

Vintage Category of current single-pane windows (Year Installed/Retrofitted)	TMA		
	Transition Start Year	Transition End Year	Avg age at Transition completion (years)
2016	2046	2060	37
2013	2043	2057	37
2010	2040	2054	37
2007	2037	2051	37
2004	2034	2048	37
2000	2030	2047	40
1992	2023	2040	40
1985	2023	2037	45
1980	2023	2032	48
1975	2023	2028	48

Market Share of VIG (ρ_t^{TMA})

CalMTA made the following assumptions about annual market share of VIG in the market for single-pane window retrofit by commercial buildings in California for the years 2023 and 2045 (Table A8). For the intervening years, CalMTA assumed a linear interpolation.

As in case of BMA, VIGs growth trajectory is assumed to fall between the growth trajectories of triple-pane windows and low-emissivity coatings. However, unlike BMA, the TMA trajectory is assumed to be closer to low-emissivity coatings which has seen substantial market success compared to triple-pane windows technology which has yet to take-off.[18]

Table A8. Assumed share of single-pane windows

Year	Assumed Annual Market Share for TMA forecast
2023	0.5%
2045	25%

Incremental Market Adoption (TMA – BMA)

Incremental market adoption in any given year is the difference between the square feet of commercial floorspace adopting the MTI in TMA, and the square feet of commercial floorspace adopting the MTI in BMA.

$$y_t^{Incremental} = y_t^{TMA} - y_t^{BMA}$$

Where:

$y_t^{Incremental}$ = Incremental annual adoption in time t that may be attributed to CalMTA interventions.

Allocation to Baseline Installation Conditions (Scenarios)

We allocated the incremental adoption ($y_t^{Incremental}$) to the baseline installation conditions (shown in Table A9). The distribution is based on share of the single-pane windows in the installed based on commercial buildings in 2018 that are metal per NREL ComStock.

Table A9. Stage 2 VIG – installation conditions

Segment	Technology	Baseline	Distribution of Incremental Market Adoption
Existing Commercial Buildings with Single-pane Windows	VIG	Tinting of Existing Single-Pane windows	78%
		T24 2022 Retrofit Metal-Framed Window	22%

[18] See Figure ES-2 of https://www.nrel.gov/docs/fy22osti/80171.pdf.

Outputs

In this section, we summarize the preliminary BMA and TMA forecasts for existing single-family households. We used the following equation to estimate the cumulative adoption units:

$$\sum_{t=2025}^{2045} y_t^{BMA} \text{ and } \sum_{t=2025}^{2045} y_t^{TMA}$$

Baseline Market Adoption Forecast

We forecasted a cumulative adoption of VIG by existing commercial buildings representing 108 million square feet of floor space over the forecast horizon in the absence of CalMTA interventions. This forecast includes repeat installation.

Total Market Adoption Forecast

We forecasted a cumulative adoption of VIG by existing commercial buildings representing 257 million square feet of floor space over the forecast horizon in the presence of CalMTA interventions.

Incremental Adoption

We calculated incremental market adoption, in terms of floor space of existing commercial buildings with single-pane windows, as the difference between TMA and BMA for 149 million square feet. Table A10A10 shows the incremental adoption as allocated to the baseline installation conditions.

Table A10. Stage 2 VIG – incremental adoption

Segment	Technology	Baseline	Incremental Market Adoption (million sq. ft. floorspace)
Existing Commercial Buildings with Single-pane Windows	VIG	Tinting of existing Single-Pane Windows	116
		T24 2022 Retrofit Metal-Framed Window	33

A.3 Cost-Effectiveness Model

Evaluating cost-effectiveness and determining the net benefit for an MTI requires the appropriate application of the outputs from the market forecasting model, initiative costs, incremental measure cost (IMC), avoided cost, load shape, and unit energy impacts (UEI). 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.

Currently, CEDARS' Cost-Effectiveness Tool (CET) is the official publicly available program to evaluate energy efficiency programs in California. The CET can be used for evaluation programs from all utilities, climate zones, using approved 8,760 load shapes, and defined avoided costs. However, since the MTI focuses on relatively new technologies and some MTIs involving new technologies require custom 8,760 load shapes not currently supported by CET, the team developed an in-house Excel-based cost-effectiveness tool versatile enough to handle all the MTIs for CalMTA.

Inputs

The cost-effectiveness model uses the following inputs to assess cost-effectiveness and develop TSB estimates. TSB is a representation, in dollars on an annual basis, of the lifecycle energy, ancillary services, generation capacity, transmission and distribution capacity, and GHG benefits of the market transformation initiative. We applied the inputs according to the formulas listed in the *Methodology* section below.

Incremental Adoption

We developed incremental market adoption of VIG windows for large buildings projected to replace their existing windows with VIG windows between 2027 and 2045. The MTI considered the following two types of existing windows as shown in Table A11. The incremental adoption, forecast in units of square feet of commercial space was converted to units of commercial large building and provided in Table A11, by applying the conversion factor of 53,628 square feet per building, to match UEI units, over the 20-year period of the MTI.

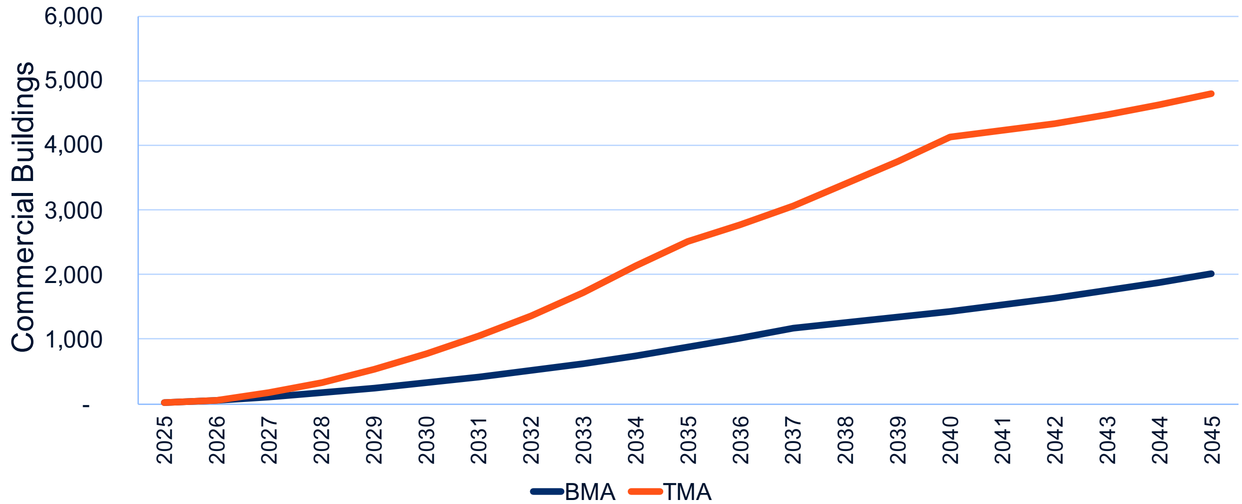
Table A11. Installation Conditions

Sector	Decision Type	Baseline Equipment Types	Efficient Equipment	Incremental Market Adoption (Units)
Existing Commercial Buildings with Single-pane Windows	Accelerated Replacement (AR), and Normal Replacement (NR)	T24 2022 Retrofit Metal-Framed Window	VIG Window	1,753 Commercial Buildings
		Existing Single-Pane Tinted	VIG Window	1,030 Commercial Buildings

The incremental units of adoption, estimated by the market adoption models, generated benefits for the duration of the EUL of VIG windows. For example, if 80,000 units were projected to be installed in 2027, these units contributed to the model for 20 years (EUL for VIG windows). Figure A1 illustrates cumulative market adoption of VIG.[19]

[19] For Phase II research, we will incorporate any updates to the EUL values.

Figure A1. Cumulative Market Adoption of VIG



Initiative Costs

Initiative costs are related to the implementation of the MTI. This includes flow down incentives (FDIs)[20] and non-incentive costs, such as administration, research and evaluation, marketing, and other related costs. The FDI costs are assumed to be implemented over five years, beginning with 25% of the incremental adoption in 2027 and ending with 50% of the incremental adoption in 2031. Non-FDI costs are applied over the length of the MTI from 2025 to 2045.

Initiative costs are inputs to the Total Resource Cost (TRC) test and Program Administrator Cost (PAC) test. In the PAC test, all initiative costs are included. Initiative costs are discounted to determine the net present value of the initiative.

Incremental Measure Cost (IMC)

The team conducted secondary research to develop estimates of incremental costs for each baseline installation condition. Since the technology is relatively new to the market and pricing was impossible to find, we referenced an article published by Peter Yost on Building Green in October 2018. The article suggested that typical passive house triple-glazed windows cost anywhere from $30 to $70 per square foot. Assuming that the cost of VIGs might fall within that range and that large commercial buildings might obtain bulk discounts, we assumed a price of $50 per square foot. For the analysis, we assumed the VIG windows would be 30 square feet, resulting in a total price of $1,500 per window.

Since the savings impacts were in terms of whole buildings with sizes of about 50,000 square feet, an approximate count of windows per building needed to be derived. We assumed that a 50,000-

square-foot building would contain about 7,000 square feet of windows, resulting in about 234 windows per building. Under these assumptions, we derived an incremental measure cost of just under $185,000 for a baseline assumption of buildings with T24 2022 Retrofit Metal-Framed windows. Similarly, we derived an IMC of $351,361 for a baseline assumption of buildings with existing single-pane tinted windows.

After determining the IMC for each installation condition, we extrapolated the costs in future years by subtracting 2% of the first-year incremental cost from each subsequent year in the MTI, to represent anticipated reduction in case costs relative to the baseline. We assumed that IMC would decrease over time due to economies of scale (that is, the price of the efficient technology is cheaper over time). The Stage 2 analysis also assumes that inflation would equally impact both the base and proposed cases and therefore did not update IMC estimates for inflation. In Phase II, we will conduct additional analysis to refine incremental cost estimates for the forecasting period.

We included IMCs in the TRC test, along with non-FDI costs for each year and each installation condition.

Avoided Costs

Avoided costs are defined as the marginal costs that the state of California would avoid in any given hour through lower energy consumption. The electric avoided costs include cap and trade, GHG adder, GHG Rebalancing, energy, generation capacity, transmission capacity, distribution capacity, ancillary services, losses, and methane leakage. The gas avoided costs include transmission and distribution, commodity, nitrogen oxides, carbon dioxide, and methane emissions.

The team developed avoided costs using the avoided cost calculator (2022) for three utilities: Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E). We developed avoided costs based on a per commercial building basis for each installation condition from 2025 to 2045 in each utility's territory. Avoided costs included energy, grid, and GHG benefits for electric and gas fuels. Because the MTI will result in market impacts outside the IOU service territories, we also estimated avoided costs for "other" non-IOU territories.[21]

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[21] Since the MTI is implemented for California as a whole, avoided costs for PG&E, SCE, and SDG&E only do not fully represent the entire state. For the Stage 2 (Phase I) analysis, we included a separate category, "other," to represent the other utilities in California, developed through population proportions and utility territory maps. Specifically, we overlayed the utility territory maps with county boundaries and assigned an appropriate proportion of the county's population to the respective utility. We developed avoided costs for the "other" category by applying population-weighted average avoided costs for the three utilities. After discussion with the CPUC, we agreed to remove benefits estimated for non-IOU territories from the Phase II cost-effectiveness calculations.

Avoided costs are used to determine the TSB, as well as TRC and PAC ratios. We applied avoided costs to the incremental adoption for PG&E, SCE, SDG&E, and "other" utilities for each installation condition in each year. We then summed and discounted these benefits to the first year of the MTI to determine the TSB. TSB is identical to the benefits used in TRC and PAC.

Load Shape

Load shape is defined as the hourly probability of activity for energy using equipment which interacts with highly efficient windows (primarily heating and cooling measures). The team determined the probability and magnitude of projected savings in each hour of the year.

Unit Energy Impacts

The team calculated per-unit energy savings and demand reduction impacts (kWh, kW, and therms) for adoption for each installation condition (Table A12). The team used EnergyPlus engine building simulations built with CBECC 2022 Title 24 (CBECC) software to evaluate a set of building thermal performance assumptions for existing buildings with single-pane windows to new replacement options, including new windows meeting minimum Title 24 requirements, and VIG windows exceeding minimum U-factor requirements. We ran annual simulations using the CBECC medium office prototype, which we modified to represent the thermal and solar performance of tinted single-pane windows commonly found in existing California office buildings.

The average annual electric savings for the two installation conditions were 11,737 kWh per building for the T24 2022 Retrofit Metal-Framed window installation condition and 30,754 kWh per building for existing single-pane tinted windows. Average annual gas savings were 729 therms for the T24 2022 Retrofit Metal-framed window installation condition and 933 therms for the existing single-pane tinted windows, resulting in an average of $6,874.73 in total avoided cost across all cases.

Table A12. Unit Energy Impacts

Installation Condition	Average Annual Electric Savings	Average Annual Gas Savings
Commercial Buildings with T24 2022 Retrofit Metal-Framed windows	11,737.24 kWh	728.53 therms
Commercial Buildings with Existing Single-Pane Tinted windows	30,753.98 kWh	933.45 therms

The team applied these UEIs to the load shape and avoided costs to determine the TSB generated by a VIG window adopted because of the MTI.

Methodology

The team took a systematic approach to developing the cost-effectiveness model that began by determining all the necessary model inputs and outputs for the MTI, further described below.

Determine Input Values

MTI cost-effectiveness inputs are broken down into six inputs: market adoption, UEIs, initiative costs, load shape, avoided costs using 2022 ACC, and IMCs. Each of these inputs is developed using product and market definitions documented by the MTI team and must have consistent units of analysis. For example, MTIs can be defined in terms of a single unit of equipment, household, whole building, or square feet. All inputs must be developed accordingly and converted into the same units.

We further broke down each input by installation condition, including fuel, technology, sector, and decision type. As such, each installation condition has its own set of adoption, UEI, initiative cost, load shape, and incremental measure cost inputs.

UEI inputs for Stage 2 consist of the three largest California utilities: PG&E, SCE, and SDG&E, and the "other" category representing other utilities in California. Therefore, each installation condition for any MTI has four sets of utility-specific UEIs. The model pairs UEI inputs with an 8,760 hourly load shape appropriate for each MTI technology that estimates how likely an end user will use the equipment in any given hour of the year.

All inputs must also be applied on a yearly basis, constrained by the EUL and the MTI lifetime. These inputs will be reviewed during Phase II and updated as appropriate. The Phase I analysis includes these EUL and lifetime assumptions for VIG windows:

- MTI lifetime = 20 years (2025 to 2045)
- EUL = 20 years
- For incremental market adoption and initiative costs over the course of the MTI, we used three assumptions:
    1. 2025 and 2026 are initiative design years. Thus, incremental adoption is non-zero starting 2027.
    2. Though there is no incremental adoption in 2025 and 2026, the MTI is still operating; therefore, we allocate non-incentive-related initiative costs to 2025 and 2026.
    3. FDIs are components of initiative costs during the first five years of incremental adoption. Incentives are assumed for 25% of buildings adopting in 2027, ramping up to 50% of buildings adopting in 2031.

Determine Required Outputs

After understanding the inputs, the team developed and reported the outputs needed for cost-effectiveness. In Stage 2, we applied a discount rate of 6% to discount outputs to the first year of the MTI to account for the time value of money. For the Phase II analysis, we will update this assumption and apply the discount rate based on the ACC. There are three outputs for reporting on the MTI: TSB, TRC ratio, and the PAC. As with the inputs, we broke down outputs by baseline installation condition. The team evaluated the TSB, TRC, and PAC for each of the two installation conditions for the MTI, determining the total for TSB, TRC, and PAC.

After collecting the required inputs and outputs, the team developed an Excel model that used all of the inputs, operated an hourly (8,760) based analysis, and reported the discounted values of both installation conditions and MTI-level TSB, TRC, and PAC. Table A13 lists the terms (based on the CET) used by the Excel model to determine the TSB, TRC, and PAC.

Table A13. Cost-effectiveness model parameters

Terms	Description	Units
ElectricBenefits	Net Benefits generated through electric savings from ACC	Dollars/kWh & Dollars/kW and associated GHG avoided costs
GasBenefits	Net Benefits generated through gas savings from ACC	Dollars/Therms and associated GHG avoided costs
OtherBenefits	Benefits generated through non-electric or gas savings. There were no OtherBenefits in Stage 2.	Dollars per unit
NumberOfUnits	Incremental adoption	Commercial Buildings
Net kWh	Net to Gross Ratio of the measure used to standardize other benefits to Electric and Gas benefits	NTG Ratio (Assumed to be 1 for this analysis)
MarketEffectsBenefits	Measure benefits generated through market forces	Dollarized Market Effects (assumed to be 0)
RefrigerantBenefits	Measure benefits generated through refrigerant savings	Dollars/unit
ElectricSupplyCost	Costs incurred in the supply of electricity	Dollars/kWh & Dollars/kW
GasSupplyCost	Costs incurred in the supply of gas	Dollars/Therms
MarketEffectsCosts	Costs incurred through market forces	Dollarized Market Costs (where present)
UnitRefrigerantCosts	Costs incurred through refrigerant losses. There were no UnitReferigerantCosts identified in Stage 2.	Dollars/Unit
TRCCost	Costs associated with the TRC test	Dollars (Initiative Admin/Marketing/Evaluation

		and Incremental Measure Costs)
PACCost	Costs associated with the PAC test	Dollars (Initiative Admin/Marketing/Evaluation and Initiative Incentive Costs

Total System Benefit

TSB is a function of the inputs described in earlier sections. For VIG, we disaggregated TSB into three components: energy, grid, and GHG benefits (categorized as refrigerant and non-refrigerant). We used the following CET-based formula to determine TSB:

$$(ElectricBenefits + GasBenefits + NumberOfUnits * (Net\ kWh + MarketEffectsBenefits) * RefrigerantBenefits) - (ElectricSupplyCost + GasSupplyCost + NumberOfUnits * (Net\ kWh + MarketEffectsCosts) * UnitRefrigerantCosts)$$

Cost-Effectiveness Ratios

Total Resource Cost

The TRC test compares the lifecycle benefits that the MTI will deliver to the costs associated with achieving those benefits from the perspective of the MTI administrator and the participant. Net benefits, initiative costs (not including FDIs), and IMC were used to determine TRC. The non-FDI initiative costs are summed together with the IMC and discounted in respect to the period of the MTI's implementation. The discounted net life cycle benefits for each installation condition are divided by the sum of the respective discounted IMC and non-FDI Initiative costs. This installation condition-specific TRC is weighted by its respective adoption total and summed with the other installation condition-specific TRC to determine the MTI TRC. Below is the CET-based formula used by the tool to determine TRC.

$$(ElectricBenefits + GasBenefits + OtherBenefits)/TRCCost$$

Program Administrator Cost

The PAC test compares the lifecycle benefits that the MTI will deliver to the costs associated with achieving those benefits from the perspective of the MTI administrator. Net benefits, and Initiative costs (including FDIs) were used to determine PAC. The initiative costs are discounted with respect to the period of the MTI's implementation. The discounted net lifecycle benefits for each installation condition are divided by the sum of the initiative costs to determine PAC. This installation condition-specific PAC is weighted by their respective adoption totals and summed to determine the PAC. Below is the CET-based formula used by the tool to determine PAC.

$$(ElecBenefits + GasBenefits + OtherBenefits)/PACCost$$

Outputs

Total System Benefit (TSB)

Table A14 shows the preliminary TSB estimates, disaggregated for energy, grid, and GHG impacts.

Table A14. Stage 2 preliminary lifetime TSB estimate – VIG windows

Idea Name	TSB ($M)	Energy ($M)	Grid ($M)	GHG Non-Refrigerant ($M)	GHG Refrigerant ($M)
VIG	145	23.5	50.5	71	0

As shown in Table A14, the Phase I model estimates that Single-Pane Retrofit will generate approximately $145 million in lifetime TSB. The largest share of the benefit can be attributed to mitigated GHG emissions, with an estimated $71 million in TSB. The smallest share of the TSB is driven by savings related to electricity and natural gas reductions, with $23.5 million in TSB. Finally, grid benefits are nearly $50.5 million in lifetime TSB.

Cost Effectiveness Ratios

The team developed preliminary TRC and PAC ratios of 0.46 and 5.10, respectively, for the MTI.

A.4 Phase II – Refined TSB and Cost-Effectiveness Estimates

The CalMTA team will conduct additional market and technology research on Single-Pane Retrofit during Phase II of the MTI, as described in the Advancement Plan. Based on that research, the team will refine TSB and cost-effectiveness estimates for the CRAWS MTI, to include analysis for Commercial Secondary Windows (CSW). These refined estimates and their detailed methodology and assumptions will be included as part of the MTI Plan required for MTI advancement to Phase III. The MTI Plan will also include an evaluation plan and a data collection plan to support ongoing evaluation.

A.5 References consulted for Appendix A

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