U.S. DEPARTMENT OF ENERGY | *Office of* ENERGY EFFICIENCY & RENEWABLE ENERGY

Research, Development, Deployment Opportunities for Opaque Building Envelope and Windows

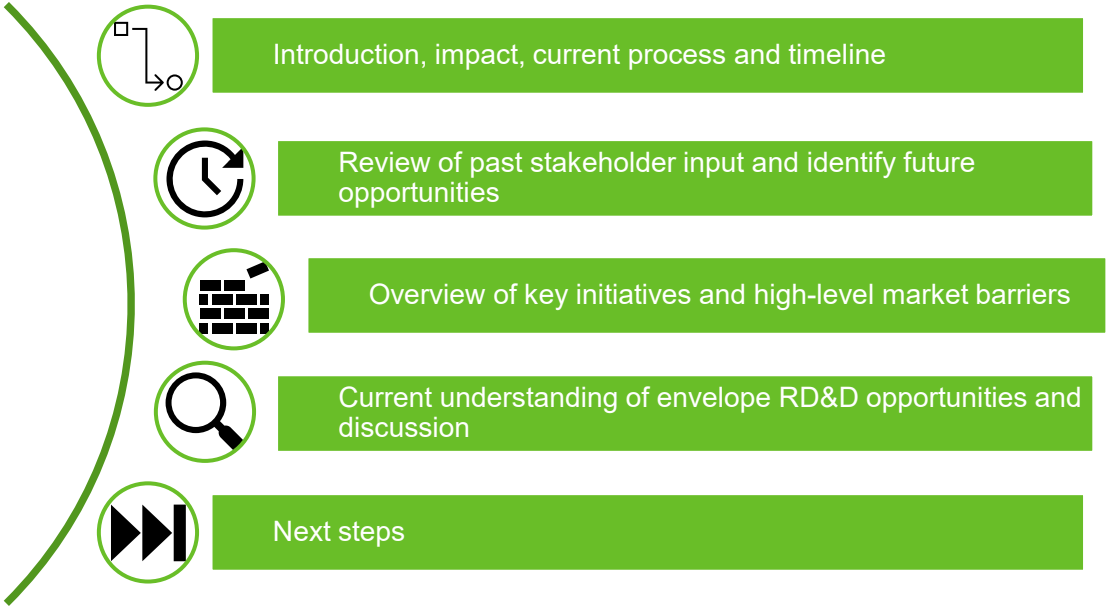
BTO Peer Review, ET Strategy Overviews

Sven Mumme, TES & Building Envelope

Marc LaFrance, Windows

October 21, 2024

Agenda


Introduction, impact, current process and timeline
Review of past stakeholder input and identify future opportunities
Overview of key initiatives and high-level market barriers
Current understanding of envelope RD&D opportunities and discussion
Next steps

Introduction to special section

Today's Session

Hear our latest thinking now (and later)

Ask questions

Share your feedback

Listen for more from BTO, on strategies

The mission

The Building Technologies Office (BTO) conducts research, development, and demonstration activities to accelerate the adoption of technologies and techniques that enable high-performing, affordable buildings that meet Americans' need for resiliency and health while also supporting a reliable energy system.

90%

The amount of time people spend in buildings.

74%

Amount of electricity consumed by buildings.

$374 billion

Amount spent on energy costs annually.

BTO RD&D Activities Support America

- Energy Efficiency
- Energy Affordability
- Innovation
- Industrial Competitiveness
- Infrastructure
- Energy Reliability and National Security
- Resilience
- Indoor Environment and Health

A practical, inclusive definition of innovation

The [Heilmeier Questions]():

01 Problem

Stated without jargon

02 Impact

If you succeed, what changes and who cares?

03 Status

How is it done today?

04 Proposal

What is the new approach, why will it succeed, and what will the output be?

05 Midterm checks

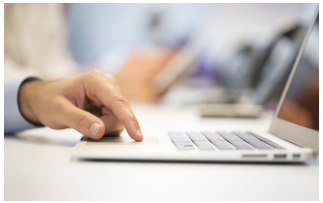
How will we know we're on the right track?

06 How much does it cost?

How long will it take? What are the risks?

Innovation for building technology is broad

It includes R&D for product development, testing, and validation. But also!



Market transformation

Partnership models

Service delivery modes

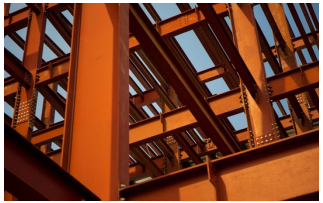
Value chain

Contractors

Trades

Specifiers

Reps



Supply chain

Materials

Components

System integration

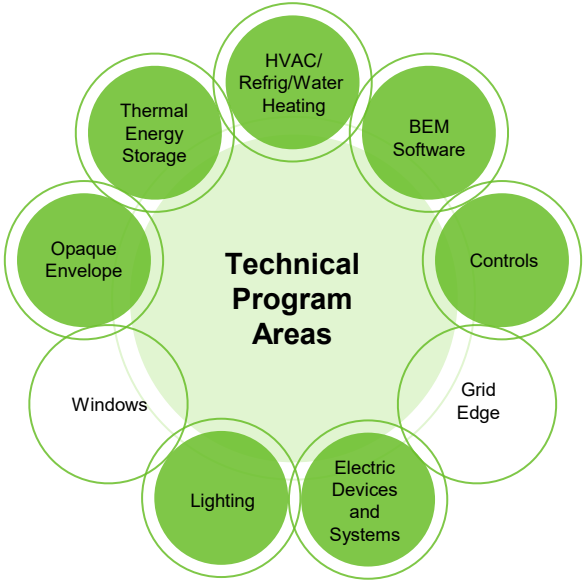
Logistics

Serendipity

Partnerships

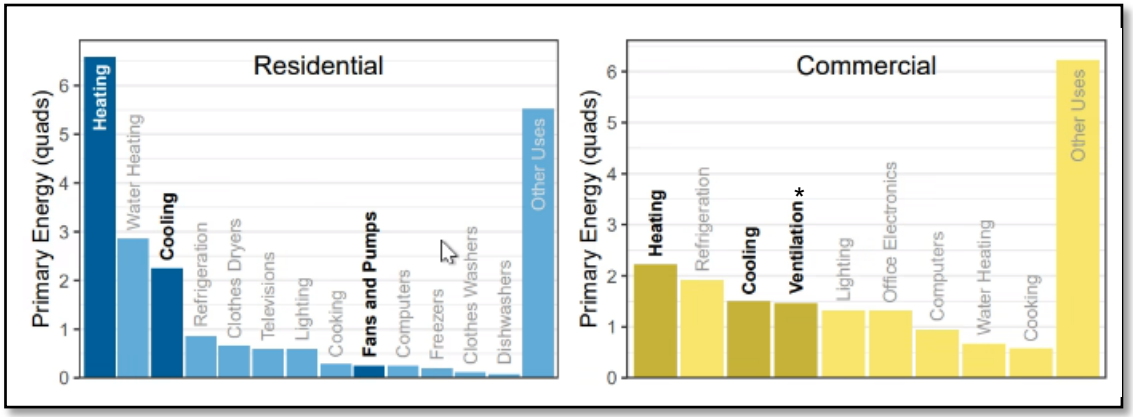
Alignment

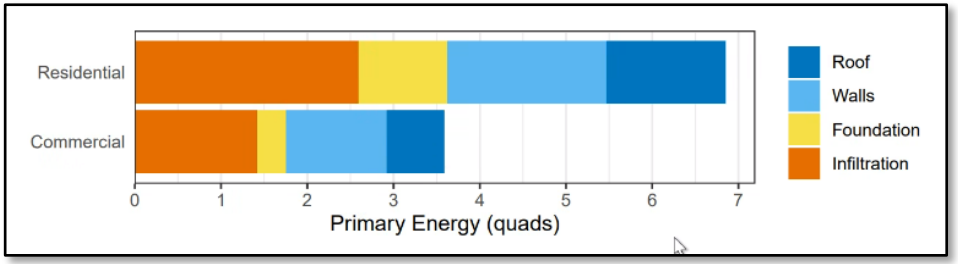
What does this strategy mean for DOE's applied R&D for buildings?



- **Reduce first costs**
- **Make it easy**
- **Deliver performance that matters**
- **Ask, who's missing that we need?**

Opaque envelope effects on energy use





*Ventilation in the AEO is energy use for fans, pumps, and other equipment used to deliver heating/cooling to the zone(s). Envelope improvements that reduce heating and cooling loads therefore also indirectly impact ventilation loads, but are not in itself a priority area for envelope R&D.

Opaque Envelope-Related Energy Use

28%
of Building Energy Use

11%
of Total U.S. Primary Energy Use

The building envelope, the interface between the indoor and outdoor environments that helps maintain occupant comfort, is the single largest contributor to primary energy use in residential and commercial buildings.

Opaque Envelope R&D Goal

Reduce the upfront cost of high-performing opaque building envelope technologies for residential and commercial buildings by 50% to dramatically lower energy bills and make buildings healthier, more resilient, and comfortable.

Technical Goals:

Insulation

R10/in at today's conventional insulation costs.

Air Leakage

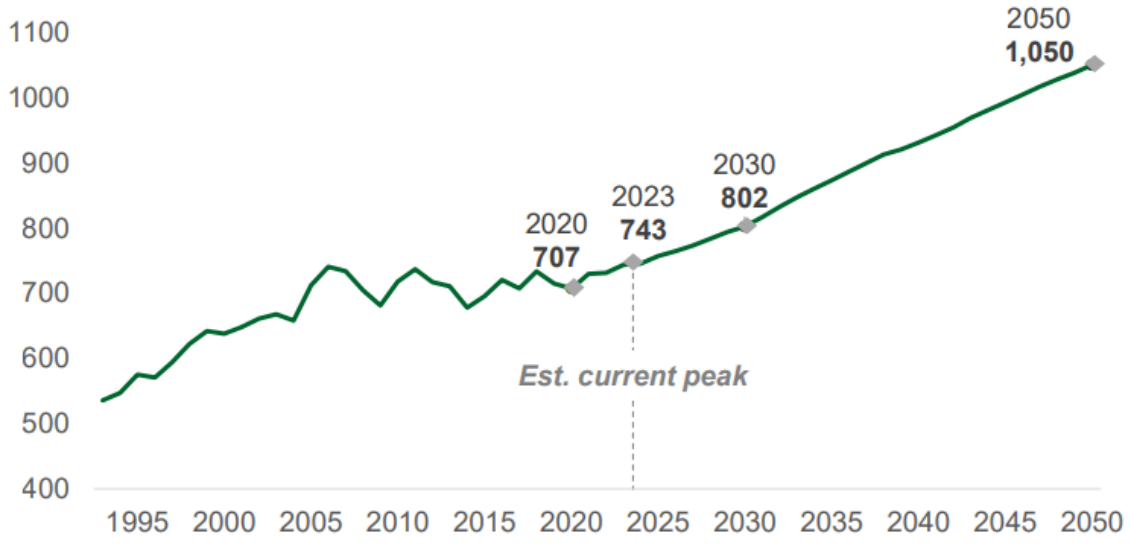
50% lower cost and 2x speed high fidelity air leakage diagnostics, and improved air sealing techniques.

Installation

50% improved retrofit installation speed via technologies that increase productivity, quality, and safety, such as robotics, drop-in retrofit solutions, and integrated components.

U.S. peak demand is expected to grow by ~60 GW between 2023 and 2030

US system peak demand, historical and projected, 1995-2050 (GW)



Source: Historical energy demand sourced from AEO; forecasted energy sourced from OP-NEMS mid-case scenario

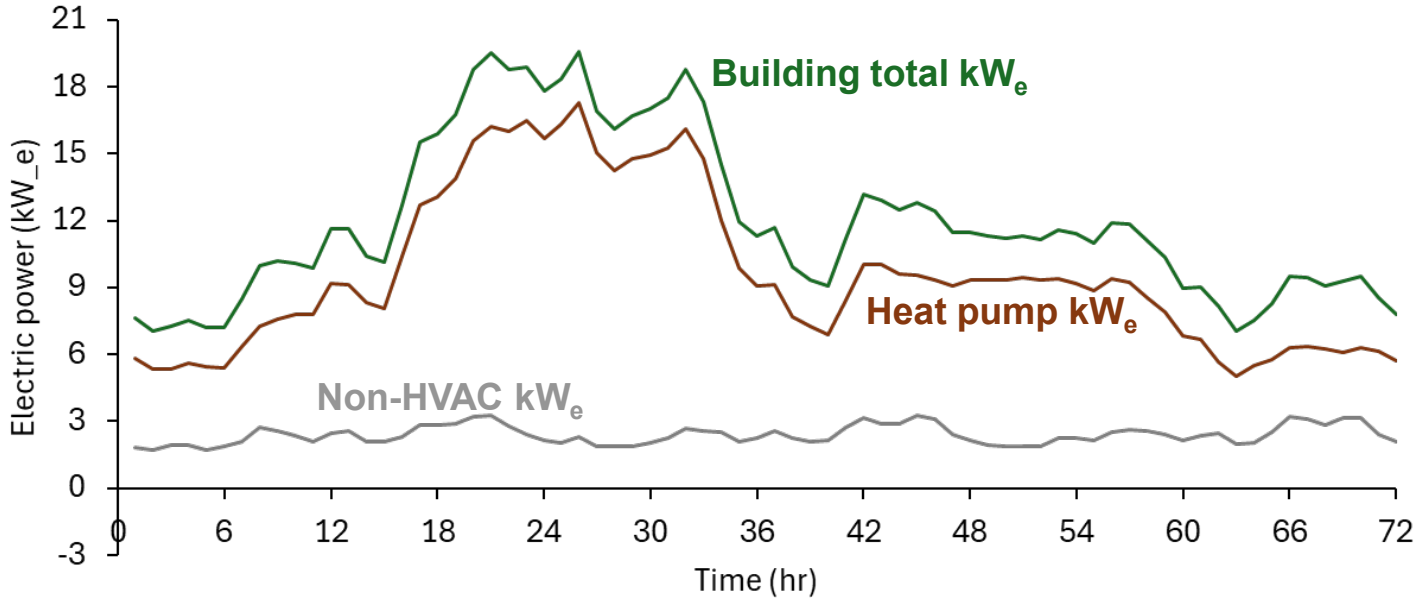
Efficiency matters: residential home analysis

Vintage	Wall insulation	Ceiling insulation	Windows	Infiltration
1980s	R-7 (U = 0.81 W/m^2-K)	R-19 (U = 0.41 W/m^2-K)	R-2 (U = 2.84 W/m2-K) SHGC = 0.6	10 ACH50
IECC2021	R-18 (U = 0.30 W/m^2-K)	R-40 (0.14 W/m^2-K)	R-3 (U = 1.70 W/m2-K) SHGC = 0.33	3 ACH50

Notes: 12 kbtu/hr = 1 ton = 3.5 kW (power);
Tonh = 3.5 kWh = 12 kbtu (energy); EER = btu/Wh

Scenarios	TES size (kWh_th)	EES size (kWh_e)	Max HP capacity (kW_th)	Max elec. capacity (kW_e)
Scenario 0	0	0	25.5	19.5

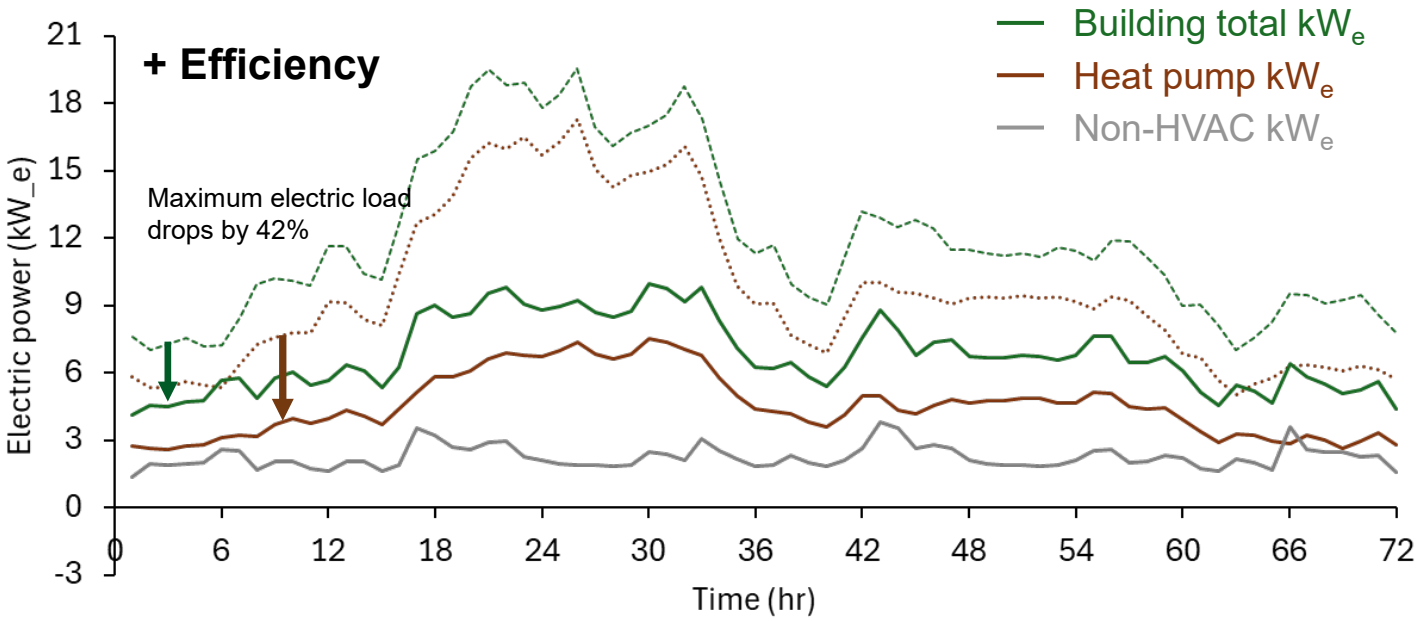
Typical 1980s home



Electric power consumption for scenario 0 on the worst-case 3-day period in Chicago, IL for TMY3 weather (Jan 26-28).

Scenarios	TES size (kWh_th)	EES size (kWh_e)	Max HP capacity (kW_th)	Max elec. capacity (kW_e)
Scenario 1	0	0	10.9	11.3

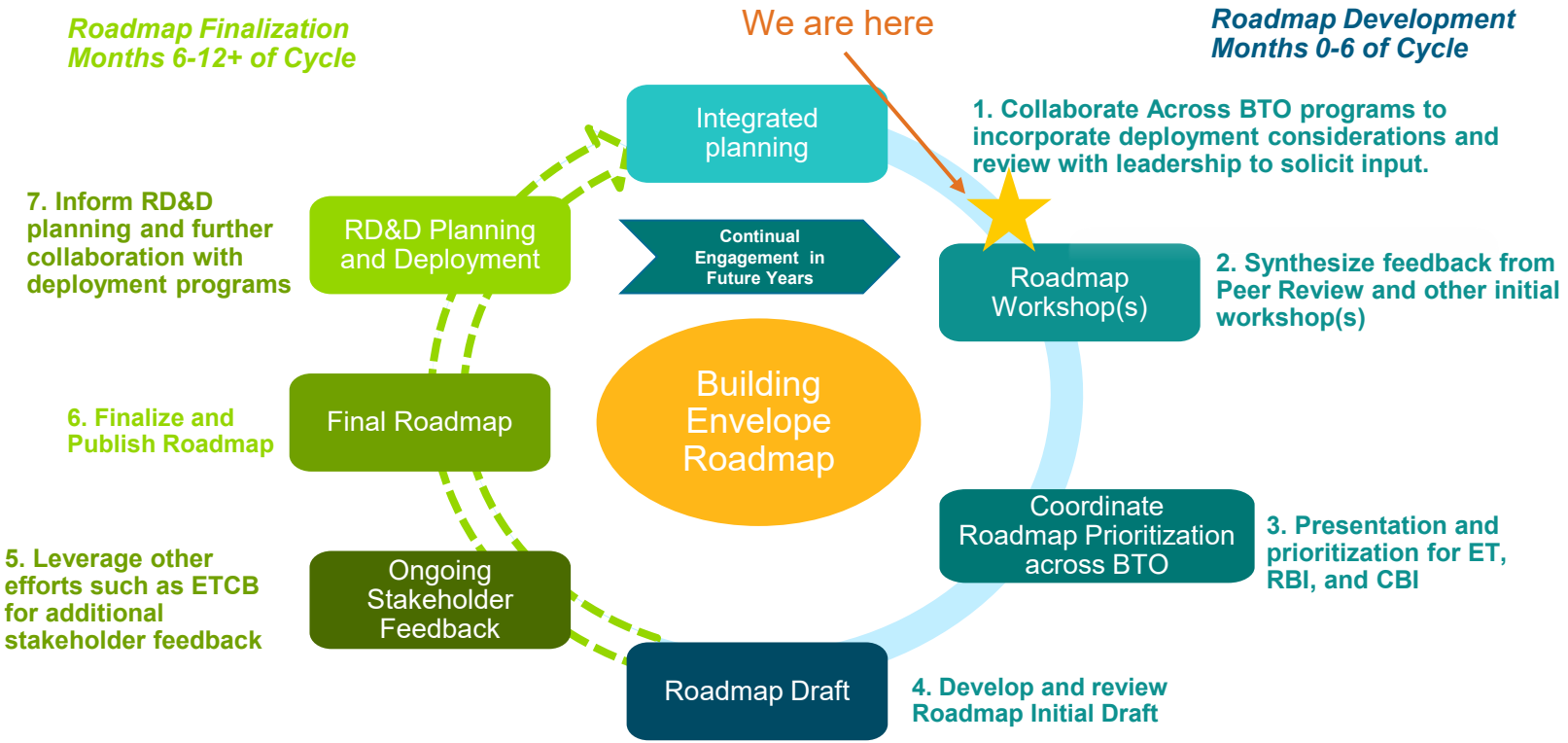
EE upgraded home



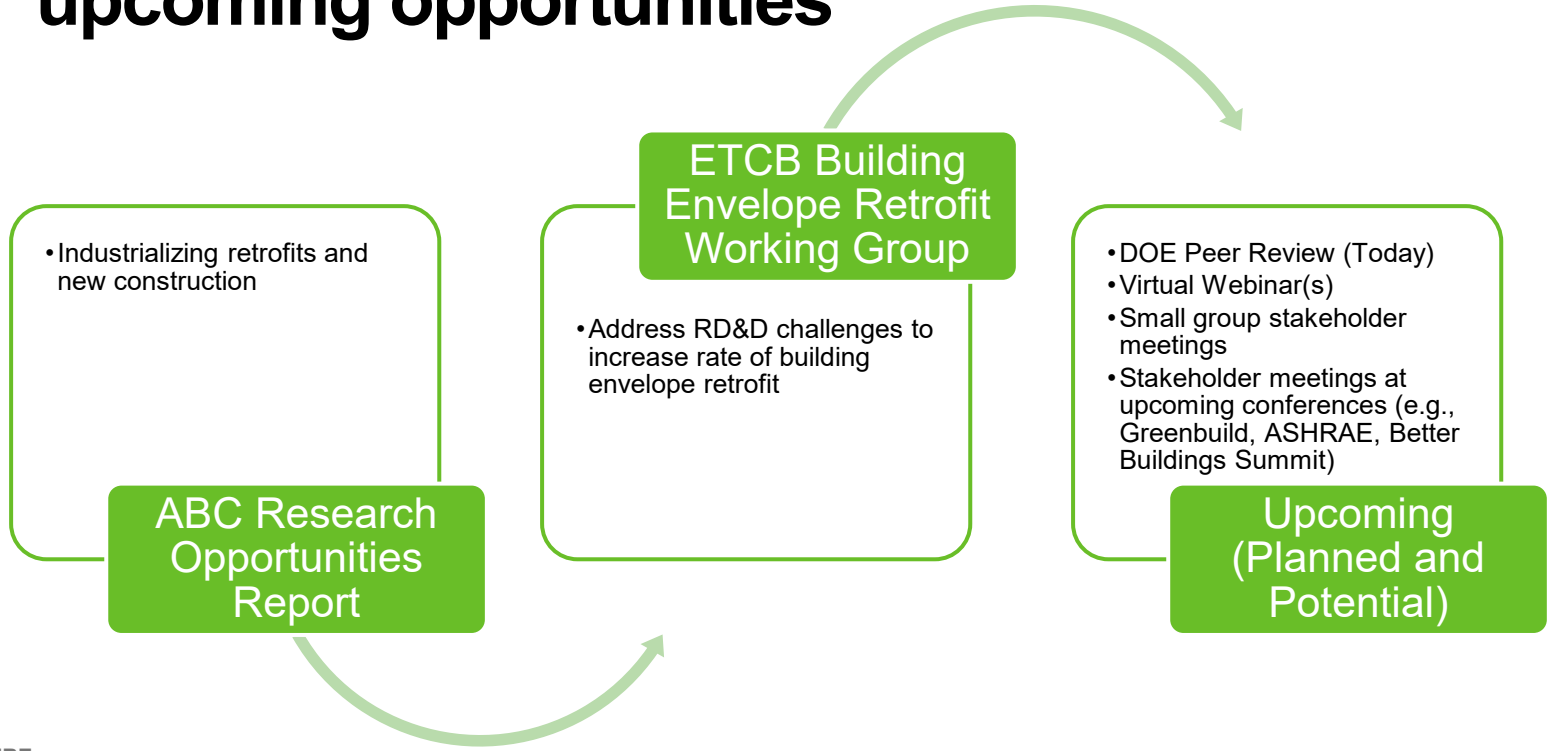
Electric power consumption post efficiency measures

Building envelope roadmap process

The figure below outlines BTO's vision for an integrated roadmap process covering Building Envelope topics, including an initial development phase, followed by finalization and informing deployment.



Previous stakeholder input and upcoming opportunities

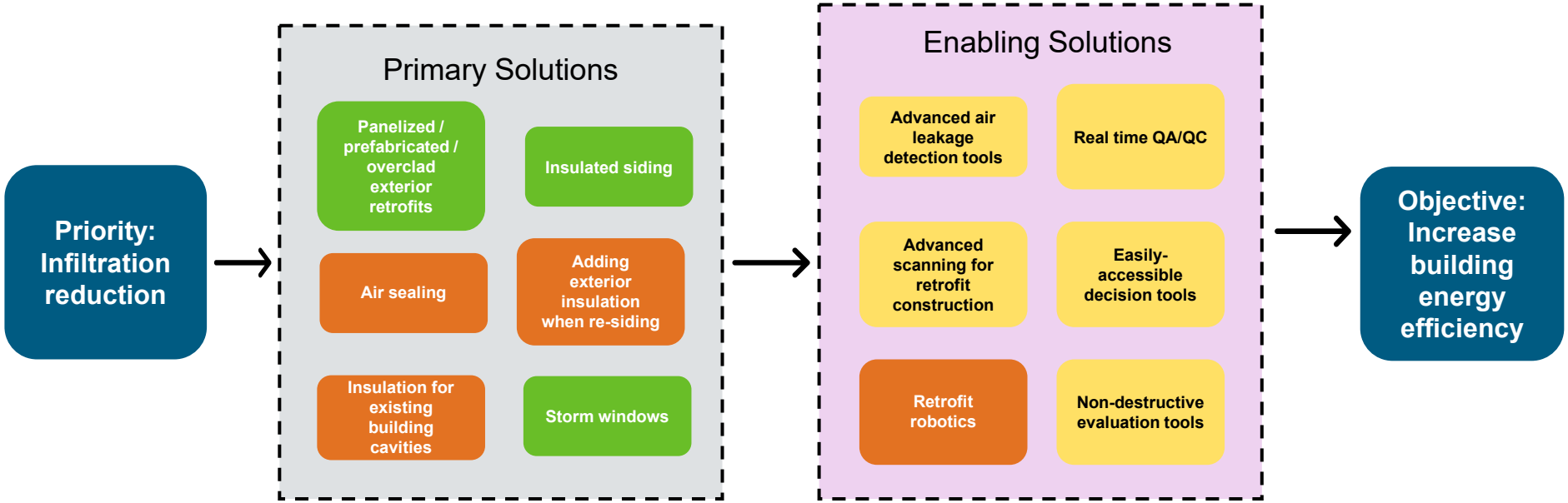


R&D opportunities for residential and commercial buildings (preliminary)

Key Initiatives	Identified Research Development Opportunities
Envelope System Innovations	• Panelized Prefabricated • Active Opaque Envelopes • Insulated Siding
Innovative Materials	• High R/in Insulation • Next-Generation Building Materials • High Performance Cool Coatings • Advanced Sealants
Enabling Diagnostic Tools	• Easily Accessible Decision Tools • Advanced Air Leakage Detection Tools • Non-Destructive Evaluation Tools • Advanced Scanning for retrofit construction • Real time QA/QC
Retrofit Process Improvements	• Insulation for Existing Building Cavities • Adding Exterior Insulation When Re-Siding • Retrofit Robotics • Air Sealing

Infiltration reduction technology mapping

Draft example



Envelope System Innovations

Innovative Materials

Enabling Diagnostic Tools

Retrofit Process Improvements

Cross-cutting Solutions

- Next-generation building materials
- High R/in insulation
- Advanced sealants

Discussion questions

What are the challenges with existing or emerging solutions for reducing infiltration? How are these different for commercial and residential buildings?

What opportunities are most significant to increasing the building retrofit rate? How are these different for commercial and residential buildings?

What opportunities are most significant to improving building envelope thermal performance? How are these different for commercial and residential buildings?

What are the most significant envelope components (i.e., reducing infiltration, walls, roofs, attics, windows) needed to address current challenges? How are these different for commercial and residential buildings?

Next steps

- Synthesize and follow up as needed on feedback from today's session
- Additional stakeholder engagement opportunities:
  - Webinar TBD
- Leverage past and current stakeholder input to prioritize research development opportunities across BTO programs
- Develop Initial Draft for additional stakeholder input Spring 2025 (tentative)

Thank you!

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Research, Development, Deployment Opportunities for Windows

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Marc LaFrance, Windows

October 21, 2024

Windows Annual Impact on Energy and Environment

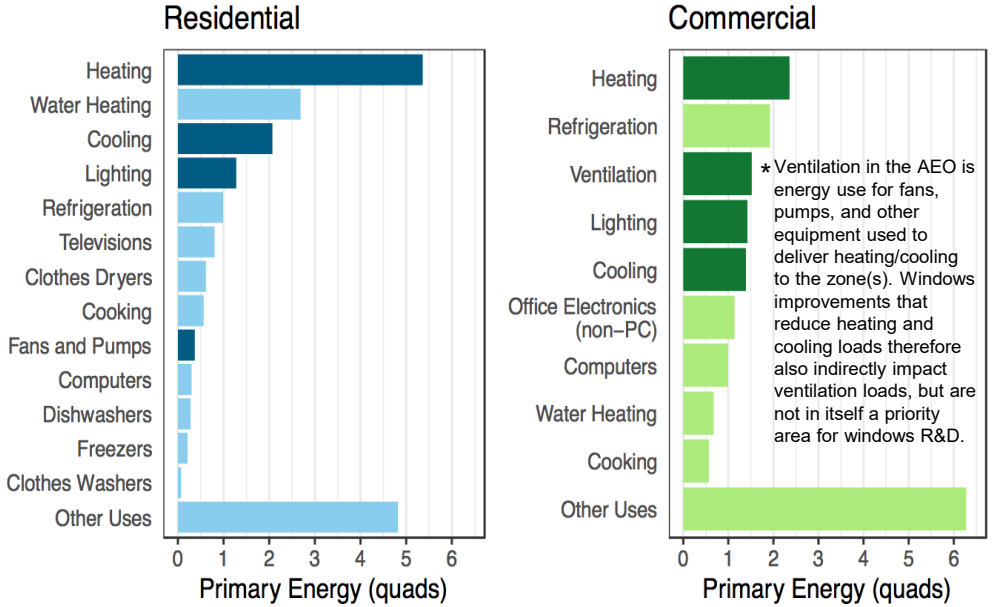
$45 Billion

3.5 Quads

160 Mt CO2

9%	U.S. building energy
4%	U.S. total energy

100%



Comfort View Daylight
Fresh-air Egress Energy

Impacts ~50% of loads

Window R&D Goal

Dramatic improvements in comfort and resiliency to extreme temperature events through the pursuit of market viable R7 to R10 highly insulating and dynamic solar control window solutions.

Technical and Commercialization Goals

Industry technical support to reduce barriers and help increase market adoption of ENERGY STAR windows (R4.5 in Northern Zone) ~ 80%.

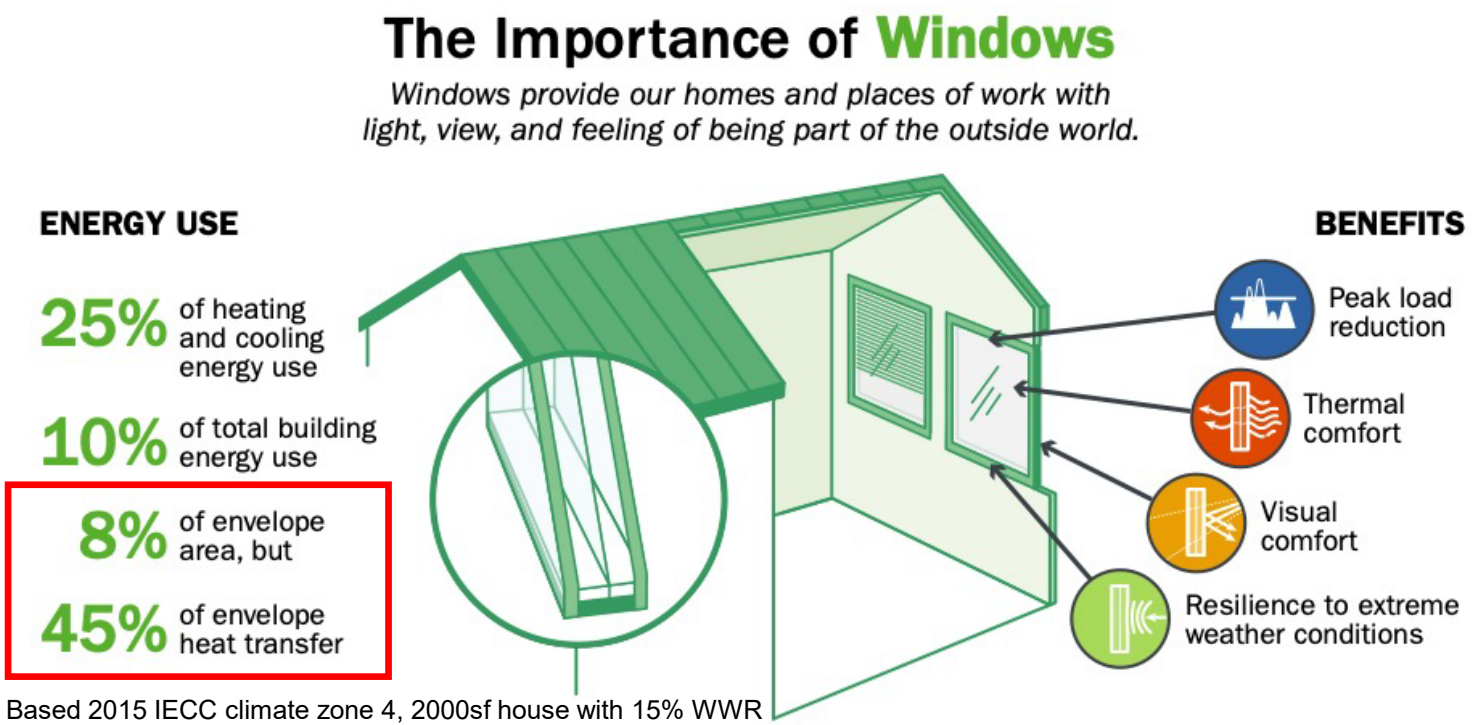
Validation of beyond zero windows in real world homes with prototypes approaching R13.

Spur Innovation with Industry Support

Maintain and expand window and window attachment ratings that reduce burden on industry compliance with private sector standard organization requirements.

Help industry dramatically exceed the current ASTM 2190 standards for durability that will lead to longer lasting windows.

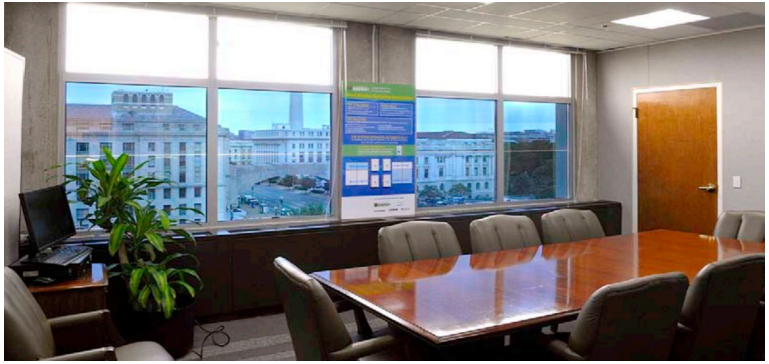
Window R&D and Deployment Opportunity



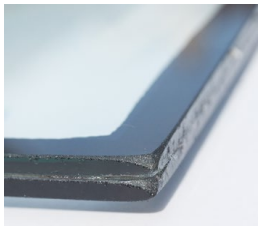
Based 2015 IECC climate zone 4, 2000sf house with 15% WWR

Reaching Net Zero: Highly Insulating Dynamic

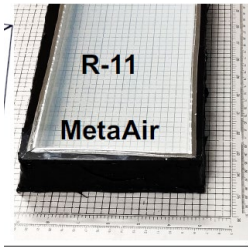
Dynamic Solar Control



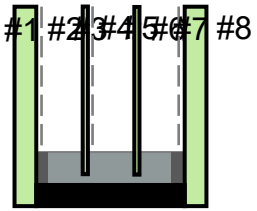
R10 Windows



Vacuum glazing



Aerogels Univ of CO



Future thin-quad, one spacer

- Largest grid electricity peak reduction > 25%
- Lighting reduction 30% - 60%, daylight
- Significant comfort improvement – thermal and visual
- Improved health and well being
- Enables heat pumps: smaller panel upgrade, higher ROI
- Significant improvements in resiliency – winter power outages
- Decarbonizes on day one independent of grid progress

Resources

Better Windows, Better Outcomes: How Electrochromics Improve Health, Productivity, and Efficiency

Better Windows, Better Outcomes: How Electrochromics Improve Health, Productivity, and Efficiency (energy.gov)

US DOE – Pathway to Zero Energy Windows – Advancing Technology and Market Adoption

Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption (nrel.gov)

Grid-interactive Efficient Buildings Technical Report Series Windows and Opaque Envelope

Grid-interactive Efficient Buildings Technical Report Series: Windows and Opaque Envelope (energy.gov)

LBNL Core Window Lab – Primer videos and resources

Outreach | Windows and Daylighting (lbl.gov)

Thank you!

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Envelope System Innovations

The commercial and residential envelope industry includes many types of envelope innovations for different needs and building types.

Envelope System Innovation	Key Climates	Market Readiness	Program Focus	Current State	2035 Goal*	2050 Goal*
Panelized / prefabricated / overclad exterior retrofits			ET, RBI, CBI	Insulating panels are primarily available for new construction, panel connection points are not easy/fast to install or universal, and existing solutions are too expensive to be widely adopted.	• Cost ≤$X/sq. ft. installed • Installed on typical home in ≤X days, small commercial building in ≤X days • X% of the market	• Cost ≤$X/sq. ft. installed • Installed on typical home in ≤X days, small commercial building in ≤X days • X% of the market
Active opaque envelopes			ET	Technologies are under development and being tested in lab settings.	• Reduce energy costs of operating buildings by at least X% • Cost ≤$X/sq. ft. installed • X% of the market	• Reduce energy costs of operating buildings by at least X% • Cost ≤$X/sq. ft. installed • X% of the market
Insulated siding			ET, RBI, CBI	R-2 to R-4 is commercially available, currently 3-5% of the residential market.	• ≥R-X/in. • ≤X inch thickness • Cost ≤$X/sq. ft. • X% of the market	• ≥R-X/in. • ≤X inch thickness • Cost ≤$X/sq. ft. • X% of the market

*Goals will be developed for residential and commercial applications as applicable

 Moderate market adoption of available solution

 Low market adoption of available solution

 No available solution

Draft

Innovative Materials

The commercial and residential envelope industry includes many types of innovative materials for different needs and building types.**

Innovative Material	Key Climates	Market Readiness	Program Focus	Current State	2035 Goal*	2050 Goal*
High R/in insulation			ET	Current insulation ranges from R-3 to R-7/inch and requires installer training and PPE.	• X% reduction in embodied carbon • Low VOC content • ≥R-X/in. • ≤$X/sq. ft. • X% of the market	• X% reduction in embodied carbon • No VOC content • ≥R-X/in. • ≤$X/sq. ft. • X% of the market
Low and negative carbon building materials			ET, RBI, CBI	Low- and negative-carbon materials have higher costs and have limited regional availability.	• X% reduction in embodied carbon • Low VOC content • Cost of low/negative carbon insulation is reduced by X% • X% of the market	• X% reduction in embodied carbon • No VOC content • Cost of low/negative carbon insulation is reduced by X% • Low/negative carbon insulation and structural timber are available throughout most of the U.S. for a wide range of building types and sizes • X% of the market
High performance cool coatings			ET, RBI, CBI	Cool roof coatings are commercially available and are used in commercial buildings and residential buildings with metal roofs. Limited availability for cool wall coatings. Limited color options.	• X albedo • X% reduction in energy use and bills • X% reduction in embodied carbon • X year lifespan • Low VOC content • ≤$X/sq. ft. • X colors available • X% of the market	• X albedo • X% reduction in energy use and bills • X% reduction in embodied carbon • X year lifespan • No VOC content • ≤$X/sq. ft. • X colors available • X% of the market
Advanced sealants			ET	Many sealants have long curing times, some short lifetimes, and can be disruptive to tenants during retrofits due to VOCs and long curing times.	• X% reduction in embodied carbon • Low VOC content • Fully cure within X hours • Last at least X years • Can be installed without tenant disruption • Costs do not exceed current sealant prices by more than X% • X% of the market	• X% reduction in embodied carbon • No VOC content • Fully cure within X hours • Last at least X years • Can be installed without tenant disruption • Costs do not exceed current sealant prices • X% of the market

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 Moderate market adoption of available solution

 Low market adoption of available solution

 No available solution

Enabling Diagnostic Tools

Draft

The commercial and residential envelope industry includes many types of enabling tools for different needs and building types.**

Enabling Diagnostic Tool	Key Climates	Market Readiness	Program Focus	Current State	2035 Goal*	2050 Goal*
Easily-accessible decision tools			ET, RBI, CBI	Existing retrofit decision tools are not made for DIY or untrained usage and are primarily residential-focused	• Homeowners and others without construction training can easily input data to retrieve retrofit solutions with recommendations • X of free or low-cost tools available	• Homeowners and others without construction training can easily input data to retrieve retrofit solutions with recommendations • X of free or low-cost tools available
Advanced air leakage detection tools			ET	Blower door tests are complex, costly, and time consuming in large multifamily and commercial buildings and require a temperature/pressure delta.	• Costs are reduced by X% • Reduced impact to onsite occupants • Provides leakage rate of entire building in addition to identifying specific leakage areas for improvement • Does not require significant temperature/pressure delta • X% of the market	• Costs are reduced by X% • Reduced impact to onsite occupants • Provides leakage rate of entire building in addition to identifying specific leakage areas for improvement • Does not require significant temperature/pressure delta • X% of the market
Non-destructive evaluation tools			ET	Tools are prevalent in other industries, such as infrastructure, but non-destructive tools for buildings currently only exist in lab settings. Current evaluation tools are damaging to envelopes and disruptive to tenants.	• Non-destructively diagnoses possible structural and durability issues in less than X hours. • Non-destructively identifies materials in less than X days. • Commercially available and applies to X% of existing buildings. • Reduced impact to onsite occupants	• Non-destructively diagnoses possible structural and durability issues in less than X hours. • Non-destructively identifies materials in less than X days. • Commercially available and applies to X% of existing buildings. • Reduced impact to onsite occupants
Advanced scanning for retrofit construction			ET, RBI, CBI	There is a lack of automated processes to go from a 3D scan to BIM to CAM for retrofit construction projects and processes are complex, time consuming, and costly; automated processes only exist in lab settings.	• Mostly automatic data transition software can create a customized set of retrofit panels that will completely cover the exterior of a building, creating a thermal break • Retrofit panel plans are interoperable with most manufacturing plants and can be designed to include various elements (i.e., windows, doors) • Integrated software that an AEC team member can use with limited additional training • X% of the market	• Entirely automatic data transition software can automatically create a customized set of retrofit panels that will completely cover the exterior of a building, creating a thermal break • Retrofit panel plans are interoperable with any manufacturing plant and can be designed to include various elements (i.e., windows, doors) • Integrated software that an AEC team member can use without additional training • X% of the market
Real time QA/QC			ET	Remote virtual inspection (RVI) exists but not at its fullest potential. No automatic QA/QC system exists for building envelopes, although visual indicators exist in the market in other industries.	• Indicator demonstrates whether a product or installation meets desired quality to installer in real time • False positives are minimized • QA/QC process or technology is automatic or drastically reduces the amount of time taken in the current inspection and rework processes • Installation processes of products is not more costly • X% of the market	• Indicator demonstrates whether a product or installation meets desired quality to installer in real time • False positives are minimized • QA/QC process or technology is automatic or drastically reduces the amount of time taken in the current inspection and rework processes • Installation processes of products is not more costly • X% of the market

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**Enabling tools can be used in combination with each other to support the adoption and scaling of other innovations.

Moderate market adoption of available solution

Low market adoption of available solution

No available solution

Draft

Retrofit Process Improvements

The commercial and residential envelope industry includes many types of retrofit process improvements for different needs and building types.

Retrofit Process Improvement	Key Climates	Market Readiness	Program Focus	Current State	2035 Goal*	2050 Goal*
Insulation for existing building cavities			ET, RBI, CBI	Solutions are costly, disruptive, and not viable across climate and building types. Current less-invasive solutions are moisture-sensitive.	• ≤$X for single-family homes • X days for single-family homes • X apartment units per day • ≤X days for small-medium commercial buildings • X% of the market	• ≤$X for average single-family homes • X days for single-family homes • X apartment units per day • ≤X days for small-medium commercial buildings • X% of the market
Adding exterior insulation when re-siding			ET, RBI	Adding continuous insulation to existing buildings is currently costly and labor-intensive, and few re-siding contractors currently offer exterior insulation services.	• Cost ≤$X/sq. ft. installed • X% of the residing market, including small commercial and residential	• Cost ≤$X/sq. ft. installed • X% of the residing market, including small commercial and residential
Retrofit robotics			ET	Robots currently perform limited and simple tasks (e.g., bricklaying), but have yet to expand to retrofit tasks.	• Helps contractors with unsafe and uncomfortable tasks • Improves access to previously inaccessible areas • Reduces retrofit time by X% • Reduces retrofit costs by X% • Works in X% of the building stock • X% of the market	• Independently performs unsafe and uncomfortable tasks • Improves access to previously inaccessible areas • Reduces retrofit time by X% • Reduces retrofit costs by X% • Works in X% of the building stock • X% of the market
Air sealing			ET, RBI, CBI	Air sealing occurs with caulk or foam, can only seal large gaps, and is invasive and costly. Some advanced methods exist for duct sealing.	• ≤$X for single-family homes • ≤X days for small-medium commercial buildings • Seals X in. gaps • Does not displace tenants • X% of the market	• ≤$X for single-family homes • ≤X days for small-medium commercial buildings • Seals X in. gaps • Does not displace tenants • X% of the market

*Goals will be developed for residential and commercial applications as applicable

 Moderate market adoption of available solution

 Low market adoption of available solution

 No available solution