U.S. Department of Energy
Advanced Research Projects Agency – Energy (ARPA-E)

Request for Information (RFI) DE-FOA-0003385 on Highly Insulating Building Enclosures

Introduction:

The purpose of this Request for Information (RFI) is to solicit input for a potential ARPA-E program focused on the development of highly insulating R-10-rated glass for windows and R-50-rated walls for residential and commercial building retrofit and new construction.[1] This RFI aims to identify potential participants and gather insights to inform the development of a potential funding opportunity focused on these transformative technologies.

Heating and cooling of residential and commercial buildings in the United States accounted for about 12% of total national energy consumption (amounting to 12 quadrillion British thermal units) in 2022.[2] Approximately 45% of this heating, ventilation, and air conditioning (HVAC) energy was used to compensate for heat transfer through the building envelope (e.g., windows, walls, doors, attic, and air leaks).[2] Reducing the energy a building uses has multiple benefits beyond lower utility costs and carbon dioxide emissions. Smaller, less expensive HVAC equipment and ducting systems would increase useful interior space and reduce demands on the electrical grid.

ARPA-E encourages responses from a broad range of entities, including:

- High-performance window manufacturers and startups
- Building materials developers
- Certification authorities
- Universities and research institutions
- National laboratories
- Experts in joining technologies, ceramics, vacuum, and/or getters
- Industrial engineers
- Other relevant stakeholders

Areas Not of Interest for Responses to this RFI:

A potential ARPA-E program would focus on highly insulating windows and walls. Approaches not of interest include:

- Frames surrounding the glass (it is assumed manufacturers will produce suitable frame designs)
- Technologies related to doors (non-glass doors), roofs, and foundations

[1] The thermal resistance R in IP units (ft^2-hr-°F/Btu) will be used to characterize the thermal performance of windows and walls in this RFI. A common measure of the thermal performance of windows is the conductance U=1/R. Conversion from R (IP) to U (SI) is given by U (W/m^2-K)=5.7/R (ft^2-hr-°F/Btu).
[2] Harris, Chioke. 2022. "Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption https://doi.org/10.2172/1866581.

RFI Guidelines:

PLEASE CAREFULLY REVIEW ALL RFI GUIDELINES BELOW.

Please note that the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that could be considered proprietary or confidential**.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on June 7, 2024.** Emails should conform to the following guidelines:

- Please insert "<your organization name>- Response to Highly Insulating Building Enclosures" in email subject line.
- In the body of your email, include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research and development center [FFRDC], government-owned/government-operated [GOGO]), email address, telephone number, and area of expertise.
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential materials, designs, or processes.

Technical Background:

The first objective of this potential ARPA-E program would be to develop technologies that enable R-10 windows (14″ × 20″ glass size) that are cost competitive with double-pane integrated glass units (IGUs) so that R-10 windows become the default for retrofit and new construction. The dual-pane IGUs available today have R-values of approximately R-3. By increasing window thermal insulation to R-10, the energy loss through windows can be decreased by a factor of 3. The windows market has several available solutions with varying market penetration and customer acceptance issues. Triple pane (R-5 to R-7) and quadruple pane (from about R-7 to R-10) IGUs have minimal market adoption due to increased thickness and weight and are thereby impractical for many retrofit applications. Similarly, commercially available windows based on vacuum insulated glazing (VIGs) that can reach R-10 are generally cost prohibitive. Aerogel-based solutions made using existing technologies are expensive and currently cannot reach the R-10 target.

The second objective of this potential ARPA-E program could be to develop low-cost methods to increase the thermal resistance of walls to R-50 for both retrofit and new applications. Typical R-values for walls are R-10 to R-30. The blanket fiberglass batt wall insulation (R-3.5 per inch) commonly used between 2″ × 4″ or 2″ × 6″ studs result in R-13 to R-20 walls. Commercially available vacuum insulated panels (VIPs) consist of a porous core wrapped with metallized polymer film and have insulating values greater than R-50 per inch. This increased insulation makes VIPs an attractive method to decrease heat loss in retrofit applications since they can be installed within existing wall cavities.[3] VIPs can also be used in mobile homes to provide high insulation while maximizing interior space. However, VIPs' high cost, fragility, and inability to be cut on-site have limited their acceptance.

This RFI primarily addresses technologies that could enable adoption of low-cost R-10 windows and R-50 walls into the retrofit market. The ability to retrofit existing buildings is of primary importance as new construction accounts for a small fraction of the building stock each year.[2]

Areas of Interest for Responses to this RFI (include, but are not limited to):

R-10 Windows

VIGs, aerogels, and other novel technologies that can reach R-10 performance for 1 meter × 1 meter (40″ × 40″) glass are of interest. Challenges associated with VIGs and aerogel-based windows are described below.

*Windows with Vacuum Insulated Glazing***.** VIGs consist of two panes of annealed or tempered glass separated by small spacers that are hermetically sealed at the edges (Figure 1). A low emissivity (low-e) coating on one or both panes is used to control radiation, and a vacuum on the order of 10^{-6} atmosphere (atm) is created between panes to minimize conduction between panes. Getters are reactive materials that remove excess gases and are included to maintain a vacuum over the life of the system. Since heat conduction through the spacers is the primary mode of heat transfer, it is desired to maximize their separation distance of spacers. Although R-17 center-of-glass VIGs can be achieved, conduction through the edge seals can greatly decrease the overall R-value to below R-10 depending on window size. Differential thermal expansion can lead to bowing of the glass and/or stress on the edge seals leading to seal failure.

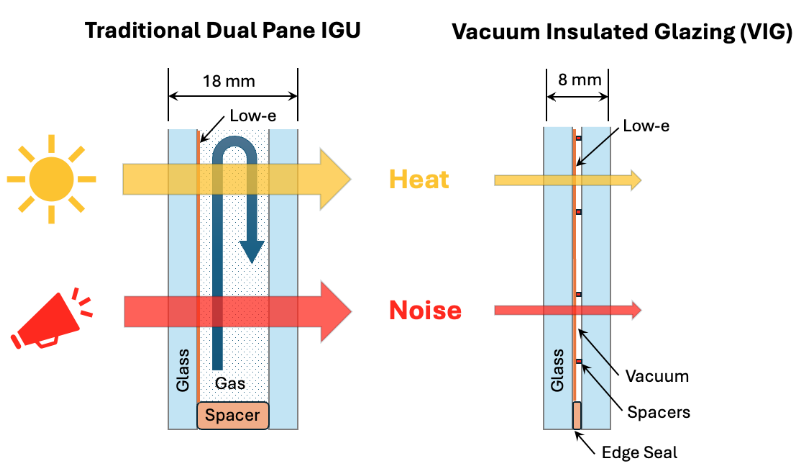

Figure 1. IGU vs. VIG construction.

[3] Potter, Thomas F., and Benson, David K. 1991. "Non-CFC Vacuum Alternatives for the Energy-Efficient Insulation of Household Refrigerators: Design and Use". https://doi.org/10.2172/6071723.

VIG manufacturing cost depends on the initial capital expenditure (CAPEX) cost and throughput. Current VIG plants produce roughly 250,000 square feet per year (ft^2/yr) and the CAPEX cost is high due to equipment and facility costs. In comparison, IGU lines produce units roughly every 30 seconds and over 2 million ft^2/yr at 5 to 10 times lower CAPEX. Cost parity with dual-pane IGUs can be achieved through decreased production cycle time. Throughput can be increased by reducing the time associated with spacer placement, room temperature edge sealing, and vacuum creation. The spacers in a typical VIG are placed at 0.8" to 1" intervals, so a 40" x 40" VIG would require rapidly setting 1,500–2,500 spacers. Room temperature edge sealing technologies can eliminate the need for large ovens to slowly heat and cool VIGs, increasing throughput and lowering CAPEX costs. Processes that reduce or eliminate the need for high-vacuum pumps and bake-off to drive off adsorbed water and other gases are needed. Lowering CAPEX by implementing new production-enabling technologies will further decrease cost of manufacturing. CAPEX reduction also lowers barriers and encourages new VIG producers to enter the market, increasing competition.

Aerogels and other nanoporous materials. Aerogels for window applications are transparent, open-cell, porous solids with low density and low thermal conductivity.[4] These materials may offer an alternate pathway to R-10 windows. Current technologies cannot produce the thickness needed to achieve the potential R-10 target at competitive cost due to the large amount of time required for solvent extraction. New processes are needed to remove the solvents quickly from thicker layers.

R-50 Walls

VIPs are made by sealing an evacuated core of polymeric fibers, fumed silica, or other materials within a laminate of polymer and metallized polymer/aluminum foil (Figure 2). If the pores in the core are 0.1 micrometers or smaller, the gas pressure can be on the order of 10^{-3} atm. Getters are added to maintain the vacuum. Conduction through the metallized film at the edges of the panel can significantly degrade VIP performance. Ideally, the useful life of VIPs can be up to 50 years.

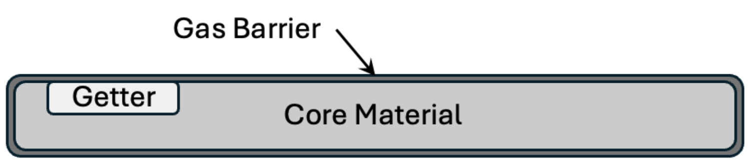

Figure 2. VIP construction.[5]

Due to high cost, VIP use is currently limited to thin wall applications where space is at a premium (e.g., refrigerators and vaccine transport coolers) or for building roofing applications where large sheets of regular shapes can be used. Custom shapes are often needed to fit around windows, doors, and vents, making VIPs more expensive. Moreover, the panels are easily damaged and require careful handling on construction sites, further adding to the cost.

Novel processes are needed to decrease the cost of VIPs by a factor of ten. VIP architecture must be modified so VIPs are cuttable and resealable in the field. Self-sealing VIPs are also of interest.

[4] Zeng, S. O., Arlon J. Hunt, and R. Greif. "Geometric structure and thermal conductivity of porous medium silica aerogel." *Journal of Heat transfer* 117, no. 4 (November 1, 1995): 1055-58, https://doi.org/10.1115/1.2836281).
[5] Mukhopadhyaya, P., S. Molleti, and D. van Reenen. "Vacuum Insulated Panels (VIPs): An historic opportunity for the building construction industry", *Interface: the Journal of the Roof Consultants Institute*, August 2014: 13-18.

RFI Questions:

The questions posed in this section are organized into several groups. Provide responses and information regarding any of the following. **ARPA-E does not expect any one respondent to answer all, or even many, of the prompts in this RFI.** In your response, indicate the group and question number in your response (e.g., A.1, B.2). Appropriate citations are highly encouraged. Respondents are also welcome to address other relevant avenues or technologies that are not outlined below with the exception of those that fall under the "Areas Not of Interest for Response to this RFI" described above.

A. R-10 Windows

Technologies related to VIGs:

1) What technologies can be used to rapidly produce hermetic edge seals using glass frit, metal-to-glass, or other materials at room temperatures without the use of large ovens?
2) What technologies are available to maintain the gap between the panes under vacuum with acceptable visual, thermal, and mechanical performance?
3) What processes can be used during manufacturing to quickly create the vacuum needed for a 50-year useful lifespan?
4) What are the quality control parameters for VIGs and how is quality ensured during production?
5) What standards must VIGs meet to offer a 20-year warranty?
6) How can the reliability of VIGs be verified?
7) What are the barriers to market acceptance?

Technologies related to aerogels:

8) What technologies can be used to rapidly extract any solvents used in aerogel manufacturing?
9) What alternate technologies can be used to produce transparent, highly insulating materials?
10) What are the challenges and possible solutions to aerogel integration into the window manufacturing process?

Other technologies:

11) What are other technologies by which R-10 windows can be manufactured?

B. R-50 Walls

1) How can the cost of VIPs be reduced?
2) What are the barriers to widespread adoption of VIPs? How can these obstacles be overcome?
3) What technologies might be used to make VIPs self-sealing and cuttable on-site?
4) How can VIPs be made more robust for handling in construction site environments?
5) What other issues should be considered regarding VIPs?
6) How can the reliability of VIPs be verified?
7) What other technologies should be considered to achieve the previously described potential program objectives?