FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)
U.S. DEPARTMENT OF ENERGY

SINGLE-PANE HIGHLY INSULATING EFFICIENT LUCID DESIGNS (SHIELD)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0001425
CFDA Number 81.135

FOA Issue Date:	October 6, 2015
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, November 10, 2015
Submission Deadline for Concept Papers:	5 PM ET, November 18, 2015
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	5 PM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	TBD
Total Amount to Be Awarded	Approximately $20 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $250,000 and $10 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- ARPA-E will not review or consider noncompliant or nonresponsive applications. For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 and III.C.2 of the FOA.

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

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REQUIRED DOCUMENTS CHECKLIST

For an overview of the application process, see Section IV.A of the FOA.

For guidance regarding requisite application forms, see Section IV.B of the FOA.

For guidance regarding the content and form of Concept Papers, Full Applications, and Replies to Reviewer Comments, see Sections IV.C, IV.D, and IV.E of the FOA.

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The Concept Paper must not exceed 4 pages in length and must include the following: ○ Concept Summary ○ Innovation and Impact ○ Proposed Work ○ Team Organization and Capabilities	Mandatory	IV.C	5 PM ET, November 18, 2015
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]	Mandatory	IV.D	5 PM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

The Advanced Research Projects Agency – Energy (ARPA-E), an organization within the Department of Energy (DOE), is chartered by Congress in the America COMPETES Act of 2007 (P.L. 110-69), as amended by the America COMPETES Reauthorization Act of 2010 (P.L. 111-358) to:

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in—
(i) reductions of imports of energy from foreign sources;
(ii) reductions of energy-related emissions, including greenhouse gases; and
(iii) improvement in the energy efficiency of all economic sectors; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

ARPA-E funds research on and the development of high-potential, high-impact energy technologies that are too early for private-sector investment. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive down the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector or the applied technology offices within DOE. By contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly lower than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have the clear disruptive potential,

e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met" and defines "development" as the "systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."[1] Applicants interested in receiving financial assistance for basic research should contact the DOE's Office of Science (http://science.energy.gov/). Similarly, projects focused on the improvement of existing technology platforms along defined roadmaps may be appropriate for support through the DOE offices such as: the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy (http://fossil.energy.gov/), the Office of Nuclear Energy (http://nuclear.energy.gov/), and the Office of Electricity Delivery and Energy Reliability (http://energy.gov/oe/office-electricity-delivery-and-energy-reliability).

B. PROGRAM OVERVIEW

1. SUMMARY

Building heating, ventilation, and air conditioning (HVAC) accounted for 14.0% of primary energy consumption in the United States in 2013, or 13.6 quadrillion British thermal units ("quads") per year. In addition to the season and weather in various U.S. regions, this consumption is determined by the heating and cooling facilities in the buildings, by the thermostat settings and other choices of building managers and occupants, and finally by the building envelopes. Windows are essential and costly elements of building envelopes, and the heat that flows out through windows in cold weather across the U.S. consumes about 3.9 quads of primary energy. The ARPA-E Single-pane Highly Insulating Efficient Lucid Designs (SHIELD) program seeks to reduce this consumption by funding the development of energy-efficient and cost-effective retrofits for the substantial remaining stock of single-pane windows in the U.S. ARPA-E analysis indicates that a fully successful single-pane retrofit campaign will reduce total building energy consumption by 1.2 quads, or 1.3% of domestic energy use. As envisioned in this SHIELD program, it will also address the water condensation and occupant discomfort that are associated with single-pane windows in cool climates.

SHIELD will support research on three broad technology categories. The first category will enable products that are applied onto existing windowpanes. The second is for manufactured windowpanes with similar weight and thickness to current panes, and that could be installed as replacements for existing windowpanes without necessitating replacement of the sash in which

[1] OMB Circular A-11 (http://www.whitehouse.gov/sites/default/files/omb/assets/a11_current_year/a11_2014.pdf), Section 84, p. 8.

the pane is mounted. For both of these research categories, the program's primary goals are to develop cost-effective technologies (i) to improve the thermal insulation (U-factor) and (ii) to reduce cold weather condensation of single-pane windows. A secondary goal of the SHIELD program is to develop synergistic improvements in window performance such as soundproofing that would make these window retrofits highly desirable to building occupants and owners. ARPA-E envisions that these technologies will be used in both the residential and commercial building sectors, and that the impact of the retrofits on the appearance of the window will be minimal. In addition to the two categories for comprehensive technology development, as a third category, SHIELD will support proof-of-principle development of innovative components that will enable superior performance in the first two technology categories.

2. MOTIVATIONS: IMPROVED SINGLE-PANE WINDOWS AND REDUCED NATIONAL ENERGY CONSUMPTION

Figure 1 illustrates estimates of the primary energy required to support heat flow out of heated buildings and through their windows in the four broad Census Bureau regions of the United States and for the residential and commercial building sectors.[2] The subdivision of each bar indicates the energies for single-pane and multipane buildings; the label at the bottom is the fraction of windows that are estimated to be single-pane. As expected, single-pane windows are relatively common in the warmer South and West regions; in the South, more than 40% of residential buildings still have single-pane windows instead of multiple pane (almost always double pane) windows. In the colder Northeast and Midwest regions, somewhat less than 30% of windows are typically single-pane.

These relatively small fractions become quite significant when heating energy is considered. For the primary energy usage calculated for each region and sector, the weighting of single-pane buildings has been doubled. This approximately accommodates the fact that single-pane windows conduct at least twice as much heat as average multi-pane windows.[3] Thus, of the 3.95 quads per year that can be attributed to heat conduction through windows, 2.0 quads per year are associated with single-pane windows. At nominal consumer rates of $10 per million BTUs,[4] this amounts to a cost of $20 billion/year. Retrofitting single-panes for improved efficiency could save about 1.2 quads/year, where we assume that the retrofit reduced the heat flow to 40% of the flow through unimproved single-panes. The associated retrofit investments would return about $12 billion/year to energy consumers.

[2] These estimates were calculated by ARPA-E using the 2011 Buildings Energy Databook, the 2009 Residential Energy Consumption Survey (RECS), and the 2005 Commercial Buildings Energy Consumer Survey (CBECS) following the methodology of ref. 3.

[3] Apte, J. and Arasteh, D., "Window-Related Energy Consumption in the US Residential and Commercial Building Stock", Lawrence Berkeley National Laboratory Report 60146 (2006).

[4] Consumer prices for natural gas are compiled by the Bureau of Labor Statistics. For the current summary for major cities, see http://www.bls.gov/regions/midwest/data/AverageEnergyPrices_SelectedAreas_Table.htm . The March 2015 average US price was $9.85 per million BTU.

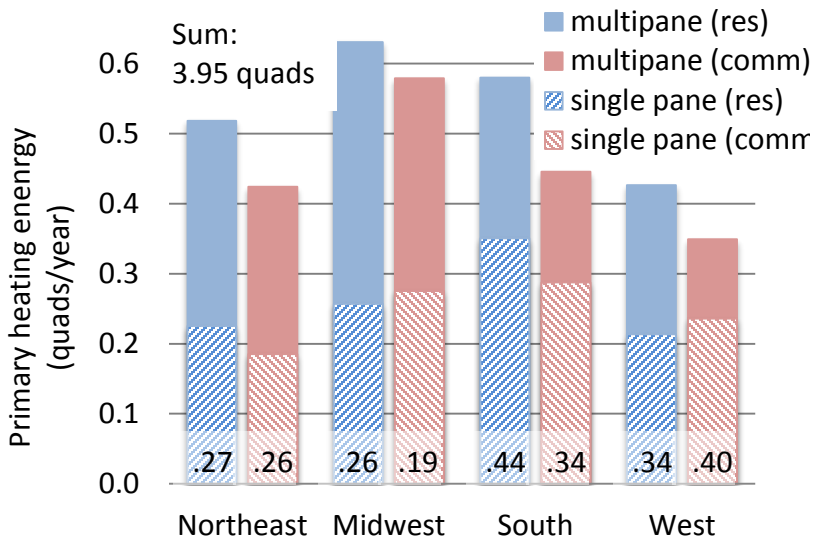

Fig. 1: Estimates of primary energy usage for heat flow through the windows of heated buildings in the four U.S. census regions. The results are given for residential and commercial buildings, and for single-pane and multipane windows. The label at the bottom of each bar indicates the area fraction of single-pane windows in each region and sector.

The dominant technology for efficient windows at present is the double-pane insulated glass unit (IGU) that incorporates a low-emissivity (low-*e*) coating on one of its panes.[5] Most new window installations in the United States incorporate these IGUs.[6] However, the area of single-pane windows is declining fairly slowly; the stock of single-pane windows in residences is declining at 2% per year.[7] The single-pane window technologies that will be developed by this research program will have properties intermediate between high performing IGUs and unimproved single-panes, and are likely to find first markets in buildings with historically and architecturally significant windows. These windows are not typically candidates for retrofitting with IGUs. As installed prices fall, the advanced single-pane technologies will be adopted in a wider range of buildings with single-pane windows. Ultimately, ARPA-E envisions that the technologies for advanced single-panes will also offer new options for reducing the cost and improving the performance of IGUs. IGUs are relatively thick and heavy compared to single-

[5] Emissivity refers to how efficiently a surface emits thermal radiation, which carries heat away from the surface. Ordinary window glass has an emissivity of 0.84; the highest emissivity is 1.0, and polished metal surfaces can have emissivities as low as 0.01. See Muneer, T., Abodahab, N., Weir, G., and Kubie, J., *Windows in Buildings: Thermal, Acoustic, Visual and Solar Performance* (Architectural Press, 2000), p. 46.

[6] 2011 Buildings Energy Databook, Tables 5.2.5 and 5.2.7 . U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

[7] This estimate is based on comparison of the 2005 and 2009 Residential Energy Consumption Surveys (Energy Information Agency). ARPA-E has not established this rate for commercial buildings. ARPA-E estimated the window areas using the floor space of US homes and commercial buildings (RECS Table HC10.1, CBECS Table B5) with single-pane and multipane windows.

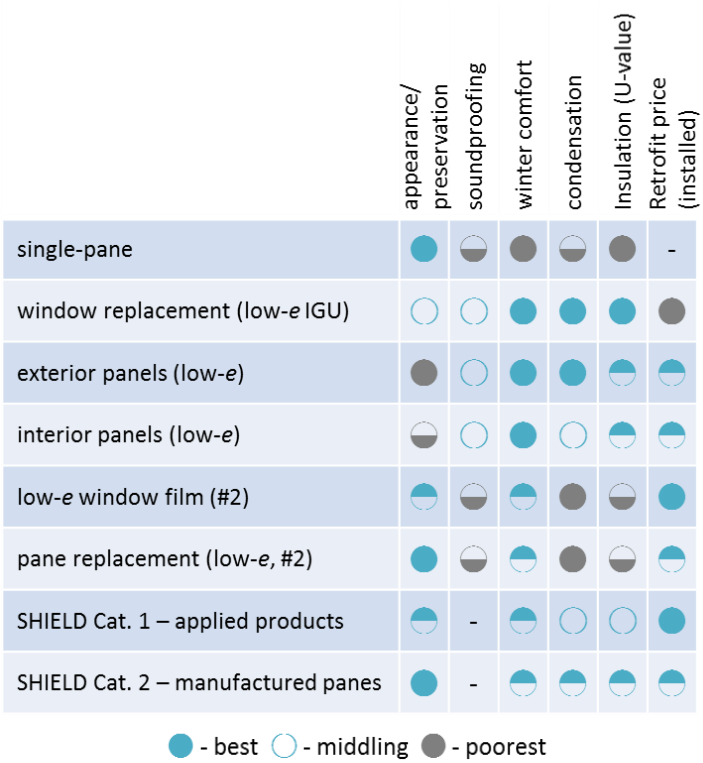

Fig. 2: Ball chart illustrating the relative performance of several window technologies for six qualities. Additional details are provided in the text.

panes, and lower-quality IGUs have suffered from short service lifetimes due to the failure of the seal between the panes.[8]

The SHIELD program does not directly address summer cooling associated with windows, which uses another 2.3 quads of primary energy annually. Cooling is mostly needed in the summer season to compensate for solar heating through windows, and is not specific to the stock of single-pane windows.[9] Solar heating is an advantage in the winter heating season.

3. CURRENT APPROACHES TO EFFICIENCY RETROFITS OF SINGLE-PANE WINDOWS

Summary chart for single-pane window retrofits. Fig. 2 is a summary of several window retrofit options using a ball chart to illustrate qualitatively the characteristics of each retrofit for appearance, soundproofing, comfort, condensation, insulation, and price. The best performance is indicated by the solid blue balls, and the poorest by the solid black balls. Thus the appearance of a single-pane window is excellent, but most of the other aspects of the window are poor. In the following, we discuss the characteristics and the retrofit options

[8] O'Mara , Deborah L., "25 years of proof: Insulating glass unit analysis bolsters independent, third party certification", *Glass Magazine*, March 26, 2009.
[9] Sawyer, K. (editor), "Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies". Building Technologies Office, EERE, U. S. Department of Energy, February 2014.

individually. The last two rows of the chart are a guide to the goals of the SHIELD program for its two categories.

Window insulation: *U*-factor. The thermal insulation of a window is quantified by its *U*-factor, which is the ratio of the heat flux *H* per unit area through the pane to the difference ΔT between the interior and exterior temperatures. Lower U-factors corresponds to better insulating windows. In American units (BTU/hour/square-foot/degree-Fahrenheit),[10] an unimproved glass pane has a *U*-factor of about 1.1.[11] The *U*-factor for an entire window, which includes the effects of the sash and the framing around the windowpane, needs to be less than 0.30 to achieve Energy Star certification in colder regions of the US.[12]

Window comfort and condensation resistance. On a cold, windy day, the temperature of the interior surface of a single-pane window is nearly as low as the outside temperature. A consequence is that a significant region around the window will be uncomfortably chilly compared to the rest of the heated interior. The cold temperature of the pane also means that moisture from the interior of a building will condense on its surface. Condensation is not merely unsightly. It also limits the humidity level of the interior of a building, which is a concern for the indoor air quality. A 30% relative humidity is a lower limit recommended by health experts.[13-15] In a single-pane building on windy days, this level of humidity can only be maintained when the exterior temperature is above -2.5 C.[16]

Window properties: soundproofing. Soundproofing by a window is often characterized by the "sound transmission class" (STC), which is one indicator of the attenuation of exterior acoustic

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[10] Metric values for *U* ($W/m^2/K$) are 5.68 times larger than the American values (BTU/hr/sf/F).

[11] Carmody, J., Selkowitz, S., Arasteh, D., and Heschong, L., *Residential Windows: Third Edition* (Norton, 2007), p. 39. *U*-factors are somewhat affected by measurement conditions; this document uses the winter U-factor conditions specified by the National Fenestration Rating Council (NFRC), which are an interior temperature of 21 C, an exterior temperature of -18 C, and an exterior wind speed of 5.5 m/s.

[12] "Energy Star performance criteria for windows, doors, and skylights", Environmental Protection Agency. Accessed May 26, 2015.

[13] Sterling, E.M., Arundel, A., and Sterling, T. D., "Criteria for Human Exposure to Humidity in Occupied Buildings", *ASHRAE Transactions*, Vol. 91, Part 1, pp. 611-622 (1985). This paper is the origin of the "Sterling Chart" summarizing the effect of indoor humidity on diseases such as respiratory infections and allergies. The authors recommend an indoor relative humidity in the range 40 – 60%.

[14] Makinen, T. M., Juvonen, R., Jokelainen, J., Harju, T., Peitso, A., Bloigu, A., Silvennoinen-Kassinen, S., Leinonen, M., and Hassi, J., "Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections", *Respiratory Medicine* 103, 456-462 (2009). doi:10.1016/j.rmed.2008.09.011

[15] Berlin, G. L., "Restoring the low limit for indoor relative humidity", *Engineered Systems,* February 2014 issue, pp. 48 – 52. Berlin takes issue with the absence of a low limit for relative humidity in ASHRAE standard 55, and recommends 30 – 35% as a reasonable low limit. The ASHRAE standard recommends a maximum relative humidity of 65% at an interior temperature of 72 F.

[16] In this document, condensation resistance will be defined in terms of the exterior temperature T_C at which condensation appears at the center of the windowpane. The interior relative humidity is assumed to be 30%. The additional, fixed conditions are those at which the winter *U*-factor is reported by the NFRC:[51] interior temperature = 70 F (21 C), exterior windspeed = 5.5 m/s, and no solar illumination (dark).

noise by the window. A window with a 1/8 inch thick single-pane typically has an STC of 29 db, where 30 db indicates approximately a thousand-fold drop in noise intensity. Thicker panes have larger STC values; a ½ inch pane has an STC of about 37.[17] Good soundproofing generally requires windows that have an STC class of 40 db, about ten times better than the single-pane.

Replacement by an IGU. A straightforward approach to improving a window's performance is to replace the entire window (frame, sash, and glazing[18]) with a modern window incorporating an advanced IGU. These are not simply double panes: they incorporate a low emissivity ("low-e") coating on one pane. Emission of thermal radiation by an unimproved glass pane is a major source of heat loss. The low-*e* coating can reduce this loss by up to tenfold. Filling the space between the panes with inert gases such as argon further improves advanced IGU insulation.

Beyond the improved efficiencies of IGUs, the ball chart illustrates that IGUs mitigate the problems of single-panes with comfort and condensation, and improve soundproofing as well. Despite these advantages, single-pane windows are being replaced by more advanced multipane windows fairly slowly in the US; the area of residential single-pane windows is declining at about 2% per year.[7] The fairly high cost of window replacement is one difficulty; one rough estimate for consumers is about $50-$100 per square foot with installation.[19] Simple payback from the energy savings of a complete replacement takes decades even in cold climates.[20] The change in a building's appearance with contemporary windows may preclude replacement by IGUs for esthetic and historical reasons (including location in an historical district),[21,22] or due to homeowner association covenants.[23] Finally, the curtain walls of some large buildings built in the 1950s and 1960s cannot support the additional weight of IGUs. The weight of an IGU is typically more than double that of the single-pane window it replaces.[24]

Storm windows and interior panels. Exterior storm windows are a long-established technology for improving the efficiency of a single-pane window. With the addition of a low-*e* coating they

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[17] Schimmelpenningh, J., "Acoustic Interlayers for Laminated Glass– What makes them different and how to estimate performance", *Glass Performance Days South America – 2012*.
[18] The term "glazing" refers to the entire transparent structure, which in this case is the IGU.
[19] "How Much Does It Cost to Replace Windows?", *Angie's List*, June 2, 2015.
[20] "Home window buying guide", *Consumer Reports*, January 2015.
[21] Sedovic, W. and Gotthelf, J. H., "What replacement windows can't replace: the real cost of removing historic windows", *Journal of Preservation Technology* **36** (4), 25 (2005).
[22] "Saving Windows, Saving Money: Evaluating the Energy Performance of Window Retrofit and Replacement", (National Trust for Historic Preservation, 2012).
[23] The Covenants, Conditions, and Restrictions (CC&R) agreements of homeowner associations can be a barrier to total window replacement. See the webpage "Installing New Windows in HOAs: Regulations and Best Practices" published by Educational Community for Homeowners.
[24] Browning, W., Hartley, A., Knop, T. and Wayne, Curtis B., *Mid-Century (Un)Modern: An environmental Analysis of the 1958-73 Manhattan Office Building* (Terrapin Bright Green LLC, 2013).

can be nearly as efficient as an IGU, and have most of the other good qualities as well.[25] They are fairly inexpensive (ca. $15 per square foot installed).[26] The primary disadvantages are their change to the exterior appearance of a building (as detailed above) and interference with opening and closing of some existing windows.

Interior panels that are sealed against the existing window frame are also much less expensive than full replacement, and again largely duplicate the good qualities of IGUs for soundproofing, comfort, and efficiency. They may interfere with the operation of the original window and with existing shades. Cold-weather condensation of water between the panel and the original pane is also a concern with interior panels.[27]

Low-*e* window films. Adhesive window films are widely used to modify the optical properties of existing windowpanes both in buildings and vehicles; they are typically applied to the interior (#2) surface of the pane. One low-*e* product reduces the winter *U*-factor of a 1/8" pane from 1.04 to 0.61.[28] Low-e window films are priced at roughly $10/sf (installed); pane replacement is about $20/sf (installed).[29] An interior surface low-*e* layer also increases comfort levels. Interior condensation resistance is diminished by the low-*e* layer. [30] Condensation also affects emissivity, and interior surface low-e layers are only effective on windows without condensation. Water and ice are high emissivity substances, and even a very thin layer of condensed water or ice is sufficient to turn a low-*e* surface back into a high-*e* one.

Low-*e* replacement panes. Windowpanes with low-*e* surfaces can replace a conventional single-pane at a price similar to that of replacing broken panes. The "hard coat" layer is a permanent and durable change of one surface of the glass pane; this type of pane is also used for low-*e* storm windows and interior panels. The layer is effective in lowering the *U*-value. As a representative example, one company's uncoated 1/8 inch glass pane has a winter *U*-factor of 1.04; a similar pane with a low-e "hard coat" has a *U*-factor of 0.66.[31] As for low-e window films, when the low-*e* layer is on the #2 (interior) surface, occupant comfort is improved compared to an unimproved single-pane, but the condensation properties are degraded.[30]

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[25] Modern IGUs often incorporate argon or xenon between the two panes, which improves their performance over a simple air gap between panes. See ref. 11.

[26] Cort, K. A., "Low-E Storm Windows: Market Assessment and Pathways to Market Transformation", report PNNL-22565 published by Pacific Northwest National Laboratory (2013).

[27] Curcija, C., Goudey, H., Mitchell, R., and Dickerhoff, E., "Highly Insulating Windowpanel Attachment Retrofit", report published by Lawrence Berkeley National Laboratory (2013).

[28] "Enerlogic 70 film technical information", webpage published by Solutia, Inc. (retrieved May 16, 2015). The visible transmittance of a clear pane with film applied is 0.70; an unimproved, clear pane's transmittance is about 0.91 .

[29] Consol, Inc. (February 24, 2014). "Energy Analysis for Internal and External Window Film Applications for Existing Homes in Florida". Report commissioned by the International Window Film Association.

[30] Wright, J. L. (2014). "The use of surface indoor low-e coatings: The implications regarding condensation resistance", presented at the ARPA-E Workshop on Single-pane Window Efficiency (November, 2014).

[31] Pilkington, Inc. products "Optifloat clear" and "Energy Advantage" panes; see *Pilkington North America Architectural Glass Product Guide*, pp. 41-42 (October 2014). The low-e layer reduces the visible transmittance of the 1/8 inch pane from 0.91 to 0.84 .

4. PROGRAM APPROACHES

The SHIELD program will support research on modifying existing glass windowpanes and on advanced manufactured windowpanes. These are to be designed as retrofits for existing single-pane windows that significantly improve their insulation. Changes in the window's appearance should be minimal. The occupant should notice improved comfort, condensation resistance, and possibly soundproofing.

U-factor and condensation in single and double pane windows: Among the existing retrofit technologies, improving the single-pane window with a low emissivity coating on the pane is the closest to achieving the combination of properties that SHIELD is targeting. The coating significantly improves the insulating properties of the pane, in some cases with only a modest change in its appearance.[28,31] However, the goals of SHIELD are not achievable by emissivity control alone.

This is explained further by Fig. 3, which illustrates design exercises for three types of window: (i) (label: single) single-pane with coatings of varying emissivity, (ii) (label: double) double pane with coatings of varying emissivity, and (iii) (label: single + barrier) single-pane with a low-e coating and a thermal barrier of varying *R*-value. The exercises compares the U-factor and condensation temperature of the glazing over a range of design parameters for each type of window.

For the single-pane exercise, each point on the curve corresponds to a different emissivity e_2 for the interior, #2 surface of a single 1/8 inch thick pane of glass. The emissivity of a surface is the ratio of its thermal radiation emission compared to the theoretical maximum for its temperature. By definition, emissivities range from 0 to 1; glass has an emissivity of 0.84, and a good low-e layer

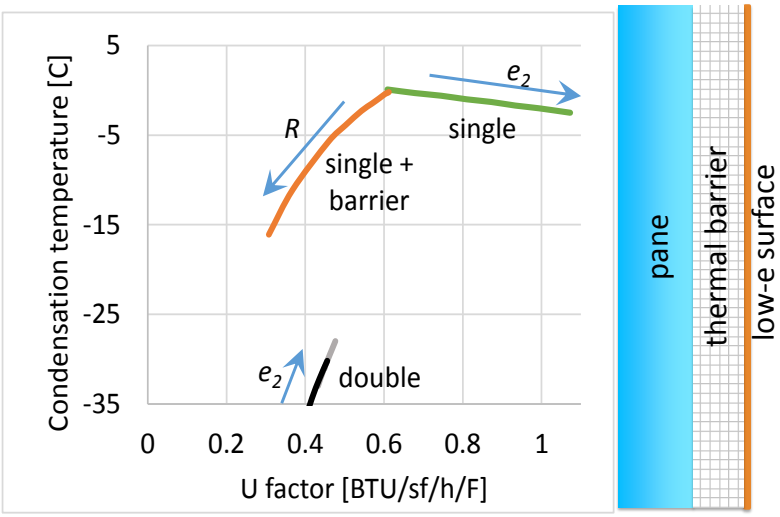

Figure 3: Condensation temperature T_C as a function of *U*-factor for three types of window: (i) (green line) Single-pane with varying surface 2 emissivity e_2. The direction of the blue arrow corresponds to e_2's change from 0.1 (left terminus) to 0.84 (right). (ii) (black) Air-filled double glazing. e_2 now indicates the varying emissivity of the interior surface of the outer pane; only the region from 0.65 to 0.84 (right terminus) is shown. (iii) (orange) Single-pane with fixed e_2 = 0.10 and a thermal barrier layer, as illustrated at right. The direction of the arrow corresponds to variation of the barrier layer's *R*-value from 0.0 (upper terminus) to 2.0 sf·hr·F/BTU.

has an emissivity of 0.1 or lower.

In the figure, the "condensation temperature" T_C is plotted against the *U*-factor for the center of the pane. In this document, T_C is defined as the exterior temperature at which condensation will appear at the center of the interior surface of the pane with standard interior & exterior conditions.[32] Physically, condensation occurs when the temperature at the center equals the dewpoint of the interior of the building. The results for the U-factor and the condensation temperature were obtained using window modeling software published by Lawrence Berkeley National Laboratory.[33]

An interesting feature for a single glass pane is that, while the lowest emissivity (e_2 = 0.10) gives a substantially lower *U* than the higher values of e_2, it also corresponds to an increased (poorer) T_C. High emissivity surfaces emit nearly the maximum possible flux of thermal radiation, and they also absorb incident thermal radiation nearly completely. Thus an unimproved, e_2 = 0.84 glass pane is warmed both by the heated air inside the room and by absorbing nearly all of the thermal radiation incident on it from the room. An improved, e_2 = 0.10 pane reflects most incident thermal radiation back into the room. This reduces the transfer of heat to the windowpane, but it also leaves the pane colder than it was for an unimproved pane. The lower *U*-factor for the improved pane is a direct consequence of this, but it also corresponds to a T_C that is 3.5 C higher than it was for the unimproved pane.[30]

The properties of a double pane window with a 0.5 inch air gap between the panes are shown near the bottom of the figure. A double pane window without a low-e coating has a center-of-glass *U*-factor of about 0.48, which is somewhat better than the single-pane with a low-*e* surface. However, the condensation temperature is far lower. This can be understood from the *R*-value $R = \Delta T/H$ between the panes, which is the ratio of the temperature difference ΔT between the panes and the heat flux *H* between them (F·sf·hr/BTU). This R-value is similar to the R-value between the interior pane and the room, and the two resistances dominate the ultimate *U*-factor calculation for the window. The interior pane's temperature is thus about halfway between the exterior temperature and the interior temperature, which is far better than the situation with a single-pane. A low-*e* layer on surface #2 (outer pane, interior surface) further insulates the space between the panes, and both the U-factor and the condensation temperature continue to improve to values typical of contemporary IGUs.[34]

The remainder of this section consists of examples of possible technical approaches to improve on the performance of a single-pane window. These examples are provided for illustration only.

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[32] The standard interior conditions are temperature of 21 C and relative humidity of 30%. The exterior wind speed standard is 5.5 m/s.

[33] The data were calculated using the "Therm" window modeling software published by Lawrence Berkeley National Laboratory; winter *U*-factors correspond to an exterior temperature of 0 F (-18 C). Therm, version 6.3 (July 2013); see the webpage "Therm – Windows and Daylight Group".

[34] Harvey, L. D. Danny, *A Handbook of Low-Energy Buildings and District-Energy Systems* (Earthscan, 2006), p. 72. Fig. 3.21 shows the temperature profiles for several designs of double pane windows.

ARPA-E welcomes all innovative solutions that meet the technical performance targets in Section I.E of the FOA.

Transparent thermal barriers. Transparent thermal barrier layers are one approach that could improve a single-pane window's properties beyond what can be obtained by emissivity control alone. These might be applied as a paint or an adhesive film to an existing pane. For newly manufactured panes, they might also be created by modifying a pane's surface at the factory, as is presently done to manufacture "hard coat" low-emissivity panes.

The third curve in Fig. 3 illustrates the T_C-U behavior of a single-pane with a thermal barrier between the pane and a low-e layer (e_2 = 0.1). The structure is illustrated at the right of the figure. As the R-value of the barrier increases, the condensation temperature falls and the U-factor of the window improves. The terminal point at U = 0.30 corresponds to an R-value R = 2.0 sf·hr·F/BTU (0.35 m^2·K/W). Achieving this with a 3 mm barrier layer would require a material with a thermal conductivity of 0.01 W/m/K. As a guide, U = 0.40 needs 0.02 W/m/K, and U = 0.50 needs 0.05 W/m/K with a 3 mm layer. For reference, 0.02 W/m/K is achieved in highly porous silica aerogels.[35]

Materials for transparent thermal barriers. Thermal barrier materials used in building envelopes are usually porous. This fact can be roughly understood from the "minimum thermal conductivities" of solids. These are estimated from the fundamental properties of phonons (the vibrational quanta that carry heat and sound). Thermal conductivity is related to the distance a phonon can travel without being scattered. The crucial assumption leading to a minimum thermal conductivity is that the worst that disorder can do is to limit this phonon scattering length to the distance between neighboring atoms. The thermal conductivity of silica glass, which is about 1 W/m/K near room temperature, is consistent with this picture.[36] A solid glass pane conducts heat well enough that it hardly affects the final U-factor for a window.[34] Introducing porosity reduces the thermal conductivity by removing the material in which phonons propagate. The thermal conductivities of porous, silica-based materials in vacuum are also fairly consistent with minimum thermal conductivity rules that allow for porosity.[36]

In practice, highly porous thermal insulators are usually used in air, and heat transfer is then via the entrained gas and not the solid matrix. The porous, air-filled materials continue to work as good thermal insulators because gases have intrinsically low thermal conductivities compared to solids. The conductivities are lowered even further when the pores are micron size or smaller, which is known as the "Knudsen effect".[37]

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[35] Baetens, R., Jelle, B. P., and Gustavsend, A., "Aerogel insulation for building applications: A state-of-the-art review", *Energy and Buildings* 43, 761–769 (2011).

[36] Hopkins, P. E., Kaehr, B., Piekos, E. S., Dunphy, D., Brinker, C. J., "Minimum thermal conductivity considerations in aerogel thin films", *J. Appl. Phys.* 111, 113532 (2012). http://dx.doi.org/10.1063/1.4729325.

[37] "Experimental validation of the Knudsen effect in nanocellular polymeric foams", Notario, B., Pinto, J., Solorzano, E., de Saja, J.A., Dumon, M., Rodríguez-Perez, M.A., *Polymer* 56, 57-67 (2015).

While low thermal conductivity materials are generally porous, in some non-porous materials thermal conductivities below "minimum" values have been found. One example is a tungsten selenide material that was found to have a thermal conductivity about six times lower than the predicted minimum thermal conductivity.[38] The fact suggests that a breakthrough in lowering the conductivity without resorting to porosity is at least conceivable. As explained further below, this approach might more readily lead to a transparent thermal barrier than do porous materials.

For transparent barrier layers, the solid material used as the matrix of a porous material is intrinsically transparent. However, the pores cause Rayleigh scattering of light, which may cause an unacceptable "haze" in the window.[39] Porous, silica-based aerogels provide a good example. Depending on their preparation, silica aerogel films may scatter light fairly strongly. This reflects a broad pore size distribution that extends to sizes comparable to the typical wavelength of sunlight (500 nm). Aerogel powders are used for translucent thermal barriers in skylights and other products,[35] but transparent forms have not yet been used for commercial windows.

There are several less-developed approaches that could also yield a transparent, porous thermal barrier layer suitable for use in windows. One approach embeds silica nanocapsules into polymer films. Here the pore size distribution has little dispersion, since it is set by the diameter of the nanocapsules. A second approach is templating of silica and other materials using self-assembled block copolymers as templates. This approach can yield porous structures that are fully periodic, again giving more control over the dispersion of pore sizes.[41] Polymer nanofoams could also potentially yield transparent porous materials if formation of larger pores can be sufficiently suppressed.[42]

Materials for low-emissivity. Low-e materials are likely be needed as part of SHIELD program technologies. Such materials have a low emissivity because their interfaces reflect thermal radiation with a wavelength around 10 microns. On the other hand they must transmit visible light nearly completely. Existing products mainly achieve this using two approaches. One is to

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[38] Catalin Chiritescu, C., Cahill, D. G., Nguyen, N., Johnson, D., Bodapati, A., Keblinski, P., and Zschack, P. "Ultralow Thermal Conductivity in Disordered, Layered WSe_2 Crystals", *Science* 315, 351-353 (2007).

[39] Haze is defined as the percentage of an incident light beam that is scattered when it passes through a window. For reference, low-*e* "hard coat" glass panes have a haze as large as 0.5 %, which is usually considered acceptable. See "Haze in Glass Products", Cardinal Glass, Inc., Bulletin #CG07 (September 2013).

[40] Liao, Y., Wua, X., Wang, Z., Yue, R., Liu, G., and Chen, Y., "Composite thin film of silica hollow spheres and waterborne polyurethane: Excellent thermal insulation and light transmission performances", *Materials Chemistry and Physics* 133 (2012) 642– 648.

[41] Coquil, T., Richman, E. K., Hutchinson, N. J., Tolbert, S. H., and Pilon, L., "Thermal conductivity of cubic and hexagonal mesoporous silica thin films", J. Appl. Phys. 106, 034910 (2009).

[42] Forest, C., Chaumont, P., Cassagnau, P., Swoboda, B., and Sonntag, P., "Polymer nanofoams for insulating applications prepared from CO_2 foaming", *Progress in Polymer Science* 41 (2015) 122–145.

sputter several layers including a very thin metal layer onto glass or onto a polymer carrier film; the resulting layers are termed "soft coat" in the trade. The second is pyrolysis at the factory to create a transparent conducting oxide on the surface of glass. This is more durable than the soft coat and has been termed a "hard coat". One commercial hard coat glass has an emissivity of about 0.15 with a visible light transmittance of more than 80%.[31] Soft coated glass or window films can have still lower emissivities, typically with lower transmittances as well.[28]

These approaches were developed for windows in the 1970s and 1980s, and have been extensively optimized. There are newer materials with potentially suitable properties that are being explored for use as transparent conducting electrodes in solar cells and transparent electronics. These include amorphous conducting oxides, graphene, and layers of nanowires or nanotubes.[43] The SHIELD program may be an opportunity to examine new structures with low emissivity interfaces that have higher visible transmittance, are less costly, or are synergistic with the requirement of improved insulation or the possibility of improved soundproofing.

Soundproofing. A single-pane of glass that is 1/8 inch thick has a sound transmission coefficient (STC) rating of about 29 db; most sound from the outside is reflected by the pane, with the reflection generally increasing with acoustic frequency. 29 db is inadequate if the exterior noise is significant. The STC rating can be increased by using more glass (the "mass law"),[44] but weighty panes and structures aren't suitable for retrofitting of existing panes and sashes. Incorporation of a sound-deadening layer is also effective. Laminated glass consists of two panes with an adhesive polymer interlayer. It was developed as a "safety glass" for vehicles, but it turns out that laminated glass also has a soundproofing property. It outperforms a monolithic glass pane with a similar weight by up to 4 db.[17] The sound-deadening performance of the interlayer is related to a remarkable "coincidence effect" for sound transmission in windowpanes and more generally in thin panels.[44] At specific combinations of frequency and angle of incidence for sound, the weight-dictated reflection of sound is nearly canceled by the launching of bending waves in the glass itself, leading to significantly enhanced sound transmission near the coincidence frequencies. The viscoelastic layer directly absorbs this sound sufficiently well that it reduces the coincidence effect sound transmission.

Polyvinyl butyral (PVB) that has been optimized for its sound deadening effect is available commercially.[45] The development was a byproduct of the widespread use of PVB as the interlayer for laminated glass, and there are likely other transparent materials with suitable properties for sound deadening that would not be suitable for lamination. Researchers have also done calculations showing additional soundproofing by marrying a viscoelastic polymer

[43] Ellmer, K., "Past achievements and future challenges in the development of optically transparent electrodes", *Nature Photonics* 6, 809-817 (2012). http://dx.doi.org/10.1038/NPHOTON.2012.282.
[44] Long, Marshall, "Thin Panels: Bending Waves and the Coincidence Effect", *Architectural Acoustics – Second Edition* (Academic Press, 2014), pp. 354-358.
[45] "Saflex® QS acoustic PVB interlayer" (Eastman Chemical Co., October 2014).

layer (such as PVB) with a porous layer.[46] That research reflects the fact that open-cell porous materials, including silica aerogels, are also well-known to have significant sound-absorbing properties.[47,48] Since porous materials are often good thermal insulators, it appears probable that layer structures on single windowpanes can be designed that will improve both the thermal insulation as well as its soundproofing.

A much more recent approach to sound absorption is acoustic metamaterials. These involve small, acoustically active structures that are engineered to manipulate acoustic waves in ways that can be quite surprising. Among other possibilities, they present the possibility of directly absorbing low-frequency acoustic waves.[49] The current approach to low frequency soundproofing relies on increasing the total weight of glass in the window to increase its mass law reflection, which is undesirable because of its usage of materials and is unsuitable for single-pane retrofitting. It is also plausible that acoustic metamaterials could be designed to mitigate the coincidence effect as an alternative to viscoelastic and porous layer soundproofing.[50] On the other hand, acoustic metamaterial structures are intricate and may be too costly to incorporate into windows; they have also not been designed with an eye to optical transparency.

The examples of possible technical approaches provided in Section I.B of the FOA are for illustration only. ARPA-E welcomes all innovative solutions that meet the technical performance targets in Section I.E of the FOA.

C. PROGRAM OBJECTIVES

The technical categories for this program are: (i) products that can be applied to existing windowpanes, (ii) manufactured windowpanes that can replace existing windowpanes in their current sashes, and (iii) innovative components that will enable superior performance in the first two categories. While the objectives for the first two categories are similar, the performance goals are more stringent for the second category. The overarching goal is to create single-pane window retrofit technologies that will be widely and rapidly adopted by building owners and managers.

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[46] Suresh, S., Lim, T.C. and Kastner, J., "Predicting acoustic transmission loss through laminated glass with air and porous layers", *Int. J. Vehicle Noise and Vibration*, Vol. 8, no. 3, pp.237–260.
[47] Allard, J. F.. and Atalla, N., *Propagation of Sound in Porous Media: Second Edition* (Wiley, 2009).
[48] Ricciardi, P., Gibiat, V., & Hooley, A., "Multilayer absorbers of silica aerogel", *Proceedings of Forum Aucusticum, Sevilla* (September 2002).
[49] "Dark acoustic metamaterials as super absorbers for low-frequency sound", Mei, J., Ma, G., Yang, M., Yang, Z., Wen, W., and Sheng, P., *Nature Communications* 3, article number 756 (2012). doi:10.1038/ncomms1758
[50] Xue Jiang, X., Liang, B., Li, R. Q., Zou, X.-Y., Yin, L.-L., Cheng, J.-C., "Ultra-broadband absorption by acoustic metamaterials*", Appl. Phys. Lett.* 105, 243505 (2014). doi: 10.1063/1.4904887.

1. HEATING ENERGY EFFICIENCY, CONDENSATION RESISTANCE, AND COMFORT

SHIELD seeks technologies that will improve cold weather *U* factors of the glass pane of a single-pane window and reduce winter energy usage. Standard temperatures and exterior wind speed for winter and summer *U*-factors have been established by the National Fenestration Research Council (NFRC).[51] While the NFRC typically rates an entire window's performance, including the window's frame and averaging over the entire area, the present document will refer exclusively to "center-of-glass" (cog) *U* values. Broadly speaking, center-of-glass *U*-factors are higher than window-average values, but this depends on the details of the sash and frame.[11] The center-of-glass *U* values should be lower than 0.5 and 0.4 for the applied product and manufactured windowpane categories, respectively, which may be compared to the unimproved value $U = 1.1$.

At the same time the condensation resistance should be improved compared to that of an unimproved single-pane of glass. The targets for the maximum condensation temperatures are T_c = -5 C and -10 C for first and second technology categories, respectively. They are 2.5 and 7.5 C better than that of an unimproved single-pane window. The targets reflect the value of a healthful minimum relative humidity indoors of 30% or larger (at 21 C).[14] Additionally, water or ice that is condensed on low-e window surfaces erases the *U*-factor and comfort improvements associated with a low-*e* coating. This erasure will occur in the coldest weather, which is when the low-e surface's insulating properties are most needed.

The more stringent *U*-factor and T_C targets are approximately those calculated for the "low-e + barrier" structure of Fig. 2 assuming a 3 mm barrier layer with thermal conductivity 0.02 W/m/K.

Occupant comfort is related to the temperature and emissivity of the innermost surface of the window as well as the properties of the rest of the room. The ASHRAE standard is that the temperature of a cool wall should be no more than 10 C below the overall temperature of the air and remaining walls of the room.[52] The temperature difference leads to a "radiant asymmetry" in a room, since the cool wall provides less radiant heating to a person than the warmer walls, ceiling, and floor. The 10 C criterion is intended to satisfy 95% of a random sample of occupants.

Huizenga, *et al.*,[53] have done a comprehensive analysis of the research behind this standard and of its applications to windows. Most work on comfort with windows has assumed an interior

[51] "Document 100-2014: Procedure for Determining Fenestration Product U-factors" (National Fenestration Research Council , 2013), p. 24.
[52] "Standard 55-2013: Thermal environmental conditions for human occupancy", ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2013).
[53] Huizenga, C., Zhang, H., Mattelaer, P., Yu, T., Arens, E., Lyons, P. "Window performance for human thermal comfort", University of California, Berkeley (February 2006). Report commissioned by the National Fenestration Research Council.

surface emissivity of 0.84, which is the value for ordinary glass. A comfort index that applies to low-e interior surfaces has apparently not been published. A plausible extension of the radiant asymmetry concept is to define a radiant temperature T_{rad} of the window that includes both the direct thermal radiation from the window and also the reflected thermal radiation originating from the other interior surfaces in the room. T_{rad} is measured by an infrared thermometer that assumes a surface emissivity of 1.0 at the point being measured.

For a room temperature of 21 C and an exterior wind speed of 5.5 m/s, which are the NFRC assumptions for winter *U*-factors, ARPA-E will use a criterion that T_{rad} should exceed 11 C for exterior temperatures greater than 0 C. This is similar to the results expected for an unimproved double pane window without a low-e coating.[53] A single-pane window with a low-e surface $e_2 = 0.1$ meets this standard.

2. CLARITY, COLOR, AND TRANSPARENCY

SHIELD seeks technologies that only minimally change the appearance of a clear single windowpane as viewed either from outside or inside the building. The clarity of the view through the windowpane can be approximately quantified using the measured "haze" of the windowpane, which is defined as the percentage of incident light that is scattered away from a normally incident beam by the window. Clean float glass has a haze that is well below 1%. Hard-coat low-*e* glass has a haze up to 0.5%, and some laminated glass products reach 1%.[39] ARPA-E anticipates that haze may be a limitation for some technologies, and has set maximum haze targets of 2% and 1% for the applied product and manufactured pane technology categories, respectively. Haze that is significantly below 1% is plainly an advantage in the marketplace, as evidenced by the informal online discussions of blue scattered light from low-*e* windowpanes under certain conditions.[54] On the other hand, only freshly cleaned windows have haze values below about 2%.[55]

The visible transmittance V_T of a window is a standard characterization, and clear single-panes transmit about 91% of visible light and reflect about 9%.[31] Windowpanes developed for this program should have V_T values greater than 70%. They also must not significantly color the transmitted light; the color rendering index R_a according to ISO standard 9050 should be 0.90 or larger.[56] ARPA-E is not setting a specific value for the reflectivity of the glazings, although lower reflectivity products may be more acceptable in the marketplace.

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[54] "Why not more complaints on haze with low-e windows?", Green Building Advisor website (posted October 24, 2013).

[55] "Appearance of installed Pilkington Energy Advantage™ Low-E Glass", Pilkington bulletin ATS 137-3 (July 13, 2005).

[56] "ISO Standard 9050:2003 Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors", International Standards Organization (2003). The standard uses a standard "D65" light source, and characterizes the light transmitted through the window with regard to the light's ability to render different colors.

3. WEIGHT AND SIMPLICITY OF RETROFIT, LOW INSTALLED COST, AND SERVICE LIFETIME

ARPA-E's goal in this program is to develop technologies that can be used with existing window frames and sashes, and that will not add substantially to the weight of the pane. Assuming the thickness of the existing windowpane is 1/8 inch, the total thickness of the improved windowpane should be ¼ inch or less, which will be usable with many existing sashes. While ARPA-E is not setting a specific value for the weight of the technologies developed for SHIELD, note that windowpane weight is an issue for some buildings.[24]

ARPA-E has set maximum manufacturing costs at $5 and $10 per square foot for Category 1 and Category 2 technologies, respectively. This cost is to apply at a manufacturing scale of 1 million square feet per annum. Installation of a product to an existing windowpane is likely to add $5 per foot to the price. Installation that requires removal of an existing windowpane and replacement by a new pane is likely to add $15 per square foot to the installed price. These prices are similar to the range of prices for installed window films[29] and for replacement of broken single windowpanes, respectively. These price targets can be set in the context of savings on heating costs. ARPA-E estimates that improvement in a single-pane from U = 1.1 to 0.4 would have saved about $1.50/square foot over the 2014 heating season in Chicago, Illinois; savings will be less in warmer climates.

ARPA-E has set service lifetime targets of 10 and 20 years (median time to failure) for the Category 1 and Category 2 technologies, respectively. For comparison, warranty periods are typically 5 years for window films and 20 years for IGUs. Warranty periods are generally substantially shorter than the actual median service lifetimes.

4. SOUNDPROOFING AND OTHER SYNERGISTIC OPPORTUNITIES

ARPA-E encourages applicants to propose the measurement and development of additional properties beyond the program objectives described above. The objective is to significantly improve the performance and marketability of products based on these technologies. Soundproofing provides one illustration. The sound transmission class (STC) of a single windowpane (1/8 inch thick) is about 29 decibels (db). An IGU with two 1/8 inch panes has an STC of about 33 db.

An additional example of a synergistic improvement is blockage of ultraviolet light. This is a considered a desirable feature because ultraviolet light accelerates deterioration of room furnishings and contributes to health problems such as skin cancer and eye damage. Ultraviolet blockage is a feature of current window films.[57]

[57] Boye, C., Presser, F., and Schaeffer, T., "UV-blocking window films for use in museums – revisited", WAAC Newsletter Vol. 32, No. 1 (Western Association for Art Conservation, January 2010), pp. 13-18.

D. TECHNICAL CATEGORIES OF INTEREST

1. CATEGORY 1: APPLIED PRODUCTS

The first category of technologies is for adhesive products that can be applied to an existing windowpane. The thickness of the applied product should be less than 1/8 of an inch. Final tests should be conducted on a single-pane window unit to which the adhesive product has been applied. Applications should specify the size of the windowpane for their technology development.

2. CATEGORY 2: MANUFACTURED PANES

The second category is for manufactured windowpanes that can be installed in existing sashes to replace 1/8 inch thick panes. The windowpane should be less than ¼ inch. The pane should be similar or better in its resistance to breakage than a 1/8 inch pane made from soda lime glass. Final tests should be conducted on a single-pane window unit into which the test pane has been installed. Applications should specify the size of the windowpane for their technology development.

3. CATEGORY 3: INNOVATIVE PARTIAL SOLUTIONS

The third category is for development of components that are beyond the current state-of-the-art and that would enable technologies to substantially exceed the performance, cost, or lifetime metrics in Section I.E of the FOA. Of specific interest are advances in (i) highly transparent thermal barrier layers and (ii) low-emissivity layers. Applicants should describe how the component would be integrated into either a Category 1 or a Category 2 technology. This category is particularly appropriate for proof-of-concept awards (see Section II.A of the FOA).

E. TECHNICAL PERFORMANCE TARGETS

For both categories, the technology should be designed for consistency with current ASTM standards for abrasion resistance (ASTM D1044) and fire safety (ASTM D635 – test for flammability, ASTM E84 – test for surface burning, ASTM D1929 – test for ignition properties, and ASTM D2843 – test for smoke density).

CATEGORY 1: APPLIED PRODUCT TARGETS

Measurement conditions and procedures are summarized below.

ID	*Property*	*Metric*
1.1	winter *U*-factor (center-of-glass)	less than 0.50 BTU/sf/hr/°F
1.2	exterior temperature for interior condensation (center-of-glass)	less than -5 C

1.3	exterior temperature at which the interior pane surface has radiative temperature 11 C (center-of-glass)	less than 0 C
1.4	haze	less than 2%
1.5	visible transmittance	more than 70%, with a color rendering index $R_a > 0.9$.
1.6	estimated manufacturing cost	less than $5 per square foot
1.7	estimated median service lifetime	more than 10 years

CATEGORY 2: MANUFACTURED PANE TARGETS

ID	*Property*	*Metric*
2.1	winter *U*-factor (center-of-glass)	less than 0.40 BTU/sf/hr/°F
2.2	exterior temperature for interior condensation (center-of-glass)	less than -10 C
2.3	exterior temperature at which the interior pane surface has radiative temperature 11 C (center-of-glass)	less than -5 C
2.4	haze	less than 1%
2.5	visible transmittance	more than 80%, with a color rendering index $R_a > 0.9$.
2.6	estimated manufacturing cost	less than $10 per square foot
2.7	estimated median service lifetime	more than 20 years

EXPLANATION OF METRICS:

SHIELD awardees will be required to demonstrate achievement of the technical metrics listed above through measurements following these guidelines.

Winter *U*-factor: Measurements of the center-of-glass *U*-factor should be consistent with NFRC document 100-2014 "Procedure for Determining Fenestration Product U-factors". NFRC defers to ASTM standard C1363 for insulation measurement procedures, but specifies its own environmental conditions for windspeed (5.5 m/s), interior temperature (21 C), and exterior temperature (-18 C).

Haze and Visible Transmittance: Measurements should be consistent with the procedures of ASTM D 1003.

Condensation temperature: Measurements of the actual temperature at the center-of-glass are acceptable instead of direct condensation measurements. This procedure assumes that condensation will occur when this temperature falls below the dewpoint in the room. For a room at 21 C and 30% relative humidity, the dewpoint is 3 C.

Radiative temperature: An infrared thermometer calibrated for a surface emissivity of 1.0 can be used to measure the radiative temperature. The measurement should be done at the center-of-glass of the window.

Estimated manufacturing cost and product lifetime: Applicants should provide assessments of manufactured cost and product lifetime to assure that large deviations from the project metrics are unlikely. Awardees will conduct technoeconomic analyses as part of their projects; the indicated manufacturing costs should be achieved for a factory producing 1 million square feet of product annually. Awardees will propose and execute accelerated lifetime measurements as part of their projects.

II. AWARD INFORMATION

A. AWARD OVERVIEW

ARPA-E expects to make approximately $20 million available for new awards under this FOA, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 12 to 15 awards under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

Individual awards may vary between $250,000 and $10 million.

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects the start date for funding agreements to be August 2016, or as negotiated.

ARPA-E encourages applications stemming from ideas that still require proof-of-concept R&D efforts as well as those for which some proof-of-concept demonstration already exists.

Applications requiring proof-of-concept R&D can propose a project with the goal of delivering on the program metric at the conclusion of the project period. These applications should contain an appropriate cost and project duration plan that is described in sufficient technical detail to allow reviewers to meaningfully evaluate the proposed project. If awarded, such projects should expect a rigorous go/no-go milestone early in the project associated with the proof-of-concept demonstration. Alternatively, applications requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, the Applicants are required to provide a convincing vision how these partial solutions can enable the realization of the program metrics with further development.

Applicants proposing projects for which some initial proof-of-concept demonstration already exists should submit concrete data that supports the probability of success of the proposed project.

ARPA-E will provide support at the highest funding level only for applications with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

ARPA-E will accept only new applications under this FOA. Applicants may not seek renewal or supplementation of their existing awards through this FOA.

ARPA-E plans to fully fund your negotiated budget at the time of award.

B. ARPA-E FUNDING AGREEMENTS

Through Cooperative Agreements, Technology Investment Agreements, and similar agreements, ARPA-E provides financial and other support to projects that have the potential to realize ARPA-E's statutory mission. ARPA-E does not use such agreements to acquire property or services for the direct benefit or use of the U.S. Government.

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[58] Accordingly, ARPA-E has substantial involvement in the direction of every project, as described in Section II.C below.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[59]

Cooperative Agreements involve the provision of financial or other support to accomplish a public purpose of support or stimulation authorized by Federal statute. Under Cooperative Agreements, the Government and Prime Recipients share responsibility for the direction of projects.

ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement, which is available at http://arpa-e.energy.gov/arpa-e-site-page/award-guidance.

2. FUNDING AGREEMENTS WITH FFRDCS, GOGOS, AND FEDERAL INSTRUMENTALITIES[60]

Any Federally Funded Research and Development Centers (FFRDC) involved as a member of a Project Team must complete the "FFRDC Authorization" and "Field Work Proposal" section of

[58] U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).
[59] The Prime Recipient is the signatory to the funding agreement with ARPA-E.
[60] DOE/NNSA GOGOs are not eligible to apply for funding, as described in Section III.A of the FOA.

the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

When a FFRDC is the *lead organization* for a Project Team, ARPA-E executes a funding agreement directly with the FFRDC and a single, separate Cooperative Agreement with the rest of the Project Team. Notwithstanding the use of multiple agreements, the FFRDC is the lead organization for the entire project, including all work performed by the FFRDC and the rest of the Project Team.

When a FFRDC or non-DOE/NNSA GOGO is a *member* of a Project Team, ARPA-E executes a funding agreement directly with the FFRDC or non-DOE/NNSA GOGO and a single, separate Cooperative Agreement with the rest of the Project Team. Notwithstanding the use of multiple agreements, the Prime Recipient under the Cooperative Agreement is the lead organization for the entire project, including all work performed by the FFRDC and the rest of the Project Team.

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs, and Federal instrumentalities (e.g., Tennessee Valley Authority) generally take the form of Interagency Agreements. Any funding agreement with a FFRDC or non-DOE/NNSA GOGO will have similar terms and conditions as ARPA-E's Model Cooperative Agreement (http://arpa-e.energy.gov/arpa-e-site-page/award-guidance).

Non-DOE GOGOs and Federal agencies may be proposed as supporting project team members on an applicant's project.

3. TECHNOLOGY INVESTMENT AGREEMENTS

ARPA-E may use its "other transactions" authority under the America COMPETES Reauthorization Act of 2010 or DOE's "other transactions" authority under the Energy Policy Act of 2005 to enter into Technology Investment Agreements (TIAs) with Prime Recipients. ARPA-E may negotiate a TIA when it determines that the use of a standard cooperative agreement, grant, or contract is not feasible or appropriate for a project.

A TIA is more flexible than a traditional financial assistance agreement. In using a TIA, ARPA-E may modify standard Government terms and conditions. See 10 C.F.R. § 603.105 for a description of a TIA.

In general, TIAs require a cost share of 50%. See Section III.B.2 of the FOA.

C. STATEMENT OF SUBSTANTIAL INVOLVEMENT

ARPA-E is substantially involved in the direction of projects from inception to completion. For the purposes of an ARPA-E project, substantial involvement means:

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.

- ARPA-E may intervene at any time in the conduct or performance of work under an award.

- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.

- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award.

- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

III. ELIGIBILITY INFORMATION

A. ELIGIBLE APPLICANTS

1. INDIVIDUALS

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[61] as the lead for a Project Team,[62] or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. DOMESTIC ENTITIES

For-profit entities, educational institutions, and nonprofits[63] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

FFRDCs are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team, but not as a Standalone Applicant.

DOE/NNSA GOGOs are not eligible to apply for funding.

Non-DOE/NNSA GOGOs are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

State, local, and tribal government entities are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

Federal agencies and instrumentalities (other than DOE) are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

3. FOREIGN ENTITIES

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team. All

[61] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[62] The term "Project Team" is used to mean any entity with multiple players working collaboratively and could encompass anything from an existing organization to an ad hoc teaming arrangement. A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.
[63] Nonprofit organizations described in section 501(c)(4) of the Internal Revenue Code of 1986 that engaged in lobbying activities after December 31, 1995 are not eligible to apply for funding as a Prime Recipient or Subrecipient.

work by foreign entities must be performed by subsidiaries or affiliates incorporated in the United States (including U.S. territories). The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application. Please refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. CONSORTIUM ENTITIES

Consortia, which may include domestic and foreign entities, must designate one member of the consortium as the consortium representative to the Project Team. The consortium representative must be incorporated in the United States. The eligibility of the consortium will be determined by reference to the eligibility of the consortium representative under Section III.A of the FOA. Each consortium must have an internal governance structure and a written set of internal rules. Upon request, the consortium entity must provide a written description of its internal governance structure and its internal rules to the Contracting Officer (ARPA-E-CO@hq.doe.gov).

Unincorporated consortia must provide the Contracting Officer with a collaboration agreement, commonly referred to as the articles of collaboration, which sets out the rights and responsibilities of each consortium member. This agreement binds the individual consortium members together and should discuss, among other things, the consortium's:

- Management structure;
- Method of making payments to consortium members;
- Means of ensuring and overseeing members' efforts on the project;
- Provisions for members' cost sharing contributions; and
- Provisions for ownership and rights in intellectual property developed previously or under the agreement.

B. COST SHARING[64]

Applicants are bound by the cost share proposed in their Full Applications.

[64] Please refer to Section VI.B.3-4 of the FOA for guidance on cost share payments and reporting.

1. BASE COST SHARE REQUIREMENT

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.B.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime Recipient must provide at least 20% of the Total Project Cost[65] as cost share, except as provided in Sections III.B.2 or III.B.3 below.[66]

2. INCREASED COST SHARE REQUIREMENT

Large businesses are strongly encouraged to provide more than 20% of the Total Project Cost as cost share. ARPA-E may consider the amount of cost share proposed when selecting applications for award negotiations (see Section V.B.1 of the FOA).

Under a Technology Investment Agreement, the Prime Recipient must provide at least 50% of the Total Project Cost as cost share. ARPA-E may reduce this minimum cost share requirement, as appropriate.

3. REDUCED COST SHARE REQUIREMENT

ARPA-E has reduced the minimum cost share requirement for the following types of projects:

- A domestic educational institution or domestic nonprofit applying as a Standalone Applicant is required to provide at least 5% of the Total Project Cost as cost share.

- Small businesses – or consortia of small businesses - will provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[67] If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the costs incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80%, but less than 100%, of the total work under the funding agreement (as measured by the Total Project Cost) the Project Team are

[65] The Total Project Cost is the sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs and FFRDCs.
[66] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988.
[67] Small businesses are generally defined as domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards). Applicants that are small businesses will be required to certify in the Business Assurances & Disclosures Form that their organization meets the SBA's definition of a small business under at least one NAICS code.

entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.[68]

- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs are required to provide at least 5% of the Total Project Cost as cost share.

- Project Teams where domestic educational institutions, domestic nonprofits, small businesses, and/or FFRDCs perform greater than or equal to 80%, of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.

- Projects that do not meet any of the above criteria are subject to the minimum cost share requirements described in Sections III.B.1 and III.B.2 of the FOA.

4. LEGAL RESPONSIBILITY

Although the cost share requirement applies to the Project Team as a whole, the funding agreement makes the Prime Recipient legally responsible for paying the entire cost share. The Prime Recipient's cost share obligation is expressed in the funding agreement as a static amount in U.S. dollars (cost share amount) and as a percentage of the Total Project Cost (cost share percentage). If the funding agreement is terminated prior to the end of the project period, the Prime Recipient is required to contribute at least the cost share percentage of total expenditures incurred through the date of termination.

The Prime Recipient is solely responsible for managing cost share contributions by the Project Team and enforcing cost share obligations assumed by Project Team members in subawards or related agreements.

5. COST SHARE ALLOCATION

Each Project Team is free to determine how much each Project Team member will contribute towards the cost share requirement. The amount contributed by individual Project Team members may vary, as long as the cost share requirement for the project as a whole is met.

[68] See the information provided in previous footnote.

6. COST SHARE TYPES AND ALLOWABILITY

Every cost share contribution must be allowable under the applicable Federal cost principles, as described in Section IV.G.1 of the FOA.

Project Teams may provide cost share in the form of cash or in-kind contributions. Cash contributions may be provided by the Prime Recipient or Subrecipients. Allowable in-kind contributions include but are not limited to personnel costs, indirect costs, facilities and administrative costs, rental value of buildings or equipment, and the value of a service, other resource, or third party in-kind contribution. Project Teams may use funding or property received from state or local governments to meet the cost share requirement, so long as the funding or property was not provided to the state or local government by the Federal Government.

The Prime Recipient may not use the following sources to meet its cost share obligations:

- Revenues or royalties from the prospective operation of an activity beyond the project period;
- Proceeds from the prospective sale of an asset of an activity;
- Federal funding or property (e.g., Federal grants, equipment owned by the Federal Government); or
- Expenditures that were reimbursed under a separate Federal program.

In addition, Project Teams may not use independent research and development (IR&D) funds[69] to meet their cost share obligations under cooperative agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under Technology investment Agreements.

Project Teams may not use the same cash or in-kind contributions to meet cost share requirements for more than one project or program.

Cost share contributions must be specified in the project budget, verifiable from the Prime Recipient's records, and necessary and reasonable for proper and efficient accomplishment of the project. Every cost share contribution must be reviewed and approved in advance by the Contracting Officer and incorporated into the project budget before the expenditures are incurred.

[69] As defined in Federal Acquisition Regulation Subsection 31.205-18.

Applicants may wish to refer to 2 C.F.R. Parts 200 and 910, and 10 C.F.R Part 603 for additional guidance on cost sharing, specifically 2 C.F.R. §§ 200.306 and 910.130, and 10 C.F.R. §§ 603.525-555.

7. COST SHARE CONTRIBUTIONS BY FFRDCS AND GOGOS

Because FFRDCs and GOGOs are funded by the Federal Government, costs incurred by FFRDCs and GOGOs generally may not be used to meet the cost share requirement. FFRDCs may contribute cost share only if the contributions are paid directly from the contractor's Management Fee or a non-Federal source.

Because GOGOs/Federal Agencies are funded by the Federal Government, GOGOs/Federal Agencies may not provide cost share for the proposed project. However, the GOGO/Agency costs would be included in Total Project Costs for purposes of calculating the cost-sharing requirements of the applicant.

8. COST SHARE VERIFICATION

Upon selection for award negotiations, Applicants are required to provide information and documentation regarding their cost share contributions. Please refer to Section VI.B.3 of the FOA for guidance on the requisite cost share information and documentation.

C. OTHER

1. COMPLIANT CRITERIA

Concept Papers are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Concept Paper complies with the content and form requirements in Section IV.C of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

ARPA-E will not review or consider noncompliant Concept Papers, including Concept Papers submitted through other means, Concept Papers submitted after the applicable deadline, and incomplete Concept Papers. A Concept Paper is incomplete if it does not include required information. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Full Applications are deemed compliant if:

- The Applicant submitted a compliant and responsive Concept Paper;
- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Full Application complies with the content and form requirements in Section IV.D of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

ARPA-E will not review or consider noncompliant Full Applications, including Full Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Replies to Reviewer Comments are deemed compliant if:

- The Applicant successfully uploaded all required documents to ARPA-E eXCHANGE by the deadline stated in the FOA.

ARPA-E will not review or consider noncompliant Replies to Reviewer Comments, including Replies submitted through other means and Replies submitted after the applicable deadline. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information due to server/connection congestion. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be noncompliant.

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Concept Papers and Full Applications. The following types of submissions will be deemed nonresponsive and will not be reviewed or considered (referred to herein as "Applications Specifically Not of Interest"):

- Applications that fall outside the technical parameters specified in Section I.E of the FOA
- Applications that have been submitted in response to other currently issued ARPA-E FOAs.
- Applications that are not scientifically distinct from applications submitted in response to other currently issued ARPA-E FOAs.

- Applications for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Applications for large-scale demonstration projects of existing technologies.
- Applications for proposed technologies that represent incremental improvements to existing technologies.
- Applications for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Applications for proposed technologies that are not transformational, as described in Section I.A of the FOA and as illustrated in Figure 1 in Section I.A of the FOA.
- Applications for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Applications that are not scientifically distinct from existing funded activities supported elsewhere, including within the Department of Energy.
- Applications that describe a technology but do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.

3. LIMITATION ON NUMBER OF APPLICATIONS

ARPA-E is not limiting the number of applications that may be submitted by Applicants. Applicants may submit more than one application to this FOA, provided that each application is scientifically distinct.

Small businesses that qualify as "Small Business Concerns" are strongly encouraged to apply under ARPA-E FOA DE-FOA-0001429 (SBIR/STTR), Single-Pane Highly Insulating Efficient Lucid Designs (SHIELD). To determine eligibility as a "Small Business Concern" under DE-FOA-0001429, please review the eligibility requirements in Sections III.A-III.D of DE-FOA-0001429 (SBIR/STTR), available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov).

Small businesses that qualify as a "Small Business Concern" may apply to only one of the SHIELD FOAs.

ARPA-E is not limiting the number of applications that may be submitted by Applicants. Applicants may submit more than one application to this FOA, provided that each application is scientifically distinct.

IV. APPLICATION AND SUBMISSION INFORMATION

A. APPLICATION PROCESS OVERVIEW

1. REGISTRATION IN ARPA-E eXCHANGE

The first step in applying to this FOA is registration in ARPA-E eXCHANGE, ARPA-E's online application portal. For detailed guidance on using ARPA-E eXCHANGE, please refer to Section IV.H.1 of the FOA and the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

2. CONCEPT PAPERS

Applicants must submit a Concept Paper by the deadline stated in the FOA. Section IV.C of the FOA provides instructions on submitting a Concept Paper.

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria in Section V.A.1 of the FOA.

ARPA-E will encourage a subset of Applicants to submit Full Applications. Other Applicants will be discouraged from submitting a Full Application in order to save them the time and expense of preparing an application that is unlikely to be selected for award negotiations. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

3. FULL APPLICATIONS

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 30 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.C of the FOA. ARPA-E reviews only compliant and responsive Full Applications.

4. REPLY TO REVIEWER COMMENTS

Once ARPA-E has completed its review of Full Applications, reviewer comments on compliant and responsive Full Applications are made available to Applicants via ARPA-E eXCHANGE. Applicants may submit an optional Reply to Reviewer Comments, which must be submitted by the deadline stated in the FOA. Section IV.E of the FOA provides instructions on submitting a Reply to Reviewer Comments.

ARPA-E performs a preliminary review of Replies to determine whether they are compliant, as described in Section III.C.1 of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

5. PRE-SELECTION CLARIFICATIONS AND "DOWN-SELECT" PROCESS

Once ARPA-E completes its review of Full Applications and Replies to Reviewer Comments, it may, at the Contracting Officer's discretion, conduct a pre-selection clarification process and/or perform a "down-select" of Full Applications. Through the pre-selection clarification process or down-select process, ARPA-E may obtain additional information from select Applicants through pre-selection meetings, webinars, videoconferences, conference calls, written correspondence, or site visits that can be used to make a final selection determination. ARPA-E will not reimburse Applicants for travel and other expenses relating to pre-selection meetings and site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for funding and make awards without pre-selection meetings and site visits. Participation in a pre-selection meeting or site visit with ARPA-E does not signify that Applicants have been selected for award negotiations.

6. SELECTION FOR AWARD NEGOTIATIONS

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA. The Selection Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

Applicants are promptly notified of ARPA-E's selection determination. ARPA-E may stagger its selection determinations. As a result, some Applicants may receive their notification letter in advance of other Applicants. Please refer to Section VI.A of the FOA for guidance on award notifications.

7. MANDATORY WEBINAR

All selected Applicants, including the Principal Investigator and the financial manager for the project, are required to participate in a webinar that is held within approximately one week of the selection notification. During the webinar, ARPA-E officials present important information on the award negotiation process, including deadlines for the completion of certain actions.

B. APPLICATION FORMS

Required forms for Full Applications are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov), including the SF-424, Budget Justification Workbook/SF-424A, and Business Assurances & Disclosures Form. A sample response to the Business Assurances & Disclosures Form and a sample Summary Slide are also available on ARPA-E eXCHANGE. Applicants may use the templates available on ARPA-E eXCHANGE, including the template for the Concept Paper, the template for the Technical Volume of the Full Application, the template for the Summary Slide, the template for the Summary for Public Release, and the template for the Reply to Reviewer Comments.

C. CONTENT AND FORM OF CONCEPT PAPERS

The Concept Paper is mandatory (i.e. in order to submit a Full Application, a compliant and responsive Concept Paper must have been submitted) and must conform to the following formatting requirements:

- The Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables.
- The Concept Paper must be submitted in Adobe PDF format.
- The Concept Paper must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.

- The first paragraph must include the Lead Organization's Name and Location, Principal Investigator's Name, Technical Category, Proposed Funding Requested (Federal and Cost Share), and Project Duration.

ARPA-E will not review or consider noncompliant and/or nonresponsive Concept Papers (see Section III.C of the FOA).

Each Concept Paper should be limited to a single concept or technology. Unrelated concepts and technologies should not be consolidated into a single Concept Paper.

A fillable Concept Paper template is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

Concept Papers must conform to the content requirements described below. If Applicants exceed the maximum page length indicated above, ARPA-E will review only the authorized number of pages and disregard any additional pages:

1. CONCEPT PAPER

a. CONCEPT SUMMARY

- Describe the proposed concept with minimal jargon, and explain how it addresses the Program Objectives of the FOA.

b. INNOVATION AND IMPACT

- Clearly identify the problem to be solved with the proposed technology concept.
- Describe how the proposed effort represents an innovative and potentially transformational solution to the technical challenges posed by the FOA.
- Explain the concept's potential to be disruptive compared to existing or emerging technologies.
- To the extent possible, provide quantitative metrics in a table that compares the proposed technology concept to current and emerging technologies and to the technical performance targets in Section I.E of the FOA for the appropriate Technology Category in Section I.D of the FOA.

c. PROPOSED WORK

- Describe the final deliverable(s) for the project and the overall technical approach used to achieve project objectives.

- Discuss alternative approaches considered, if any, and why the proposed approach is most appropriate for the project objectives.

- Describe the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach. Provide specific examples of supporting data and/or appropriate citations to the scientific and technical literature.

- Describe why the proposed effort is a significant technical challenge and the key technical risks to the project. Does the approach require one or more entirely new technical developments to succeed? How will technical risk be mitigated?

- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.

- Estimated federal funds requested; total project cost including cost sharing.

d. TEAM ORGANIZATION AND CAPABILITIES

- Indicate the roles and responsibilities of the organizations and key personnel that comprise the Project Team.

- Provide the name, position, and institution of each key team member and describe in 1-2 sentences the skills and experience that he/she brings to the team.

- Identify key capabilities provided by the organizations comprising the Project Team and how those key capabilities will be used in the proposed effort.

- Identify (if applicable) previous collaborative efforts among team members relevant to the proposed effort.

D. CONTENT AND FORM OF FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

E. CONTENT AND FORM OF REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

F. INTERGOVERNMENTAL REVIEW

This program is not subject to Executive Order 12372 (Intergovernmental Review of Federal Programs).

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

H. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

To apply to this FOA, Applicants must register with ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). Concept Papers, Full Applications, and Replies to Reviewer Comments must be submitted through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx). ARPA-E will not review or consider applications submitted through other means (e.g., fax, hand delivery, email, postal mail). For detailed guidance on using ARPA-E eXCHANGE, please refer to the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

Upon creating an application submission in ARPA-E eXCHANGE, Applicants will be assigned a Control Number. If the Applicant creates more than one application submission, a different Control Number will be assigned for each application.

Once logged in to ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx), Applicants may access their submissions by clicking the "My Submissions" link in the navigation on the left side of the page. Every application that the Applicant has submitted to ARPA-E and the corresponding Control Number is displayed on that page. If the Applicant submits more than one application to a particular FOA, a different Control Number is shown for each application.

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Concept Paper, or Full Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

Applicants should not wait until the last minute to begin the submission process. During the final hours before the submission deadline, Applicants may experience server/connection congestion that prevents them from completing the necessary steps in ARPA-E eXCHANGE to submit their applications. **ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.**

ARPA-E will not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications will be deemed noncompliant (see Section III.C.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

- Failing to comply with the form and content requirements in Section IV of the FOA;
- Failing to enter required information in ARPA-E eXCHANGE;
- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

ARPA-E urges Applicants to carefully review their applications and to allow sufficient time for the submission of required information and documents.

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

ARPA-E performs a preliminary review of Concept Papers and Full Applications to determine whether they are compliant and responsive (see Section III.C of the FOA). ARPA-E also performs a preliminary review of Replies to Reviewer Comments to determine whether they are compliant.

ARPA-E considers a mix of quantitative and qualitative criteria in determining whether to encourage the submission of a Full Application and whether to select a Full Application for award negotiations.

1. CRITERIA FOR CONCEPT PAPERS

(1) *Impact of the Proposed Technology Relative to FOA Targets* (50%) - This criterion involves consideration of the following factors:

- The extent to which the proposed quantitative material and/or technology metrics demonstrate the potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;

- The extent to which the proposed concept is innovative and will achieve the technical performance targets defined in Section I.E of the FOA for the appropriate technology Category in Section I.D of the FOA; and

- The extent to which the Applicant demonstrates awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

(2) *Overall Scientific and Technical Merit* (50%) - This criterion involves consideration of the following factors:

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;

- The extent to which the Applicant proposes a sound technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;

- The extent to which project outcomes and final deliverables are clearly defined;

- The extent to which the Applicant identifies techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and

- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

Submissions will not be evaluated against each other since they are not submitted in accordance with a common work statement. The above criteria will be weighted as follows:

Impact of the Proposed Technology Relative to FOA Targets	50%
Overall Scientific and Technical Merit	50%

2. CRITERIA FOR FULL APPLICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

3. CRITERIA FOR REPLIES TO REVIEWER COMMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

B. REVIEW AND SELECTION PROCESS

1. PROGRAM POLICY FACTORS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

2. ARPA-E REVIEWERS

By submitting an application to ARPA-E, Applicants consent to ARPA-E's use of Federal employees, contractors, and experts from educational institutions, nonprofits, industry, and governmental and intergovernmental entities as reviewers. ARPA-E selects reviewers based on their knowledge and understanding of the relevant field and application, their experience and skills, and their ability to provide constructive feedback on applications.

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments. In addition, ARPA-E trains its reviewers in proper evaluation techniques and procedures.

Applicants are not permitted to nominate reviewers for their applications. Applicants may contact the Contracting Officer by email (ARPA-E-CO@hq.doe.gov) if they have knowledge of a potential conflict of interest or a reasonable belief that a potential conflict exists.

3. ARPA-E SUPPORT CONTRACTOR

ARPA-E utilizes contractors to assist with the evaluation of applications and project management. To avoid actual and apparent conflicts of interest, ARPA-E prohibits its support contractors from submitting or participating in the preparation of applications to ARPA-E.

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. ANTICIPATED ANNOUNCEMENT AND AWARD DATES

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

VI. AWARD ADMINISTRATION INFORMATION

A. AWARD NOTICES

1. REJECTED SUBMISSIONS

Noncompliant and nonresponsive Concept Papers and Full Applications are rejected by the Contracting Officer and are not reviewed or considered. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Concept Paper or Full Application was rejected.

2. CONCEPT PAPER NOTIFICATIONS

ARPA-E promptly notifies Applicants of its determination to encourage or discourage the submission of a Full Application. ARPA-E sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. ARPA-E provides feedback in the notification letter in order to guide further development of the proposed technology.

Applicants may submit a Full Application even if they receive a notification discouraging them from doing so. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. The purpose of the Concept Paper phase is to save Applicants the considerable time and expense of preparing a Full Application that is unlikely to be selected for award negotiations.

A notification letter encouraging the submission of a Full Application does not authorize the Applicant to commence performance of the project. Please refer to Section IV.G.2 of the FOA for guidance on pre-award costs.

3. FULL APPLICATION NOTIFICATIONS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

B. ADMINISTRATIVE AND NATIONAL POLICY REQUIREMENTS

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

C. REPORTING

[TO BE INSERTED BY FOA MODIFICATION IN JANUARY 2016]

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

Upon the issuance of a FOA, only the Contracting Officer may communicate with Applicants. ARPA-E personnel and our support contractors are prohibited from communicating (in writing or otherwise) with Applicants regarding the FOA. This "quiet period" remains in effect until ARPA-E's public announcement of its project selections.

During the "quiet period," Applicants are required to submit all questions regarding this FOA to ARPA-E-CO@hq.doe.gov. Questions and Answers (Q&As) about ARPA-E and the FOA are available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, please send an email with the FOA name and number in the subject line to ARPA-E-CO@hq.doe.gov. Due to the volume of questions received, ARPA-E will only answer pertinent questions that have not yet been answered and posted at the above link.

- ARPA-E will post responses on a weekly basis to any questions that are received. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- ARPA-E will cease to accept questions approximately 5 business days in advance of each submission deadline. Responses to questions received before the cutoff will be posted approximately one business day in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.

- Responses are posted to "Questions and Answers" on ARPA-E's website (http://arpa-e.energy.gov/faq).

Applicants may submit questions regarding ARPA-E eXCHANGE, ARPA-E's online application portal, to ExchangeHelp@hq.doe.gov. ARPA-E will promptly respond to emails that raise legitimate, technical issues with ARPA-E eXCHANGE. ARPA-E will refer any questions regarding the FOA to ARPA-E-CO@hq.doe.gov.

ARPA-E will not accept or respond to communications received by other means (e.g., fax, telephone, mail, hand delivery). Emails sent to other email addresses will be disregarded.

During the "quiet period," only the Contracting Officer may authorize communications between ARPA-E personnel and Applicants. The Contracting Officer may communicate with Applicants

as necessary and appropriate. As described in Section IV.A of the FOA, the Contracting Officer may arrange pre-selection meetings and/or site visits during the "quiet period."

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings. ARPA-E provides Applicants with a notification encouraging or discouraging the submission of a Full Application based on ARPA-E's assessment of the Concept Paper. In addition, ARPA-E provides Applicants with reviewer comments on Full Applications before the submission deadline for Replies to Reviewer Comments.

VIII. OTHER INFORMATION

A. FOAS AND FOA MODIFICATIONS

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA are also posted to these websites. You can receive an e-mail when a modification is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

B. OBLIGATION OF PUBLIC FUNDS

The Contracting Officer is the only individual who can make awards on behalf of ARPA-E or obligate ARPA-E to the expenditure of public funds. A commitment or obligation by any individual other than the Contracting Officer, either explicit or implied, is invalid.

ARPA-E awards may not be transferred, assigned, or assumed without the prior written consent of a Contracting Officer.

C. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

Applicants are required to make a full and complete disclosure of the information requested in the Business Assurances & Disclosures Form. Disclosure of the requested information is mandatory. Any failure to make a full and complete disclosure of the requested information may result in:

- The rejection of a Concept Paper, Full Application, and/or Reply to Reviewer Comments;
- The termination of award negotiations;

- The modification, suspension, and/or termination of a funding agreement;

- The initiation of debarment proceedings, debarment, and/or a declaration of ineligibility for receipt of Federal contracts, subcontracts, and financial assistance and benefits; and

- Civil and/or criminal penalties.

D. RETENTION OF SUBMISSIONS

ARPA-E expects to retain copies of all Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions. No submissions will be returned. By applying to ARPA-E for funding, Applicants consent to ARPA-E's retention of their submissions.

E. MARKING OF CONFIDENTIAL INFORMATION

ARPA-E will use data and other information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments strictly for evaluation purposes.

Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions containing confidential, proprietary, or privileged information must be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

The cover sheet of the Concept Paper, Full Application, Reply to Reviewer Comments, or other submission must be marked as follows and identify the specific pages containing confidential, proprietary, or privileged information:

> Notice of Restriction on Disclosure and Use of Data:
>
> Pages [___] of this document may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

The header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure." In addition, every line and paragraph containing

proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

F. TITLE TO SUBJECT INVENTIONS

Ownership of subject inventions is governed pursuant to the authorities listed below. Typically, either by operation of law or under the authority of a patent waiver, Prime Recipients and Subrecipients may elect to retain title to their subject inventions under ARPA-E funding agreements.

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions. If they elect to retain title, they must file a patent application in a timely fashion.

- All other parties: The Federal Non-Nuclear Energy Research and Development Act of 1974, 42. U.S.C. 5908, provides that the Government obtains title to new inventions unless a waiver is granted (*see below)*.

- Class Waiver: Under 42 U.S.C. § 5908, title to subject inventions vests in the U.S. Government and large businesses and foreign entities do not have the automatic right to elect to retain title to subject inventions. However, ARPA-E typically issues "class patent waivers" under which large businesses and foreign entities that meet certain stated requirements, such as cost sharing of at least 20% may elect to retain title to their subject inventions. If a large business or foreign entity elects to retain title to its subject invention, it must file a patent application in a timely fashion. If the class waiver does not apply, a party may request a waiver in accordance with 10 C.F.R. §784.

G. GOVERNMENT RIGHTS IN SUBJECT INVENTIONS

Where Prime Recipients and Subrecipients retain title to subject inventions, the U.S. Government retains certain rights.

1. GOVERNMENT USE LICENSE

The U.S. Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world. This license extends to contractors doing work on behalf of the Government.

2. MARCH-IN RIGHTS

The U.S. Government retains march-in rights with respect to all subject inventions. Through "march-in rights," the Government may require a Prime Recipient or Subrecipient who has elected to retain title to a subject invention (or their assignees or exclusive licensees), to grant a license for use of the invention. In addition, the Government may grant licenses for use of the subject invention when Prime Recipients, Subrecipients, or their assignees and exclusive licensees refuse to do so.

The U.S. Government may exercise its march-in rights if it determines that such action is necessary under any of the four following conditions:

- The owner or licensee has not taken or is not expected to take effective steps to achieve practical application of the invention within a reasonable time;
- The owner or licensee has not taken action to alleviate health or safety needs in a reasonably satisfactory manner;
- The owner has not met public use requirements specified by Federal statutes in a reasonably satisfactory manner; or
- The U.S. Manufacturing requirement has not been met.

3. U.S. MANUFACTURING REQUIREMENT

ARPA-E requires that awards address whether products embodying or produced through the use of subject inventions (i.e., inventions conceived or first actually reduced to practice under ARPA-E funding agreements) are to be substantially manufactured in the United States by Project Teams and their licensees. The requirement varies depending upon whether an awardee is a small business, University or other type of awardee. The Applicant may request a modification or waiver of the U.S. Manufacturing Requirement.

H. RIGHTS IN TECHNICAL DATA

Data rights differ based on whether data is first produced under an award or instead was developed at private expense outside the award.

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.

- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to five years in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

I. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

Applicants may not include any Protected Personally Identifiable Information (Protected PII) in their submissions to ARPA-E. Protected PII is defined as data that, if compromised, could cause harm to an individual such as identity theft. Listed below are examples of Protected PII that Applicants must not include in their submissions.

- Social Security Numbers in any form;
- Place of Birth associated with an individual;
- Date of Birth associated with an individual;
- Mother's maiden name associated with an individual;
- Biometric record associated with an individual;
- Fingerprint;
- Iris scan;
- DNA;
- Medical history information associated with an individual;
- Medical conditions, including history of disease;
- Metric information, e.g. weight, height, blood pressure;
- Criminal history associated with an individual;
- Ratings;
- Disciplinary actions;
- Performance elements and standards (or work expectations) are PII when they are so intertwined with performance appraisals that their disclosure would reveal an individual's performance appraisal;
- Financial information associated with an individual;
- Credit card numbers;
- Bank account numbers; and
- Security clearance history or related information (not including actual clearances held).

IX. GLOSSARY

Applicant: The entity that submits the application to ARPA-E. In the case of a Project Team, the Applicant is the lead organization listed on the application.

Application: The entire submission received by ARPA-E, including the Concept Paper, Full Application, and Reply to Reviewer Comments.

ARPA-E: is the Advanced Research Projects Agency – Energy, an agency within the U.S. Department of Energy.

Cost Sharing: is the portion of project costs from non-Federal sources that are borne by the Prime Recipient (or non-Federal third parties on behalf of the Prime Recipient), rather than by the Federal Government.

Deliverable: A deliverable is the quantifiable goods or services that will be provided upon the successful completion of a project task or sub-task.

DOE: U.S. Department of Energy.

DOE/NNSA: U.S. Department of Energy/National Nuclear Security Administration

FFRDCs: Federally Funded Research and Development Centers.

FOA: Funding Opportunity Announcement.

GOGOs: U.S. Government Owned, Government Operated laboratories.

Milestone: A milestone is the tangible, observable measurement that will be provided upon the successful completion of a project task or sub-task.

Prime Recipient: The signatory to the funding agreement with ARPA-E.

PI: Principal Investigator.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.

R&D: Research and development.

Standalone Applicant: An Applicant that applies for funding on its own, not as part of a Project Team.

Subject Invention: Any invention conceived or first actually reduced to practice under an ARPA-E funding agreement.

Task: A task is an operation or segment of the work plan that requires both effort and resources. Each task (or sub-task) is connected to the overall objective of the project, via the achievement of a milestone or a deliverable.

Total Project Cost: The sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs, FFRDCs, and GOCOs.

TT&O: Technology Transfer and Outreach. (See Section IV.G.8 of the FOA for more information).