Single-Pane Window Efficiency Workshop Breakout Session Summaries

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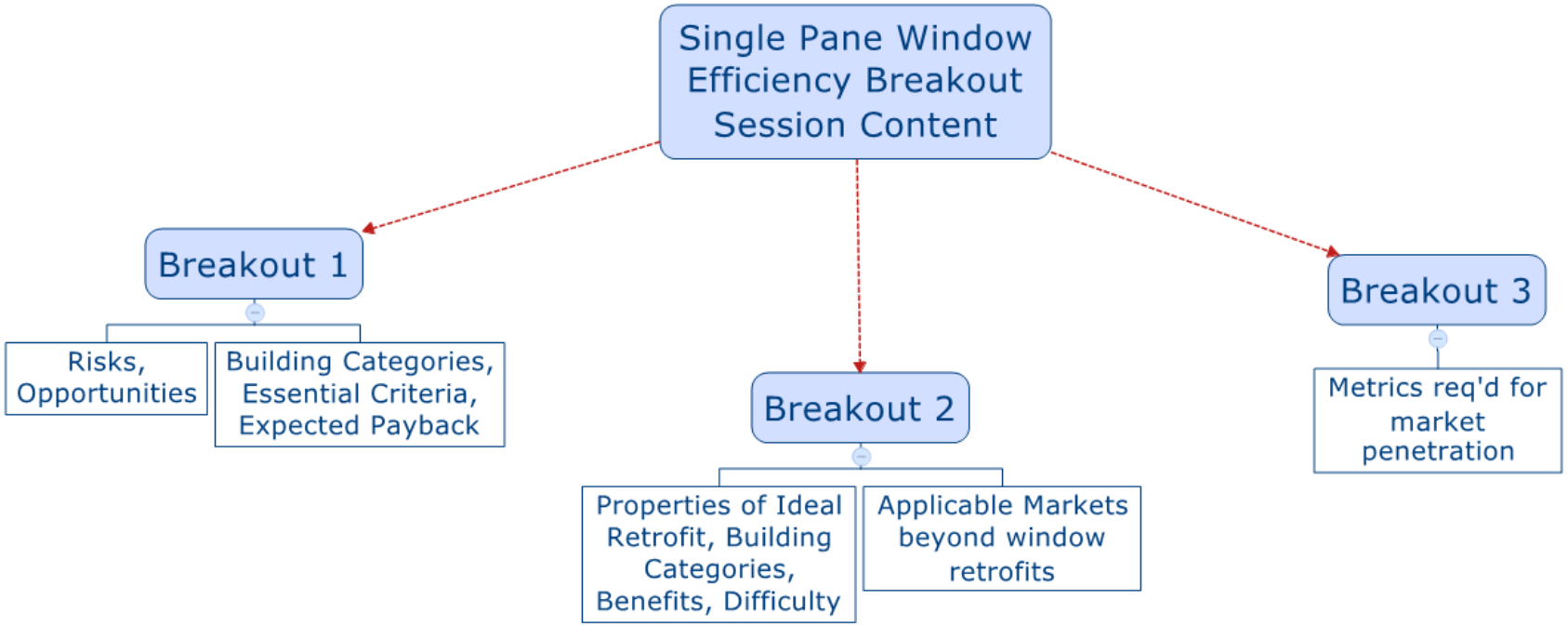
General structure of breakout sessions



Breakout 1, Team 1

- Task 1: What are risk factors and value-added for potential purchasers of single pane window retrofits?

Risks and Opportunities	
Inertia, disinterest	Drafts, infiltration
True cost of ownership	Condensation
No performance monitoring	UV- protection
Aesthetics	Energy cost
Security during the retrofit	Installation
Occupant comfort	Systems approach
Multi-functional	

Breakout 1, Team 1

- Task 2: Describe building categories, and the expected payback period for each.

Building category	Essential Criteria	Payback [yrs]
Historical		10
Specialty (e.g. hospital)	Indoor air quality, comfort	4-8
Office	Comfort	1-3
Single family	Comfort	5-7
Multi-family	Comfort	Varies
Government	Comfort, security, blast resistance	10
Commercial	Comfort	1.5
Storefront	Comfort, UV rejection, product view	1.5
Hotel	Don’t impact view, comfort	1.5
Restaurant	Don’t impact view, comfort	
Athletic (eg. Gym)	Safety, impact glazing, comfort	

Breakout 2, Team 1

- Task 1: What are the properties of your dream single-pane window retrofit? What building categories would it apply to?

Spray-on low-e coating	Easily configurable panel	Dynamic U-factor control
Insulating, air sealing, dynamic solar control, easy/inexpensive to install	Standoff films	Thermal energy storage
Glass and frame coating	Embedded energy harvesting	Cheap, but easily removed/re-applied
Useful coating with no other change in other properties	Energy harvesting in the frame	Retrofit window with virtual window
Functionality verification	Superhydrophobic/ superhydrophilic	Electrical energy storage
Long life (10-20 years)	Self-cleaning	Desiccation
Roll on or paintable	Active, dynamic solar control	Paintable, generates electricity
Optical switching	DIY	Scratch resistance
Vacuum glazing	Residential economizer (active ventilation)	Acoustic energy harvesting
Noise reduction	Blast resistance	

Breakout 2, Team 1

- Task 2: What markets – beyond window retrofits – could these technologies be applied to?

Appliances	Airplane coating (de-icing)	Eyewear – ski goggles, eyeglasses, sunglasses
Automotive/transportation	Wicking clothing	Roofing
Walls	Pipes	Solar panel coatings
Beverage bottles	Liquid nitrogen storage	Helmets – motorcycle, space, snowmobile
Supermarket display cases	Tents/sleeping bags	Cell phones

Breakout 2, Team 1

- Task 3: Brainstorming – discuss research concepts, building categories that they could be applied to, and rate the difficulty from 1 (trivial) to 5 (impossible)

Clear, organic PV spray on	Virtual window	High IR absorption for anti-condensation
Sprayable aerogels	Variable gap size	Defects that decrease thermal conduction
Small vacuums	Electrochromic/photochromic/thermochromic	Air curtain
Negative index materials	Doping semiconductors	Nanoscale thermal break
Mixed/multilayer coatings or panels	Solid-liquid gel phase change material	Baffle on the outside
Superhydrophilic coatings	Clear piezoelectrics	Polymer density changes (phase change)
Transparent desiccants (silica), incorporate exothermic	Transparent conduction oxides as heating elements	Screens that overlap in some way when the temperature changes
Vacuum panel	Doping (transition metal ions)	Self-assembling based on temperature (follows a leak)
Transparent foam	High IR absorption for anti-condensation	Physical cap for the frame
Cellulose-based nanoparticles	Defects that decrease thermal conduction	3D printed retrofits
Nanoparticle paint for frame	Aerogel frame	

Breakout 3, Team 1

- Task: For the previously identified building categories, what metrics would a technology need to achieve to penetrate this market?

Building category	Simple payback	Visible transmittance
Historical	7	>70%
Small residences	2-3	>40% (S) >50-60% (N)
Multi-family	?	>50-60%
Commercial	5	>40%
Mid-rise/high rise	3-10	>50-60%

- The warranted lifetime is a marketing issue that will evolve on it's own; group recommends that it should not be a metric; ARPA-E could employ a metric for physical durability.
- Removability should be considered, and warranty may need to include visible performance.
- Haze <5% for all building categories
- Condensation resistance is a good metric.

Breakout 1, Team 2

- Task 1: What are risk factors and value-added for potential purchasers of single pane window retrofits?

Risks and Opportunities: Residential	
Breaking the window	Resale value (sealing, inspection, etc.)
Installation process	Payback is not owner/user's priority
Displacing the occupants	Quality of the contractor
Capital cost and rate of return	"Should I wait for better technology?"
Visibility and clarity	

Breakout 1, Team 2

- Task 1: What are risk factors and value-added for potential purchasers of single pane window retrofits?

Risks and Opportunities: Institutional	
Lowest bid constraint	Certain improvements seem necessary during design phase, but during construction can be viewed as extras
Restrictions on historical buildings	
Simplicity	

Risks and Opportunities: Commercial	
Tennant/owner problem	Quality of the contractor
Value of space and internal planning	Design implemented by poorly-trained personnel
Uncertainty – trust in energy savings estimates	Certain windows cannot be replaced
All incentive-driven retrofits are considered saving and are not checked afterwards	Benefit is very small fraction of overall expenses that other factors (safety, hassle) dominate

Breakout 1, Team 2

- Task 2: Describe building categories, essential criteria, and the expected payback period for each.

Building category; Residential. Payback - Lifetime of windows
UV blockage
Excessive light blockage
Tunable
Comfort and convenience (for appearance, reading, etc.)
Installation is far greater than the cost of the window
Permitting based on local regulations and requirements, associated expenses
Customer mindset and misunderstanding of performance
Appearance, comfort can play a greater role in making decision than energy savings
Lack of tools to allow potential customers to make an educated decision

Breakout 1, Team 2

- Task 2: Describe building categories, essential criteria, and the expected payback period for each.

Building category; Commercial. Payback - Lifetime of windows
How it is valued by an appraiser
Might be split into small portions, i.e. one floor at a time based on occupancy
Permitting, regulatory variations in different jurisdictions
Working with utilities to make it a net zero cost based on energy savings
Clever financing that can drive the incentives to do a window upgrade

Breakout 2, Team 2

- Task 1: What are the properties of your dream single-pane window retrofit? What building categories would it apply to?

Dream Retrofit	Technology Needed and Properties of
Stable and transparent aerogels	10 years lifetime with >60% transmittance, less than 2% haze. Use atomic layer deposition to stabilize the aerogel
Self-cleaning	Low-stick component, photocatalytic component that can destroy the contaminates, superhydrophobic, super roughness, eliminating
High thermal resistance and low-e	Silica-based, aerogel-like
Spectrally selective films to control UV-vis-IR light	99% UV filtration is not technologically challenging (degradation limit), IR filtration already exists
Tunable spectral properties controllable by the user	10,000 cycles, no electrical wiring, modulate between near IR and visible, cost is the key problem, neutral color, electrochemical approach, electro-chromic, photo-chromic
Laminate coating that can significantly improve the U value (>R3), dynamic transmission	Silica-based nanoparticles, aerogel, nano-films, cellulose-based, super-insulating materials
Vacuum retrofit of a 1-pane window	Require 20-30 year lifetime, spacers, low-e before a vacuum package is viable. Package laminate system, flexible glass
Tunable conductance (low conductance)	
Air quality control	Catalytic, photocatalytic
Acoustic control, dampened acoustics	Surface acoustic wave damping, aerogels

Breakout 2, Team 2

- Task 2: Brainstorming – discuss research concepts, building categories that they could be applied to, and rate the difficulty from 1 (trivial) to 5 (impossible)

Layer of transparent aerogel, vacuum package*	Two-layer solution electro-chromic structure with conductive transparent layer, integrated photovoltaic for power source*	UV reflectivity and other adjustment to avoid bird collision
Low surface energy to suppress the onset of condensation	Nano-particle based thin film thermo-chromic coating, using nano-particles increases the bandgap and transparency	Dynamic coating with directional reflectivity for diffused/direct light transmissivity (micro-prisms)
Superhydrophobic surface for dropwise condensation and collection system (a wick to evaporate the condensate	Storm window retrofit to eliminate or reduce condensation	Well-trained and sophisticated contractors for installation
Ceramic thermal super insulating material, nano-pore materials (2-3 nm pore size)*	Pyrolytic coating with enhance U factor and solar heat gain coefficient properties	Photo-catalytic coating for air quality/thermal resistance
Plasma process to wipe the glass for user installation	Retrofit of the window sash (not necessarily entire window)	Solution-type coating (solution will evaporate and residues provide the
Ultrasound crack/leak detection without pressurizing the room	Touch screen windows, display integration, display advertising for payback, for inside space display	Adjustable infiltration through the window coating
Outside shading system to provide some level of thermal insulation and reduce condensation, control solar throughput		

*Rated by the panel at a difficulty of 4/5 – ARPA-E hard

Breakout 3, Team 2

- Task: For the previously identified building categories, what metrics would a technology need to achieve to penetrate this market?

Building category	Warranted lifetime (yrs)	Simple payback	Visible transmittance	Haze (transmittance)
Historical	15*	10+	80% +base	<3%
Small residences	Vary	Vary	60-70% base**	<3%
Multi-family	10-15	5-10	60-70% base**	<3%
Standard institutions	20+	10-15	80% base**	<3%
Mid-rise/high-rise apartment	20+	2-7	80% base**	<3%
Commercial office	20+	2-7	80% base**	<3%

*contractor installed
**region and orientation dependent

Breakout 3, Team 2

- For the previously identified building categories, what metrics would a technology need to achieve to penetrate this market?

- Notes and Comments from the Team 2
  - Condensation resistance should be equal or greater than double-glazed windows
  - A figure of merit for cost should be defined, across performance, payback, and upfront costs, including region and orientation multipliers embedded in the figure of merit
  - Condensation should be no worse than starting point
  - Aesthetics impose a constraint on transmittance
  - Transmittance should not be a fixed target because it depends on the region and orientation
  - The metrics as stand do not capture the communities concerns

*contractor installed
**region and orientation dependent

Breakout 1, Team 3

- Task 1: What are risk factors and value-added for potential purchasers of single pane window retrofits?

Risks	
High cost, long payback time, ROI*	Perception of retrofit/install as inconvenient
Won't be durable*	Disruptiveness to normal work
People don't want to *change* the appearance of a window*	Worries about self-install, or poor performance risk with new technology
Lowered visible transmittance	Installation errors causing defects (not user friendly installation)
Not knowing ROI – uncertainty*	Unintended consequences
Lack of customer understanding of potential benefits	Regionally dependent preferences (tinting)
Condensation	Preparation work
Not realizing payback	Self-install vs. contractor install
Early adopter penalty	

*rated by panel as a top risk

Breakout 1, Team 3

- Task 1: What are risk factors and value-added for potential purchasers of single pane window retrofits?

Value-added for purchasers	
Comfort*	Security against breaking and entering
Lack of condensation	Privacy
Social responsibility	Sound proofing*
Downsize HVAC (change windows out at same time as changing HVAC)	Extend life of HVAC
Light management – reduced glare, manipulate color of light in room*	Aesthetics (architecture, curb appeal)
Less impact (UV fading) to furniture and carpet	Resale and rental value increases
Productivity improvements – occupant health/happiness via better light management	Self-cleaning – reduce frequency of cleaning
Safety – hazed glass (thief looking in window)	Light control – ability to see out (no blinds)

*rated by panel as a top value-add

Breakout 2, Team 3

- Task 1: What are the properties of your dream single-pane window retrofit? What building categories would it apply to?

Dream Retrofit	Benefits
Tunable properties • Visible transmittance • Solar transmittance • Acoustic properties	• Energy savings • Easier to sell • Tunable comfort (want daylighting sometimes, reduced glare) • Privacy (visual and auditory)
Generates income, or is “net” free	Widespread adoption
Generates electricity	Can provide energy for other functionality, including tunable properties
Easy to install	Cost and convenience
Smells good	Making people happy
Unlimited useful lifetime	
Recyclable	Overall green footprint, plus green marketing
Shouldn’t use energy (lifecycle energy)	
Ease of installation – consumer can install without a contractor, Is reversible, and upgradable	Adapt to new technologies
Spray on and removable	

Breakout 2, Team 3

- Task 1: What are the properties of your dream single-pane window retrofit? What building categories would it apply to?

Dream Retrofit	Benefits
Improves air quality inside	
Can be used as a TV	Sell advertising space
Warranty	
Indicator that demonstrates effectiveness	
Ability to confirm/test building energy savings	
Test other environmental properties (radon, carbon monoxide)	
R value over 20 – close to 100	
Comfort near window	
Work with remote control applications, Bluetooth enabled	
Thermal storage	

Breakout 2, Team 3

- Task 1: What are the properties of your dream single-pane window retrofit? What building categories would it apply to?

Dream Retrofit	Benefits
Local sourcing – use locally sourced materials and labor	
Adds value and makes the retrofit desirable	
Meets/exceeds double-pane window properties	
Retrofit that adds a double pane, but also adds functionality in between panes	
Sourced from readily available renewable materials	
Air purifying	Selling point
Improve safety factor	
Can still open and close	For people who use/like natural ventilation
Invisible from inside and outside	
Change color	
Have “knowledge” of desired temperature	

Breakout 2, Team 3

- Task 2: What are the properties of your dream single-pane window retrofit? What building categories would it apply to?

Product Visions
Spray-based retrofit that provides a thin film that does everything. R values greater than 20, and the film responds to light to change the refractive index and becomes more and more transparent with changes in intensity of light or temperature. It has self-tuning properties based on environmental conditions.
Dynamic transmission properties (blocking solar radiation, visible transmittance, glare control, solar gain control, R 20, looks good and provides acoustic damping.
Take existing windows and put insulating foam on outside. Add another layer which is a photovoltaic, then another layer which is an HD TV, then a layer which acts as a motion sensor and camera; while still acting like a window.

Breakout 2, Team 3

- Task 2: What markets – beyond window retrofits – could these technologies be applied to?

Opportunities	Notes
Greenhouses	Stay warm at night, have temperature control, and control the spectrum to make an optimized growing environment
Displays	Could be used in TVs, computer monitors, and others where glass or a thin film is used to improve optics. This is especially true for dynamic properties (if LED based). Also for thermal management to mitigate heat from light sources in a display
Automobiles	
Airplanes	
Interior walls	Control what I see – privacy, partition larger rooms, whiteboards
Replace walls with windows	
Bottles of water, drinks	Reduce energy to keep drinks cold
Lamps	Thermal management
Bus shelters	More comfortable and better than plexiglass; serve as a break between you and the outside world
Architectural lighting	

Breakout 2, Team 3

- Task 3: Brainstorming – discuss research concepts, building categories that they could be applied to, and rate the difficulty from 1 (trivial) to 5 (impossible)

Research concept	Building category	Difficulty [1-5]
Specular transparency, monolithic aerogels	All	4
Thermochromic coating layer, in addition to insulating layer	All – especially important in south, southwest	3
Photochromic aerogel monolith that doesn't allow heat to come in at appropriate times. Change refractive index with light and temperature to become transparent	All	5
Electrochromic aerogel film	Historical or buildings where cost is no object	4.5

Breakout 2, Team 3

- Task 3: Brainstorming – discuss research concepts, building categories that they could be applied to, and rate the difficulty from 1 (trivial) to 5 (impossible)

Research concept	Building category	Difficulty [1-5]
Coating to prevent thermal bridging on frame and reduce infiltration, improve water resistance of frame (reduces the likelihood of rot, creates water barrier	All (must be transparent on historical)	2
Single-step low-e and thermal insulation retrofit	All	4
Anti-condensation, doesn't adsorb water on an internal surface	All	1
Glass/low-e/insulating to reduce condensation and stabilize low-e layer (might be a glass insulating low-e)	All	4

Breakout 2, Team 3

- Task 3: Brainstorming – discuss research concepts, building categories that they could be applied to, and rate the difficulty from 1 (trivial) to 5 (impossible)

Research concept	Building category	Difficulty [1-5]
Coating to protect aerogel layer and inhibits water condensation. Index matching sealant (cross-linked at the top surface of an aerogel). Can be delivered in a three step process - Spray coat the aerogel, perform the cross-linking, and then the final seal	All	4
Thin glass (like Gorilla glass) with an aerogel attached	All	4
Retrofit to virtual double pane with an air gap (>1 mm) or even 10 mm	All	2
Thin film that reacts with air to form a vacuum	All	6
Field applied low e coating, such as room temperature plasma sprayed metal, deposited in situ under ambient conditions	Contractor applied	3

Breakout 3, Team 3

- Task: For the previously identified building categories, what metrics would a technology need to achieve to penetrate this market?

Building category	Warranted lifetime	Simple payback	Visible transmittance	Haze (transmittance)
Historical	20	7	65%	1%
Small residences	10	3	North-60% South -40%	1%
Multi-family	10	2.5		1%
Standard institutions	10	5	50%	1%
Commercial Office	10	2	35%	1%
Mid-rise/high-rise apartment	10	2.5		1%

*contractor installed
**region and orientation dependent

Breakout 3, Team 3

- For the previously identified building categories, what metrics would a technology need to achieve to penetrate this market?
- The team identified that bottom edge condensation resistance should be better than 55% [better than double-pane] for all building categories
- Up-front costs were listed as Not Applicable, except in the case of a residence, where the team estimated a cost of $100/window would be useful.
- For consumer acceptability, the team emphasized that key parameters were maintenance free, and no change to curb appeal across all categories.

*contractor installed
**region and orientation dependent