ELECTROCHROMIC COATING FOR DYNAMIC CONTROL

Cleantech to Market

Project Team

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Cleantech to Market Team

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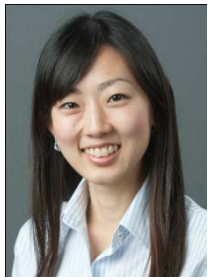

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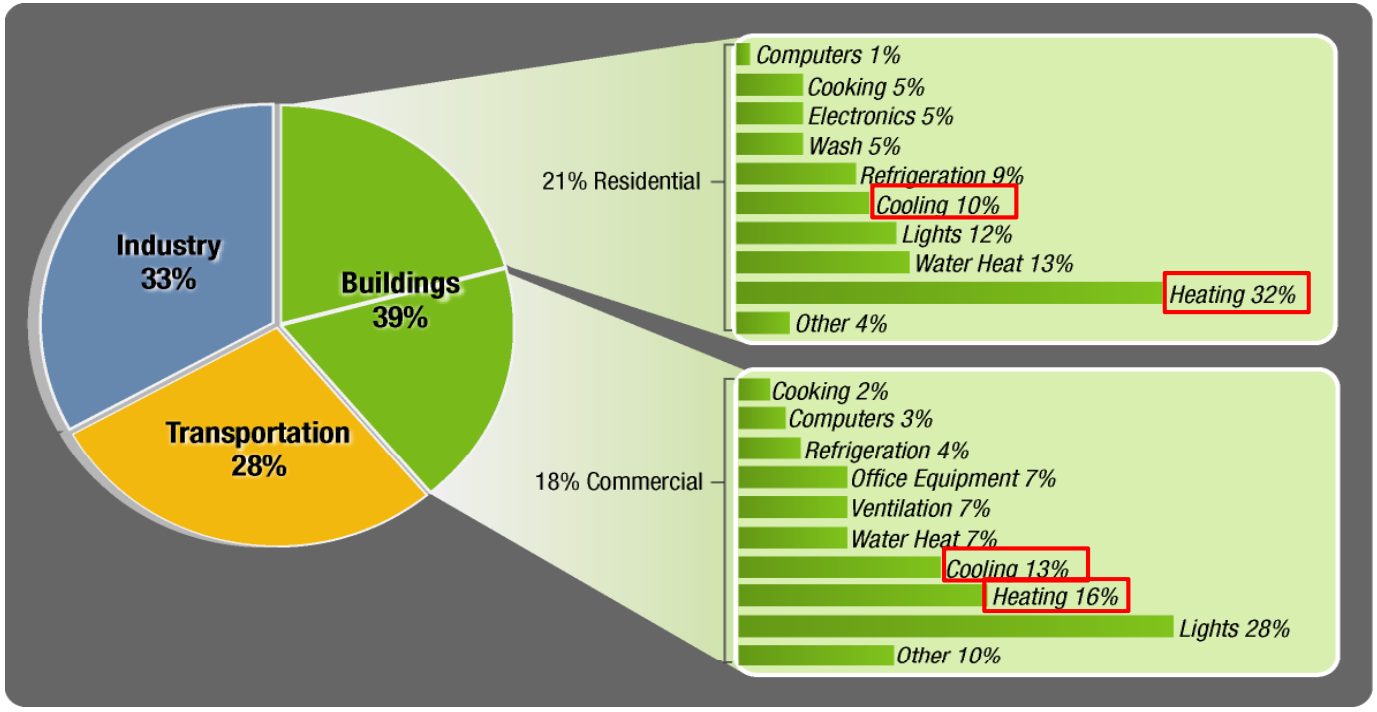
Executive Summary

Technology	Nanoparticle film that modulates transmission of near-infrared radiation (heat)
Status	Lab scale proof of concept; solid electrolyte and product prototype yet to be developed, manufacturing costs and energy savings to be determined
Purpose	Determine and evaluate potential entry markets; propose target entry point and research recommendations

Recommendation: target greenhouse market to develop technology and prove reliability, then expand into commercial windows market

US Energy Consumption by Sector

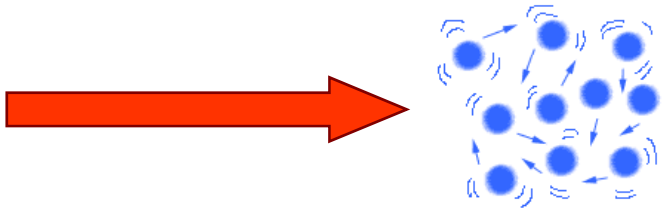
Heating & cooling of buildings accounts for ~15% of total energy use



*Source: Selkowitz 2011

Motivation for Near Infrared (NIR) Control

NIR



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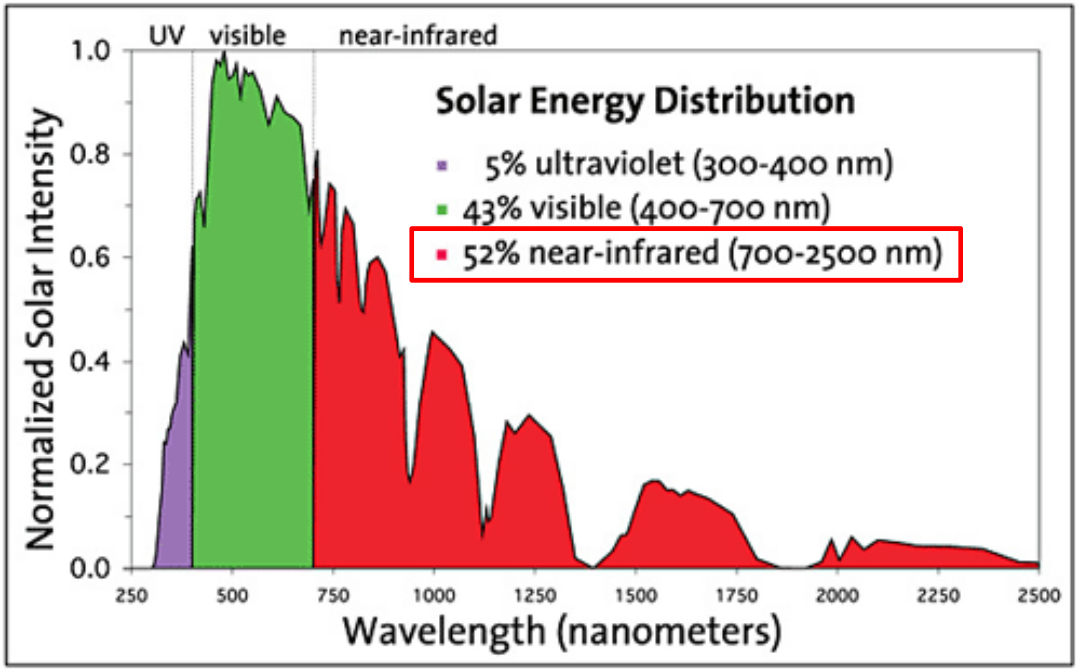


Image credit: Memo Garcia

Motivation for *Dynamic* Control of NIR

Climate

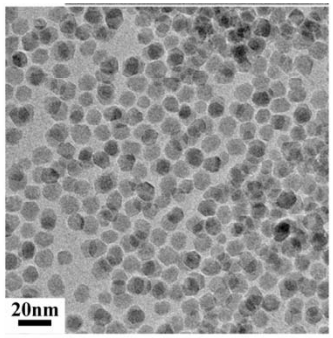
Optimum solar heat gain

Weather

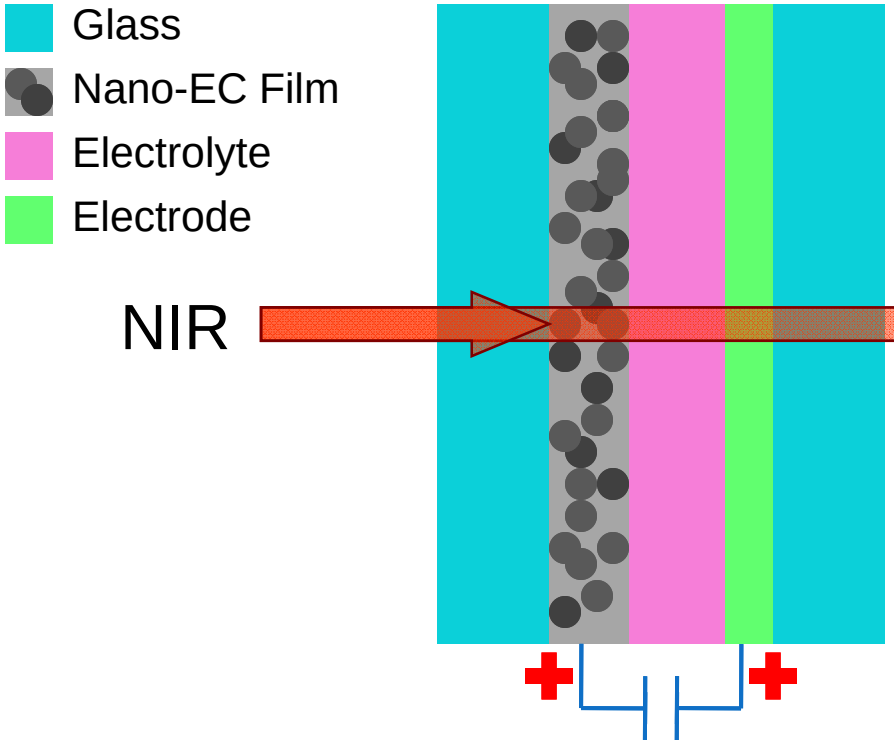
Time of Day

Minimize heating/cooling loads by real-time response to *dynamic* conditions

Technology Overview



Our innovation: Nanocrystal electrochromic films that **modulate NIR transmittance**



Advantages:

- Low cost process
- Fast switching
- Durability
- Aesthetics
- Energy savings

Approach

Diverge/Converge → Preliminary Market Assessment → Deep Dive

IR Applications

- Optical Filters
- Fiber Optic Switching
- Eyeglasses
- IR Sensors
- Satellite
- Forensic Photography

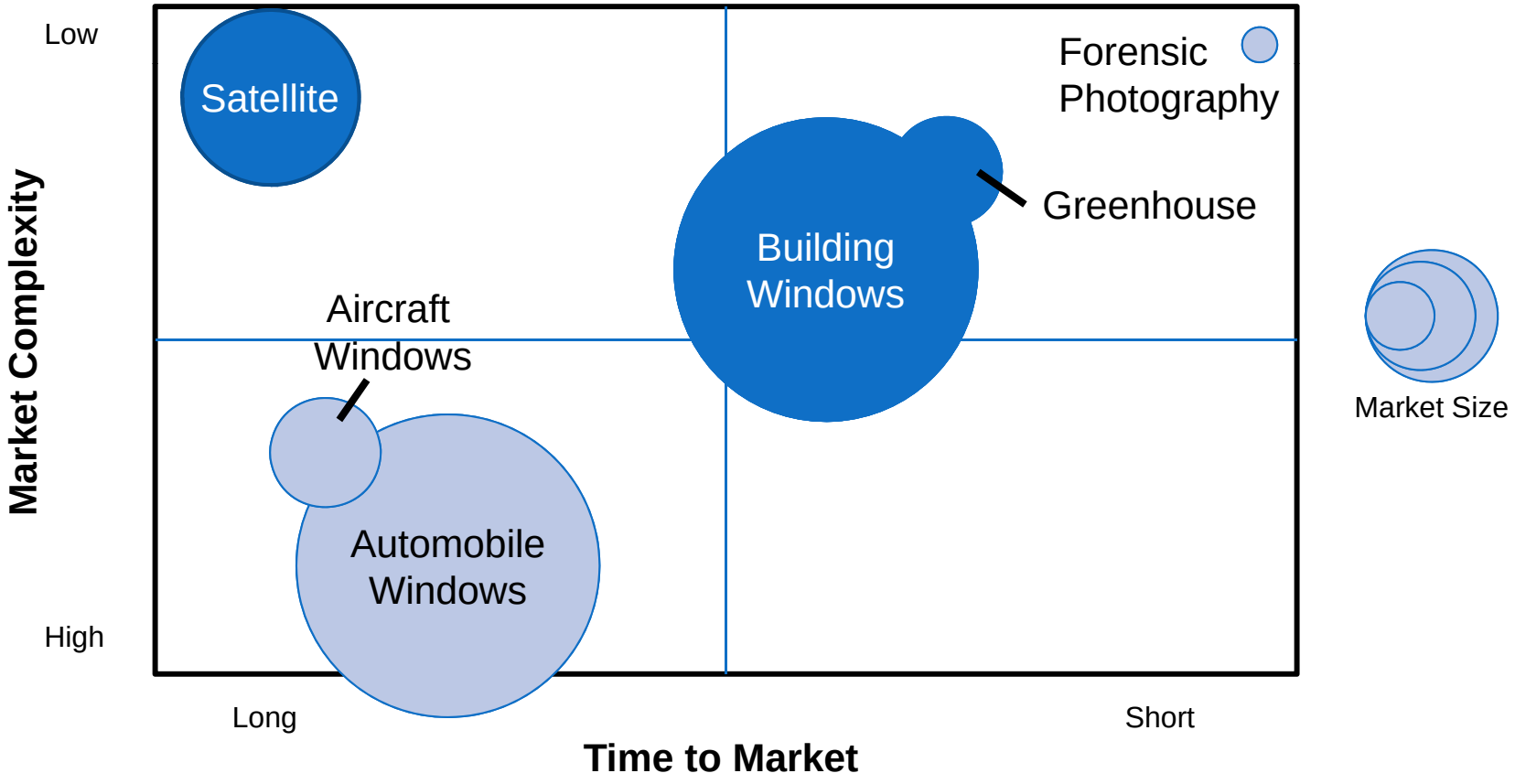
Glass Market

- Building Windows
- Aircraft Windows
- Display Cases
- Greenhouses
- Automobile Windows
- Glass Bricks
- Building Envelopes

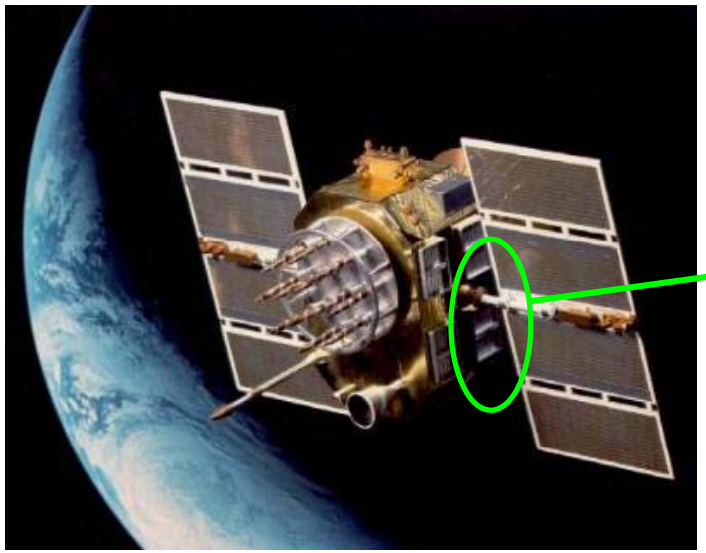
Selection Criteria: 1) Practical need for dynamic IR switching, and 2) Technical feasibility

Approach (cont'd)

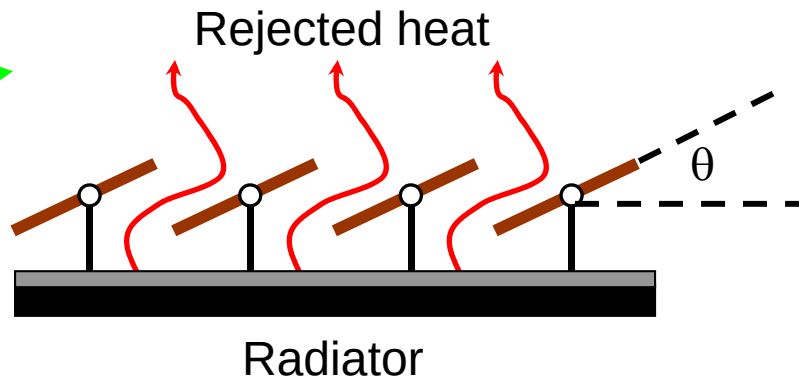
Diverge/Converge → **Preliminary Market Assessment** → Deep Dive



Satellites:
Thermal Control Subsystem (TCS)



Future Radiator Technology:
Electrochromic Film



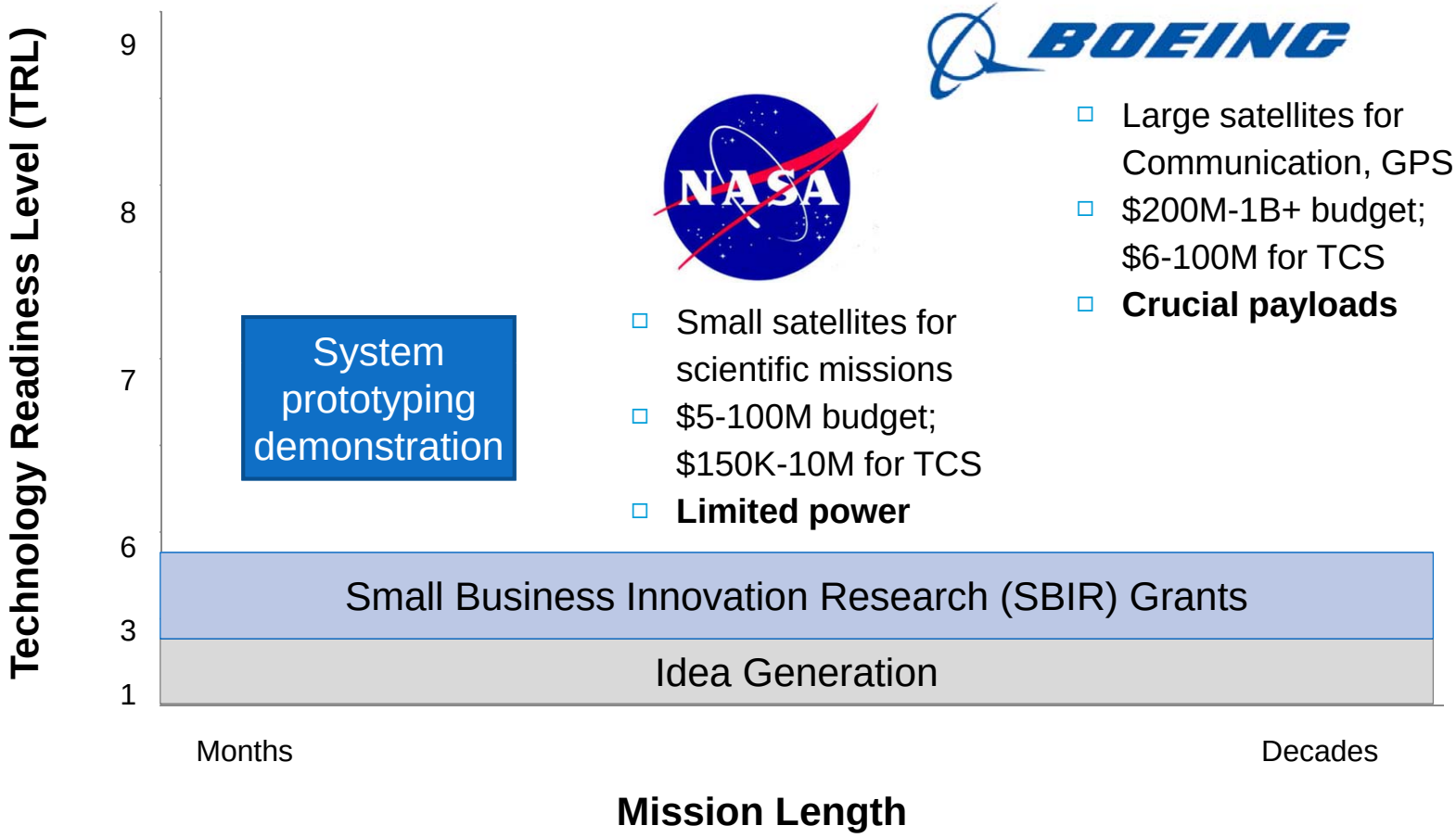
Issues

- Actuators and electronics
- Power consumption
- Dust particles

Value Proposition

- Power and weight savings
- No moving parts

Satellites:
Technology Development Path



Interview with Ted Swanson, NASA Goddard Space Center on 3/29/2011
Interview with Millan Diaz-Aguado, NASA Ames on 4/1/2011

Commercial Windows: Overview

Market Size

- Domestic market for new building construction: ~$530M
- Global Market: $4,060 ~ 5,280M
- Smart glass accounts for ~2%

Market Trend

- Stronger trend than residential sector
- Regulatory trends
  - Increasing interest in LEED certificates
  - Building energy codes
  - European energy efficiency regulation
- Rising energy costs

Competitive Landscape

- Extremely crowded with 400+ players in US
- 5 players dominating ~60% of the US market

PILKINGTON
NSG Group Flat Glass Business

PPG Industries

AGC ASAHI GLASS

Cardinal Glass Company

GUARDIAN
Glass • Automotive • Building Products

Source: BCC Research (2009), IBIS World (2010), Pilkington (2009)

Commercial Windows: Value Proposition

Customer Needs		Our Tech	Low-e	Traditional EC
Initial Cost	▫ Expect 5-7 year payback period	?	✓	✗
Operating Cost	▫ Minimize heating and cooling loads	✓	✗	✓
Appearance	▫ End-user needs differ based on preference ▫ Architects desire clear windows	✓	✓	✗
Reliability	▫ Track record in reliability/durability is important	✗	✓	✗

Greenhouses: Overview

Market Size

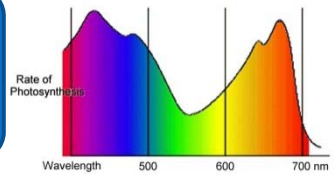
- 2005 US new greenhouse construction market: $134.7M[1]
- Total glass revenue: $5.3M-10.6M
  - Total sq. ft. of glass: 2.6M ft. sq.[2]
  - Average cost of glass: $2-4 per sq. ft.[3]

Market Trend

- Follows general market trends; expected to be flat in the near future
- No energy efficiency regulations
- Energy efficiency is top priority
  - Heating and cooling is ~70% of total energy costs[4]

[1,2] NGMA Survey 2006 (http://www.greenhousegrower.com/magazine/?storyid=386)
[3] Interview with Rob Tanzer, Rough Brothers on 3/31/2011
[4] "Greenhouse Energy Efficiency", Scott Sanford, 11/18/2005

Greenhouses: Value Proposition

		Greenhouse Owner Needs	Value Proposition
Photosynthetic Active Radiation (PAR)		▫ Need maximum transmission in **visible range (400-700nm)**	▫ Modulates NIR with **no impact to visible range** ✓
Energy Efficiency		▫ **Second highest cost** ▫ Current solutions: Energy Retention Systems and IR films	▫ **Reduces heating and cooling loads** ✓
Temperature Control		▫ **Consistent temperature** for plant quality	▫ **NIR control** based on external environment ✓
Cost		▫ **Cost sensitive** ▫ Expect 3-5 year payback	▫ Energy Retention Systems are cheap ?

Market Summary

Positive

Negative

	Comm. Windows 	Green-houses 	Satellites 
Market Size			
Time to Market			
Value Proposition			
Willingness to Pay			
Substitutes			
Competition in EC			
Value Chain Complexity			
	Large market, significant competition	High value proposition, small market	Long development time, price insensitive

Recommendations

Research

- Develop solid electrolyte
- Build product prototype
- Test operating durability
- Investigate low cost manufacturing techniques
- Determine energy savings

Greenhouse Entry

- Partner with research greenhouse (e.g., Oxford Greenhouse)
- Partner with small glass manufacturers

Comm. Window Entry

- License to large glass manufacturers (e.g., PPG)
- License to chemical manufacturers (e.g., Dow)

Appendices

Commercial Window: Market size and competitive landscape

Estimated Market Size

US flat glass market for construction *1	$2,343 ~ 2,620 MM
×	
% New building construction market (vs. Retrofit and Interior) *2	39%
×	
% of Commercial building market (vs. residential building) *3	58%
÷	
% of US market *4	10-13%
=	
Domestic target market size (commercial window market for new construction)	**~$530 MM**
Global target market size	**$4,060 ~ 5,280MM**

Competitive players

- More than 400 companies involved in flat glass market
- Around 300 engage in “advanced flat glass” manufacturing
- NSG, AGC, PPG, Cardinal and Guardian accounts for 60% of total advanced flat glass market

Competitive Technologies

- Low-emissivity coating
- Reflective coating

} Dominant in the industry

- Thermachromic
- Traditional electrochromics: More than 18 companies work on electrochromic technology (incl. non-window application

*1: IBIS report, 2010, Freedonia Focus, 2010
*2: Volume basis, Pilkington, 2009
*3: Overall building construction basis, Freedonia Focus, 2009
*4: BCC Research, 2008

Commercial Windows: Supply Chain

Key Stakeholders
Other Stakeholders
Selection Criteria

- Cost
- U-Value
- Appearance

2
- Create architectural design
- Select material specifications
- Make suggestions on manufacturers

3
- Input on material selection

- Reliability (manufacturer)
- Cost

Architect

Building Contractor

Purchase

4

Supply

Window Manufacturer

1
- Project request
- Request For Proposal

5 Construction

6 Delivery

Building Owner

- Visible aspects of windows
  - Frames and handles
  - Color
- Do not care about
  - Manufacturers/brands
  - Performance

Greenhouse: Value Chain

Key Stakeholders

Other Stakeholders

Greenhouse Owner	Architect	General Contractor	Specialized Contractor	Supplier
▫ User groups work with architects to define greenhouse requirements	▫ Define performance needs and specifications (e.g., type of glass, metrics, and manufacturer)	▫ Manage specialized contractors (e.g., greenhouse, electrical, plumbing) to develop greenhouse	▫ Work with vendors to source materials (e.g., glass/ glazing, heating/ cooling) ▫ Greenhouse contractors occasionally act as consultants for architects	▫ Provide materials based on specs ▫ Regular glass manufacturers (e.g., PPG, AGC)