The Future of
High Performance Glazing in Commercial Buildings

James J. Finley
PPG Industries, Inc.

Overview

- Megatrends
- What's in the future for commercial glazing?
- Is the Glass Industry up to the challenge?
- Product Areas
- Industry Payback on Investment
- Summary and Conclusion

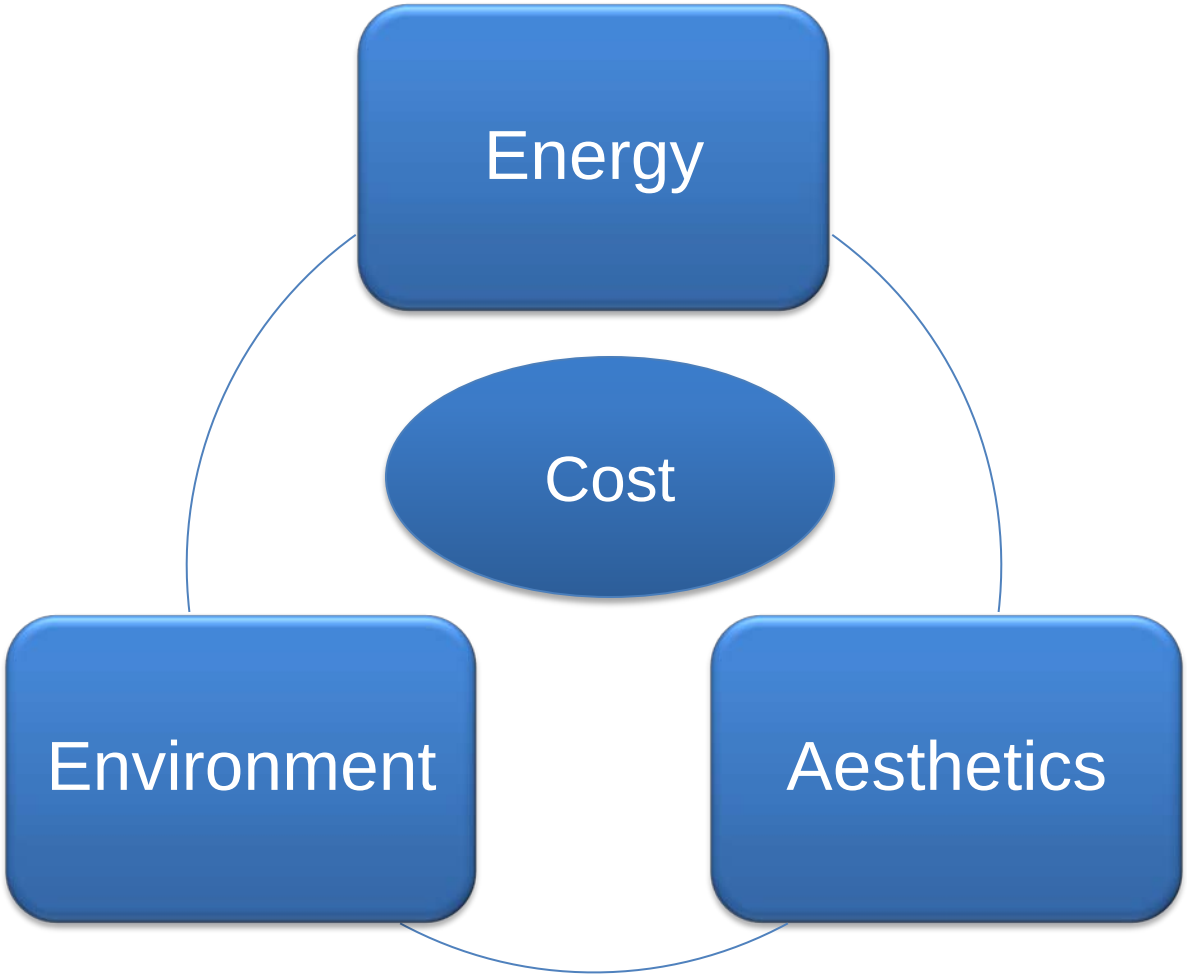
Megatrends

What is a megatrend?

Definition: a large over-arching direction that shapes our lives for a decade or more.

It guides marketing and R&D efforts to innovate new products for tomorrow's marketplace.

Megatrends



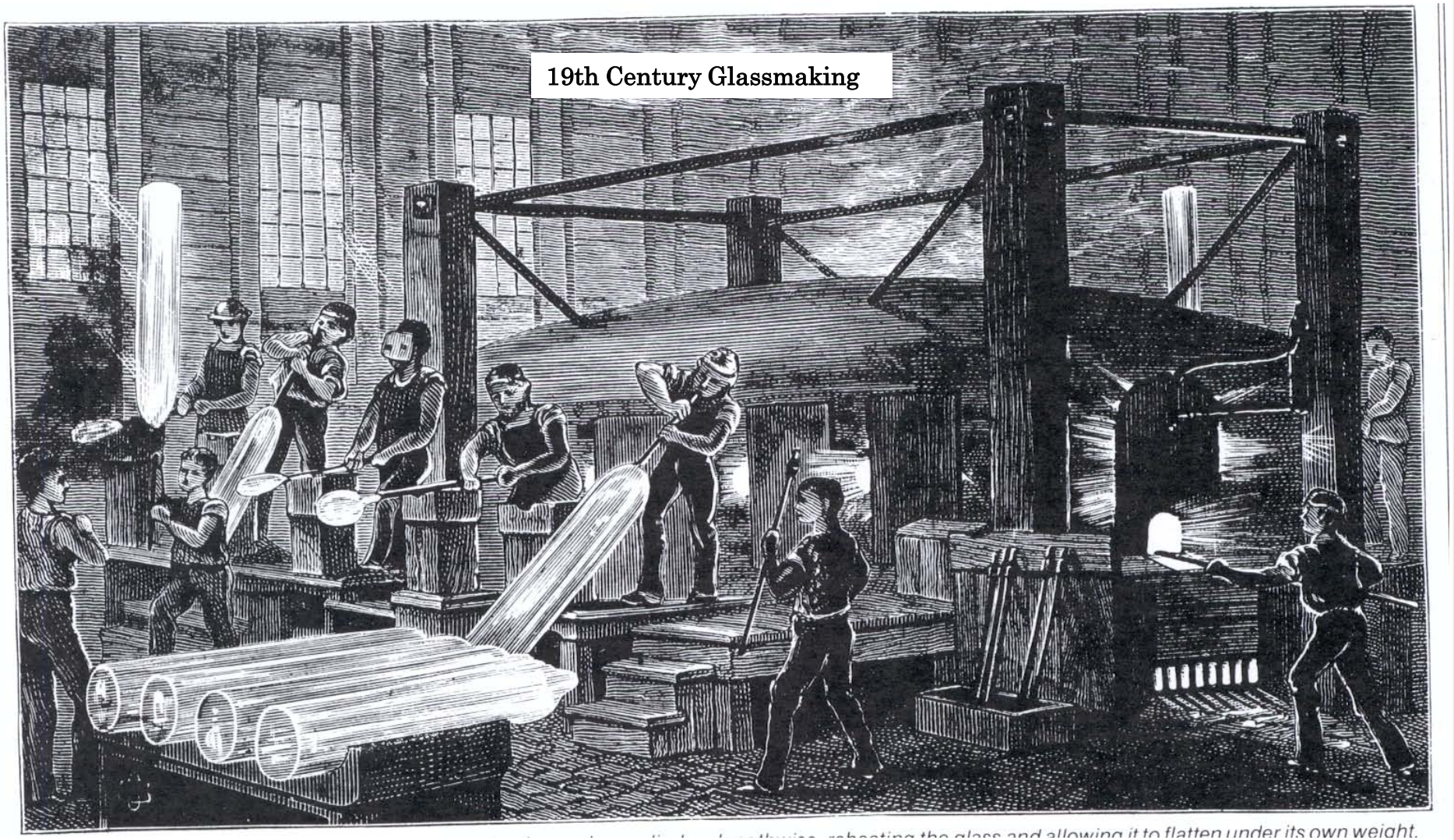
What's in the future?

- What will the commercial building products of the future look like?

- What will they do? Or not do?

- How will they help the architects meet the global challenges of energy conservation, environmental protection and the drive toward carbon-neutral, self-sustaining (ZEB) buildings - GREEN?

Is the Glass Industry up to the challenge?

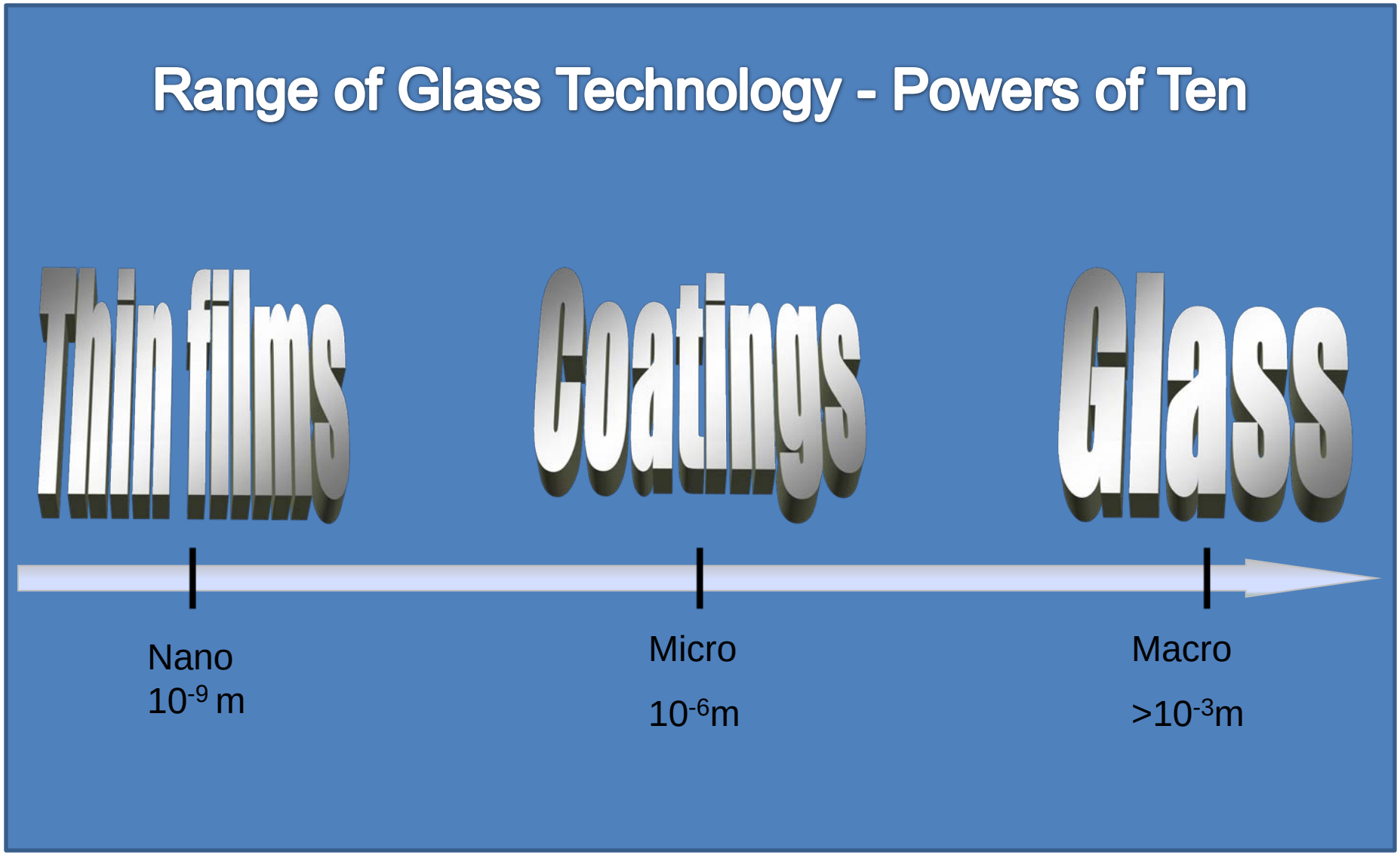


Is the Glass Industry up to the challenge?

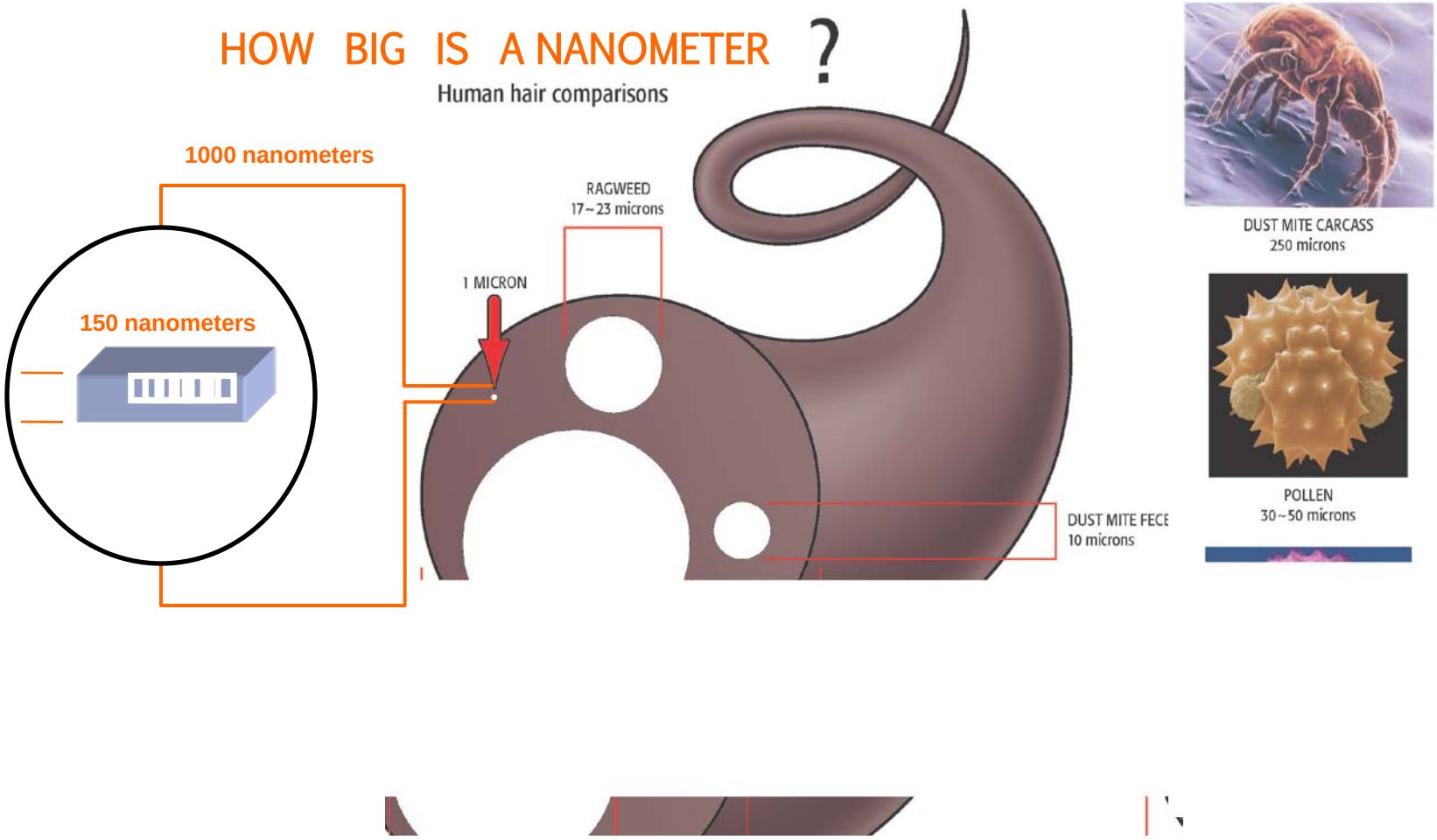
Glass Industry Technology

Glass Industry	Glass	Technology
• Continues to evolve from a producer of “commodity” clear float to added value products. •*Specialty glass and coatings*	• Has transformed from a basic construction element to an aesthetic design element •*Enhanced energy savings and energy conservation functions.*	• R&D focus in fields of advanced materials and nanotechnology •*Leading to products with quality and performance that could only be imagined a decade ago.*

Is the Glass Industry up to the challenge?



Is the Glass Industry up to the challenge?



Glass Industry Product Areas

- Spectrally Selective Glazing
- Photovoltaics
- Switchable Glazing

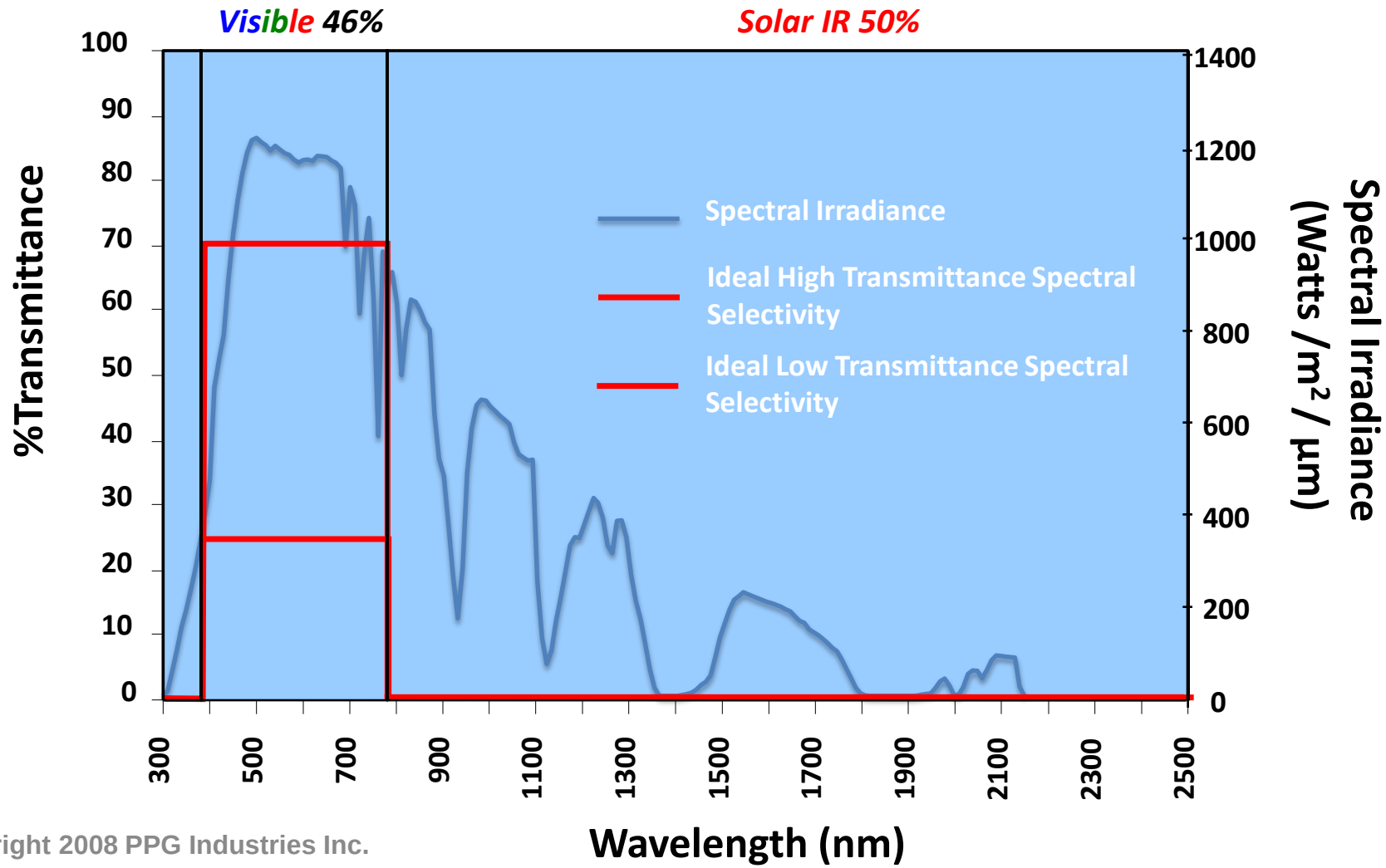
Glass Industry Product Areas

PPG IdeaScapes
Glass • Coatings • Paint

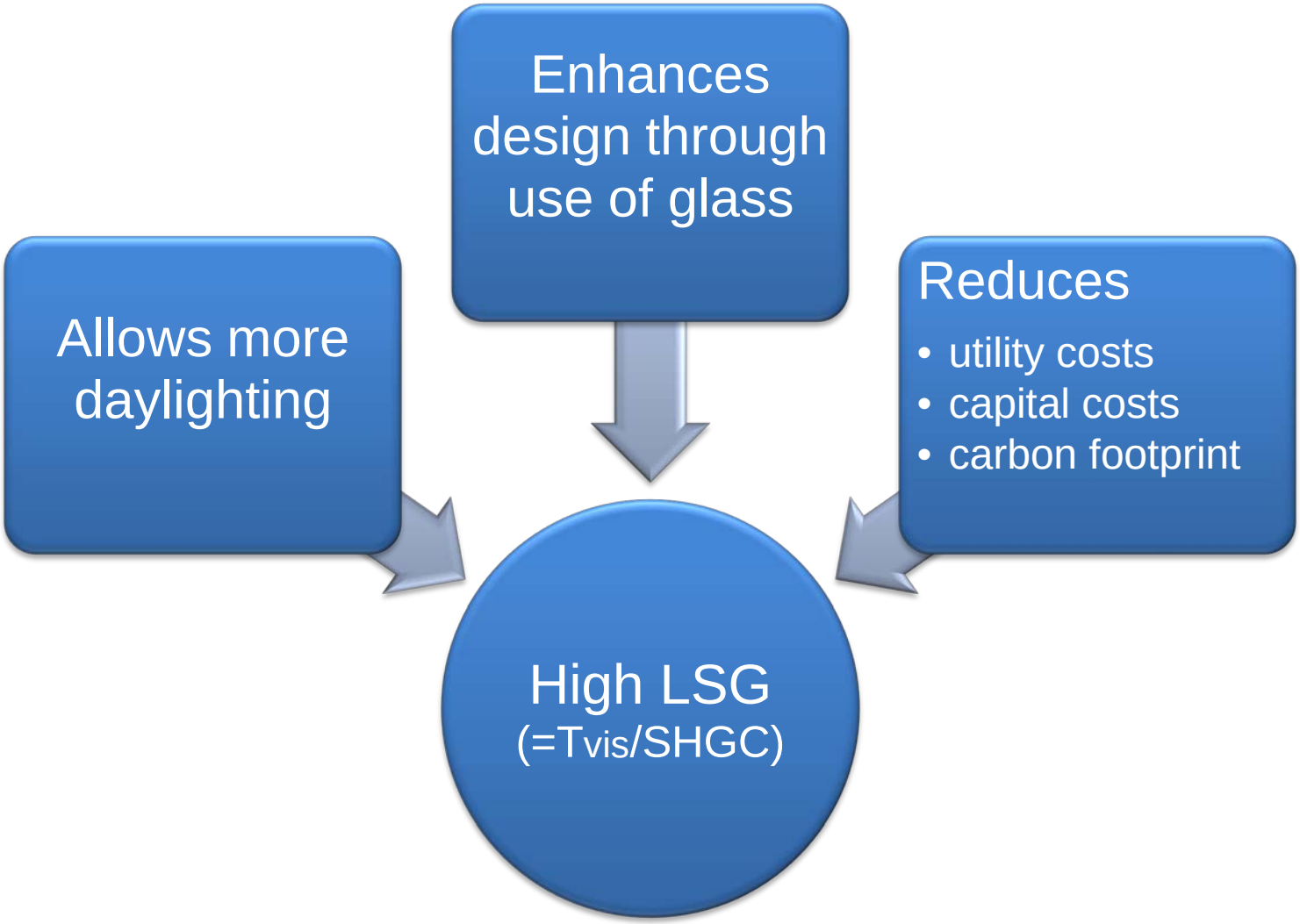
- Spectrally Selective Glazing
- Electrochromic Glazing
- Photovoltaics

Spectrally Selective Glazing - LSG

Solar energy distribution at sea level for air mass = 2

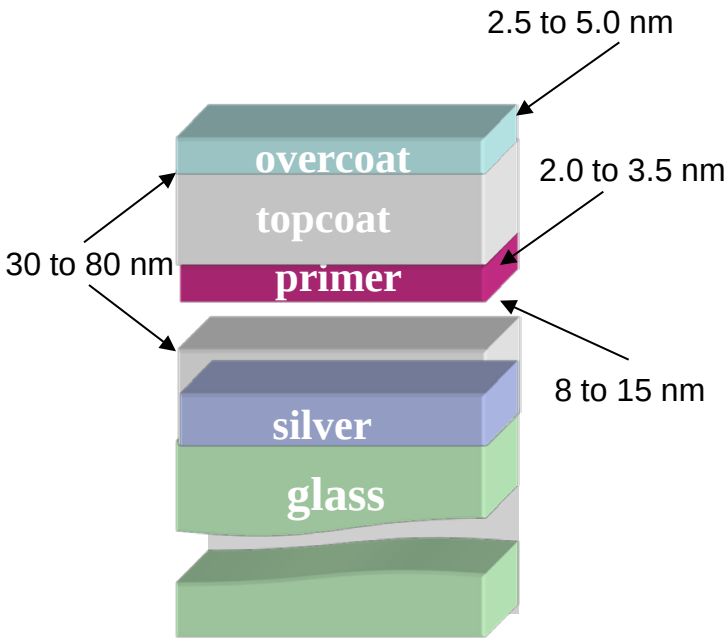


Spectrally Selective Glazing



Spectrally Selective Glazing

- Silver Layer
  - provides solar & thermal performance
  - reflective in visible and IR
- Dielectric Layers (base and topcoat)
  - antireflect the silver layer in the visible
  - acts as a nucleation layer for silver
  - protects and provides chemically & mechanically durability
  - non-absorbing in visible spectrum
  - low cost and non-toxic
- Primer (sacrificial) Layer
  - protects silver during sputtering process
  - provides durability
  - stabilizes coating at high temperature
- Overcoat Layer
  - (optical) extension of topcoat
  - provides additional durability



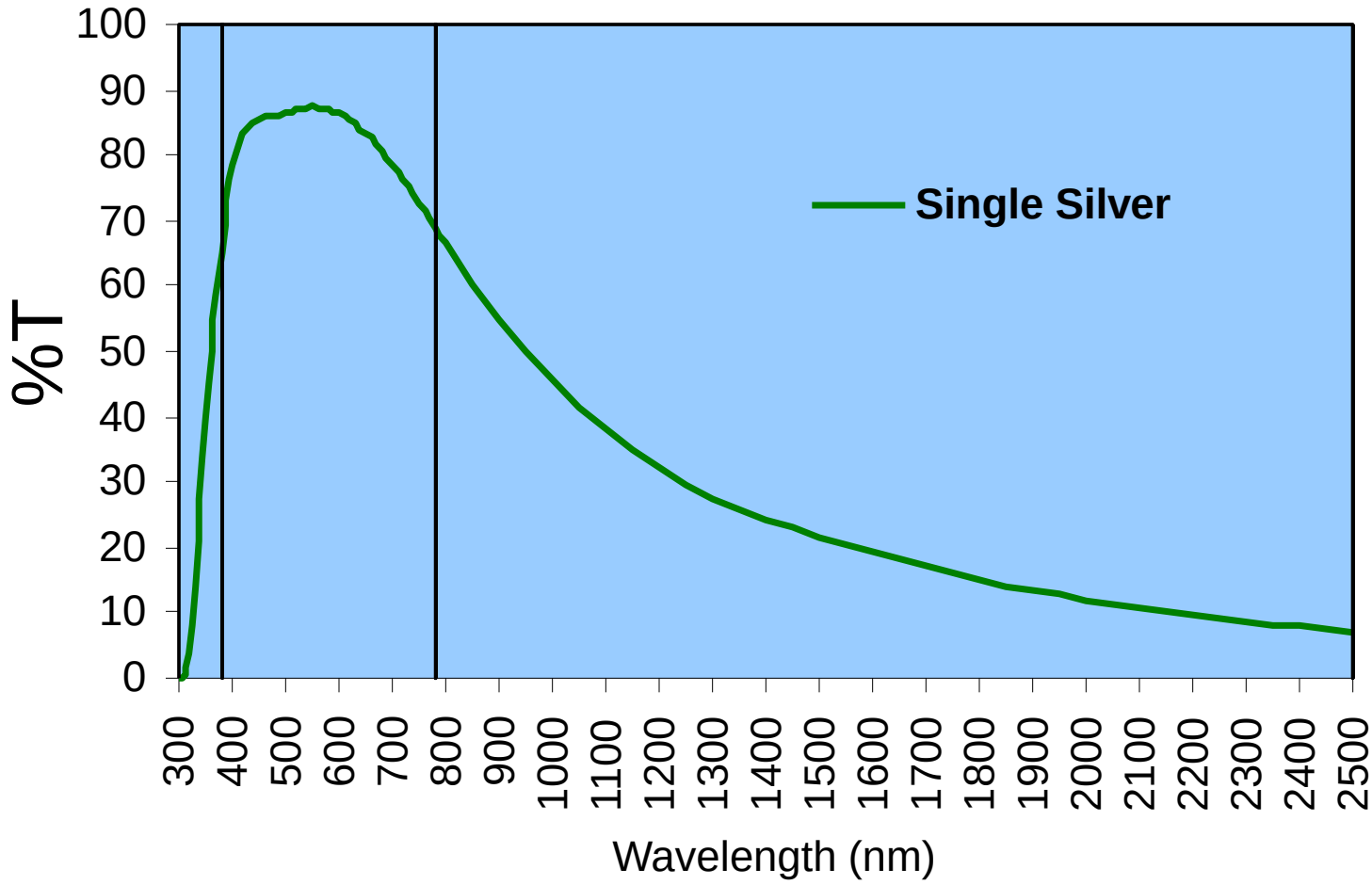
1 Layer Silver

Dielectric/Silver/Dielectric Stack

Spectrally Selective Glazing

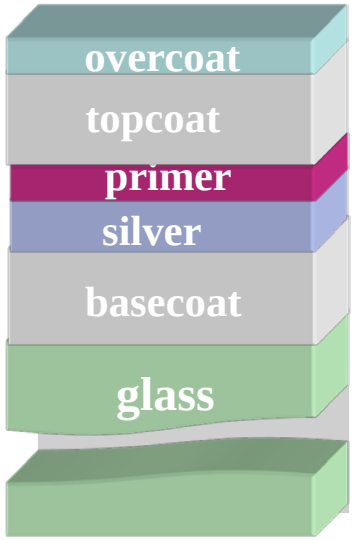
Coating Performance

(3mm clear float glass)

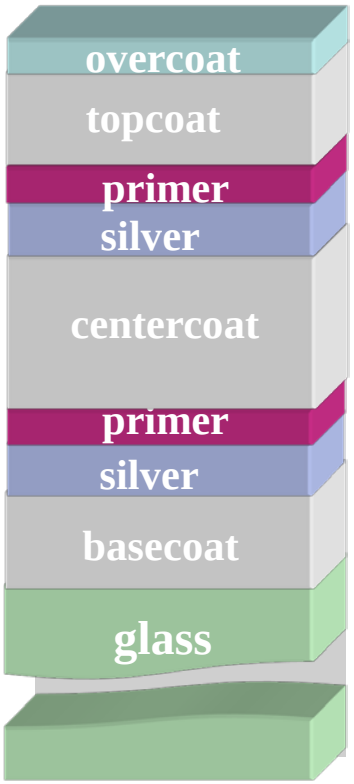


Spectrally Selective Glazing

Building “spectrally selective” Multilayer Silver Stack



1 Layer Silver



2 Layer Silver

from J. J. Finley, PPG Industries Inc.

Spectrally Selective Glazing

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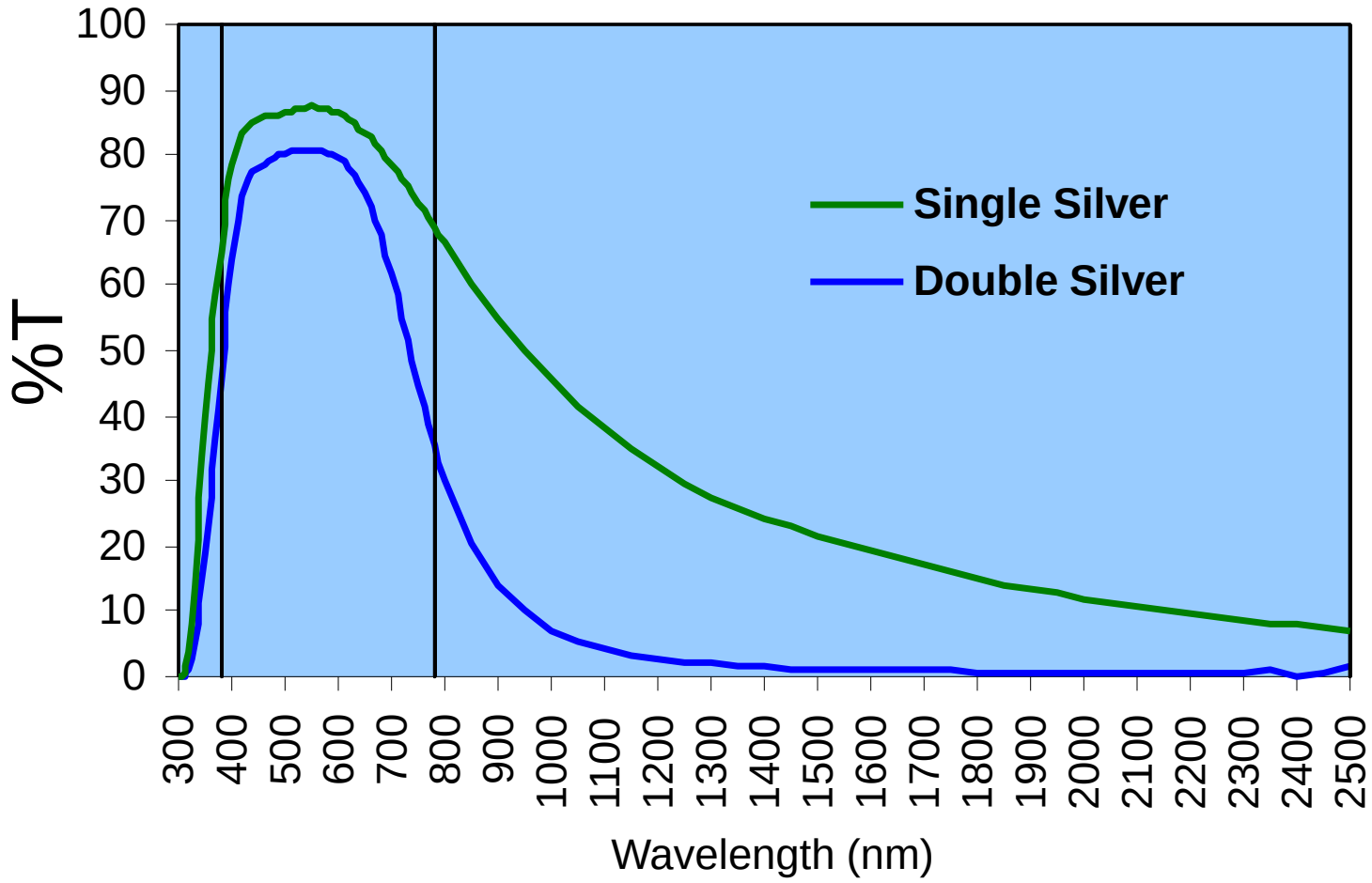
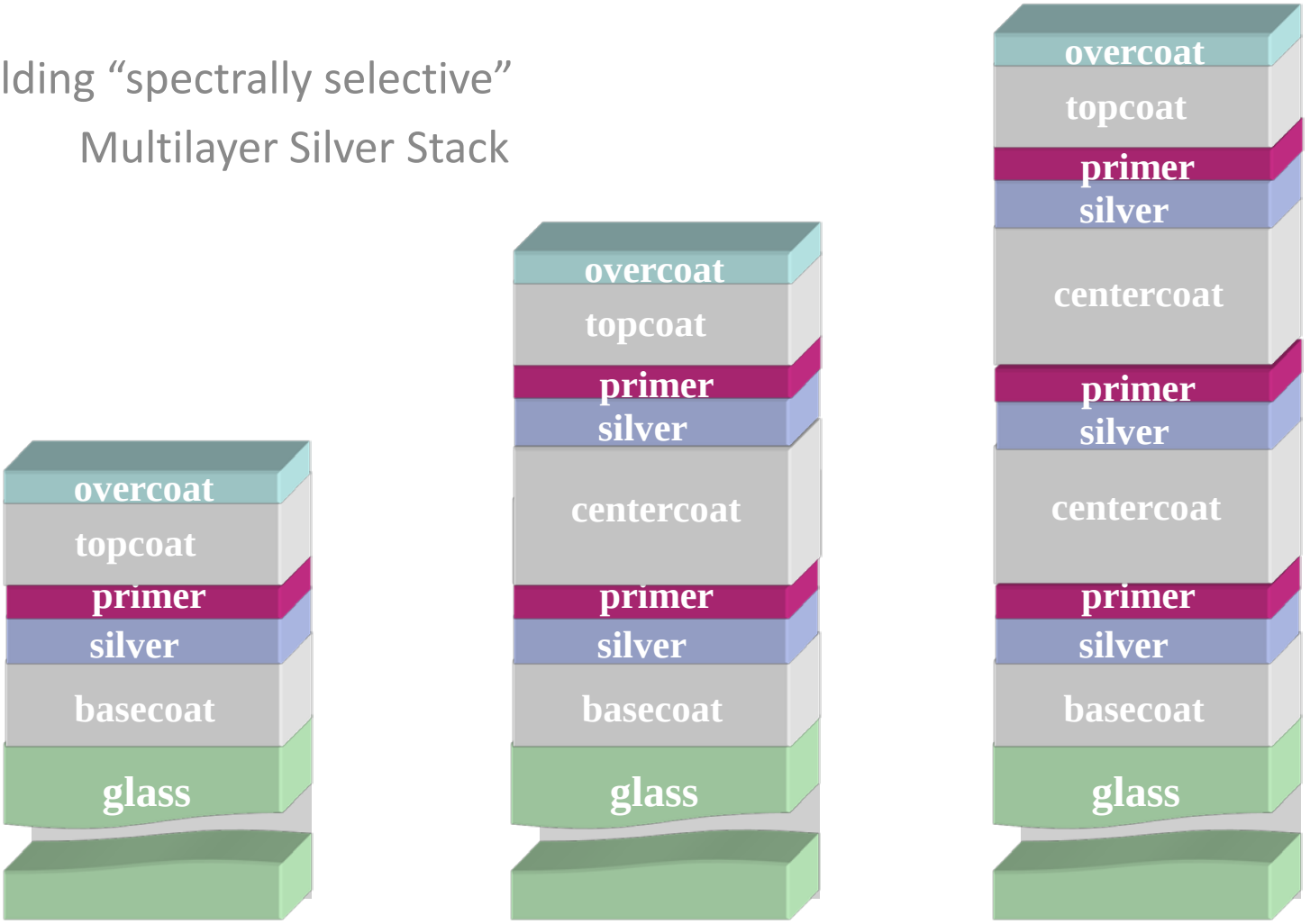
Coating Performance

(3mm clear float glass)



Spectrally Selective Glazing

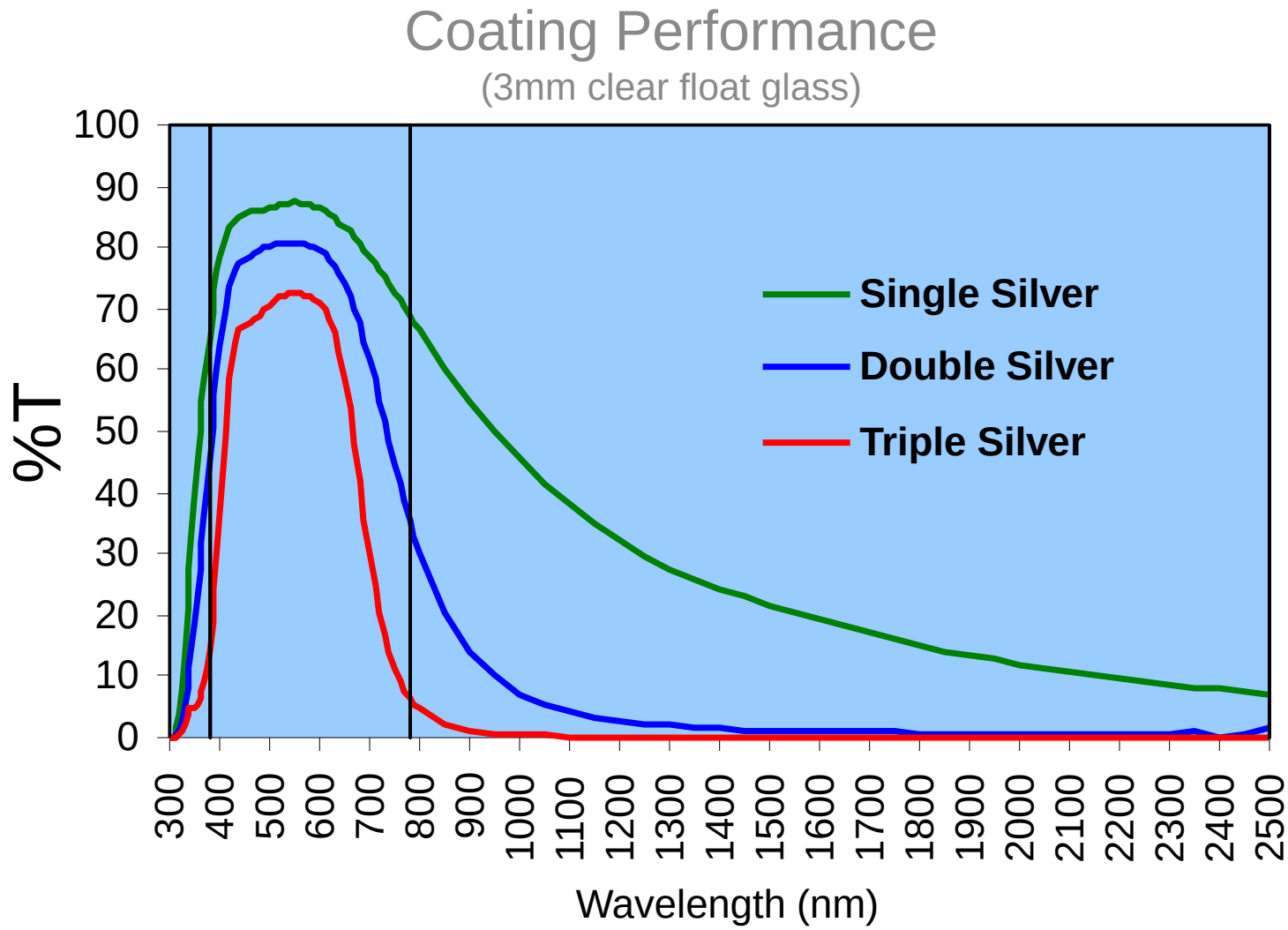
Building “spectrally selective”
Multilayer Silver Stack



1 Layer Silver **2 Layer Silver** **3 Layer Silver**

from J. J. Finley, PPG Industries Inc.

Spectrally Selective Glazing



Spectrally Selective Glazing

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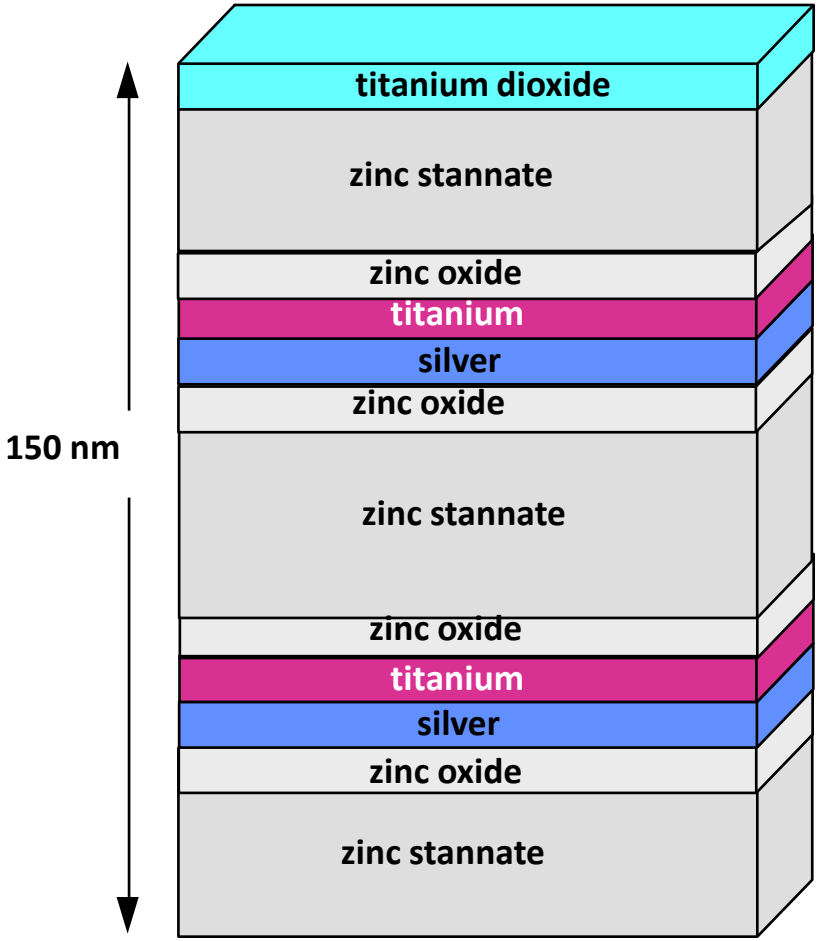
Spectrally Selective
Double Layer Silver Coating



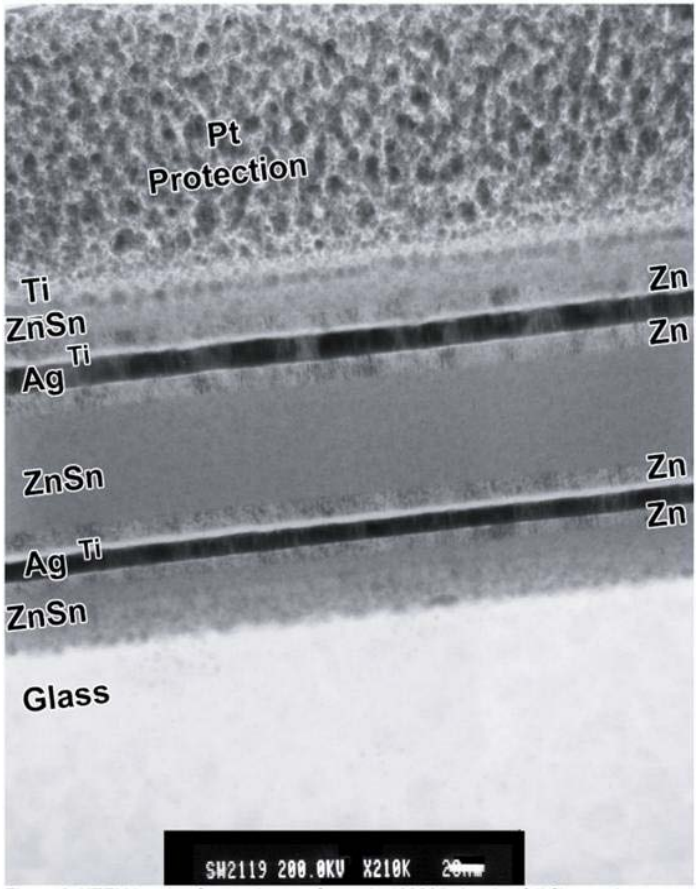
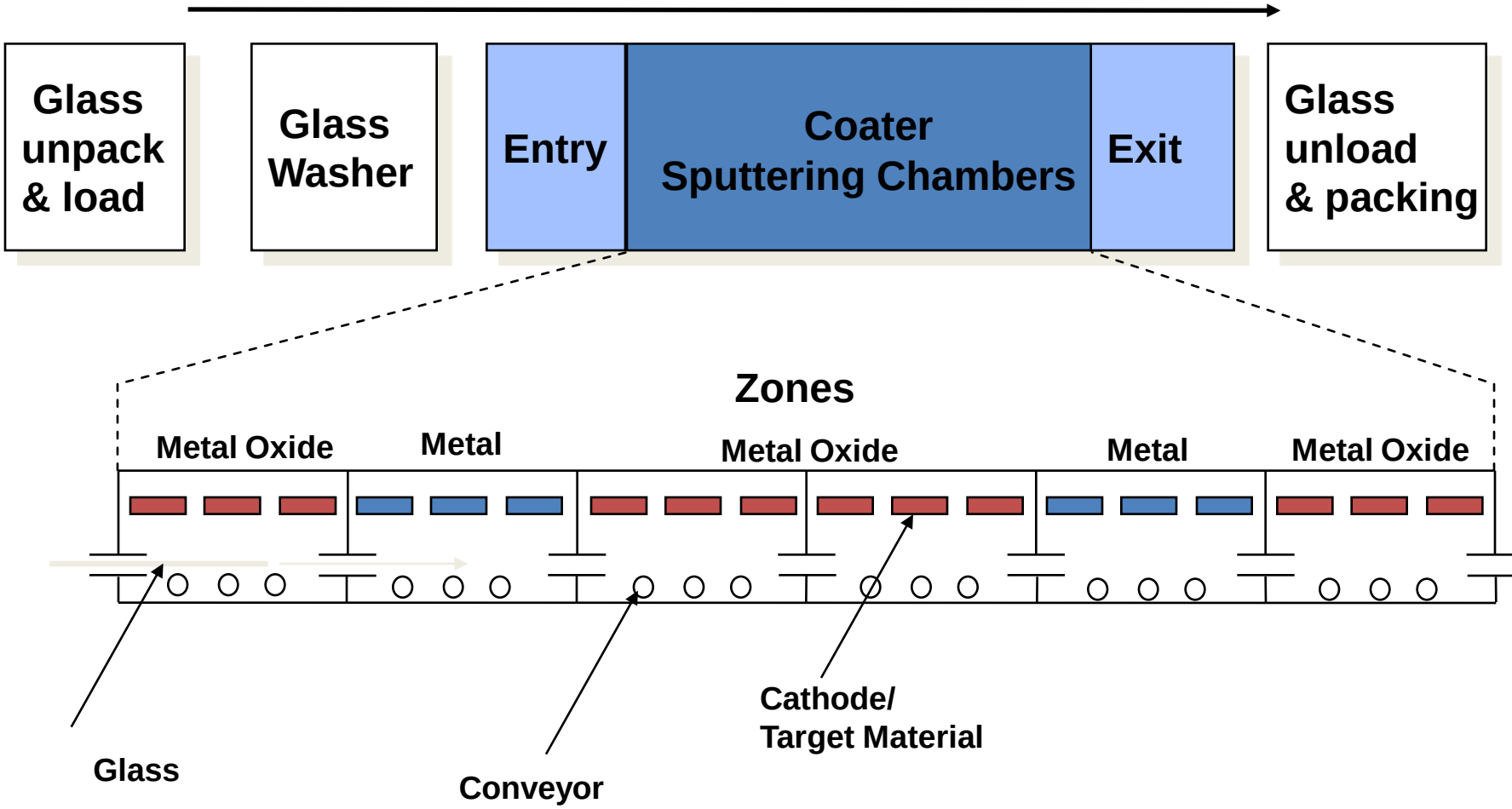


Figure 3 XTEM image of a good area of sample 103285 showing full film stack.

Spectrally Selective Glazing

MSVD Coating Line *In-Line Process*



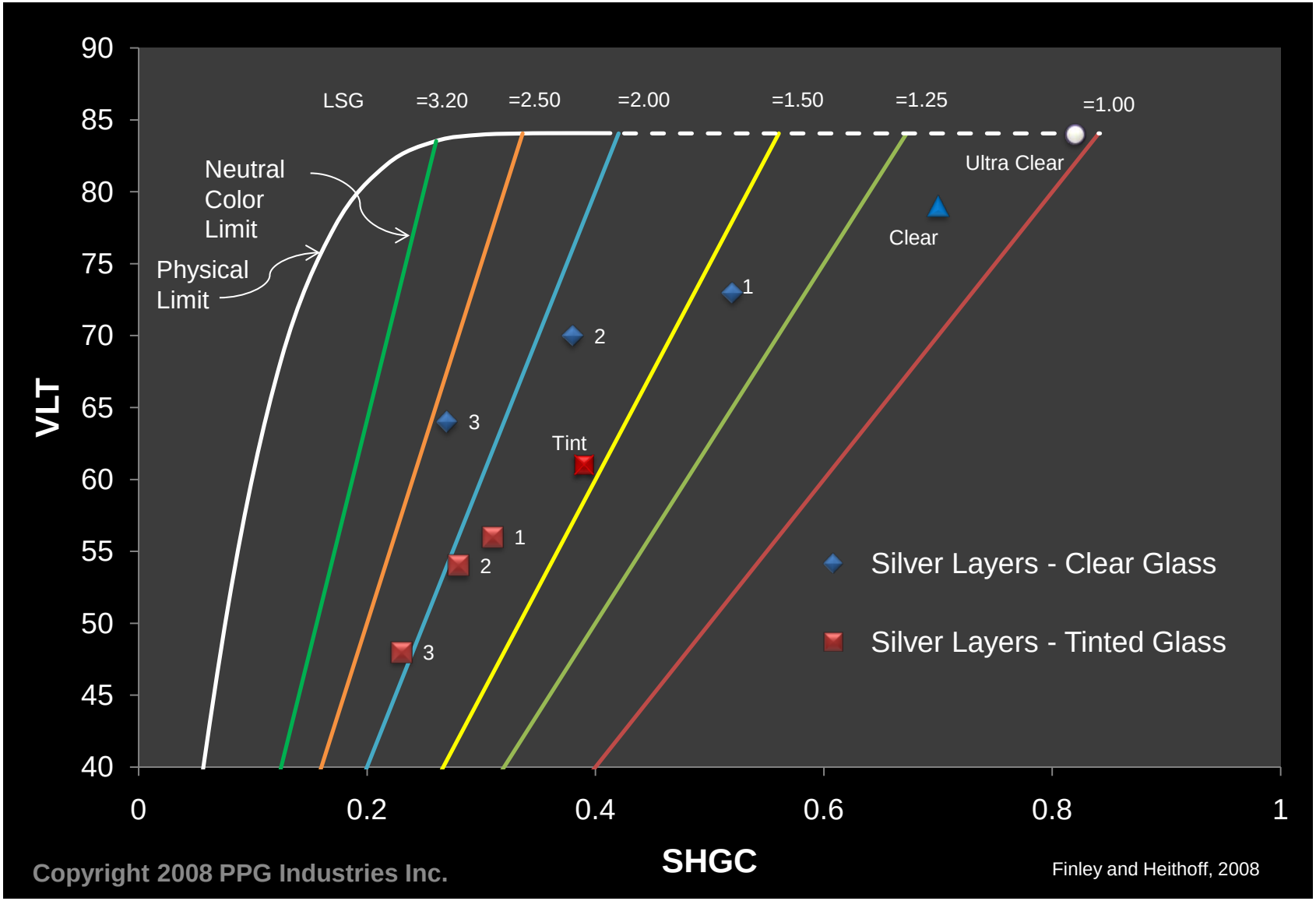
Spectrally Selective Glazing

Low Emissivity Coating Performance

Number of Silver Layers [metal oxide – silver – metal oxide]	VLT	SHGC	LSG	U-Value
Uncoated	79	0.70	1.13	0.48
1 Layer	73	0.52	1.40	0.31
2 Layers	70	0.38	1.84	0.29
3 Layers	64	0.27	2.37	0.28

Commercial IG Unit: 1-inch units with ½-inch airspace and two 1/4-inch clear lites

Spectrally Selective Glazing - Landscape



Finley and Heithoff, 2008

Spectrally Selective Glazing

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Economic Impact

City - Boston	Total Operating Cost	Total Capital Cooling HVAC Costs	Annual Operating Cost Savings of vs. Tinted	Initial Capital Cost Savings vs. Tinted
Tinted	$853,540	$2,326,967	-	-
2 layer-silver	$793,066	$2,123,627	$60,474 7.1%	$203,341 8.7%
3 layer-silver	$756,001	$1,928,086	$97,539 11.4%	$398,881 17.1%

See **A Comparison of Energy, Economic and Environmental Benefits of Transparent Low-E Glasses**
Based on eight-story glass-walled office building
Total Glass Area: 50,967 ft2
Total Floor Area: 270,000 ft2

Spectrally Selective Glazing

HVAC CO_2 Emissions Reductions

City - Boston	Annual CO_2 Savings vs. Tinted (Tons)	40 Year Building Life CO_2 Savings vs. Tinted (Tons)
Tinted	0	0
2 layer-silver	228	9,120
3 layer-silver	354	14,160

See **A Comparison of Energy, Economic and Environmental Benefits of Transparent Low-E Glasses**
Based on eight-story glass-walled office building
Total Glass Area: 50,967 ft2
Total Floor Area: 270,000 ft2

Spectrally Selective Glazing

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Current and Future Status

	Current Status	Future Status
Commercial Applications	➢ High LSG-based products yield immediate energy and environmental payback with strong growth	➢ Integrated design processes (BIM) and in-building monitoring and feedback are driving product glazing optimization for Green building ZEB goals
Glass Industry	➢ R&D and capital investment continue to drive the shift from commodity to added value products	➢ Assets are leveraged to focus on specialty products and reduce cost and time to market
Manufacturing Process	➢ Process focuses on spectrally selective and low-E coatings	➢ Increased volume of solar products (PV) are integrated into processes

Glass Industry Product Areas

Switchable Glazing

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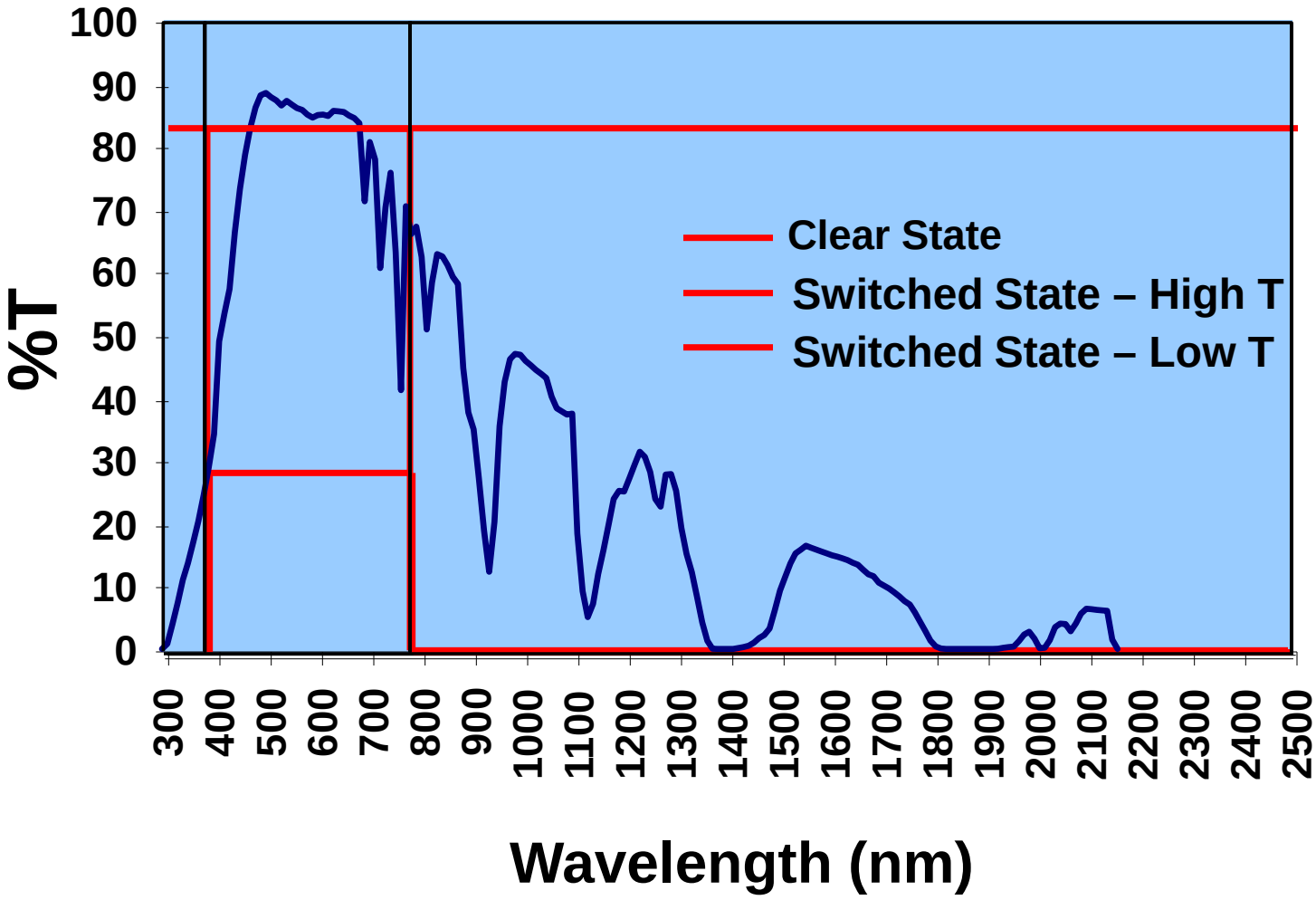
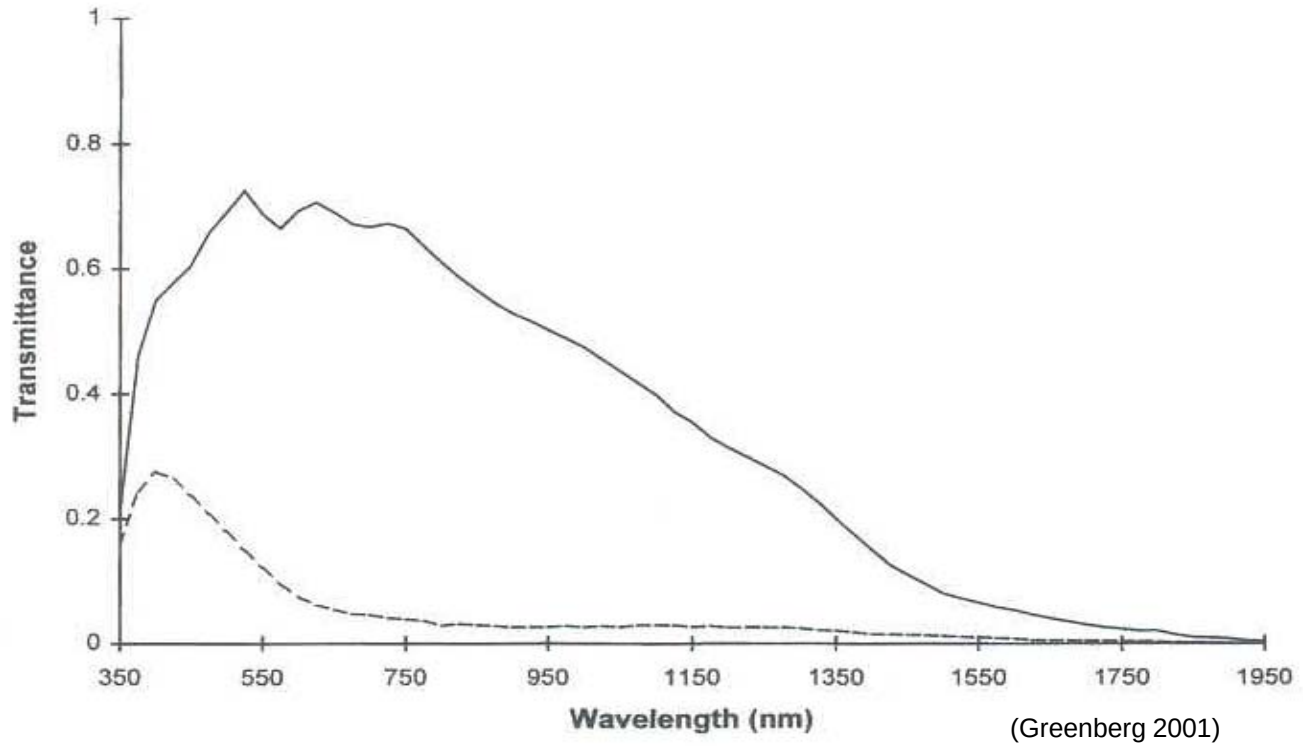
Dynamic Spectrally Selective



Electrochromatic Glazing

Tungsten Oxide (WO_3) Based Cell

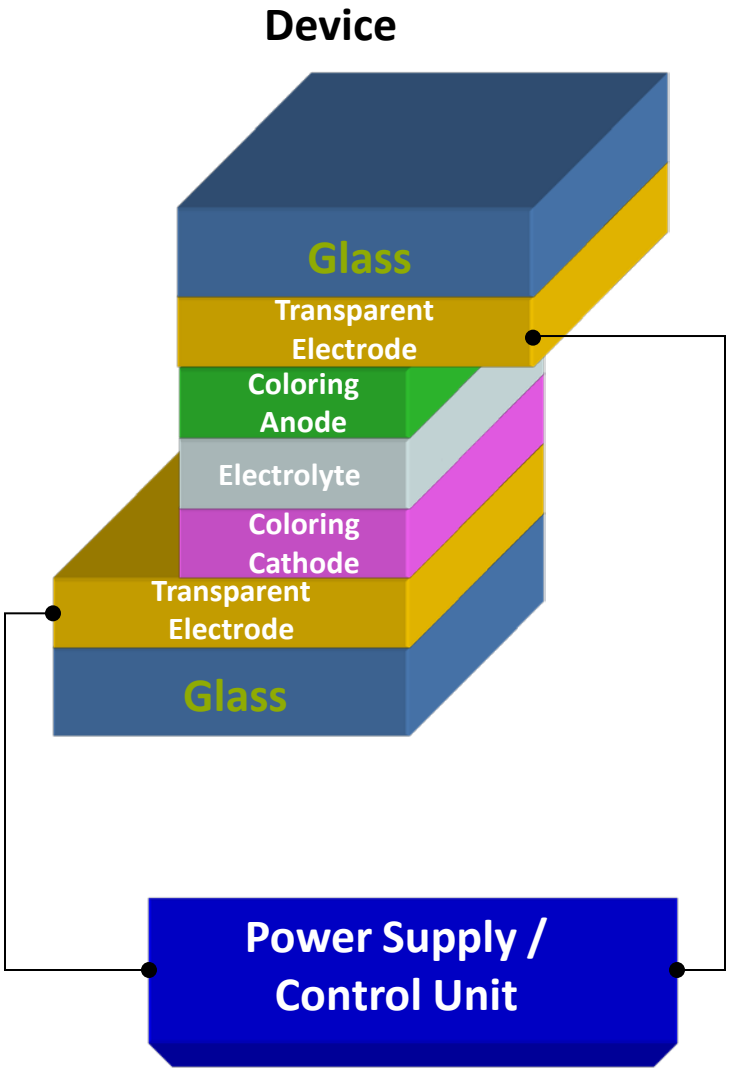


(Greenberg 2001)

EC Device & Circuit

Electrochromic Device

- Glass is coated with a transparent electrode
- Coloring anode and cathode provide visible and solar IR shading (polymer, dye, organic)
- Electrolyte supplies electrical charge to darken and lighten anode and cathode (liquid or solid state)
- Voltage cycles electrical charge to cathode and anode
- Power Supply/Control Unit provides voltage to power and switch device
- Sensors (not shown) adjust device to environmental conditions



Other Similar Technologies

- Liquid crystals
- Thermochromic
- Photochromic
- Suspended particle display (SPD)
- Combined electrochromic and photovoltaic windows

Switchable Glazing

Current and Future Status

System	Application	Current Status	Future Status
Thin Film Inorganic (WO_3)	Window glazing, sunroofs	➢ Niche product ➢ Optimum for direct shading applications	➢ Requires manufacturing efficiencies for price point and growth ➢ Independent spectral selectivity is doubtful
Dye Based (Viologin)	Small Area Applications	➢ Recent scale- up to cabin windows ➢ Response in visible spectrum	➢ Continued market growth in next five years
Organic (Conjugated Polymer)	Internal partitions, displays	➢ Concept stage ➢ Product lifetime uncertain	➢ No commercial window product in foreseeable future

Glass Industry Product Areas

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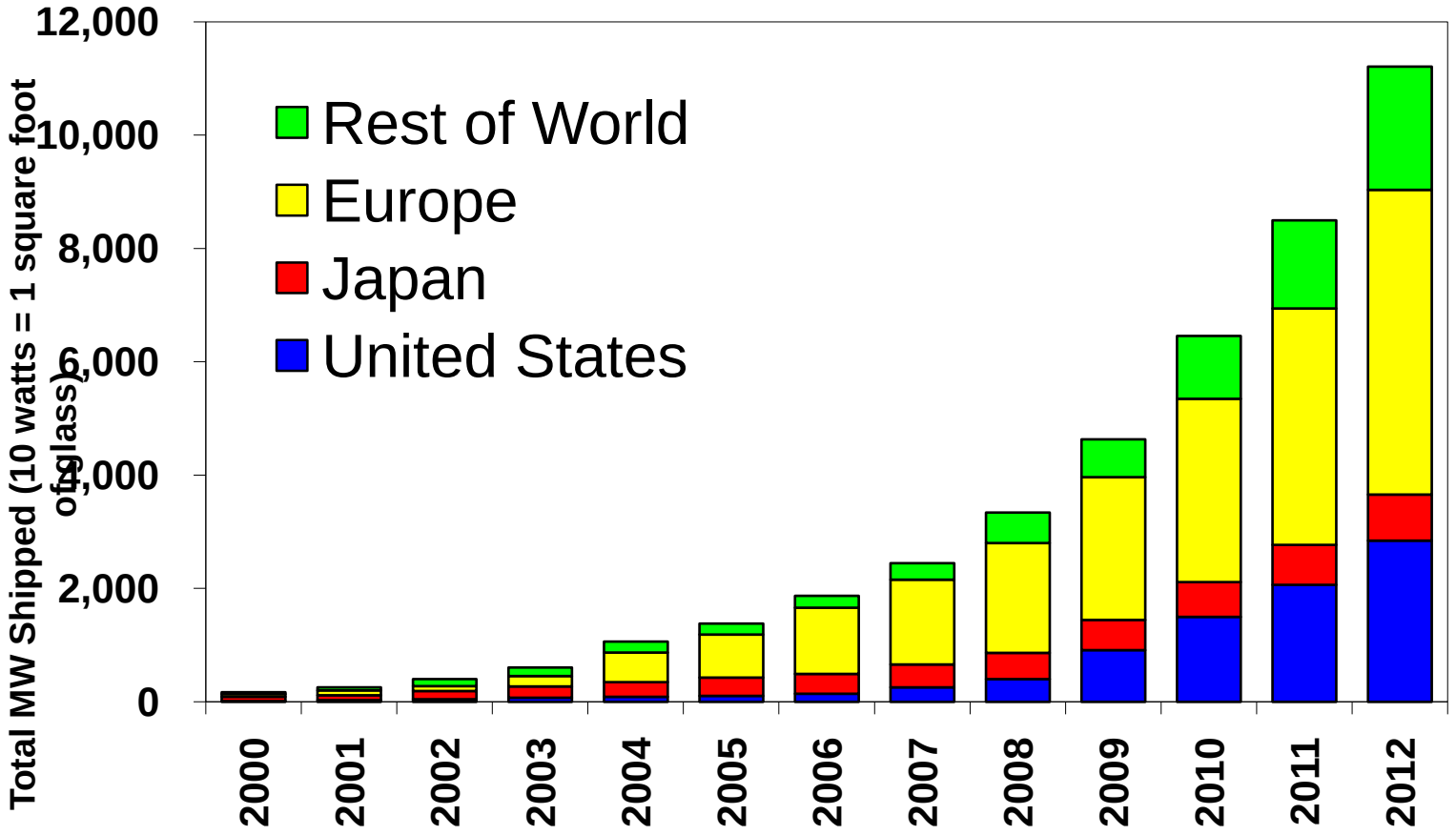
- Spectrally Selective Glazing
- Photovoltaics
- Switchable Glazing

Photovoltaics (PV)

- Solar power generation continues to grow at accelerated rate
- Focus area for glass industry
  - Transparent conductive oxide coatings (TCO's)
  - High transmission glass
  - Antireflective coatings
  - Glazing products for BIPV
- Explore low cost organic and dye based systems

Worldwide PV Shipments

(In MW)



Source: Travis Bradford & Paul Maycock, Solar Power 2007, September 2007

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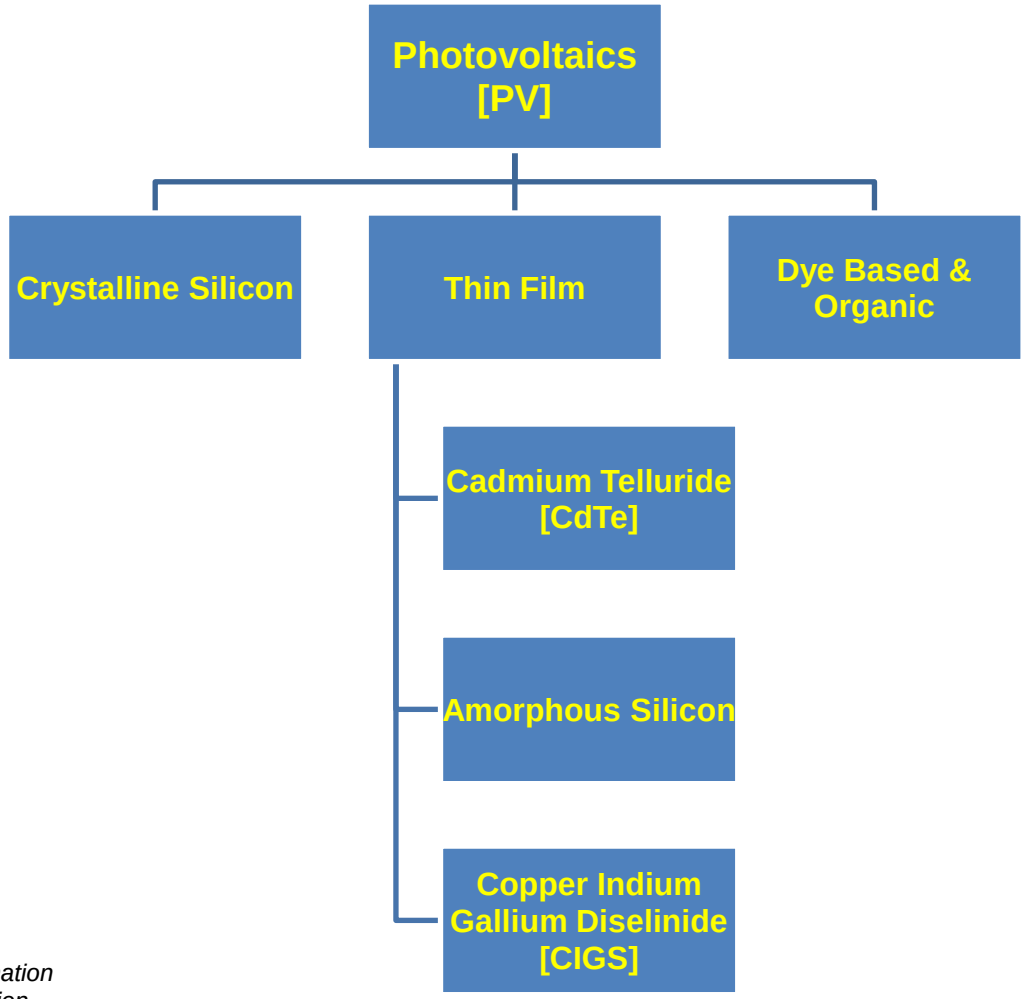
Photovoltaics

Solar Industry Market Structure



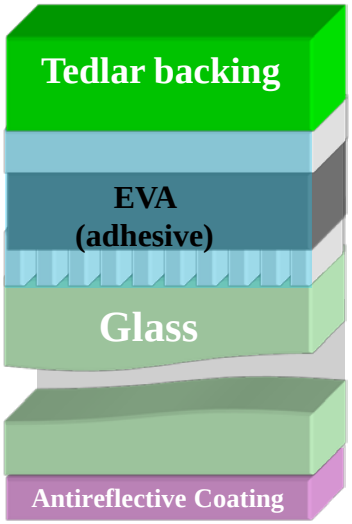
DOE

Energy Information Administration

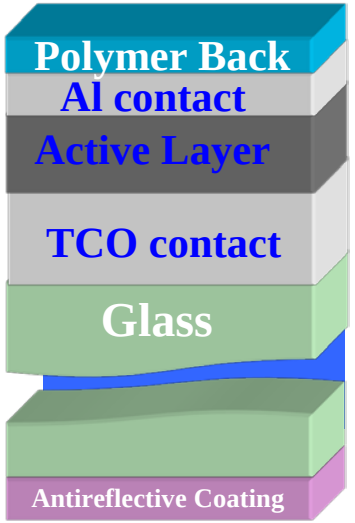
Photovoltaics

Modules

c – Silicon

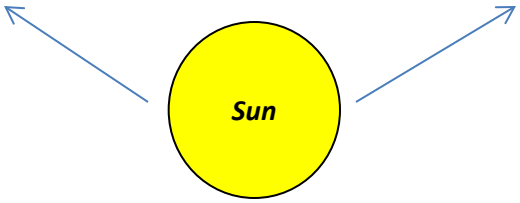


Thin Film



F: SnO
ZnAl Oxide
ITO

Multilayer
High/low index
coatings



Photovoltaics

Glass Technology Needs for PV Technology Segments

PV Technology	Low iron, high T glass substrate	AR Coated Glass	TCO Coated Glass
Crystalline Silicon	*	*	
Amorphous Silicon	*	*	*
CdTe, CIGS Thin Film	*	*	*

Building Integrated Photovoltaics (BIPV)

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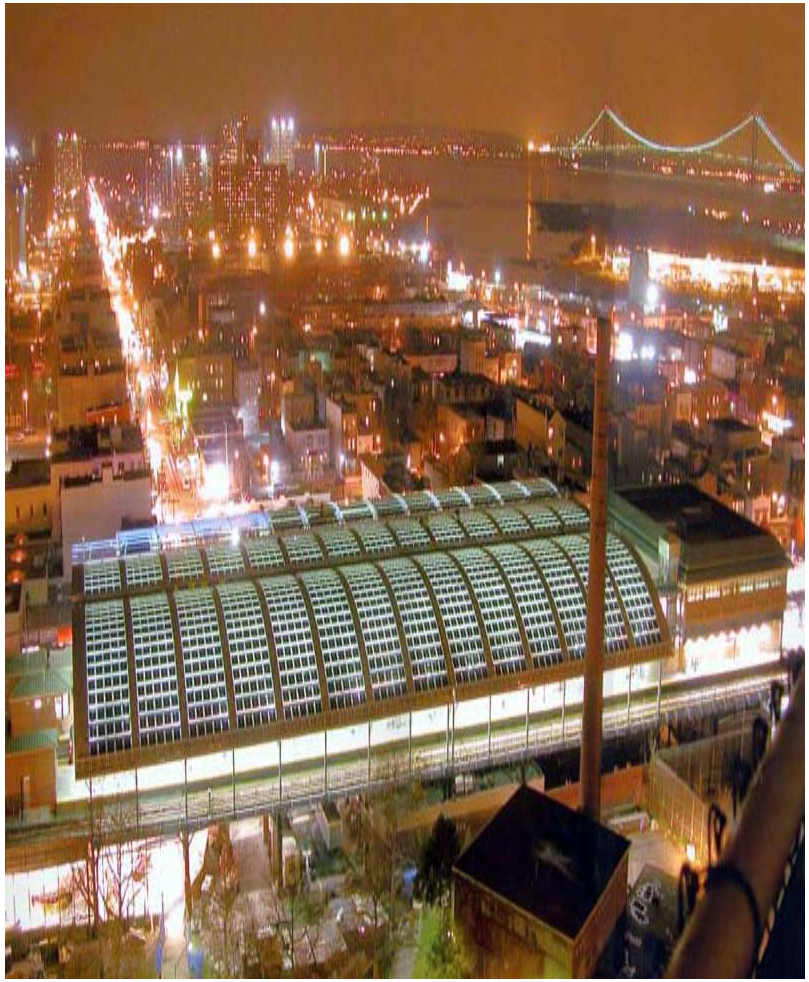
- 4,000+ square feet solar cells roof installation
- Maximum theoretical output of 60 kilowatts

Adam Joseph Lewis Center for Environmental Studies
Oberlin College, Oberlin, Ohio

Renewable Energy: An Energy Destination for the West June 21-22, 2002

Building Integrated Photovoltaics (BIPV)



Kiss + Cathcart, Architects

Coney Island's Stillwell Ave Terminal

Kiss + Cathcart, Architects

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Photovoltaics

Current and Future Status

System	Current Applications	Current Status	Future Status
Crystalline Silicon	➢ Solar farms ➢ BIPV ➢ Rooftops	➢ 90% of PV market ➢ Most efficient (≈19%) and expensive ➢ Limited aesthetic appeal ➢ Heavyweight construction	➢ Incremental cost reduction ➢ Efficiency gains near limit ➢ Remains workhorse of industry
Thin Film	➢ Solar farms ➢ BIPV ➢ Mobile consumer products	➢ Less efficient (≈ 9% to 12%) and less expensive ➢ Broader aesthetic appeal ➢ Lightweight	➢ Efficiency gains and cost reduction ➢ Very large area production capability ➢ Increase BIPV for façade installations
Organic/ Dye	➢ Mobile consumer products	➢ Potentially least expensive ➢ Lowest efficiency issues ➢ Lightweight	➢Stability issues limit progress ➢ 5 years (?) to large area commercialization ➢ Increase in efficiency

Industry Payback on Investment

- To alleviate costs, reduce risks and accelerate progress the glass industry will
  - Focus investment in key areas dictated by the megatrends
  - Form partnerships
  - Leverage existing assets
- Rate and degree of development will depend on
  - Legislation/incentives to drive investment
  - Increasing price for traditional forms of energy
  - Net positive effect on the environment

The Future of Architectural Glass

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- **Architectural glass will be driven primarily by energy, environmental, and aesthetic megatrends.**
  - – Products combining specialty glass and nanotechnology solutions will continue to lead the way.
  - – Energy efficiency will be guided by integrated design processes (e.g., BIM) and measurement and feedback of real world systems.
- **Current industry investments**
  - –**are driving towards added value products** that optimize energy efficiency and providing aesthetics while continuing to improve manufacturing efficiencies.
- **Future industry investments**
  - – **will shift to solar technologies (PV)** as efficiencies become increasingly dependent on glass and coating components;
  - – **will focus on new materials** to provide innovative solutions that produce breakthrough technologies.
- **To alleviate costs, reduce risks and accelerate progress the glass industry will form partnerships in key areas.**

Conclusion

- The glass industry's future path will see more change than any time in its long history
- The opportunity for growth will be great and driven primarily by energy, environmental, and aesthetic megatrends

Thank You