Glass R&D – Solar Technologies

CSP Portfolio Review Meeting

February 9-11, 2010

High Performance Reflector Panels for Concentrating Solar Power Assemblies

PPG Industries

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Enabling Energy
Glass & Coatings
for Solar Power

Glass Technology
Since 1883

PPG Industries

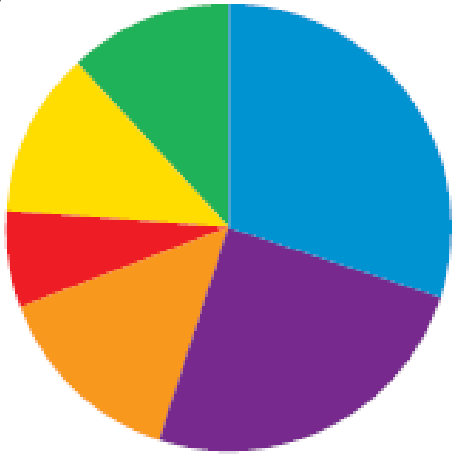
- A global maker of coatings, chemicals, optical products, specialty materials, glass and fiber glass
- Founded in 1883 with headquarters in Pittsburgh, PA
- More than 140 manufacturing facilities and equity affiliates
- Employs 40,000 worldwide and operates in more than 60 countries

PPG Performance Glazings

- First commercially successful glass producer in North America
- Produces flat, fabricated and coated glass – most complete producer in North America
- Production capability well positioned to serve the Solar Technologies market

2008 Segment Net Sales

2008 Sales of $13.5 Billion



- Performance Coatings (30%)
- Industrial Coatings (25%)
- Architectural Coatings EMEA (14%)
- Optical & Specialty Materials (7%)
- Commodity Chemicals (12%)
- Glass (12%)

part of

Glass Technology Since 1883

PPG Glass Business and Discovery Center

Harmar Township, PA (near Pittsburgh)

Since 1910, a team of world-class scientists and engineers committed to creating the highest value for our customers through innovation.

- **Fundamental and applied research**
- **Development**
- **Prototyping**
- **Technology transfer**
- **Customer support**

- Glass Composition
- Glass Melting & Forming
- MSVD (Vacuum) Coatings
- CVD and Pyrolytic Coatings
- Glass Surface Chemistry
- On-glass Electronics
- Tempering & Laminating
- Complex Shapes & Fabrication
- High Strength Composites
- Adhesives / Attachments
- Nanotechnology

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Alignment of Interests

- PPG and DOE investment in the US Solar industry
  - The glass industry will be a key component of the solar supply chain
  - PPG has invested significant R&D resources to establish advanced glass products for photovoltaic and solar thermal technologies
  - The DOE investment in advancing the state of renewable energy complements and accelerates the industry's, e.g., PPG's, own development portfolio

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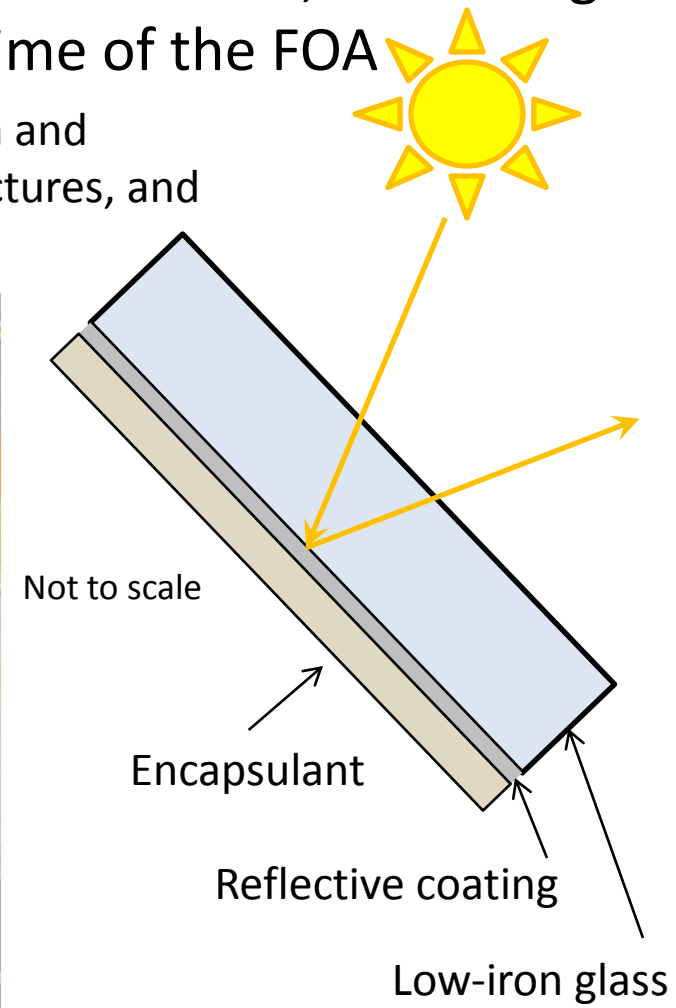
Project Objective

- The overall objective of this project is to develop and commercialize large-area second-surface mirrors that are superior in value, in terms of cost and performance, to existing mirrors available on the market at the time of the FOA
  - ➢ This objective will be accomplished through research and development activities into alternate materials, structures, and fabrication processes for reflector components



Timeline

- Preliminary PPG Work — 2007 - early 2008
- DOE Proposal Submission — August 2007
- DOE Project Award Notification — November 2007
- DOE Project Start Date — March 2008

Subtask	Description	Completion Date	Comment
1.1	Protective coating feasibility demonstration	Sept 2008	Testing continues
1.2	Design verification and bending evaluation	Sept 2008	Testing continues
1.3	Estimate impact on LCOE / Phase 1 Report	Sept 2008	5% LCOE reduction for trough
2.1	Protective coating and optical layer development	March 2010	
2.2	High rate fabrication manufacturing process development	March 2010	
2.3	Product and process design validation through field testing	March 2010	Date for medium-area prototypes in the field
2.4	Analysis of field tests	March 2010	Based on accelerated testing
3.1	Production equipment design, installation and pilot production	April 2011	
3.2	Final testing; begin customer qualification	July 2011	
3.3	Phase 3 report	Sept 2011	
3.4	Project Management and Reporting	Sept 2011	

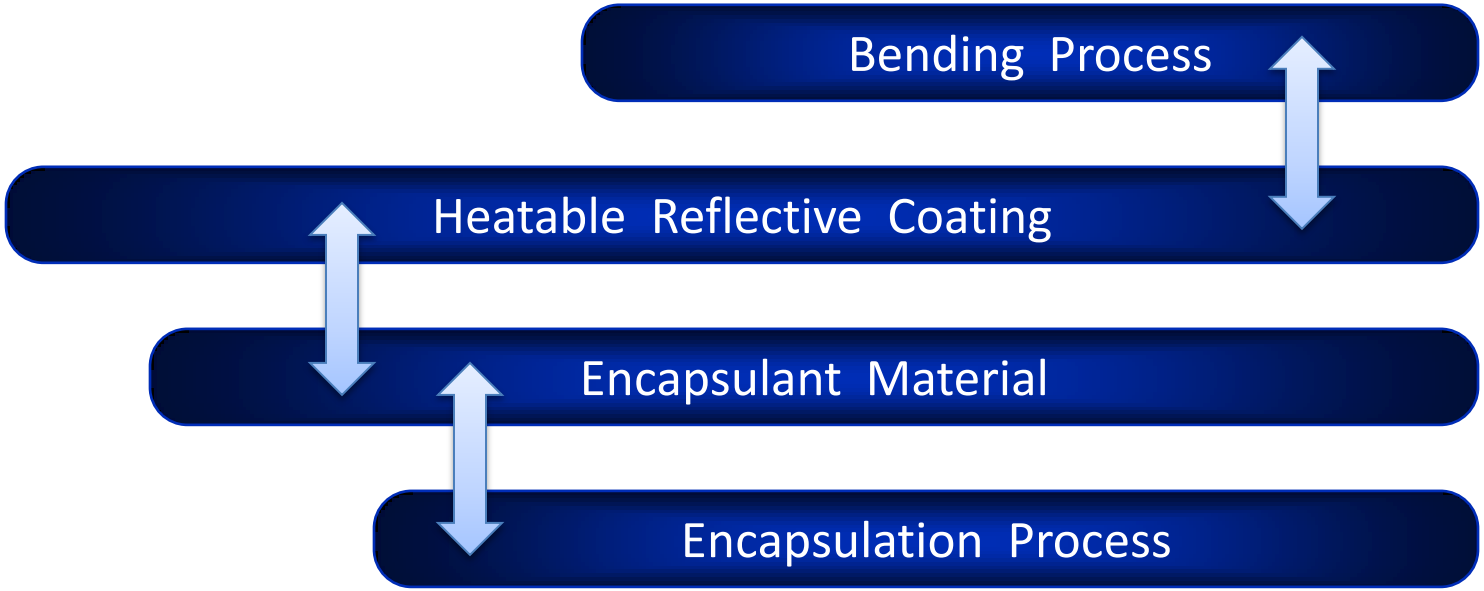
Milestones

Phase	Milestone	Status
1	Identification of protective coating candidates	Complete
1	Update on progress towards design verification and bending evaluation	Complete
1	Critical: Go / No Go recommendation	Go
2	Identification of process parameters for scaled-up manufacturing process (encapsulant)	Approaches identified
2	Identification of process needs for large scale, high-rate mirror fabrication	Approaches identified
2	Prototype mirror samples for validation	Lab testing recent improvements
2	Critical: Go / No Go recommendation	Anticipate Go
3	Production mirror samples suitable for validation	
3	Finalize initial target customers and supply samples from robust manufacturing process	
3	Critical: Technical report and presentation on anticipated impact of this technology	

Solarphire® HVM Glass (High Value Mirror)

Three product types:	flat annealed flat tempered bent

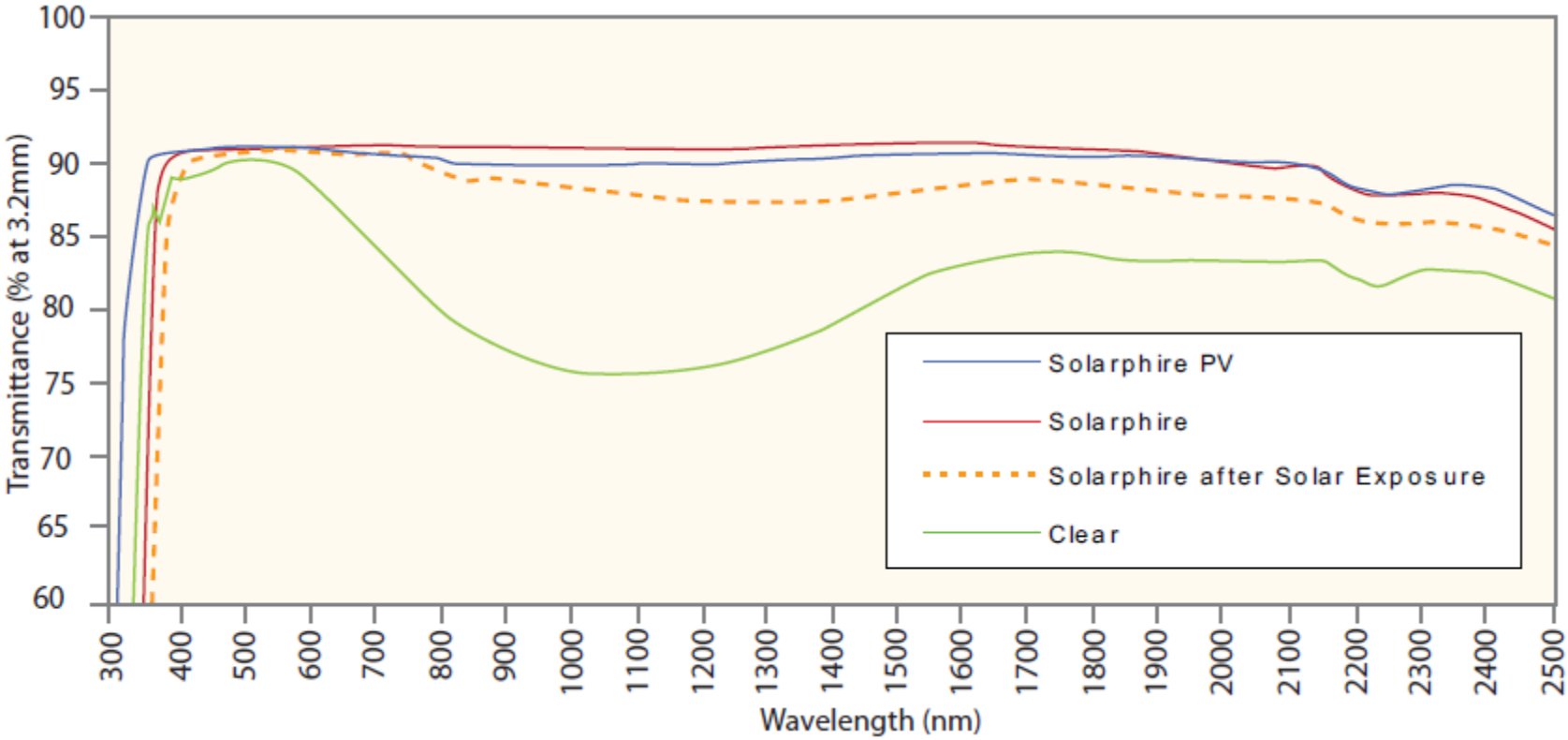
Parallel development of



while assessing and improving **durability** and checking compatibility with various adhesives.

Glass Superstrate – Solarphire® PV Glass

- PPG low-iron glass development just before the start of this project



Glass Thickness		Transmittance				Reflectance	
inches	mm	Ultra-violet (%)	Visible (%)	Infrared (%)	Total Solar (%)	Visible (%)	Total Solar (%)
1/8	3.2	88	91	90	91	8	8

Figures may vary due to manufacturing tolerances. All tabulated solar performance data are based on the methodology prescribed in ISO 9050, 2003 except Infrared which is based on P. Moon solar irradiance, 800-2100nm. Slight changes in transmitted optical properties may occur on exposure to sunlight.

Reflective Layer - Optical Performance Results

Product ID / Customer & Published Specifications	ISO 9050 % Reflectivity as-deposited	ISO 9050 % Reflectivity post-heat
PPG 2.1mm Solarphire® HVM glass	94.2	95.5
PPG 3.2mm Solarphire® HVM glass	93.3	94.3
PPG 4.0mm Solarphire® HVM glass	92.4	93.7
Customer #1 specification (3.2mm)	>92.5	
Supplier #1 product brochure (4mm)	>93.5 (parabolic) >93.0 (flat, low lead) >92.3 (flat, lead free)	

Accomplishments

- PPG Solarphire® HVM glass surpasses benchmarks and can be tempered, heat-strengthened, and/or bent with a performance boost of up to 1.3%
- Have made flat annealed mirrors as large as 89” x 126” on production equipment

NOTE: Much of this development was independent of DOE funding

Environmental Durability

- **No existing industry standards for solar mirrors**
- **Customers looking to mirror suppliers to define suitable test protocols & metrics**

What a mirror needs to do - service life in the field

Withstand sunlight, heat, humidity, cold, condensation, freezing, wind, sand, rain, snow, acid rain, other environmental contaminants, etc. for 20 to 30 years, while remaining attached to the support structure.

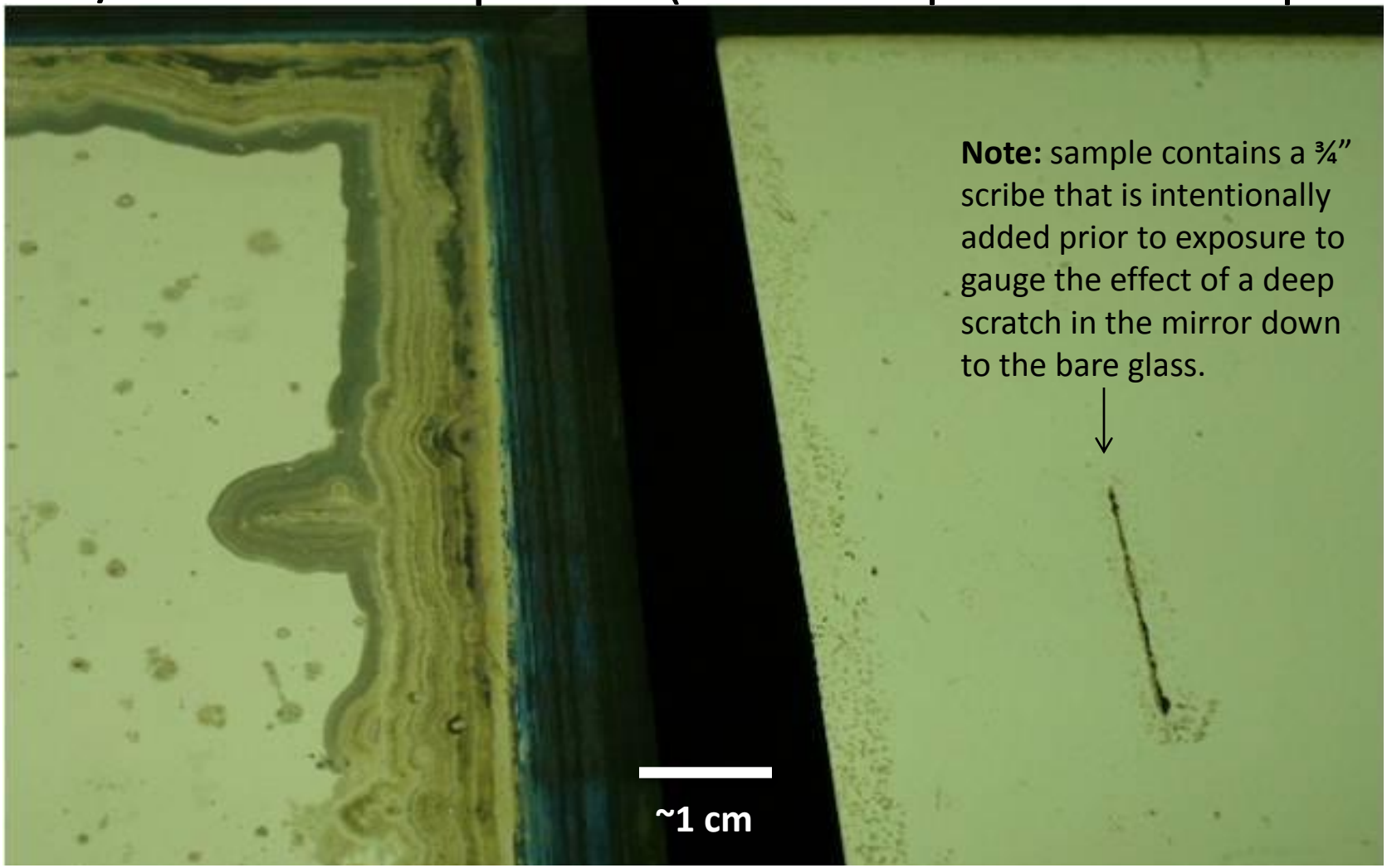
What accelerated testing means

An accelerated test can only suggest durability to a *limited number* of factors.
(That is, accelerated testing only drives certain failure mechanisms, usually independently.)

→ **85°C / 85%RH Damp Heat – heat combined with humidity**
5% salt fog, CASS , 20% salt fog – environmental contaminants (limited)
SO_2 (Kesternich) – acid rain (approximate)
Cleveland and 38°C/100%RH humidity – condensation and humidity (and heat)
Thermal cycling – temperature changes
Humidity-freeze – temperature changes combined with heat and humidity
Weather-O-Meter (WOM) – light, heat, humidity
Outdoor exposure (not accelerated) – conditions of only one location & time frame

Identified by NREL as most aggressive test on solar mirrors that they have tested

85°C / 85%RH Damp Heat (Non-encapsulated = no paint)



Note: sample contains a ¾" scribe that is intentionally added prior to exposure to gauge the effect of a deep scratch in the mirror down to the bare glass.

January 2008 mirror (26 weeks exposure)

April 2008 mirror (20 weeks exposure)
- Looks similar at 74 weeks exposure

- Development work improved durability in 85/85 testing in the non-encapsulated (unpainted) state
- Encapsulation (with suitable material) further improves the durability in 85/85 testing

85°C / 85%RH Damp Heat

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Oct 2008 mirror
Non-encapsulated
(55 weeks exposure)
(2 different samples)

Degradation:
Edge: up to several mm
Face spots: very few
Scribe: very minor degradation (<1 mm)

Oct 2008 mirror - **Encapsulated**
(47 weeks exposure)
(same sample)

Degradation:
Edge: usually none; <1 mm in places
Face spots: none
Scribe: no degradation

Accomplishment

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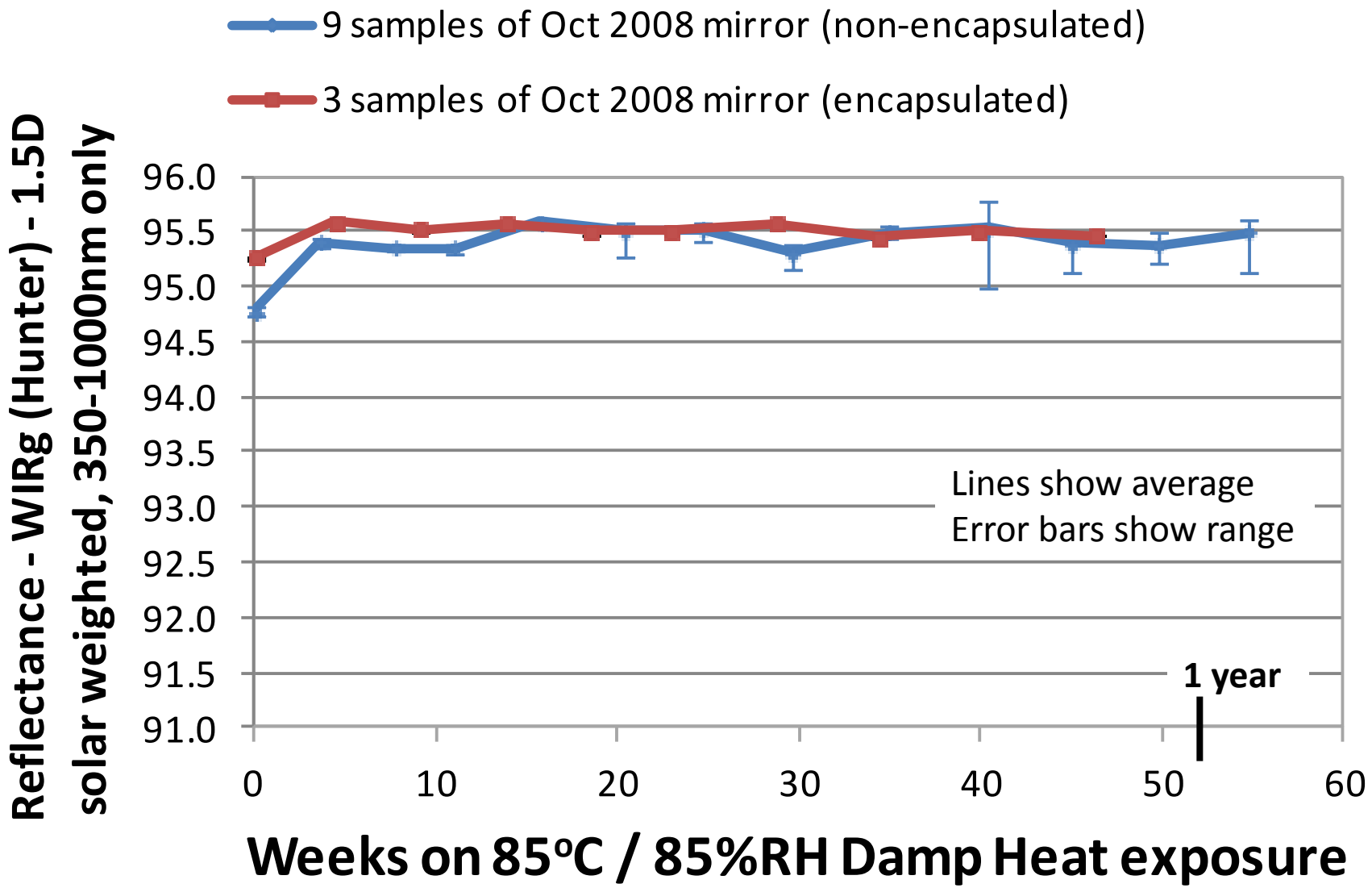
85°C / 85%RH Damp Heat



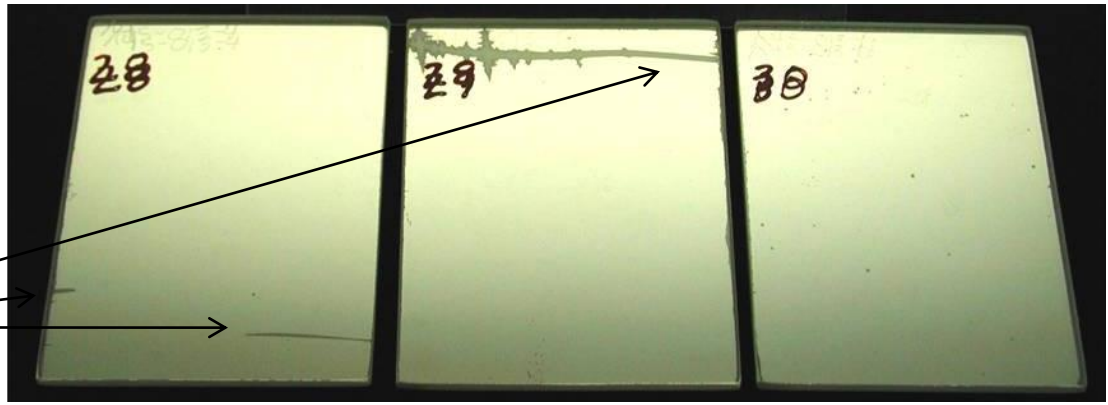
Accomplishment

- **No reflectance loss after 1 year of accelerated exposure**

CASS Testing*

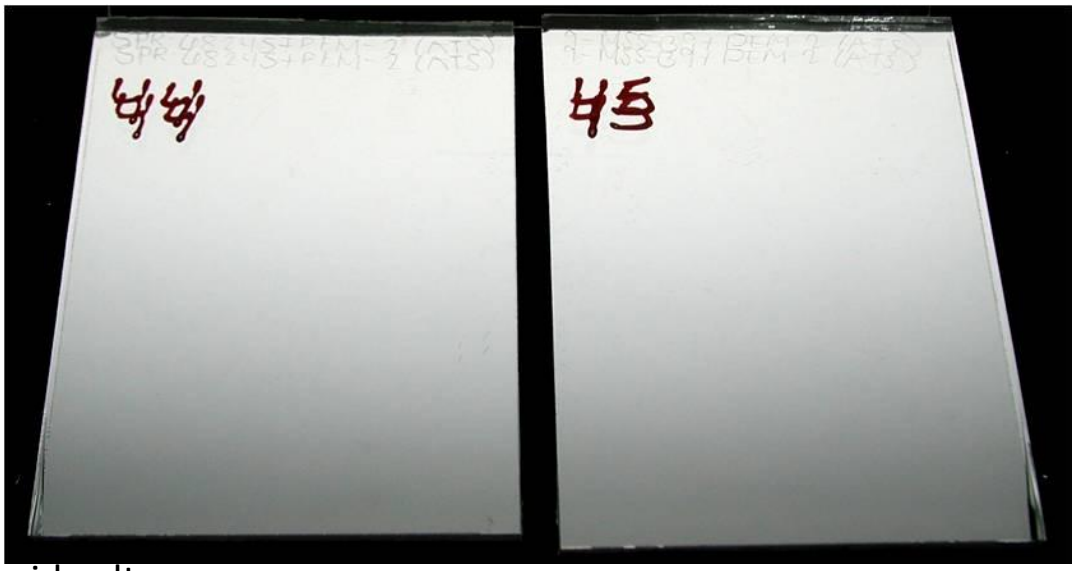
Mirror degrades when coated with regular developmental lead-free backing (cut then paint)

Challenge



Seaming the mirror edges prior to painting helps, but ingress can still occur

Breakthrough



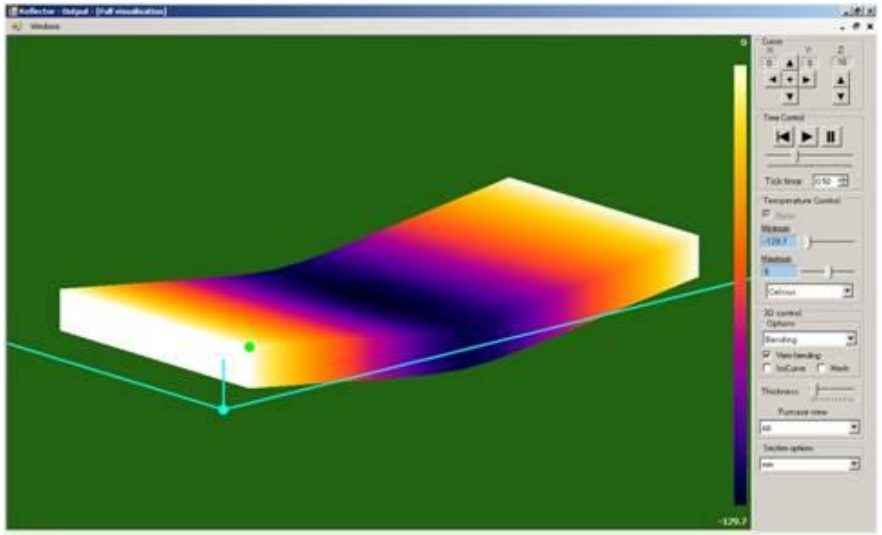
Mirrors (without seaming) show no degradation with recent lead-free encapsulant formulation

➢Currently working through the development of this promising approach

*120-hours of copper-accelerated acetic acid-salt spray

Geometry / Shape Fabrication

- Computational models
- Trials demonstrate bending feasibility
  - 36” x 48” Solarphire® HVM glass samples bent with cylindrical geometry to a depth of 1.2” (LS-3 / LS-4 “radius”)
  - Good optics achieved for both 3.2mm and 4.0mm thicknesses



Additional Bending Trial

- Bent samples in sizes up to 61.8" x 74.8“ (LS-4 size), as shown in picture
- bent with a cylindrical radius of 160” (LS-3 / LS-4 “radius”)

Accomplishment

Summary

- PPG is continuing the development of a new second-surface glass mirror for CSP applications
  - High reflectivity
  - Mirror can be tempered and/or bent (before encapsulation)
  - Proven bending feasibility of LS-4 size on commercially available glass bending equipment
  - >1 year non-encapsulated durability in 85°C/85%RH damp heat
  - Lead-free encapsulation system with little to no visible corrosion after 120 hours of CASS exposure

  - ➢ Large-area prototypes have been made & sold
  - ➢ Compatibility with adhesives
  - ➢ No wet-chemistry wastes and no lead used
  - ➢ Merit design of full-scale manufacturing process to estimate capital and operating costs

Next Steps (6-12 months)

- Continue development of new encapsulation formulation and validate with lab testing
- Test mid-size to large-size prototypes in the field at multiple locations
- Develop the business case and the path forward for PPG prior to entering Phase 3 of this project

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