

---

# 2008 Solar Annual Review Meeting

**Session: CSP Advanced Systems: Optical Materials**

**Organization: National Renewable Energy Laboratory**



---

Cheryl Kennedy

NREL

303-384-6272

[cheryl\\_kennedy@nrel.gov](mailto:cheryl_kennedy@nrel.gov)

NREL/PR-550-43334

Presented at the Solar Energy Technologies Program (SETP) Annual Program Review Meeting held  
April 22-24, 2008 in Austin, Texas





# Relationship to Solar Program Goals

**“...to make CSP cost competitive in the intermediate power markets by 2015 (~7¢/kWh with 6 hours of storage) and in baseload power markets (~5¢/kWh with 16 hours of storage) by 2020.”**

## 1. Optical Materials project overview

- a) Project description: Characterize advanced reflectors, perform accelerated and outdoor testing of commercial and experimental reflector materials, and provide industry support.
- b) Major FY08 Activities:
  - Mirror Characterization and Testing
  - CSP Advanced Concepts FOA Support
    - 3M – Hardcoats for Polymeric Mirrors
    - Abengoa – Advanced Front Surface Polymeric Reflector
    - Alcoa – Aluminum reflector
    - PPG – High Value Mirrors



# Relationship to Solar Program Goals

**“...to make CSP cost competitive in the intermediate power markets by 2015 (~7¢/kWh with 6 hours of storage) and in baseload power markets (~5¢/kWh with 16 hours of storage) by 2020.”**

## 1. Project overview (continued)

Project description:

### c) Planned Milestones

- Level 5:
  - Complete installation of new accelerated exposure chambers (3/08)
  - Determine new optical performance, lifetimes, and cost goals with input from technical community (3/08)
  - Report summarizing durability silvered thin-glass copper-free & lead-free mirrors after accelerated and outdoor exposure (6/08)
- Level 4:
  - Report summarizing durability of candidate solar mirror samples (9/08)
  - Report summarizing FOA support activities (9/08)

# Relationship to Solar Program Goals



## 1. Project overview (continued)

Project description

d) Budget Table (FTEs, \$FTE, Subcontract Info)

Agreement	FTEs	\$(K)	Subcontract \$(K)
Mirror Characterization & Testing	0.93	310	
FOA Support	0.93	250	
FOA:			1900
3M – Hardcoats for Polymeric Mirrors			350
Abengoa – Advanced Front Surface Polymeric Reflector			448
Alcoa – Aluminum reflector			399
PPG – High Value Mirrors			323

# Relationship to Solar Program Goals



## 1. Project overview (continued)

Project description:

e) Personnel contributing to the project:

NREL: Total <1 FTE

Cheryl Kennedy, Kent Terwilliger

Student interns: Marc Oddo, Andrea Warrick

## 2. Relevance to Program Plans & Goals

Solar Program Multi-Year Technical Plan targets cost reductions of up to 50% to the solar concentrator and recommends one of the ways the goals could be achieved is through technology advances that include lightweight front-surface reflectors that contain anti-soiling coatings.

# FY08 Progress Report



## 1. What has been accomplished thus far?

### a) Technical highlights:

- Continued durability testing of solar mirrors by accelerated and outdoor exposure in Colorado, Florida, and Arizona
- Responding to numerous (daily) industry requests for technical assistance & data
- Restoring capabilities
  - hiring staff
  - purchasing new accelerated weathering equipment
  - purchasing new optical measurement equipment
- Helped DOE organize “Specialty Glass Needs of the U.S. Solar Industry” workshop
- Organized 2 CSP Applications & Desalination sessions at SolarPACES
- Presented 2 invited papers at industry meetings

# FY08 Progress Report



## 1. What has been accomplished thus far?

b) Issues that have come up; solutions proposed:

- Insufficient resources to meet urgent requests for technical information & data from established and emergent CSP (& CPV) industries; plus increased testing & evaluation for FOA awardees & industry.
  - Hiring replacement staff
  - Purchasing replacement equipment
  - Will not have sufficient resources to meet all requests
- Reduced number of outdoor test facilities
  - Discussing possible loan agreement w/ Excel (Pueblo, CO) & PPG (Pittsburg, PA)
- Working with industry to develop new goals & standards
  - Industry acceptance after Solar Glass Workshop
  - US/International: Glass, Silvering, Coating, Utilities, Developers

# FY08 Progress Report



## 1. What has been accomplished thus far?

c) Costing (current level; projected end-year balance)

	FY06 Budget	FY07 Budget	FY08 Budget
Advanced Concepts	\$130k	\$135K	\$310k
Advanced Concepts FOA Support	\$0k	\$0k	\$250k
Capital Equipment	\$0k	\$113k	\$283k



# Broad Industry Collaboration:

## Glass Mirror

- Thick (>3-mm) Glass

- Flabeg
- NSG Pilkington
- Cristaleria Espanola S.A  
(i.e., Saint-Gobain)
- Saint-Gobain
- PPG (CSP FOA)
- RioSolar
- CSR (formerly Pilkington  
Australia → Veridian → CSR)
- Arch
- Cardinal
- Guardian

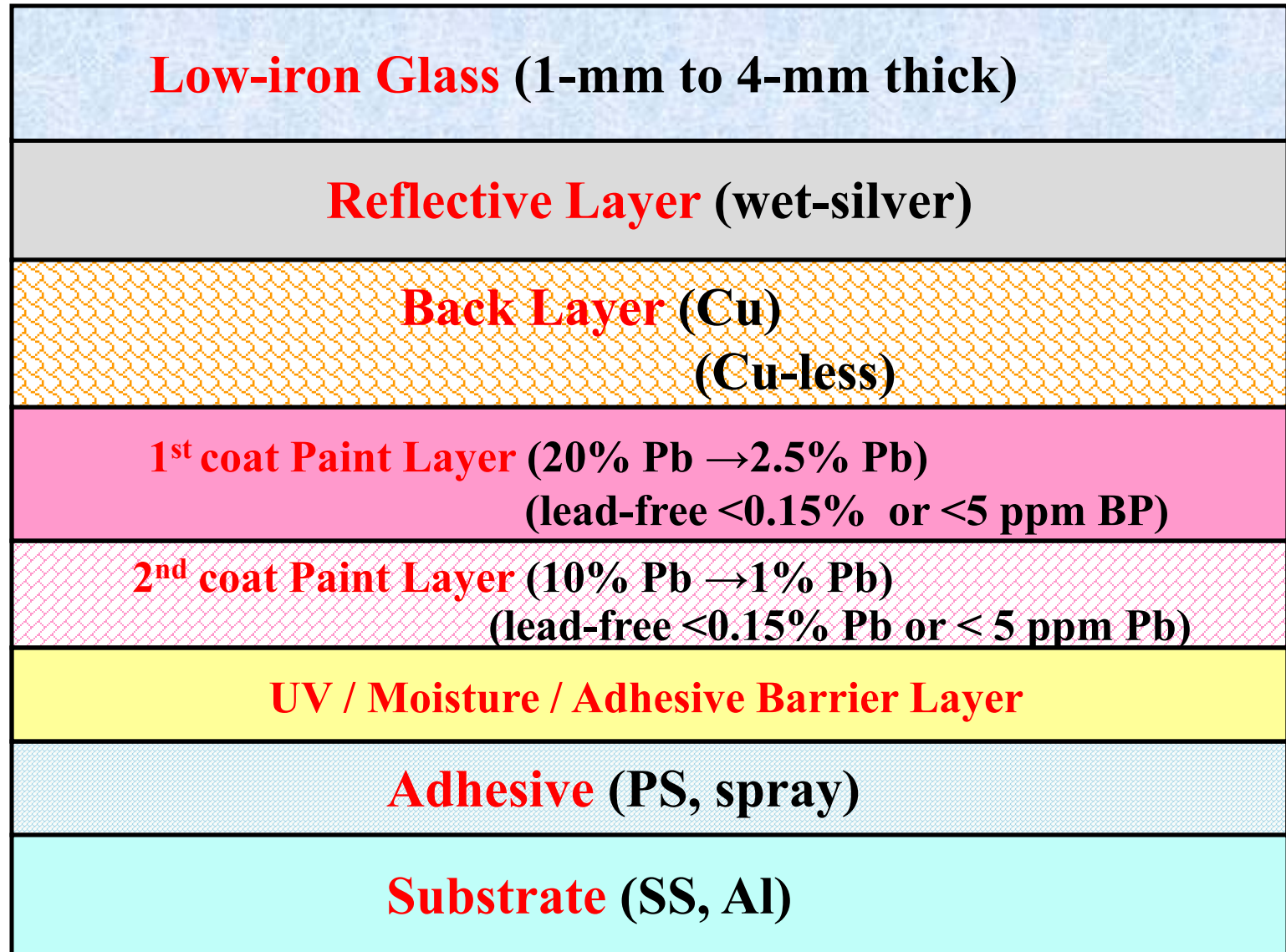
- Thin (~1-mm) Glass

- AGC Belgium  
(i.e., Asahi Glass Company  
formerly Glaverbel)
- AGC Thailand
- AGC Indonesia
- Naugatuck Glass Company

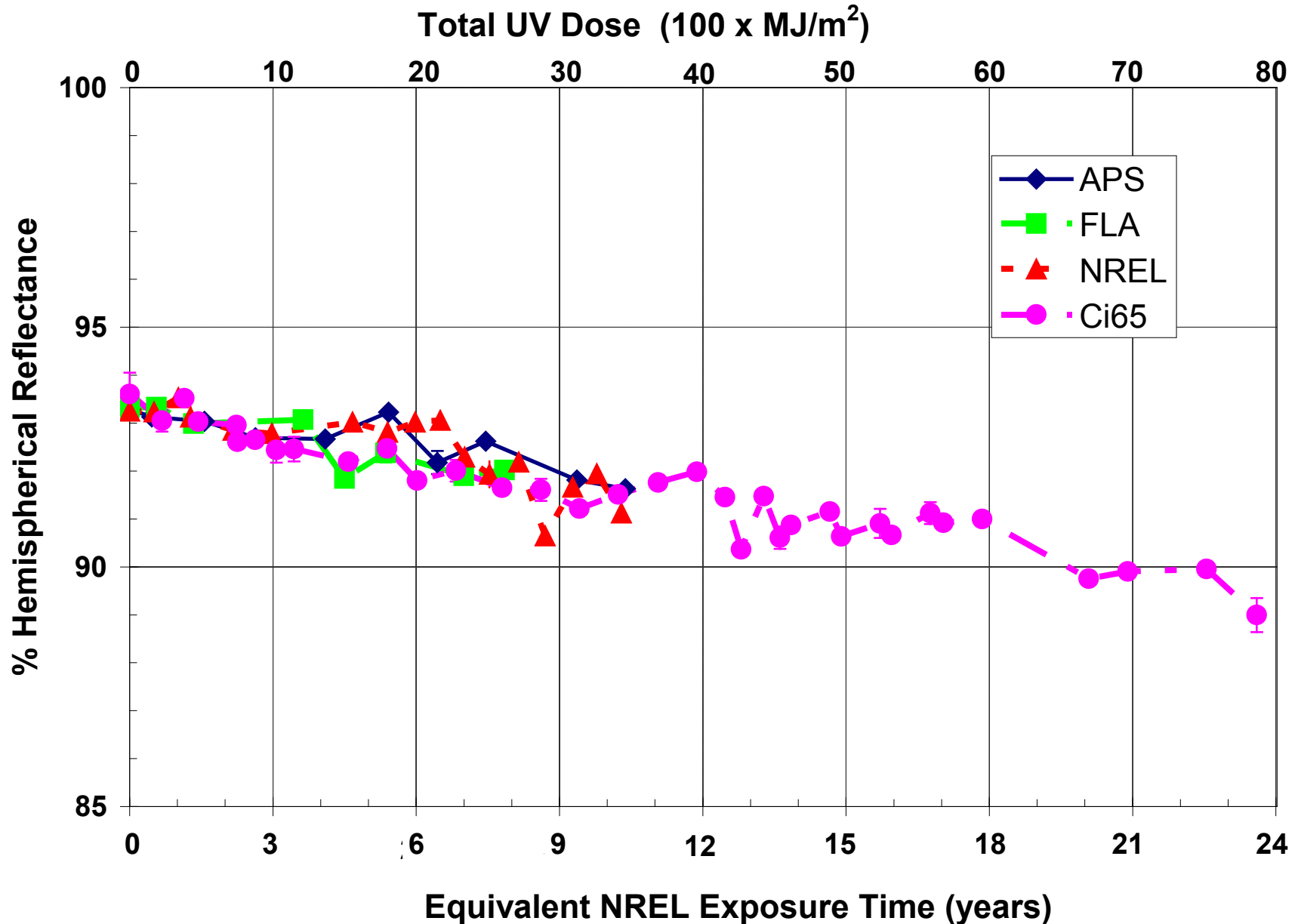
- Mirror Coating

- Valspar
- Spraylat

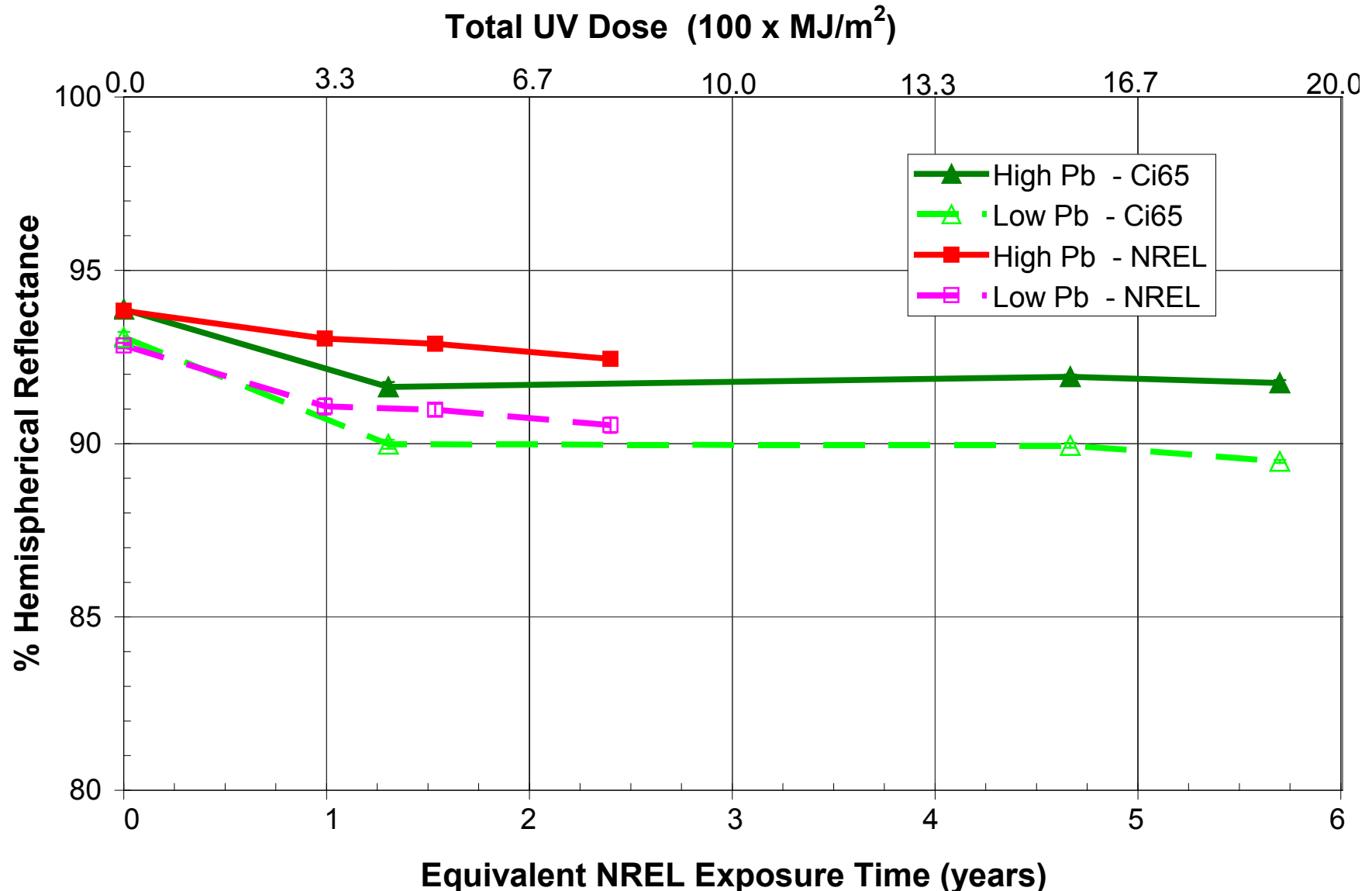
# Architecture of Glass Mirror



# Original High-Pb Flabeg is durable

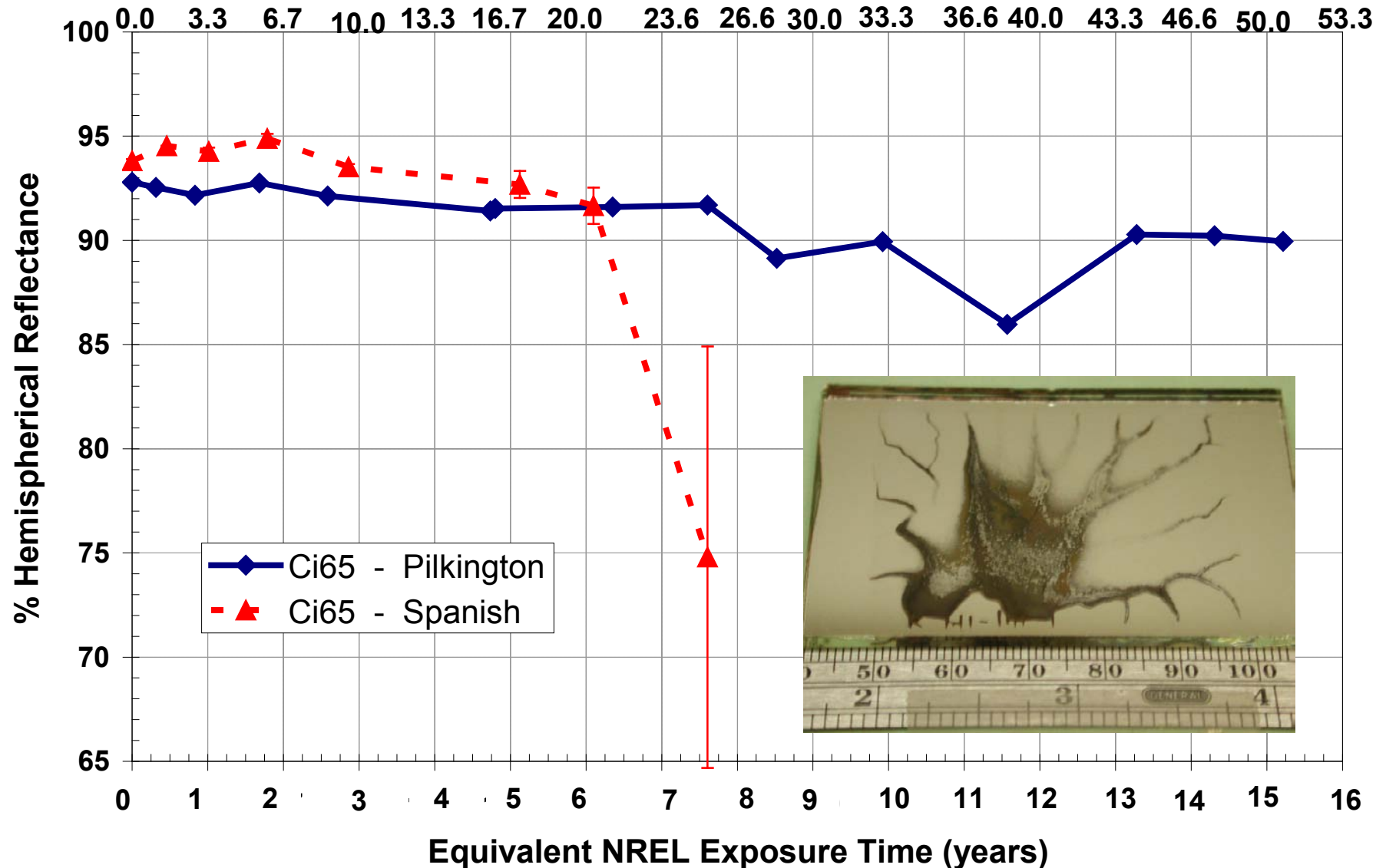


# Low-Pb Flabeg Mirror may be less durable than high-Pb



# Alternate Thick Glass Mirror

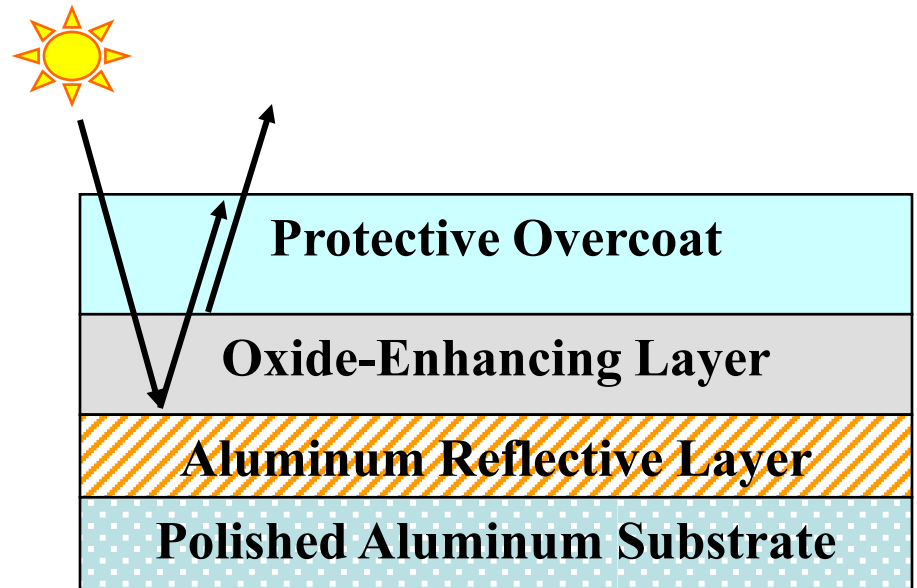
Total UV Dose (100 x MJ/m<sup>2</sup>)



# Industry Collaboration:

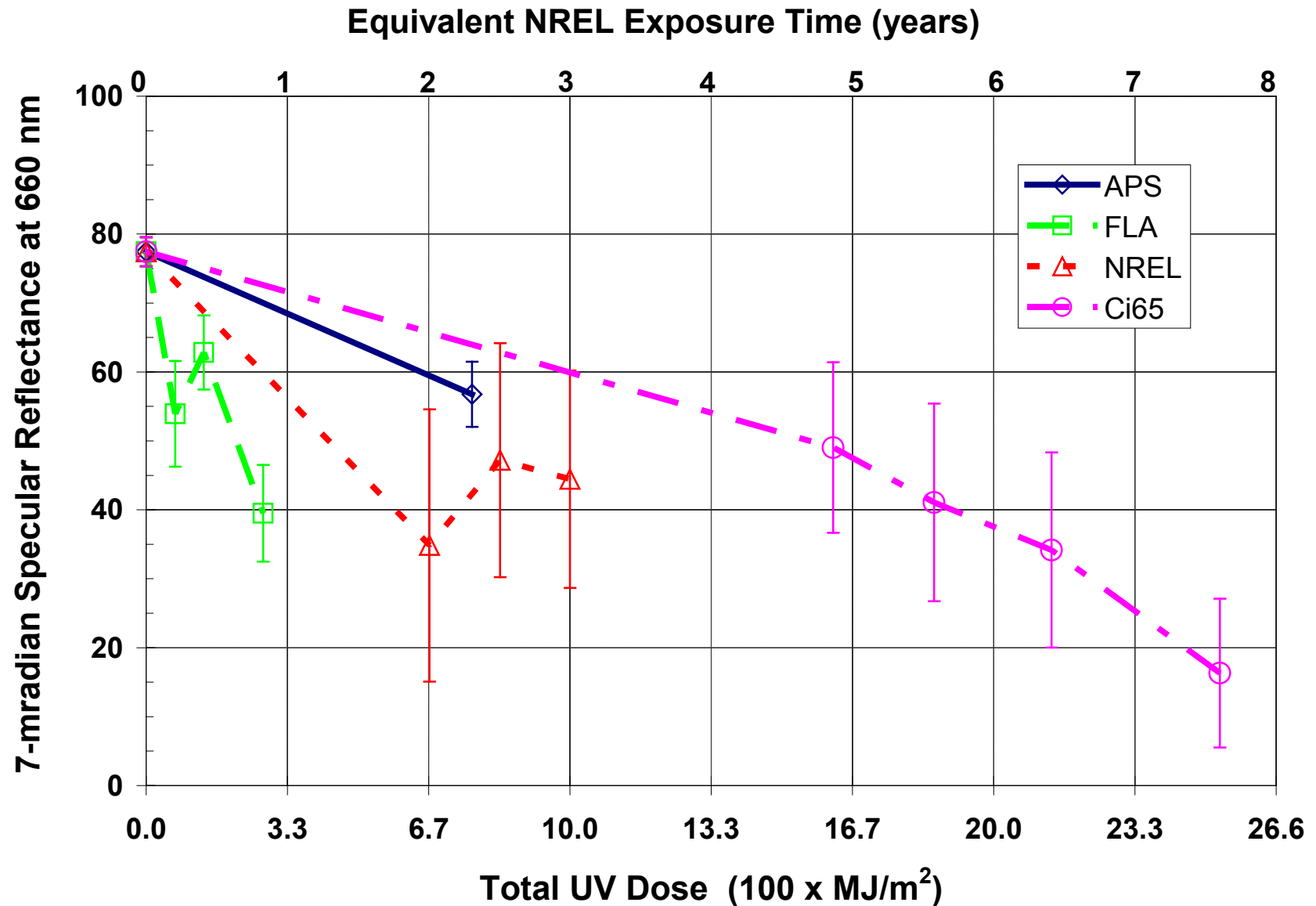
## Aluminized Mirror

- Alanod
- Alcoa (CSP FOA)
- Alcan
- Aluminum Coil Anodizing (ACA)

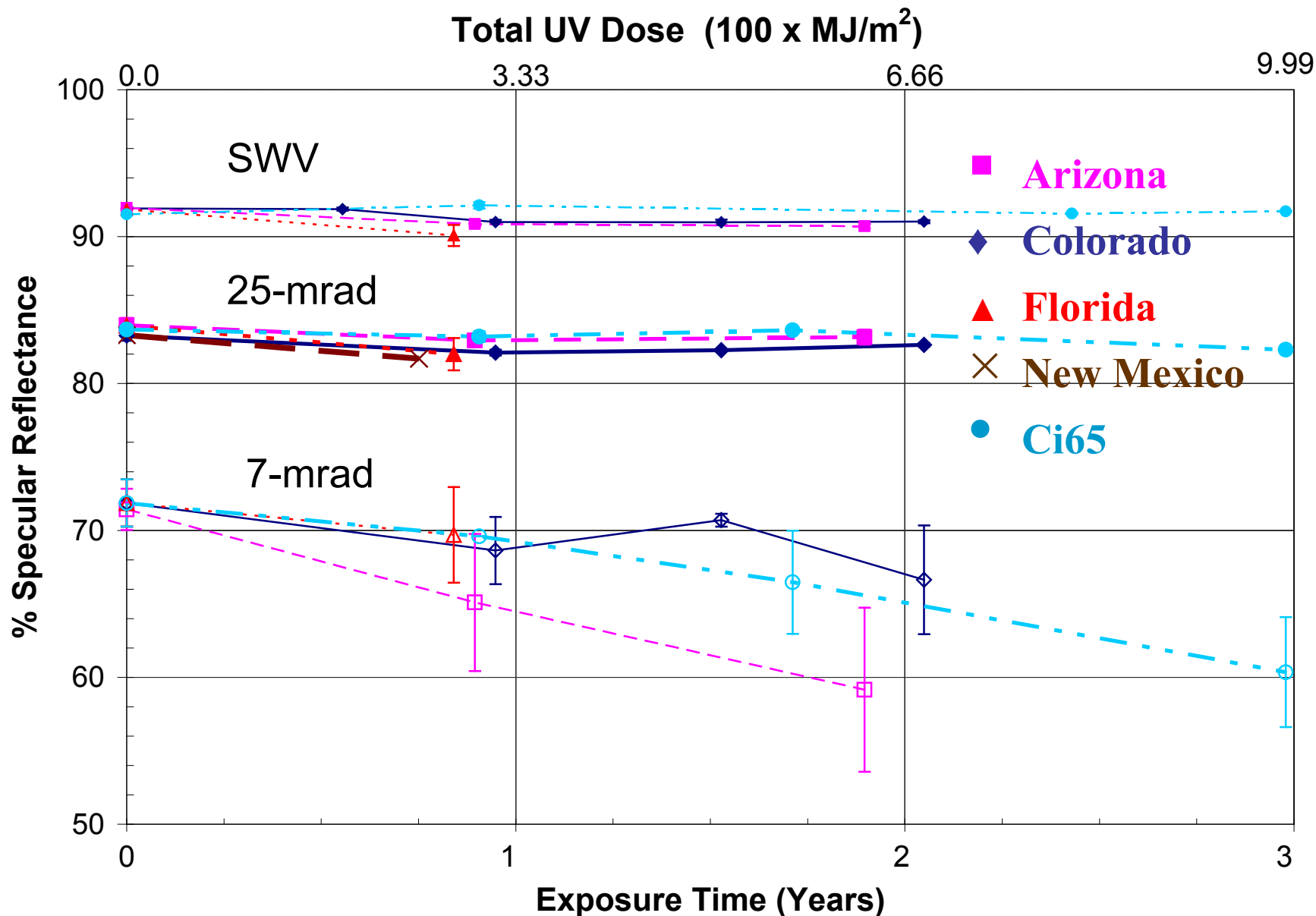


Architecture of aluminized mirrors

# Loss of Specularity of Alanod Aluminized Reflector w/ Fluoropolymer Overcoat



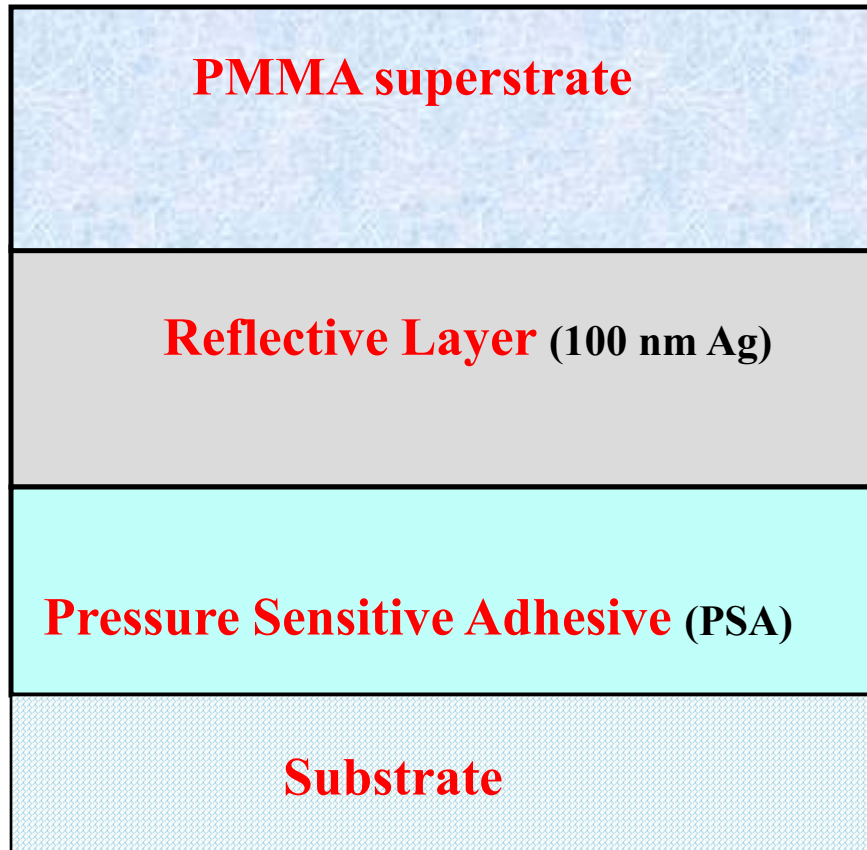
# Alanod Aluminized Reflector with Nanocomposite oxide layer





# Development of Improved 3M Polymer Mirror

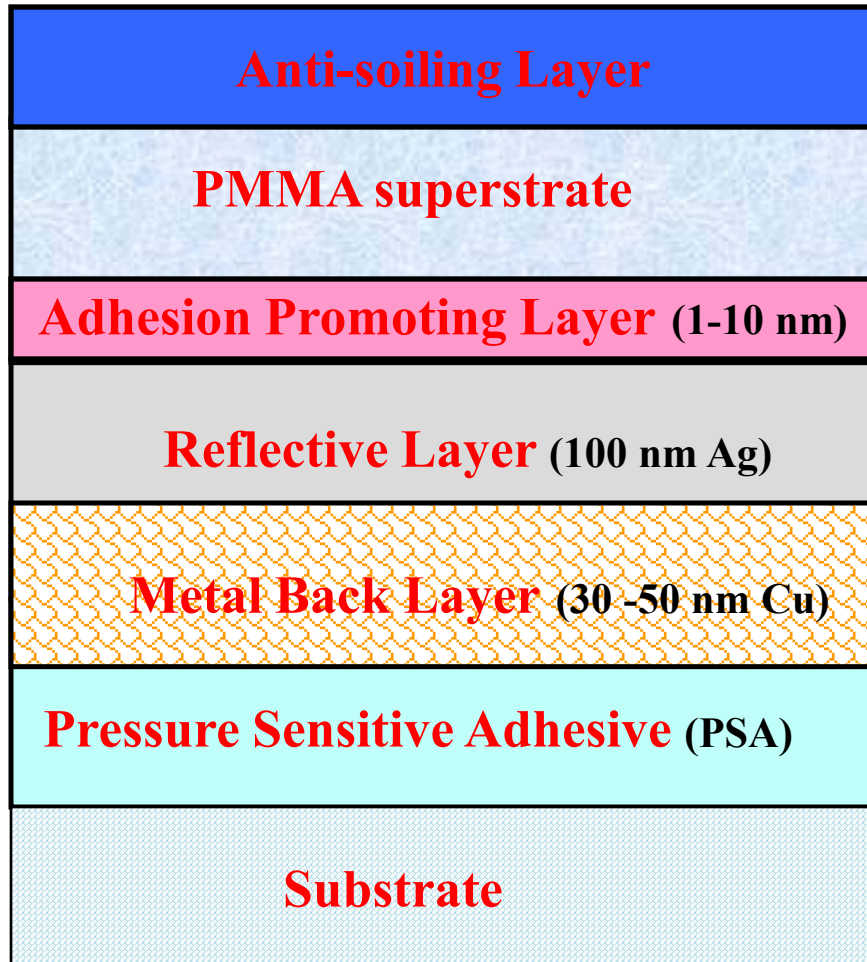
- based on prior NREL collaborations



- Antisoiling/hardcoat (FOA)
- Adhesion promoting layer
- Possibly provide laminated to substrate and heat treated
- Built on:
  - Joint NREL/3M subcontract
  - NREL patent
  - 2 NREL DDRDs

# Development of Improved 3M Polymer Mirror

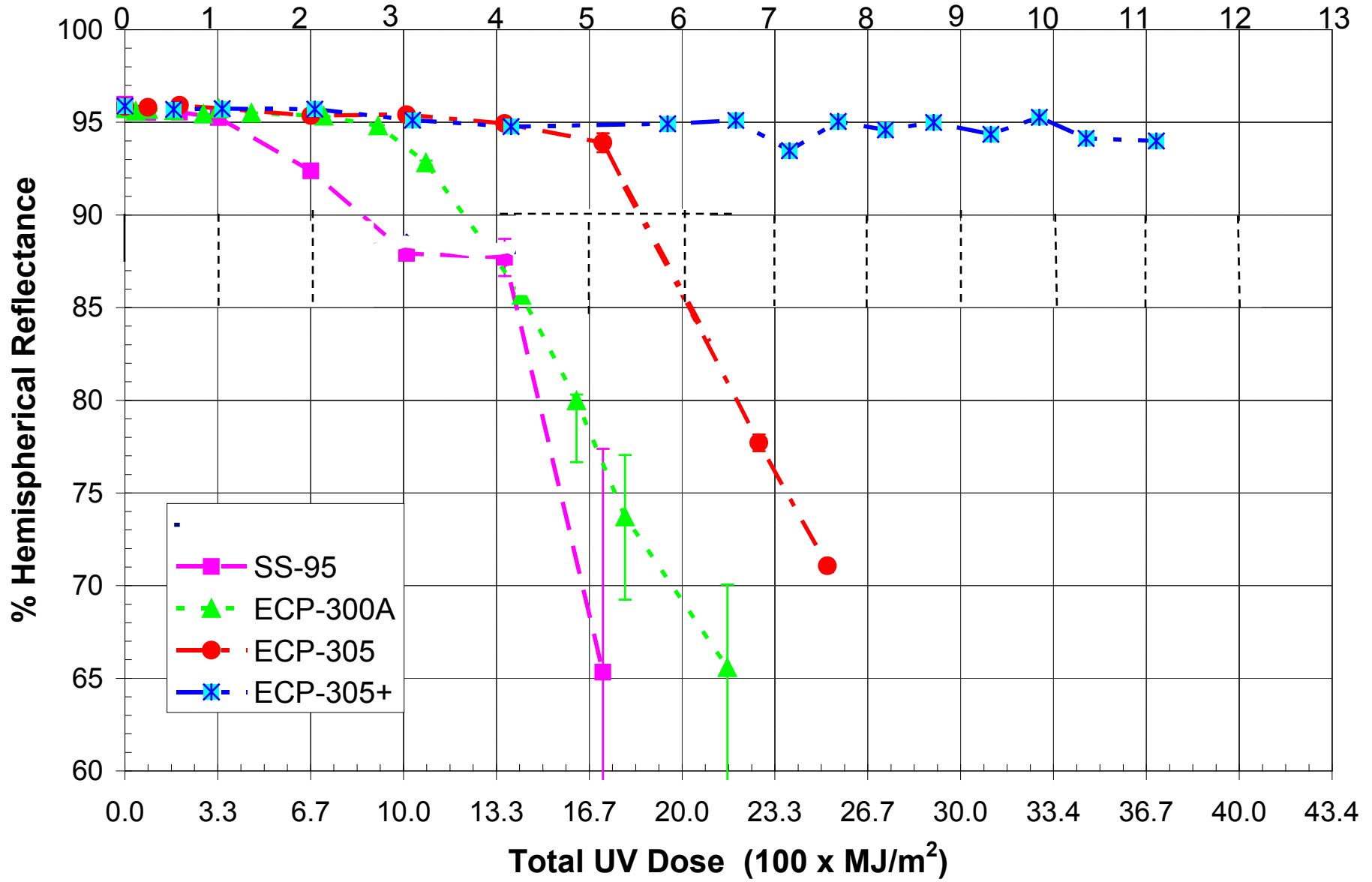
- based on prior NREL collaborations



- Antisoiling/hardcoat (FOA)
- Adhesion promoting layer
- Possibly provide laminated to substrate and heat treated
- Built on:
  - Joint NREL/3M subcontract
  - NREL patent
  - 2 NREL DDRDs

# 3M Metallized Polymer Films

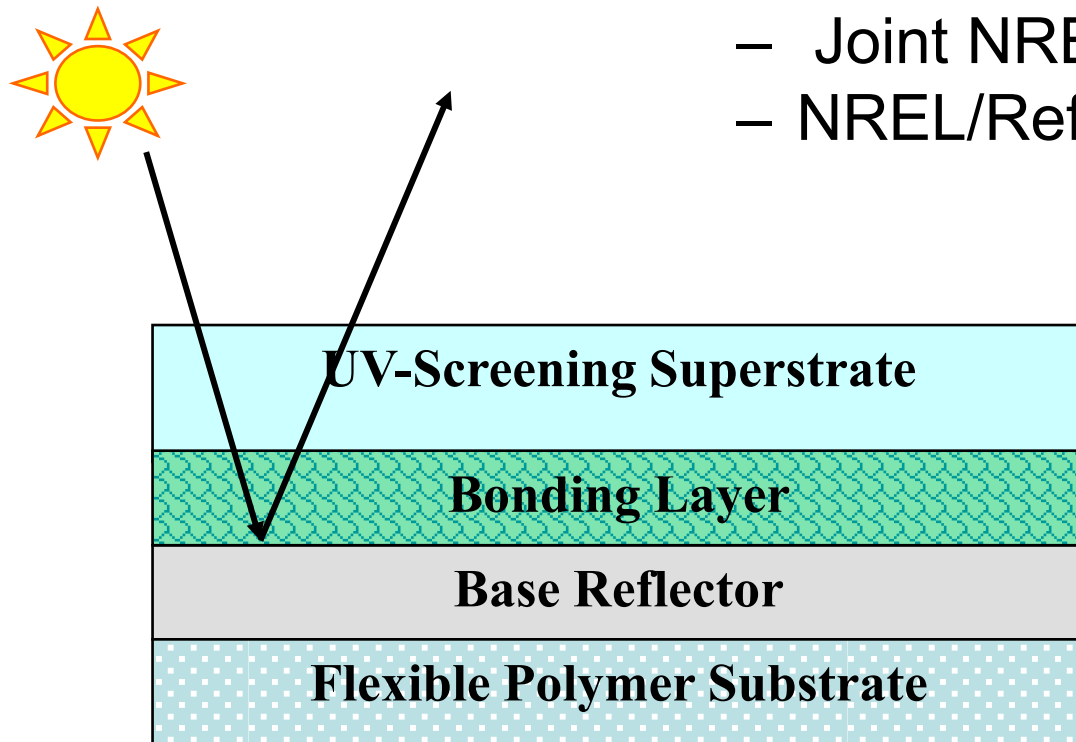
NREL Exposure Time (years)



# Development of Improved Polymer Mirror

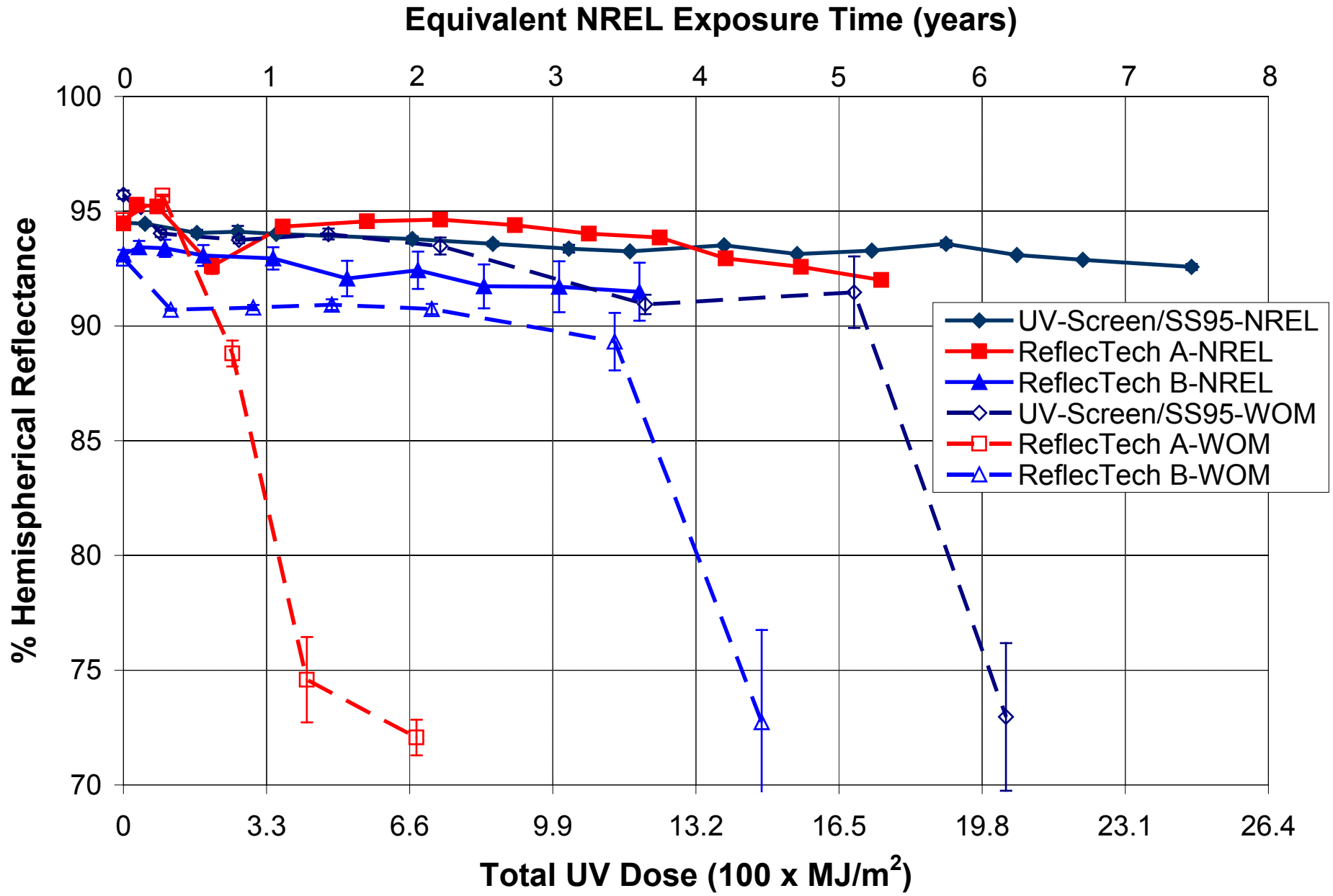
- based on prior NREL collaborations

- ReflecTech CRADA
  - Hardcoats
- Built on:
  - Joint NREL/ReflecTech patent
  - NREL/ReflecTech subcontract



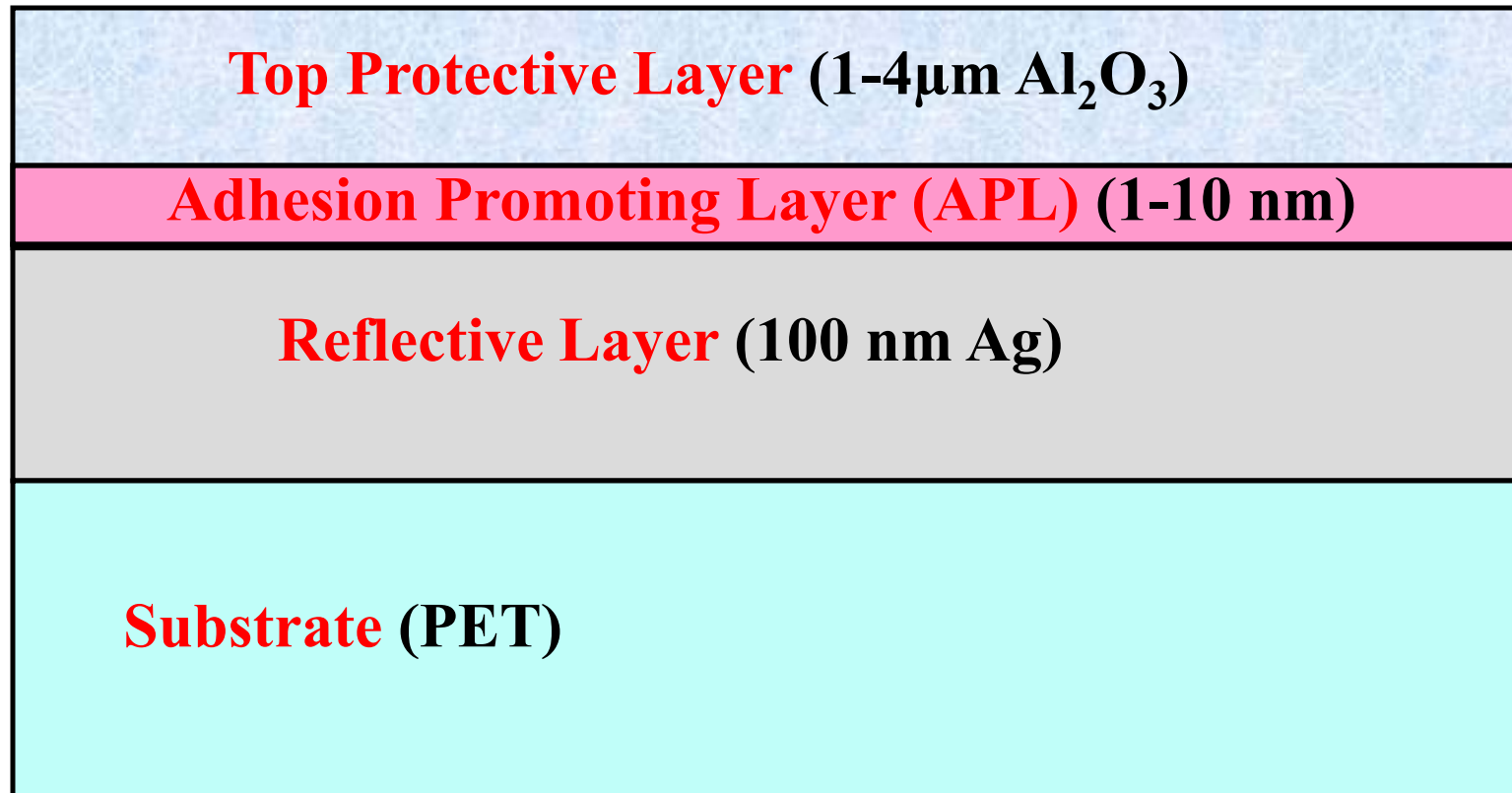
**ReflecTech**

# ReflecTech Prototypes



# Front Surface Solar Reflector Architecture

- Abengoa Solar (CSP FOA)
  - commercialize NREL / SAIC IBAD  $\text{Al}_2\text{O}_3$  ASRM subcontract



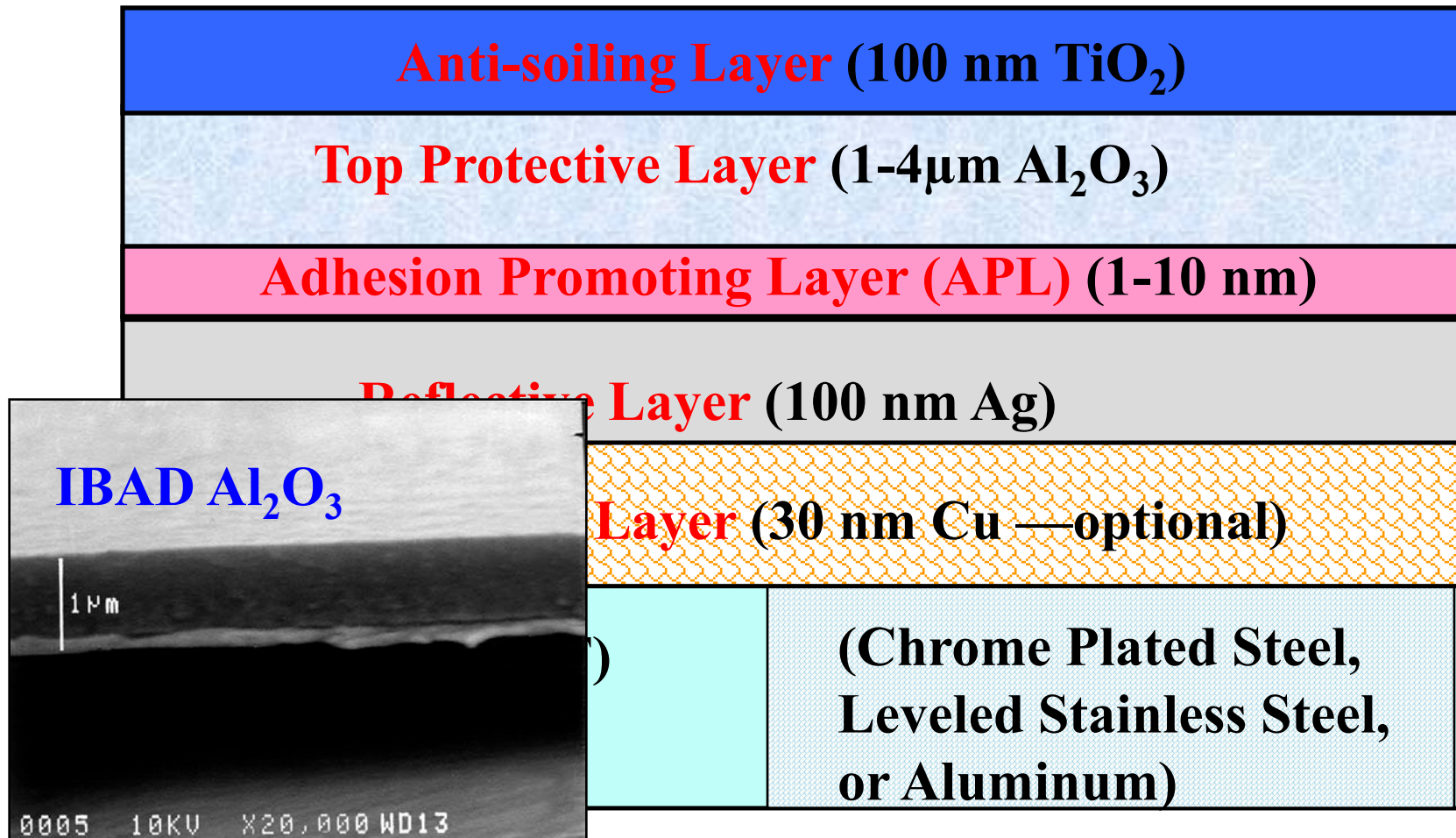
# Front Surface Solar Reflector Architecture

- Abengoa Solar (CSP FOA)
  - commercialize NREL / SAIC IBAD  $\text{Al}_2\text{O}_3$  ASRM subcontract

<b>Anti-soiling Layer</b> (100 nm $\text{TiO}_2$ )	
<b>Top Protective Layer</b> (1-4 $\mu\text{m}$ $\text{Al}_2\text{O}_3$ )	
<b>Adhesion Promoting Layer (APL)</b> (1-10 nm)	
<b>Reflective Layer</b> (100 nm Ag)	
<b>Metal Back Layer</b> (30 nm Cu —optional)	
<b>Substrate</b> (PET)	(Chrome Plated Steel, Leveled Stainless Steel, or Aluminum)

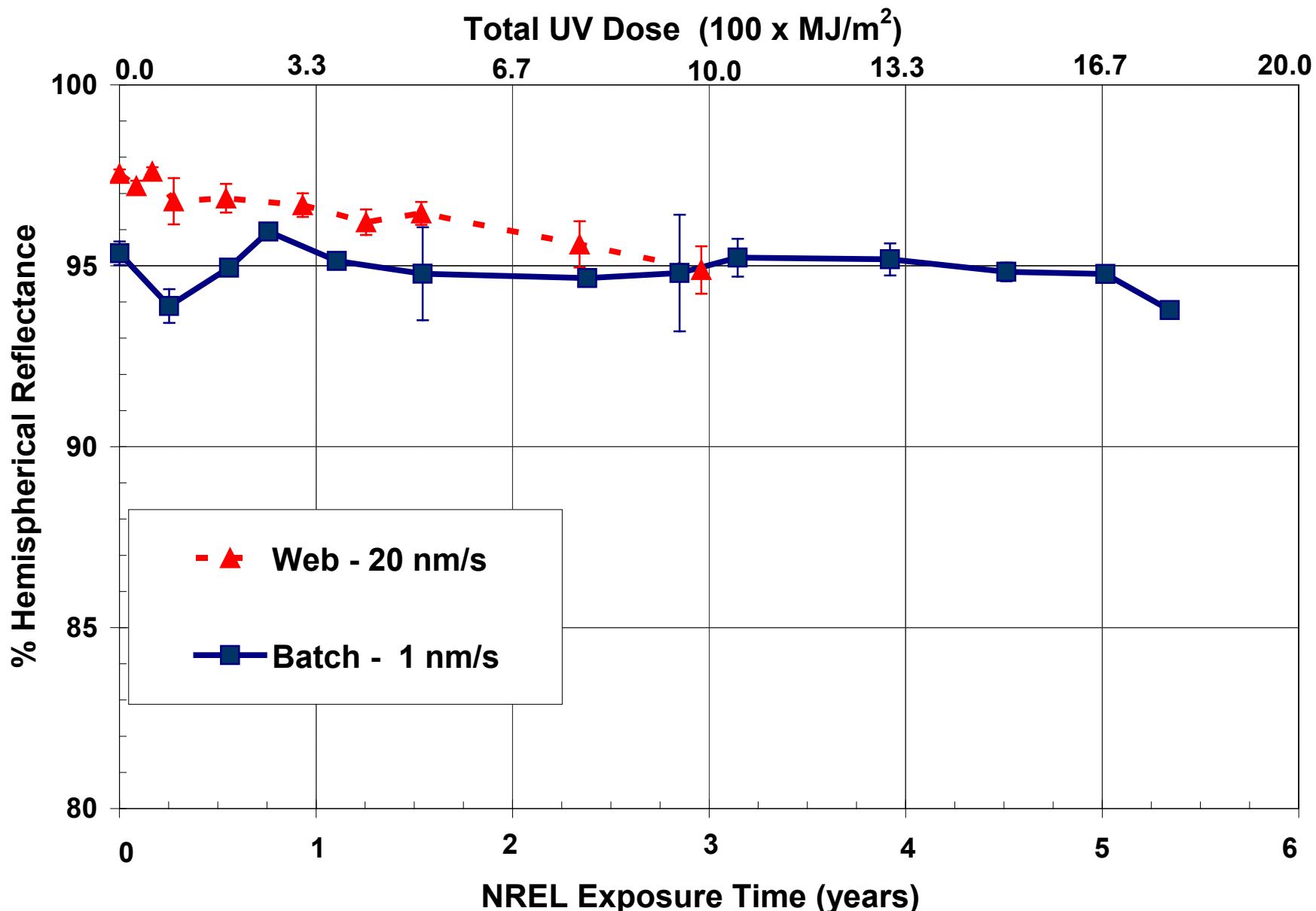
# Front Surface Solar Reflector Architecture

- Abengoa Solar (CSP FOA)
  - commercialize NREL / SAIC IBAD  $\text{Al}_2\text{O}_3$  ASRM subcontract





# Outdoor exposure at NREL of Roll-Coated IBAD $\text{Al}_2\text{O}_3$ Samples



# FY08 Progress Report



## 2. What will be accomplished in the 3<sup>rd</sup> and 4<sup>th</sup> Quarters?

### Status of milestones:

#### a) Level 5:

- Complete installation of new accelerated exposure chambers
- Determine new optical performance, lifetime, and cost goals with industry
- Report summarizing durability silvered thin-glass copper-free & lead-free mirrors after accelerated & outdoor exposure testing

#### b) Level 4:

- Report summarizing durability of candidate solar mirror samples
- Report summarizing FOA support activities

# Future Activities



## 1. FY09 Planned Activities

### a) Follow-on efforts:

- Continue current R&D activities
- Continue to support of CSP FOA awards & industry
- Additional support of Phase II FOA awards
- Upgrade database to web accessible

### b) New directions:

- Determine acceleration factor for damp-heat
- Reproduce service lifetime prediction (SLP) methodology for new 3M ECP-305+
- Develop standards and qualification tests with industry for solar mirrors
- Determine soiling rates for different materials at sites

# Future Activities



## 1. FY09 Planned Activities

c) Budget Table - assuming level budget

	FTEs	\$FTE	Purchase	Subcontract
Advanced Concepts	0.83	\$248K	\$100k	\$60k
Advanced Concepts FOA Support	0.63	\$188K	\$100k	\$1900k
Capital Equipment				\$290k

d) Projected Milestones

- Report on solar mirrors and FOA projects
- Upgrade database to web accessible
- Report on soiling rates
- Durability of solar mirror review article

# Future Activities



## 2. FY10 (FY09?) and Beyond Ideas

### a) Future Projects:

- Continue to test advanced solar mirrors
- Continue to provide FOA & industry support
- Expand service lifetime prediction (SLP) methodology to other FOA (PPG, Alcoa, Abengoa) materials
- Correlate barrier properties (water & oxygen) with durability for advanced front surface reflectors
- Develop advanced front surface reflector concepts
- Develop advanced antisoiling coatings & cleaning techniques
- Develop CSP/CPV reflector standards

# Future Activities

## 2. FY10 and Beyond Ideas



### b) Outside the Box Ideas:

- Overloaded with current task plans and urgent industry request and to need bring new staff up to speed before can brainstorm “Outside the Box” ideas

### c) Your vision of the solar future:

- Deployment of parabolic troughs, dishes, and heliostats that use 30 to 50 M m<sup>2</sup> of highly specular, durable, low-cost, lightweight, advanced solar reflectors with coatings that prevent soiling thus reducing O&M and water usage