

# Progress Toward Roll Processing of Solar Reflective Material

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## Goal:

Demonstrate that it is possible to cost-effectively produce high performance solar reflective material using vacuum deposition techniques.

### high performance:

Specular reflectance above 90% for at least 10 years

### cost effective:

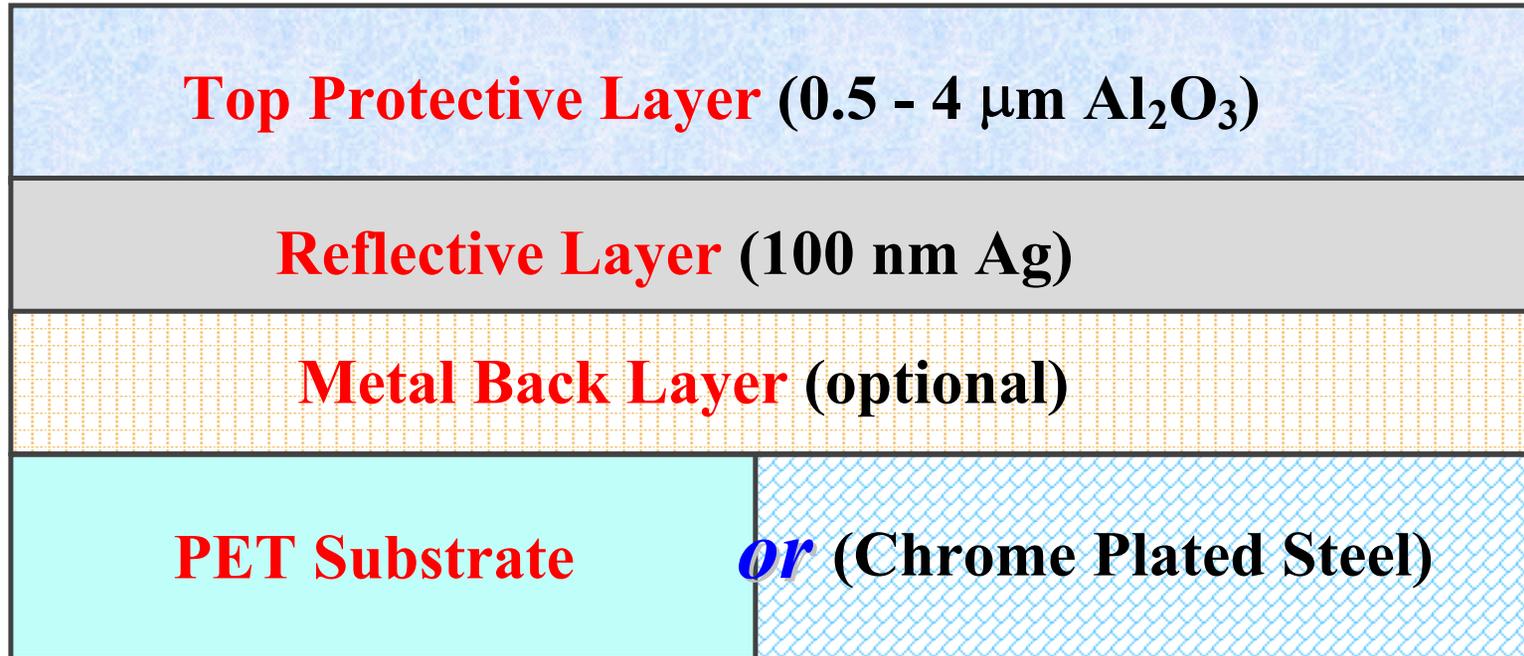
\$10.8 per square meter (\$1 per sq ft.)

## Approach:

Develop roll coating process for a first surface silver mirror with a protective alumina coating.

Focus on increasing durability and lowering production costs.

# First Surface Mirror under Development to Replace Thin Glass



- Vacuum evaporate metal layers
- Deposit alumina coating by EB-PVD technique called ion beam assisted deposition
- Process compatible with roll coating for efficient production

# Possible Application for Material: Dish/Engine System

Mirrors arrayed on a dish concentrate sunlight onto Stirling engine

Pictured system was designed and built  
by SAIC (Golden, CO)

Concentrator:

- stretched-membrane faceted dish
- 90 square meters
- 1 mm thick silvered thin glass
- 90% reflectivity



**Issues:**

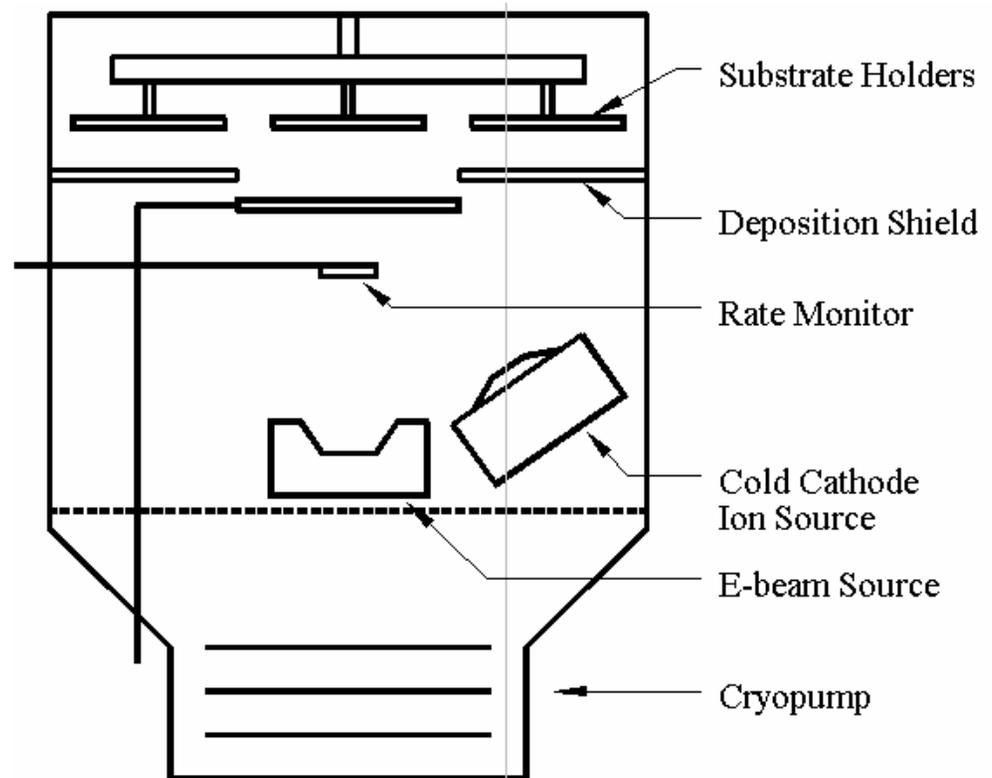
- Individual panes of glass are cut and glued to stainless steel membrane-very labor intensive
- Reduction in cost of complete system possible if steel membrane could be supplied with mirror finish

## Outline of Program

- 1994 First sample of solar reflector material produced at Armstrong World Industries.
- 1995 Start of funding by NREL to make samples on PET with coating 0.5 to 5.6 microns thick using small box coater. Prepare analysis of cost to produce material in roll coater.
- 1997 Build large coating system at SAIC.
- 1998 Increase alumina deposition rate from 1 nm/s to 10 nm/s.
- 1999 Increase alumina deposition rate to 20 nm/s.
- 2000 Build web-handling machine and integrate into SAIC coating system.
- 2001 Produce solar reflector material on 12 foot long strips of chrome-plated steel web (underway).

# First Test Samples Produced in Small Box Coater

- 66 cm wide box coater
- Electron beam evaporator
- Cold cathode ion source
- 8 kW power supply
- Quartz crystal rate monitor/ controller
- No direct cooling of substrates

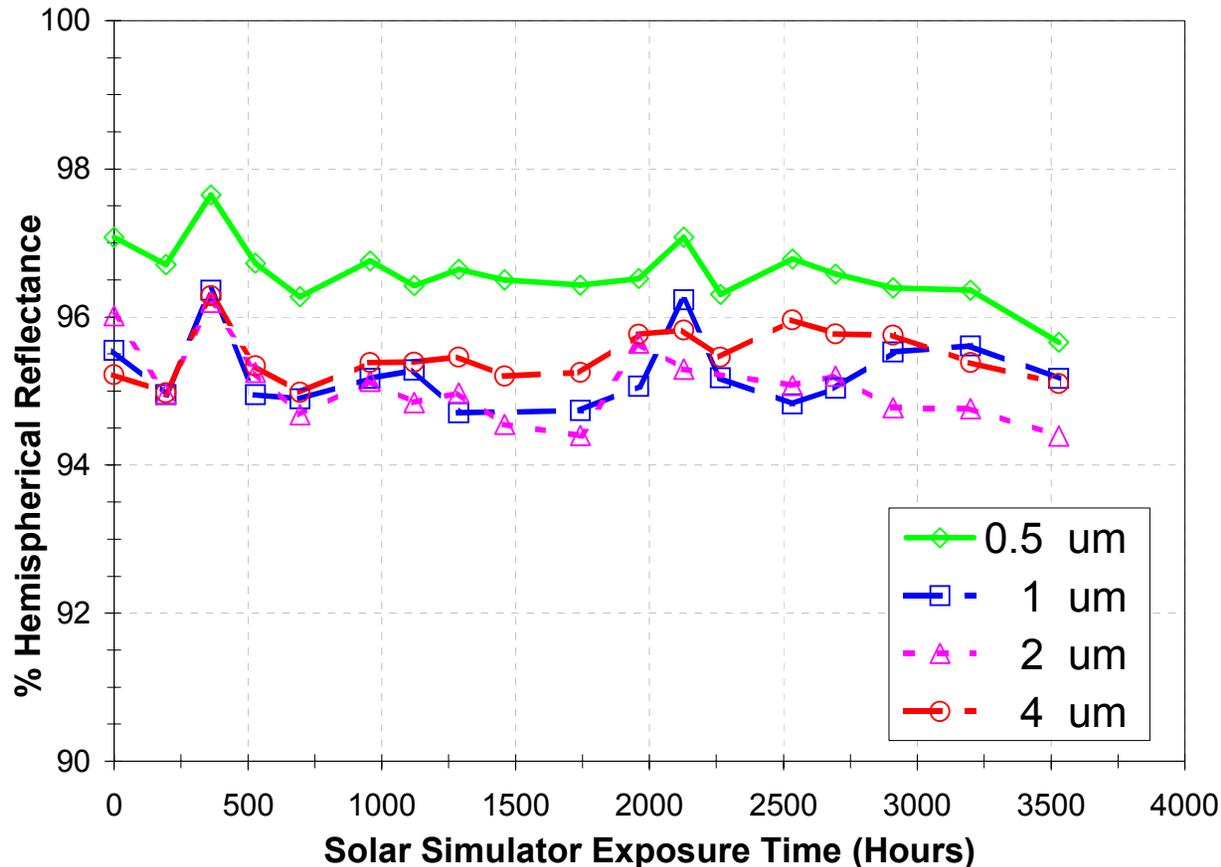


Box coater located at Armstrong World Industries, then Penn State University

# Typical Deposition Procedure

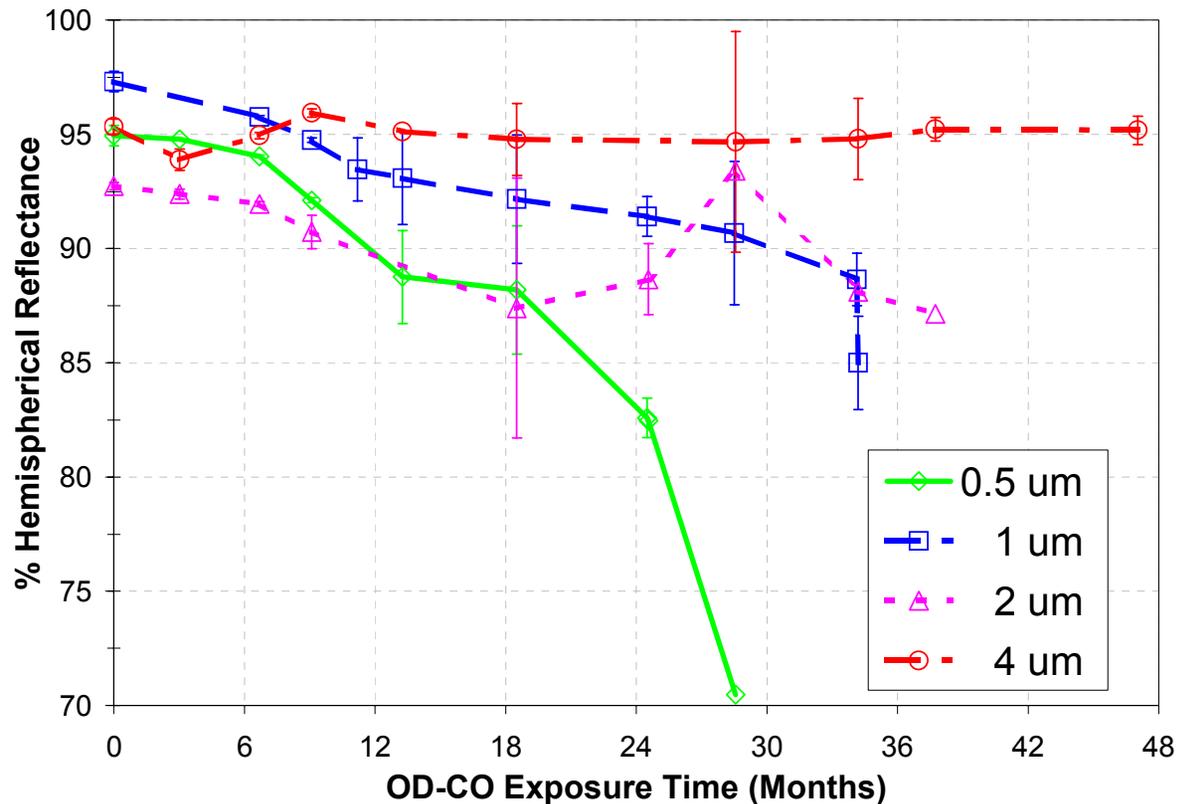
1. 6" x 6" PET sheets stretched over shim stock holder, mounted on rotating planetary holders.
2. Sputter clean PET with argon ion beam for 5 minutes
3. Evaporate copper, 50 nm thick @ 1 nm/s
4. Evaporate silver, 100 nm thick @ 1 nm/s
5. Evaporate alumina, 0.5-4  $\mu\text{m}$  thick @ 1 nm/s

# Solar Simulator Data of First Surface Mirrors with Alumina Coating (1nm/s deposition rate)



Longest durability in solar simulator of any first surface mirror

# Outdoor Colorado Exposure Data of First Surface Mirrors with Alumina Coating (1 nm/s deposition rate)



Sample with 4 micron coating lasts 4 years outdoors

# Cost Model to Produce Solar Reflective Material in Roll Coater (circa 1995)

## Geometry

Web length            2400 ft  
Web width             3.5 ft  
Web diameter    12 inches

## Evap Process

Capital Equipment    \$1M  
Web line speed    80 ft/hr  
Cycle time/web    30 min  
Workers            1 @ 100%

## IBAD Process

Capital Equipment            \$1.19M  
Cycle time/web    83.4 hr @ 32 nm/s  
Workers                        2 @ 100%

## Plant Operation

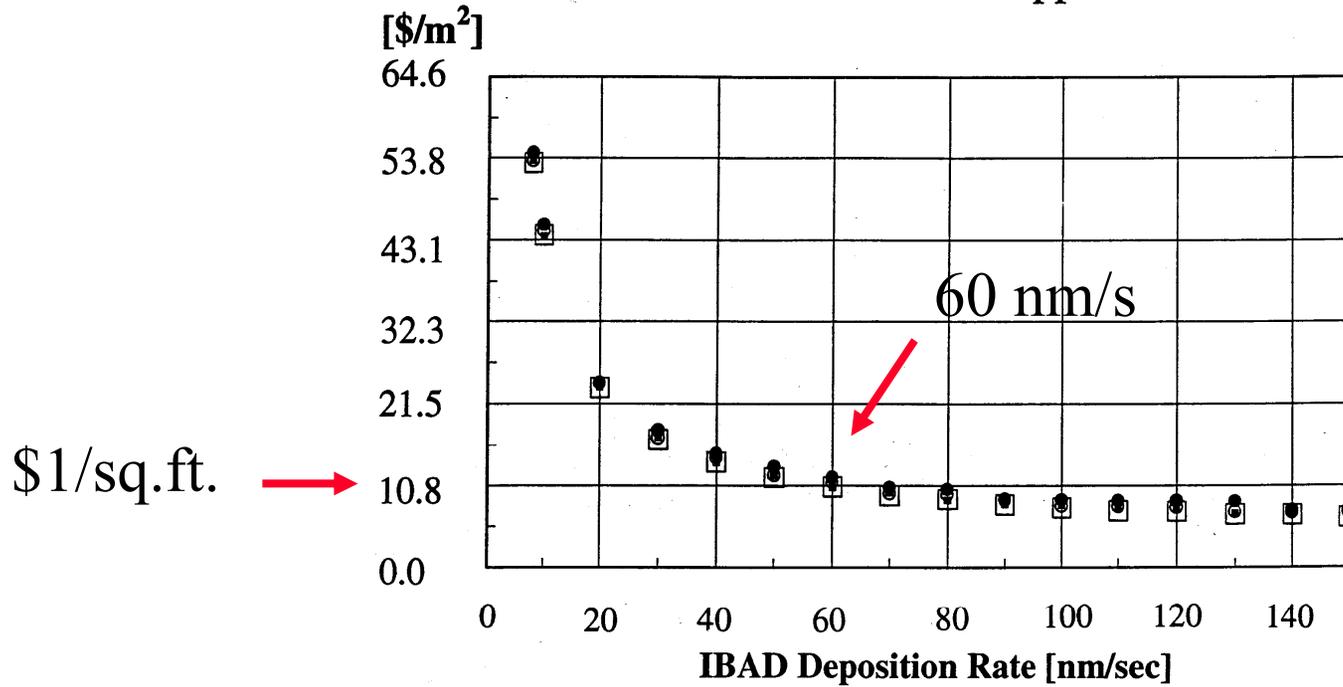
300 days/yr  
3 shifts/day  
8 hr/shift  
15% capital recover cost  
5% capital recovery period  
\$35 wage rate  
\$0.10 electricity/kW-hr

## Materials Cost

Alumina                        \$12/lb  
Silver                        \$200/lb wire  
Copper                        \$2.5/lb wire  
PET                             \$1.5/lb

# Result of Cost Model to Produce Solar Reflective Material in Roll Coater

Structure: alumina/silver/copper/PET substrate



Maximum Production Volumes for Available Equipment  
Film Thickness: Al<sub>2</sub>O<sub>3</sub> 4 μm, Cu&Ag 200 nm

When alumina coating is 4 micron thick, need 60 nm/s rate for \$1/sq.ft.. (Assumes production volume one million sq. meters per year.)

# Build Bigger Coating System at SAIC to Increase the Deposition Rate

- Vacuum system walk-in sized
  - cylinder 7 ft diameter, 12 ft long
  - Stokes 412 roughing pump
  - three CTI-10 cryopumps
- Evaporators
  - rod fed source (2" OD)
  - 4 pocket source (each 60 cc)
  - 14 kW Temescal power supply
- Ion source
  - 16 cm CSC gridded, high output  
1.25 A @ 1000 V



# Increase Alumina Deposition Rate + Sheet Size

Cooled Al plate mounts sheets 7"x25"

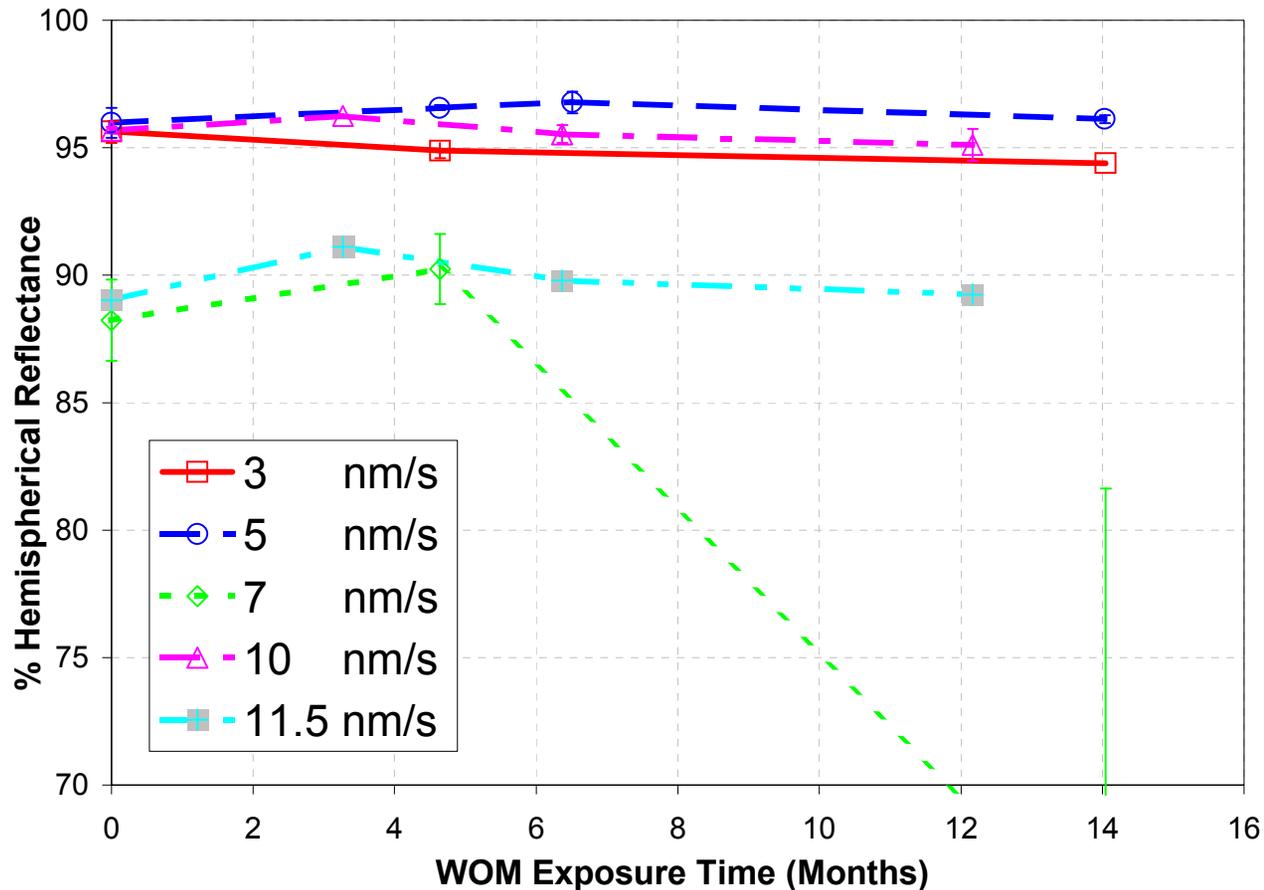


Cooled Al plate in chamber



Evaporators and ion source located  
at bottom of chamber

# WOM Data of First Surface Mirrors with Alumina Coating (higher deposition rate)

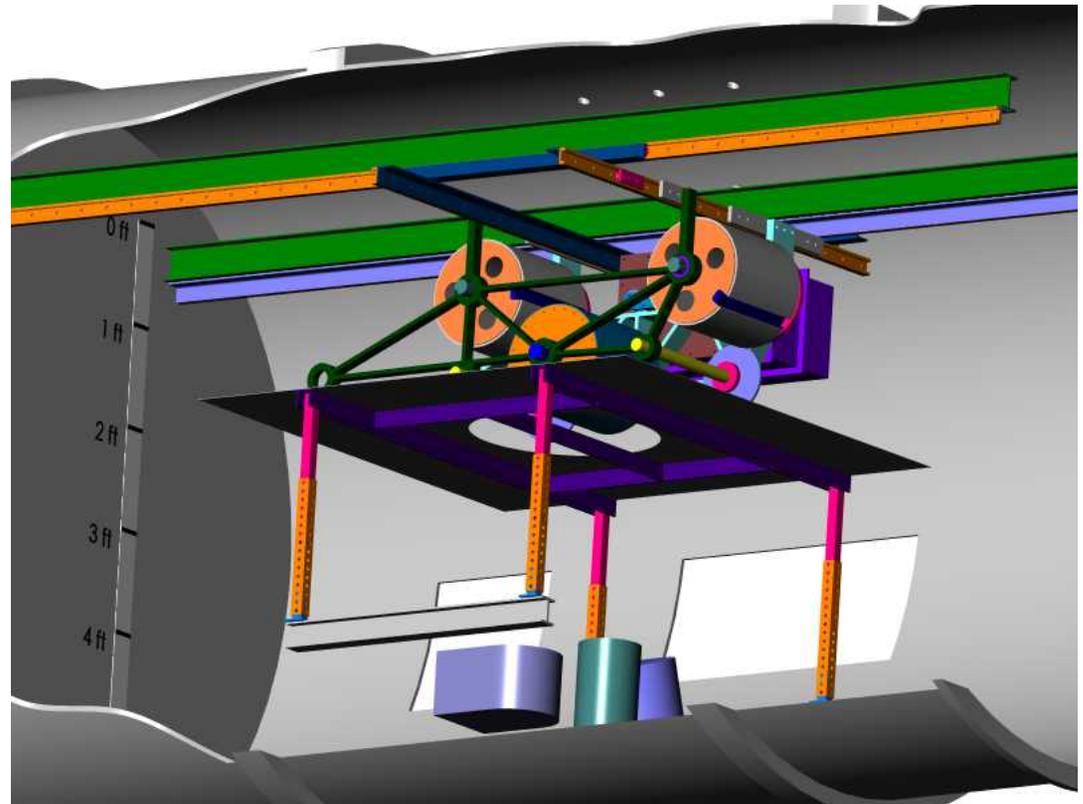


Samples with 10x increase in deposition rate still durable.

# Roll Coater Design

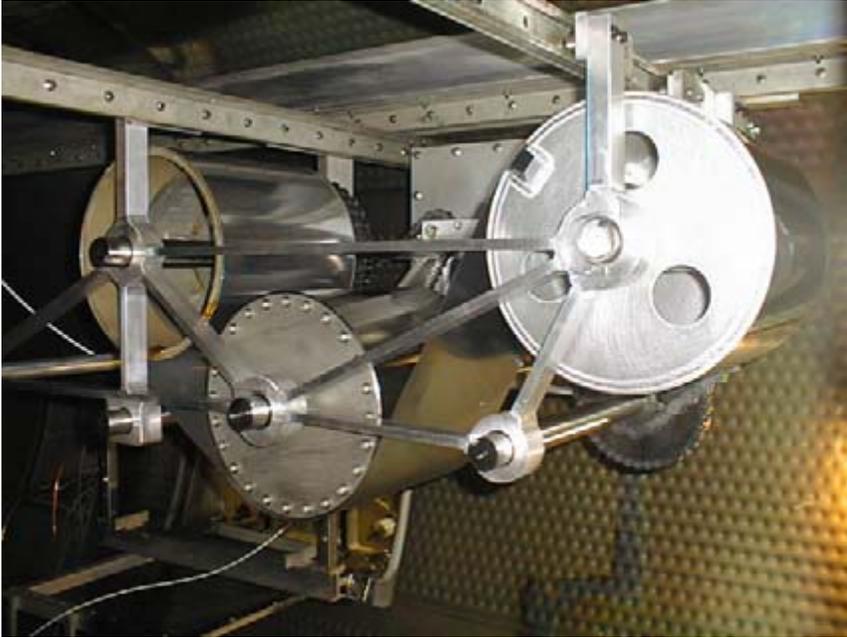
## Specifications

Web width 30.5 cm  
Web speed 1-89 cm/min  
Web tension 1-189 N  
Reel ID 30.5 cm  
Drum temperature  $> 77$  K

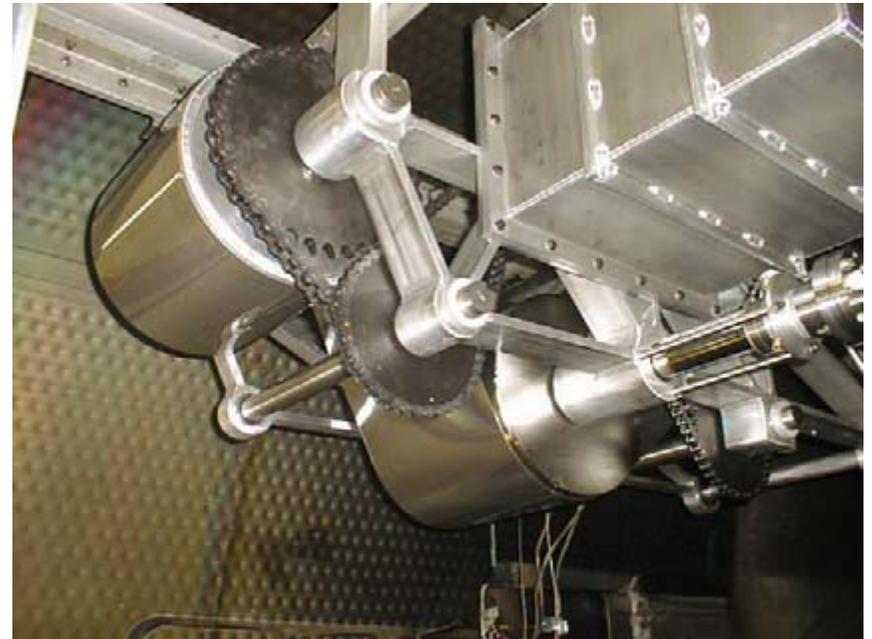


Intended web is chrome-plated steel strip, 12" wide, 8 mil thick

## Roll Coater at SAIC (McLean, VA)

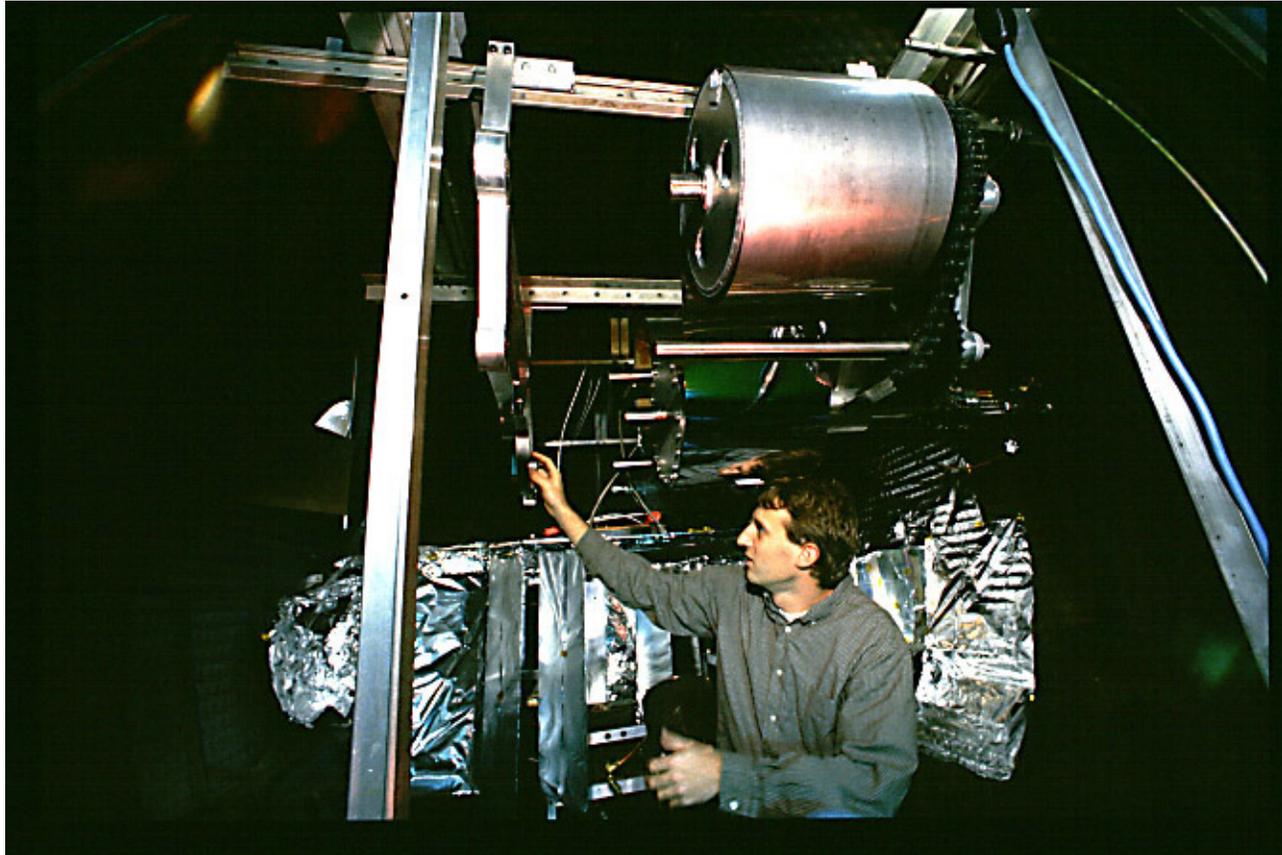


Front view showing steel web advanced over 12" drum



Rear view showing chain drive

# Roll Coater at SAIC (McLean, VA)



# Development Path to Commercial Application of Solar Mirror

## Current Work:

- Transition coating process from PET to chrome-plated steel web (12" wide).
- Produce solar reflective material on 12' long strips of chrome-plated steel.

## Future Work:

- Produce 280 lineal feet of solar material for field trials.
- Increase the alumina deposition rate beyond 20 nm/s.

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