Specialty Glass Needs for the U.S. Solar Industry Workshop

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Summary Report and Proceedings

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Executive Summary

The solar electric power market is growing very quickly. Worldwide photovoltaics (PV) production, in particular, has had an average annual growth of 40% during the last ten years, and reached 49% in 2007. Concentrating solar power (CSP) has recently started to grow very quickly. Rapid growth is expected to continue due to a variety of causes. These include (a) improved product reliability and performance, (b) decreased costs for manufacturing as new processes and economies-of-scale become significant, (c) increased public awareness of solar power's advantages, and (d) government subsidies (including tax credits and feed-in tariffs). The Department of Energy's (DOE) Solar America Initiative (SAI) has ambitious cost goals for solar power which will require high-performance low-cost glass products. More information can be found at http://www.eere.energy.gov/solar/solar_america/index.html.

Most solar power systems use glass products. The products have special requirements, including high transmissivity for PV; high reflectivity, coating delamination resistance and special geometrical shapes (bent glass) for CSP systems; and low soiling for both PV and CSP. In addition, PV glass for thin-film modules often requires one or more transparent conductive coatings to facilitate current collection. Borosilicate glass is required for some thin-film PV technologies because of its higher working temperature (compared to the more conventional, and less expensive, soda-lime glass). Glass can be formulated and fabricated to provide these functions. Whether that is done in the United States on a commercially-viable basis to meet future domestic demand for solar energy is a key question.

This report summarizes discussions from the workshop "Specialty Glass Needs of the U.S. Solar Industry" held in Golden, Colorado, on April 2-3, 2008, to identify business and product development issues of servicing these specialty glass needs. The DOE Office of Energy Efficiency and Renewable Energy's (EERE) Industrial Technologies Program and Solar Energy Technologies Program coordinated the workshop. Going into the workshop, DOE was unclear whether this was to be a one-time event to increase awareness, facilitate business interactions, and consider the job done; or whether this was the beginning of an on-going process. The latter was the clear preference of the workshop group. The follow-on items and next steps are discussed in this report. The workshop was also planned with the valuable experience and insight of the Steering Group (members listed in Appendix A) which convened four conference calls in the months preceding the workshop to determine the content, emphases, and desired outcomes. DOE tremendously appreciates their input, which was a major factor in the success of the workshop.

The workshop gathered approximately 60 technical and market experts and stakeholders from the glass and solar industries. The intent of the workshop was to understand what specific kinds of solar specialty glass are needed, and to determine what issues should be addressed, to enable wider manufacturing of these solar glass products within the United States. All of the manufacturing entities represented at the workshop have production facilities in the United States.

Separate breakout sessions focused on the needs of four critical solar glass topics: coatings, concentrating solar power (CSP), photovoltaics (thin films), and photovoltaics (crystalline silicon). Breakout session participants determined key technical and market issues and then

voted on top priorities. In the figures below dealing with Technical and Market Issues and Needs, the blue dots by various items indicate the number of votes received.

Similar themes were prevalent among the breakout sessions, and are enumerated here as action items or next steps in the process.

1. To facilitate understanding of each other's businesses, the participants were highly in favor of a future tutorial workshop that would enable the glass and solar industries to gain a better understanding of each other's manufacturing environments and product needs. Subsequent to the workshop, DOE conducted a two-day "Solar-Glass Tutorial" (including a half-day Solar Tutorial) on May 28-29, at DOE Headquarters in Washington, DC.
2. The workshop group thought a valuable role DOE could play would be to coordinate the development of glass standards for various solar applications and suggest topics that the standards should cover, such as strength, performance testing, longevity, and mirror and coating compositions.
3. Standardized measurement procedures would probably need to be developed. In the longer term, it may be important to consider packaging, installation and maintenance issues, and power company perspectives when developing the standards. Standards will need to be coordinated and consistent with international and other organizations like ISO, ANSI and ASTM. (See http://www.isostandardsguide.com, http://www.ansi.org, and http://www.astm.org for more information.)
4. As a technical issue, the workshop group suggested the need for research into increasing glass strength. Since the actual strength of glass is far below the theoretical level, some fundamental and applied research could prove beneficial in identifying opportunities.
5. Overall, increased information exchange between the glass and solar industries, and improved cost models and economic forecasts using credible data, would be extremely valuable.

The solar and glass industry participants raised several technical questions for each other and concluded that increased meeting opportunities would spur future collaboration and development opportunities. Future collaboration might be achieved through small-group meetings, workshops, and on-line forums to gain perspectives from players throughout the glass and solar supply chain. Separate working groups composed of industry representatives and researchers might discuss standards development, technical requirements for materials and finished products, and market issues. They might also explore approaches for incentives.

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Format of the Workshop

The workshop consisted of three primary sessions:

- A plenary session with background presentations
- Concurrent facilitated breakout sessions focused on the four primary topic areas
- A summary session which included presentation and discussion of results from the breakout sessions, as well as discussion of next steps and closing remarks

The final workshop agenda is provided in Appendix B; a listing of workshop participants is included in Appendix C; and a glossary of terms is included in Appendix D.

Plenary Session

The plenary session provided workshop participants an opportunity to hear about the rationale for holding the workshop, perspectives from the solar and glass industries, ongoing DOE and NREL solar programs and research activities, and solar market data and trends. (See http://www.eere.energy.gov and http://www.nrel.gov for more information.)
The following is a brief synopsis of the presentations presented; the PowerPoint slides used by the presenters are included in Appendix E.

- Dr. Jeffrey Mazer (DOE-Solar Energy Technologies) opened the meeting by welcoming participants and sharing some insights about the DOE Photovoltaics program.
- Glenn Strahs (DOE-Industrial Technologies Program) also welcomed participants and discussed the planning of the workshop and DOE Industrial Technologies program's interest. Glenn also provided a statement regarding anti-trust considerations that instructed participants to avoid disclosing sensitive information subject to anti-trust laws.
- Tom Rueckert (DOE-Solar Energy Technologies Program) provided background information on the DOE Concentrating Solar Power (CSP) program.
- Michael Bruce (DOE-EERE) shared some perspectives on how DOE-EERE has approached overcoming the "valley-of-death" during technology development.
- Dr. Robert Margolis (NREL) summarized historic trends and projections for solar market growth.
- John Benner (NREL) discussed technology development efforts at NREL and shared information on how industry could collaborate with NREL.
- Cheryl Kennedy (NREL) provided an overview of glass requirements for concentrating solar power and shared results of NREL's ongoing research.
- Chris Constantine (Oerlikon Solar) shared insights on material requirements from a solar product manufacturing perspective.
- Doug Hall (Corning) and Steven Weidner (Pilkington) provided an overview on glass markets as well as an overview of the scale and general economics for large-scale glass manufacturing.
- Keith Jamison (Energetics) concluded the plenary session by providing some logistical and instructional information for the breakout sessions.

- Scott Hennessey (SEIA), as the luncheon speaker, provided an update on solar legislation and policies.

Breakout Sessions

Four breakout sessions were held during the workshop, with two topics being discussed concurrently. During the planning of the workshop, many participants on the steering committee indicated interest in participating in multiple sessions. To accommodate this and keep the length of the workshop within the original scope, it was decided to conduct two sessions concurrently for a period of approximately 90 minutes each.

The first "round" of facilitated breakout sessions included Photovoltaics (focusing on crystalline silicon) and Coatings. The second "round" included Photovoltaics (focusing on thin films) and Concentrating Solar Power. Workshop participants were allowed to self-select those breakout sessions they wanted to attend.

Each breakout session was conducted in the same manner. All participants were invited to share technical and market issues and needs relevant to their particular breakout session. Following the identification and some discussion of these issues and needs, participants in each breakout voted to identify the most critical technical and market issues and needs.

The pages that follow summarize the discussions during each of the four breakout sessions, held on the afternoon of the first day of the workshop.

Coatings

Availability of robust and reliable coatings is critical for advancing the performance of PV cells and CSP mirrors. This breakout session identified several key technical and market factors that affect the development and availability of high-performance solar glass coatings (Figure 1). Participants then voted to prioritize the issues and needs; full voting results are included in Figures 2 & 3. Participants consisted of representatives mostly from the solar and glass industries, including mirror manufacturers, coatings suppliers, equipment manufacturers, and researchers. Due to the very large number of participants in this breakout session, after identifying and prioritizing technical and market barriers, participants divided themselves into two groups to discuss coatings-related issues specific to PV and CSP applications, respectively.

Figure 1: Key Technical and Market Issues and Needs for Coatings

Technical

- Accelerated, accurate tests for lifetime performance
- Self-cleaning or hydrophobic coatings
- Greater understanding of how targets differ between CPV and CSP (thermal)
- Minimizing front surface reflections
- Standards for solar mirror requirements
- Choosing the best coating for TCOs, e.g., zinc oxide vs. tin oxide

Market

- Redefine existing cost model for PV and CSP applications
- Clearer DOE role in encouraging U.S. glass manufacturers to focus on solar technologies
- Development of coatings standards to lower costs
- No lead or zero lead mirrors

<u>Coatings Technical Issues and Needs</u>

- *Accelerated tests that accurately predict lifetime performance*
  Solar producers would like a better understanding of the basis of mirror lifetime estimates, especially for mirrors that claim 15-30 year lifetimes. Development of a standard test was proposed as a potential solution, but more time is needed to generate enough data to support test results. In addition, a standard test would pose challenges because no single test can accurately predict lifetime expectancy, especially if applied to multiple product types.

- *Use of self-cleaning or hydrophobic coatings*
  Coatings need to ensure panels stay clean and retain reflectivity with minimal maintenance and water requirements. This is especially critical for dry climates, where water availability and transportation to remote sites may be limited. In addition, coating reapplication processes need to be simple.

- *Well defined requirements for CPV and CSP (thermal) mirror applications*
  Since CPV and CSP (thermal) mirror requirements differ, a better understanding of these differences will enable developers to anticipate future needs of each application.

- *Greater understanding of current activities to minimize front surface reflections*
  Anti-reflective (AR) coatings in front glass need to enhance photovoltaic efficiency and display thermal stability. The advantage of one-coat applications vs. multiple layers has not been demonstrated for enhancing AR coating efficiency. What is the current state-of-the-art for AR coatings development, and who is involved?

- *Standards for solar mirror requirements*
  Standards on coating property specifications should focus on reflectivity, thermal stability, or minimum performance requirements. In addition, a standard on the physical application of the coating would ensure product consistency, whether the glass manufacturer or fabricator applies the coating.

- *Choosing the best transparent conductive oxides (TCO) coating, e.g., zinc oxide (ZnO), tin oxide (SnO_2), or alternative*
  The outlook is not clear on which TCO coating (ZnO, SnO_2, or other) will be used more predominantly, or which process will be best. The advantages and disadvantages of applying coating at the glass manufacturer versus the PV manufacturer have not been determined.

<u>Coatings Market Issues and Needs</u>

- *Refine existing cost models for PV and CSP applications*
  Data sharing among meeting participants could facilitate the development of more comprehensive, updated cost models for both PV and CSP applications. Improved cost models could also help set R&D priorities and allocate funding accordingly.

- *Determine DOE role to encourage U.S. glass manufacturers to focus on solar applications*
  Courses or tutorial sessions were suggested means for informing glass manufacturers about solar opportunities. Additional meetings or online networking forums could create collaboration opportunities between the glass and solar industries.

- *Identify opportunities for standardizing coatings to lower costs*
  Standards addressing technical specifications and performance could lower costs. Suggested standard topics should cover property specifications, measurement/testing, and the physical coating application process.

- *Anticipation of lead content restrictions (i.e., no lead vs. zero lead)*
  Will industry or customers demands drive lead content restrictions? Customers may demand lower content even if a coating complies with Toxicity Characteristic Leaching Procedures (TCLP).

FIGURE 2: TECHNICAL ISSUES AND NEEDS FOR COATINGS

- Accelerated tests → relation to real life performance ●●●●●●●●●
- "Self-cleaning" or hydrophobic coatings (re-application) ●●●●●●
- How do CPV and CSP (thermal) mirror targets differ? ●●●●●
- What is being done to minimize front side surface reflections? ●●●●
- Need for standardization of requirements for solar mirrors ●●●●
- ZnO and SnO_2 are both considered for TCOs. Which will win? Which process is best, cheapest? ●●●●
- What are the top three TCO alternatives viewed today and why? ●●●
- Develop standard measurements (e.g., light transmission, abrasion resistance) ●●●
- Are there other TCOs (besides ITO, SnO_2, ZnO) that industry is pursuing for large-scale PV manufacturing? ●●●
- What was the basis for the 30 year mirror lifetime (field tests, accelerated aging, lab tests)? ●●
- Standards are currently focused on the final, finished product. Can standards be developed for sub-components with coatings? ●●
- What additional issues arise for producing coatings for bent glass surfaces? ●
- Is anyone producing laminated mirrors? If so, what is the cost (relative to single ply-glass) ●
- Technical requirements: volumens ●
- For mirrors, what are the best current back-side coating schemes? What is the cost impact? ●
- Glass specification (flatness, spectrum) ●
- AR (anti-reflective) coatings ●
- How to judge TCO coatings? Potential properties: haze (texture structure), conductivity, transmission interface, shape. Others? ●
- What is the acceptability of solar mirror back coatings that contain lead that pass TCLP? ●
- Transparent conducting coatings that are used in superstrate type of solar cells using amorphous hydrogenated silicon or cadmium telluride may need to be developed further to minimize the problem of corrosion in high voltage photovoltaic systems in hot and humid climates
- AR coatings on front glass that can reduce reflected sunlight and then enhance photovoltaic efficiency need to be developed for making them last 25-30 years
- Specific to CSP life expectancy: 15, 20, 25, 30+ years. Which is NREL & DOE focusing on
- Standardization and related concerns are important. Green tags get at this
- Transmissivity of tin oxide vs. other coatings
- What are critical cradle to cradle issues
- Front surface coatings need to be dense with good barrier properties adherent, excellent transmission crack-resistant, pinhole free
- The alkalinity and sodium associated with float glass are traditional problems. Do they still exist. And where is the primary impact/problem. Do we need multifunctional TCO/barrier coatings
- Need industry accepted qualification and tested standards to qualify new mirror coating manufacturer as CSFOPV suppliers and acceptance by financial industries
- Are there advanced methods for accelerated testing for quicker feedback, at the plant levels
- Post temperable mirror coating for parabolic shapes
- Purpose of coatings for PV: a) adhesion to substrate, b) sheet resistance lowering, c) impedance matching for incoming light
- Can we match suitable non-ITO coatings to specialty glass for diff. application beyond cost and potential supply constraints?
- Mirror protective coatings - long-term stability, compatibility with common adhesive materials
- What infrared reflective coatings are being used on glass
- Adhesion enhancement coatings for encapsulants with UV filter
- For crystalline silicon, will it ever be the case that top-side glass can be replaced by coating
- Is AR coating highly preferred for thin film panels? What is thermal stability requirement for AR coatings on thin film glass?
- Does a standardized AR coating do enough to increase efficiency? Should there be more, i.e., multi-layer?
- Low iron glass rolled or float glass or both
- Is "End of Life" cost (recycling) accounted for in: a) "green" footprint and b) total cost
- Anti-soiling coatings - how effective, at what cost, lifetime
- What are the pros and cons of TCO on manufactured glass vs. TCO manufactured by the PV producer. Why not a co-design in optimized materials. Process?
- Quality control issues associated with glass surface - coating life, handling damage, other, adhesion

FIGURE 3: MARKET ISSUES AND NEEDS FOR COATINGS

- NREL and DOE re-define existing cost model based on data generated at this session - PV and CSP ●●●●●●●●●
- What role should DOE play to encourage U.S. glass manufacturers to focus on solar technologies (PV & CSP) ●●●●
- Reduced costs associated with standards, opportunities for "standard coatings" (TCO, AR, Reflector) ●●●●
- No lead or zero lead mirrors ●●●
- Cost and supply situation of solar glass (in U.S./Global) ●●
- Why are there cost differential between Asia vs. US on an automated process? ●●
- Need national effort to guide glass industry on renewables (SEMETEC model) ●●
- $2.50/ft^2 glass and coating (target price) ●
- Any "industry agreement" on guarantees for coatings be they mirrors or AR coats ●
- How important is a "green" totally environmentally friendly mirror - disposed (end of life) ●
- At what volume level does TCD become cost negligent ●
- How does the industry create the demand for solar energy products?
- Should the automotive industry be involved in this group?
- What is the market size of coatings in solar products? What percentage of glass is coated?
- Need suppliers for integrated product
- Industry needs to step up to solar challenge or watch more solar companies build over lines
- Does a 30-year warranty require cover all components? Indoor mirrors have 5+ year lifetime
- Unmet needs: $ value per additional percentage for CSP reflectors
- Leaded vs. low lead - customer or industry driven
- For PV makers - do you get benefit from applying the TCO or buying the TCO

Coatings Requirements for PV Applications

Coating reliability is a major concern and could be controlled by several factors. For example, a standardized coating application process would increase product reliability, whether the glass manufacturer or fabricator performs the application. The need for standardized property measurement techniques is also considered a high priority.

Participants expressed the need for additional R&D on high-performance TCOs for large-scale PV manufacturing. R&D should address zinc oxide, tin oxide, and alternatives that could lower deployment costs. In addition, enhanced TCOs should minimize corrosion problems in high voltage PV systems that operate in hot, humid climates.

Environmental concerns will also affect development of improved coatings in PV applications. Coatings need to meet TCLP requirements while also reducing soiling and cleaning frequencies, especially for regions with limited water supplies. In addition, some thin film coatings may contain heavy metals that could limit disposal options. Improved recycling methods that remove contaminants will ensure that solar technologies remain environmentally friendly.

Coatings Requirements for CSP Applications

Main concerns surrounded the development of coating performance standards. Ideal coating properties include highest possible reflectivity, 30-year life warranty, reliable destructive testing, lead-free composition, and self-cleaning glass surfaces. Suggested standards to address these specifications include establishing: (1) minimum level of reflectivity, (2) minimum life expectancy, and (3) minimum testing performances.

Concentrating Solar Power

Concentrating solar power (CSP) represents a low-cost opportunity to deliver power during periods of peak demand. Representatives from the solar and glass industries identified several technical and market factors to enhance CSP opportunities in U.S. power markets, then voted to prioritize the issues and needs. The voting results are summarized in Figure 4, and the full voting results for technical and market issues are included in Figures 5 & 6, respectively.

Figure 4: Key Technical and Market Issues and Needs for CSP

Technical

- Cooperative standards development of solar glass designs and specifications
- Technologies to reduce cleaning frequency and water use
- Adequate supplies of high-quality bent glass
- Increasing U.S.-made glass for CSP companies (domestic and international)

Market

- Greater understanding of specific mirror requirements for various CSP technologies
- Understanding of solar industry's competition for glass supply (i.e., with architecture or transportation industry)
- Sufficient glass capacity to cover future solar industry growth
- Positive public perception: environmentally friendliness of mirrors

<u>CSP Technical Issues and Needs</u>

- *Cooperative standards development of solar glass designs and specifications*
  Participants stressed that standards would be developed most effectively with input from both glass and solar industries. When mirror manufacturers apply coatings to glass of varying quality, the resulting reflectivity differs between batches of mirrors. Specifications would enable mirrors manufacturers to expect glass of a certain quality and then determine mirror reflectivity more accurately. It may be important to engage installers and power companies rather than focusing solely on the product.

- *Identifying technologies that can reduce cleaning frequency and water use*
  Water availability and transport logistics reinforce the need for self-cleaning or low-maintenance CSP technologies in dry climates. Mirrors with self-cleaning or hydrophobic coatings can alleviate these problems, but projecting the overall costs of each option will be difficult. Thus, setting R&D priorities may also prove challenging.

- *Ensuring adequate supply of high-quality bent glass*
  Bent glass capacity for CSP is not limited; however imports represent a large proportion of bent glass in CSP applications. Glass producers in the U.S. could increase bent glass production with clearer understanding of solar industry needs and requirements.

- *Increasing U.S.-made glass for CSP companies (domestic and international)*
  The quantity of CSP companies has expanded by four times over the past year, but U.S. glass manufacturers supply only a small proportion of their glass needs. What types of opportunities would enable U.S. glass manufacturers to target CSP companies?

FIGURE 5: TECHNICAL ISSUES AND NEEDS FOR CSP	
MISC. TECHNICAL	**STANDARDS**
• Water use - technologies that can reduce cleaning frequency ●●● • The number of CSP companies has grown 4x this past year. How can U.S. glass manufacturers become suppliers for these companies (US & International) ●●● • Are there enough bent glass manufacturers with proper equipment and technical capabilities to service the CSP needs? ●●● • Understand the value of improved performance (e.g., weight, reflectronics) ● • How to improve transmittance, AR coating, and reflectivity of receivers and mirrors • Forum for concurrent engineer needs/desires • Logistics of material supply with effort concentrated in the Southwest • Are there ways to apply CSP technology to reduce the carbon based energy in glass manufacturing • Bent glass box - low cost • How many light transmission does low iron require (CSP) • Is there value to limited spectrum reflectors for CPV (i.e., thermal cut-off) • Low iron sand scarce raw material • What type of enclosures or mounting will be used for the various CSP • Are exposed edges a critical concern? How? • Develop roadmap on how to achieve costs required for unsubsidized power • Are CSP project developers looking for advanced material components (reflectors), or systems? Supply Chain? • Does air transport of glass samples affect glass properties due to extreme environment? • Can national labs assist with performance or longevity issues for various CSP glass materials? • Can a model be established via cooperation between glass and solar industries to predict long-term durability? • Silvering capacity - ability to silver bent substrates, ability to silver thin substrates, durability to reflector • Not sure how Fe content affects reflectivity. Impact of glass color can have it look white on back, pink on front - must be reflectivity impact reflectivity has huge impact on profitability of CSP plant	• Should develop glass specs, cooperatively, to get suitable design and performance requirements ●●●●●●●●●●●● • Need to define "spec" for solar glass and define through supply chain ●●● • NREL can ask this group to submit standards/specs that would be useful, then NREL can sort, synthesize, and share results ●● • Establish common material specifications required by the solar industry and convey it to the glass industry ● • Does U.S. need to develop standards that are consistent with international standards as thru ISO or other organizations ● • Standard (specifications and test methods) for CSP glass may not be pass/fail at the beginning ● - standards must be reasonable for manufacturers and users - standard measurement techniques are also needed • Scale/standards and ability to handle measurement for bending/coating - cosmetic specification is less important here - focus on performance specification • Specify surfaces for reliable, durable attachment methods, materials • Work across solar and glass industry to define glass specification understanding how silvering, processing, bending, etc. impact specification, and try to ensure consistency of lots

CSP Market Issues and Needs

- *Greater understanding of specific mirror requirements for various CSP technologies*
  Mirrors for different CSP technologies differ by number of coats, lead content, and type of protective top coat. All are available today, but may not have been tested thoroughly. Increased collaboration between glass manufacturers and CSP developers could sharpen the focus on the needs of different CSP applications.
- *Understanding of solar industry's competition for glass supply (i.e., with architecture or transportation industry)*
  The glass industry's main consumers currently include the architecture and the transportation markets. The solar industry will eventually take its place, but will not directly affect float glass availability for other applications.
- *Sufficient glass capacity to cover future solar industry growth*
  Mirror manufacturers assert that its capacity can easily satisfy solar demands in the U.S. More than 26 lines of mirrors with different specifications are available. The biggest issue surrounds allocating R&D funds for enhancing those mirrors toward a "moving target."
- *Positive public perception: environmental friendliness of mirrors*
  Participants reached consensus that CSP technologies should be environmentally friendly and should consider lead content and end-of-life cycle processes. Industry researchers are already working toward a long-term and sustainable solution. However, determining warranties will be an issue due to the time required for extensive testing.

FIGURE 6: MARKET ISSUES AND NEEDS FOR CSP

- What are specific mirror requirements for various CSP technologies ●●●●●●●●●
- How does solar compete with architectural automotive needs for glass capacity ●●●●●
- How important are environmentally-friendly mirror coating to the market place ●●●●
- Capacity to cover growth (future) ●●●●
  - capacity availability depends on which CSP technology you are discussing (e.g., low-Fe, 4-5mm vs. 0.7mm, bended)
- Be given tax incentives to promote domestically produced components ●●
- Explore the industry's capacity to supply high quality products in a fast expanding market (maybe 30-40% per year - "units" growth of ~1 million square in) ●
- Provide growth rates/capacity of glass for (PV) ●
- Demand forecasting by CSP sector and reliability of forecast ●
- This is not auto or architectural market
- This is global industry - need specs that allow sourcing globally
- How long is the CSP field design cycle, and how long before breaking ground are mirror design and materials specified?
- How do we address inevitable delays (e.g., environmental permitting delays) that demand forecasting impact?
- Pursue concurrent engineering in both industries to ease the potential for supply-demand imbalances (information exchange)

Photovoltaics (Crystalline Silicon)

Photovoltaic technologies using crystalline silicon wafers currently dominate the worldwide solar electric market. However, with great interest in the concurrent Coatings session, the crystalline silicon session was lightly attended and most participants were representatives from the glass industry. Participants reiterated that issues subject to anti-trust regulations needed to be avoided during the discussions. Participants identified several technical and market factors, mostly relating to glass processing and properties, that could enhance photovoltaic opportunities in U.S. markets, then voted to prioritize the issues and needs. The voting results are summarized in Figure 7, and the full voting results for technical and market issues are included in Figure 8.

Figure 7: Key Technical and Market Issues and Needs for PV (Crystalline Silicon)

Technical

- General specifications would be useful
- Higher strength glass is a potential game-changing enabler
- Evaluation of a broader set of glass compositions should be pursued
- Improved glass melting technology that reduces capital requirements could help improve cost structure for glass manufacturing

Market

- Reliability of general photovoltaic growth forecasts
- Commodity glass industry not used to hockey-stick type growth rates
- Number of GW-size PV crystalline silicon plants that would be built in the U.S.
- Lead time required for building new glass plants

PV Crystalline Silicon Technical Issues and Needs

- *General specifications would be useful*
  Participants stressed that general specifications for glass property requirements would be valuable. These specifications would ensure that required properties were met, but that requirements from customers were consistent and not based on arbitrary levels that may increase costs unnecessarily.

- *Higher strength glass is a potential game-changing enabler*
  Participants noted that the strength of current glass products is much less than glass's theoretical strength. Developing approaches to increase the strength of glass products could enable the use of thinner glass and reduce glass material costs.

- *Evaluation of a broader set of glass compositions should be pursued*
  The properties of glasses used in PV applications are often based on properties used in traditional glass markets, and may not be optimized for use in solar applications. Participants noted evaluation of different glass compositions may be of significant value to increase solar efficiency.

- *Improved glass melting technology that reduces capital requirements could help improve cost structure for glass manufacturing*
  The capital costs required for glass furnace equipment represent a significant proportion

of total glass product costs. Technologies that improve capital effectiveness for glass melting, such as the submerged combustion melter currently under development, may assist the glass industry in reducing costs.

PV Crystalline Silicon Market Issues and Needs

- *Reliability of general photovoltaic growth forecasts*
  Participants stressed that without reliable forecasting on projected growth, business decisions for expanding capacity and its required investment are challenging to make.
- *Commodity glass industry not used to hockey-stick type growth rates*
  Participants noted that the commodity glass industry is generally conservative, and is not used to very rapid growth. Specialty glass producers such as Corning have taken greater risks in fast-growing markets, but investments have not always been successful, such as the optical fiber market in the late 1990s.
- *Number of GW-size PV crystalline silicon plants that would be built in the U.S.*
  Co-location of a float glass facility would be economically attractive for GW-sized PV fabrication facilities since at that size, the PV plant could utilize and shipping costs would be minimized. However, participants noted that most PV crystalline silicon plants, which are still much smaller than GW-size, are being built outside of North America. In addition, a greater proportion of PV products in the U.S. are utilizing thin film technology.
- *Lead time for building new glass plants*
  Building a greenfield glass plant often requires between two to three years, from site selection, internal approvals and funding, permitting, and construction. Rapid demand growth for glass products could become a concern at some point from a capacity perspective. Additionally, if co-location is desirable, advanced planning would be needed.

FIGURE 8: TECHNICAL AND MARKET ISSUES AND NEEDS FOR PV (CRYSTALLINE SILICON)	
TECHNICAL ISSUES AND NEEDS	**MARKET ISSUES AND NEEDS**
• General specifications would be useful ●●●●●●●●●●●●●●●●● • Higher strength glass - game changing enabler ●●●●●●●●● • Glass types ● • PV manufacturers looking for other structures (non-glass) • Standards: specs and testing • Specifications - is automotive glass sufficient? • Improving glass melting technology (lower capital cost) • Absorption and transmission in glass - how to improve • Pattern glass	• Reliability of growth forecasts ●●●●●●●● - Particular capacity needed for crystalline silicon • Raw material availability ●●●● • Need close to 3-year lead time for new rolled plant ●●●● • How many GW PV plants will be built in USA - co-location issue ●●● • See most growth outside North America • Co-location concerns over environment regulations (especially CA) ● • Many different forecasts for solar and associated glass demand ● • Cost/benefit trade-offs • Most glass for PV in USA made in USA • Maximizing glass for solar - % of product line • Thin film may be ramping faster due to slow reaction for crystalline • Glass-conservative industry • Glass plant capacity costs • See most growth outside North America • Commodity glass industry not used to hockey stick growth rates

Photovoltaics (Thin Films)

Photovoltaics utilizing thin films are rapidly growing within the United States in comparison to crystalline silicon. A broad cross-section of representatives from the solar and glass industries identified several technical and market factors to enhance thin film PV opportunities in U.S. power markets, then voted to prioritize the issues and needs. The voting results are summarized in Figure 9, and the full voting results for technical and market issues are included in Figure 10.

Figure 9: Key Technical and Market Issues and Needs for PV (Thin Films)

Technical

- Basic glass course and customer education for PV industry
- Customer education - technical requirements
- Float glass manufacturing requirements
- Thin, flexible glass development

Market

- Agreed standard specification for glass substrate
- Size of future solar modules
- Sufficiency of glass supplies
- Value for gains in solar efficiency

PV Thin Films Technical Issues and Needs

- *Basic glass course for PV industry*
  Participants indicated that a greater sharing of information on the science and technology utilized by glass manufacturers would be of value for the solar industry.
- *Customer education - technical requirements*
  Participants noted that educating solar industry customers on specific technical requirements for glass products would be beneficial. For example, a guidance chart on glass tempering has been assembled by the Glass Association of North America (GANA). See http://www.glasswebsite.com for more information.
- *Float glass manufacturing requirements*
  Participants stressed that many properties and requirements need to be considered in the manufacture of float glasses for solar applications, such as iron content, optical properties, and size requirements.
- *Thin, flexible glass development*
  Participants inquired about how far is the glass industry from making "thin flexible glass" and whether there would be advantages to "thin flexible glass" substrates (e.g., laminated to something else to make the module).

PV Thin Films Market Issues and Needs

- *Agreed standard specification for glass substrate*
  Participants stressed that standard specifications for glass substrate properties would be beneficial, including properties such as flatness.
- *Size of future solar modules*
  Participants noted that over time, solar modules may become larger, but at this point, it is unclear how large they may become. Larger modules would have implications for glass products and glass production lines employed.
- *Sufficiency of glass supplies*
  Participants questioned whether there could be shortage of available glass supplies at some point in the future, and if so, what efforts could be undertaken today to remedy these concerns. Associated with this, participants questioned at what volume level (tonnage) would a change in the supply chain become necessary.
- *Value for gains in solar efficiency*
  Participants inquired about the value of efficiency gains in solar markets, and whether the solar industry would pay a premium for a gain in efficiency. This could also become an avenue for glass to provide value to the solar industry.

FIGURE 10: TECHNICAL AND MARKET ISSUES AND NEEDS FOR PV (THIN FILMS)	
TECHNICAL ISSUES AND NEEDS	**MARKET ISSUES AND NEEDS**

• Basic glass course for PV industry - science technology ●●●●●●
• Customer education - tech requirements ●●●
  - guidance chart - GANA tempering chart
• Float glass manufacturing requirements - content - low iron, optics, thickness, sizes, etc. ●●
• Glass size - what is the optimum glass size for thin film PV 0.72 m^2, ~1.4 m^2, 5.7m^2 - pros and cons ●
• Are there advantages to "thin flexible glass" substrate (e.g., laminated to something else to make the module).
• How far out is the glass industry from making "thin flexible glass? ●
• How do we insure module reliability? ●
• How does industry deal with leaching of materials out of glass?
• Can glass company make double coats SnO_2 for conductivity and ZnO for interface ●
• Is borosilicate glass ever going to be cost competitive with float glass for thin film PV manufacturing ●
• Glass strength ●
  - rigidity strength ●
• Best place for "secondary" coatings (AR, barrier, anti-soil) - glass manufacturer, PV fab, aftermarket/3rd source ●
  - simplest for module manufacturing
  - also edging and tempering
• Non or less toxic replacement for cerium (not antimony) UV filter
• For CIGS, is glass sandwich package required? If yes, how is edge sealing accomplished? If no, how do you avoid issues of moisture
• Standard measurement method for the glass substrate
• PV industry doesn't understand glass industry and vice versa - where can I get glass information
• What is the thinnest you can temper
• Reduced thickness strength - improved strength
• What is the largest size that can be tempered at present
	• Agreed standard specification for glass substrate - flatness/wave/etc. ●●●●●
	• Future modules - how large may they get? ●●●●
	• What is the next best material to glass ●●
	• When does "co-location" of PV fab and glass tank make sense ●●
	• Can there be glass shortage and what can be done now to avoid it ●●
	• How much is an absolute % point of (solar) efficiency worth - premium for efficiency ●
	  - avenue for glass to provide value
	• Cost modeling for different approaches - efficiency improvements ●
	• Can glass be formed such that it has bezels for better edge barrier seal ●
	• How do we develop the PV market in the US? ●
	• What is the price differential between float and rolled glass
	• At what volume level (tonnage) does a change in supply chain become necessary
	• For C-Si, glass is added after the cells are made. For thin-film, the glass is integrated into the cell fabrication by way of deposition
	• Establish a standard to TCO glass. Glass size, haze, conductivity, transmission
	• Glass supply next 5-10 years

Summary Session and Moving Forward

On the second day of the workshop, the summary session began with brief presentations by representatives from each of the breakout sessions. Tom McMahon (NREL) then shared some brief insights from the Solar Accelerated Aging workshop held earlier the same week.

Discussions followed on what next steps should be. Participants expressed strong interest in developing close relations between the solar and glass industries. Suggestions include:

- Workshops or tutorials on glass industry basics (manufacturing processes, industry statistics, and market forecasts) for the solar industry. Likewise, courses could be developed to introduce PV and CSP needs to the glass industry.
    - DOE could host these forums, or courses could be held in conjunction with other industry meetings.
    - Float glass manufacturers could provide a "hands-on" overview or even facility tour. These would enable solar producers to visualize the complex production process of glass manufacture.
    - Webinar format would enable larger participation and sharing.
    - Glass Association of North America (GANA) provides video overviews on float glass manufacturing and mirror production: http://glasswebsite.org/video/fgmd.asp.
- Hold meetings to address standards development
    - DOE is not a standards developer, but could facilitate discussion among industry members in coordination and preparation to ISO, ASTM, etc.
    - Participants suggested that NREL could compile suggestions on suitable standards and specifications. Any standard should be consistent with any existing glass standards (through ISO, ANSI), if applicable, and NIST should be contacted/involved as well. (See http://www.nist.gov for more information on NIST.)
- Encourage attendance at industry meetings:
    - SPIE: Conference, Courses, and Exhibition – Aug. 10-14, San Diego, CA http://spie.org/optics-photonics.xml
    - Annual "Glass Week" – 2009 date TBD
    - Glass Problems Conference in Columbus, OH in November
- Assemble an industry task force to explore incentives for solar production and use.
- Companies should take the lead in establishing collaborative working groups to discuss product development and standards while the industry is still young. As the industry matures, competitors could be less willing to collaborate.

Before the workshop concluded, each participant was given the opportunity to provide a closing comment. While participants were complimentary of the workshop efforts and reiterated key messages from the earlier sessions, many remarked that this workshop was a good first step, but additional efforts were needed.

Dr. Jeffrey Mazer and Glenn Strahs provided some final thoughts and thanked attendees for their participation before adjourning the workshop.

Over twenty workshop participants stayed for the optional afternoon tour of NREL solar laboratories, such as the Process Development Integration Lab and characterization labs of the Science and Technology Facility for PV. For CSP, the participants toured the Field Test Laboratory building.

Appendix A: Workshop Steering Group

MaryLee Blackwood	Energetics, Inc.
Michael Greenman	Glass Manufacturing Industry Council
Doug Hall	Corning, Incorporated
Scott Hennessey	Solar Energy Industries Association
Bob Hershey	Engineering and Management Consulting
Keith Jamison	Energetics, Inc.
Juris Kalejs	American Solar Technologies
Dave Kearney	Kearney and Associates
Cheryl Kennedy	National Renewable Energy Laboratory
Elliott Levine	DOE Industrial Technologies Program
Tom Mancini	Sandia National Laboratories
Jeffrey Mazer	DOE Solar Energy Technologies Program
Jim McCamy	PPG Industries
Bill McGrail	Guardian Industries
Tim McKittrick	Pilkington North America
Paul Medwick	PPG Industries
Peter Meyers	First Solar
Chris O'Brien	Oerlikon Solar
Adam Polcyn	PPG Industries
Scott Reed	Sandia National Laboratories
Larry Sherwood	Sherwood Associates
Scott Sklar	The Stella Group
John Stanton	Solar Energy Industries Association
Glenn Strahs	DOE Industrial Technologies Program
David Strickler	Pilkington North America
Stephen Weidner	Pilkington North America
Jim West	Guardian Industries
John Winter	PPG Industries

Appendix B: Workshop Final Agenda

Time	Activity	
Wednesday, April 2		
7:15 – 8:00	**Registration and Continental Breakfast**	
8:00 – 8:20	*Welcoming Remarks and Photovoltaics Overview* **–** Dr. Jeffrey Mazer, DOE Solar Energy Technologies Program	
8:20 – 8:35	*Glass and Workshop Overview* **–** Glenn Strahs, DOE Industrial Technologies Program	
8:35 – 8:50	*Concentrating Solar Power Overview* **–** Thomas Rueckert, DOE Solar Energy Technologies Program	
8:50 – 9:20	*DOE Technology Commercialization Perspectives* – Michael Bruce, DOE Office of Energy Efficiency and Renewable Energy	
9:20 – 9:50	*Solar Energy Market and Data* – Dr. Robert Margolis, National Renewable Energy Laboratory	
9:50 – 10:05	**Break**	
10:05 – 10:35	*NREL Solar and Glass Activities* **–** John Benner, National Renewable Energy Laboratory	
10:35 – 10:55	*Glass Requirements for Various Sectors of the Solar Industry* **–** Cheryl Kennedy, National Renewable Energy Laboratory	
10:55 – 11:25	*Solar Industry Perspective* **–** Chris Constantine, Oerlikon Solar	
11:25 – 11:55	*Glass Industry Perspectives* **–** Doug Hall, Corning and Steven Weidner, Pilkington	
11:55 – 12:10	*Breakout Sessions and Instructions* **–** Keith Jamison, Energetics	
12:10 – 1:15	**Lunch** (speaker starting at about 12:45) *Solar Legislation and Policies* **–** Scott Hennessey, Solar Energy Industries Association	
1:15 – 1:30	**Break and Proceed to Breakout Rooms**	
1:30 – 3:10	**Facilitated Breakout Discussions (concurrent)**	
	Coatings	Photovoltaics (crystalline silicon)

3:10 – 3:30	**Break**	
3:30 – 5:00	**Facilitated Breakout Discussions (concurrent)**	
	Concentrating Solar Power	Photovoltaics (thin films)
5:00	**Adjourn**	
5:30 – 7:00	**Social Gathering: Light Snacks and Cash Bar**	
	Dinner (on your own)	
Thursday, April 3		
7:15 – 8:00	**Continental Breakfast**	
8:00 – 9:40	Summary Session: Review Breakout Results and Discussion	
9:40 – 10:00	**Break**	
10:00 – 11:30	Summary Session: Continue Discussion, Next Steps, and Closing Comments	
11:30	**Adjourn**	
1:00 – 4:00	**NREL Lab Tour (Optional)**	

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Appendix D: Glossary

ANSI	American National Standards Institute
AR	Anti-Reflective coating
ASTM	American Society for Testing and Materials
C-Si	Crystalline silicon—includes both single-crystal and polycrystalline material
CSP	Concentrating Solar Power—refers to electric power from the concentration of sunlight on a working fluid, e.g., in a Sterling engine
GW	Gigawatt, i.e., one billion watts
CIGS	Copper-Indium-Gallium-Diselenide—a thin-film photovoltaic material
CPV	Concentrating Photovoltaics
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy—a directorate of the DOE
GANA	Glass Association of North America
ISO	International Organization for Standardization
NIST	National Institutes of Standards and Technology
NREL	National Renewable Energy Laboratory—a U.S. Department of Energy laboratory
PV	Photovoltaics—solar cells and modules for the direct conversion of sunlight into electric power
SEIA	Solar Energy Industries Association
SPIE	Society of Photo-Optical Instrumentation Engineers—now known as SPIE—The International Society for Optical Engineering
TCLP	Toxicity Characteristic Leaching Procedures
TCO	Transparent Conducting Oxide

Appendix E: Speaker Presentations

Introduction to the Workshop and Brief Overview of DOE's Solar America Initiative (SAI)

Workshop on Specialty Glass Needs for the U.S. Solar Industry

Golden, Colorado 2 & 3 April 2008

Jeffrey Mazer
Solar Energy Technologies Program
Office of Energy Efficiency and Renewable Energy

http://www.eere.energy.gov/solar/

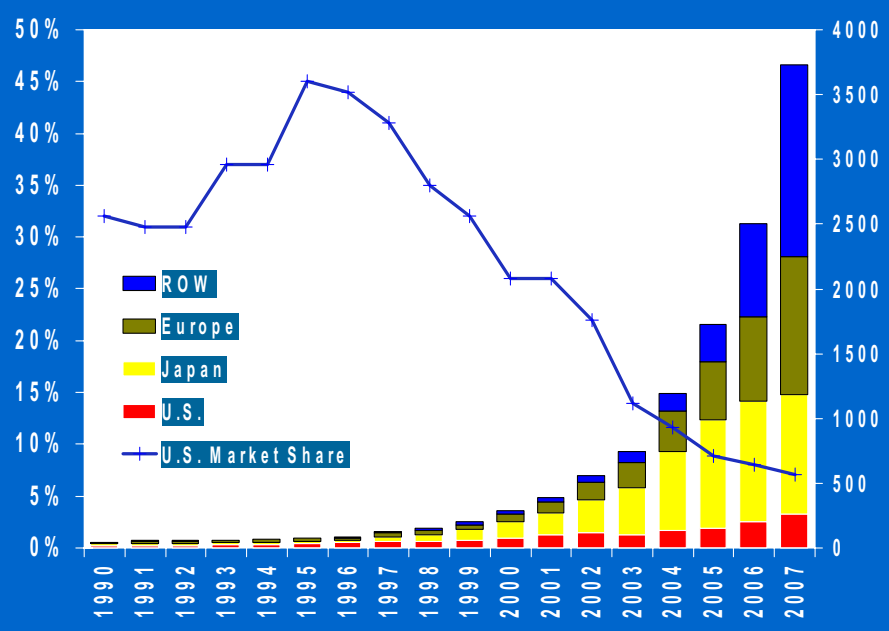
Purpose and Goals of the Workshop

- The workshop brings together the solar and glass industries to address the imminent gigantic demand for glass products
- Goals of the workshop:
  - Discuss the role of the glass industry in the rapid expansion of solar energy
  - Address specific questions that elucidate future solar glass needs
- Great demand for solar glass will be driven by three factors:
  - Solar energy technologies will continue to require glass in their designs
  - Concentrating solar power has demanding geometrical specifications for glass
  - Photovoltaics, and more recently CSP, are expanding very rapidly

Photovoltaic Modules Use a Lot of Specialty Glass

- Crystalline silicon PV modules use a 5-layer thermo-compression sandwich:
  - (low-iron) glass sheet on top for mechanical and vapor protection
  - EVA (ethylene vinyl acetate) polymer encapsulant
  - solar cells connected in series with soldered ribbon tabs
  - EVA
  - polyvinyl fluoride (Tedlar®) /polyester laminate backplane
- Anti-reflective coatings can be applied by the glass producer
- Thin-film modules also use glass: substrate (CIGS) or superstrate (CdTe). Can be supplied with metal or transparent conducting oxide depositions.
- PV's 10-yr production expansion rate averages > 40% / yr. (49% in 2007)

PV Shipments and U.S. Market Share



Details of PV's Rapid Expansion

- Direct module manufacturing costs < $2 / W; but the shortage of electronic-grade silicon feedstock limits production
- Production is mostly crystalline-silicon based (90% in 2007)
- Thin-film PV is growing because of shortage of electronic-grade Si feedstock as well as very low production costs
- In U.S., thin-film PV in 2007 was ~ 175 MW out of 266 MW *
- SAI will make PV an important part of the national energy mix by 2015: seeks 5–10 ¢ / kWh and 5–10 GW of installed PV

* *PV News* (Prometheus Institute), vol. 27, p.8, *March 2008*

DOE Photovoltaic Budget Trends

Solar America Initiative has dramatically increased PV funding:

FY	DOE PV Budget ($ millions)
2005	67
2006	61
2007	148
2008	138

DOE's Solar America Initiative has Technical and Non-Technical Components

- Systems-oriented, industry-led, public-private teams called technology pathway partnerships (TPPs)
- Projects to enable small companies and non-Fed institutes to achieve prototype manufacturing by 2010 (PV Incubator)
- Projects to support universities in SAI and post-SAI efforts
- Projects to deal with issues of permitting, consistent codes and standards for installation, utility acceptance, installer training, and solar business development (Market Transformation)

TPP Awardees in FY 2007 (only partial year funding)

Minimum 50% cost share

Company	FY 2007 DOE Funding ($)	Description
Amonix	2,200,000	Low-cost, high-concentration PV system for utility markets.
Boeing	3,400,000	High-efficiency concentrating photovoltaic power system.
BP Solar	4,000,000	Low-cost approach to grid parity using crystalline silicon.
Dow Chemical	1,600,000	PV-integrated residential and commercial building solutions.
General Electric	4,600,000	A value chain partnership to accelerate U.S. PV growth.
Greenray	591,353	Development of an AC module system.
Konarka	868,805	Building-integrated organic photovoltaics.
Nanosolar	4,750,105	Low-cost, scaleable PV systems for commercial rooftops.
Soliant	2,098,991	Low-profile high-concentration PV systems for rooftop applications.
SunPower	4,400,000	Grid-competitive residential solar power generating systems, and PV cell-independent effort to improve automated manufacturing systems.
United Solar Ovonic	2,821,859	Low-cost thin-film building-integrated PV systems.
DOE TOTAL	**31,331,113**	

SAI Photovoltaic Incubator

- ~ $27 M from DOE in first 18-month budget period (starting in CY 2007)
- Intended for small businesses and non-federal research institutes
- Prototypes must have demonstrated proof-of-concept for manufacturing
- Successful companies can compete in the 2010 round of TPP solicitations
- Re-competition every 9 months; piece-meal support based on deliverables
- 10 companies have been selected; funding has started

PV Incubator First-Round Funding

Minimum 20% cost share

Company	First Round DOE Funding ($)	Description
AVA Solar	3,000,000	Low cost, high-throughput, automated fabrication of CdTe thin film cells and modules.
Blue Square Energy	2,990,000	Silicon solar cells on low cost substrates.
Calisolar	3,000,000	Manufacturing high efficiency cells using upgraded metallurgical grade silicon.
EnFocus	2,900,000	Pilot manufacturing of rooftop-ready solar panels using high concentration photovoltaics.
MicroLink Devices	2,400,000	Development of lower cost, high-efficiency, solar cells for concentrating applications.
Plextronics	3,000,000	Economic on-grid solar energy via organic thin-film technology.
PrimeStar Solar	2,980,000	Production scale-up of world record CdTe/CdS cell.
Solaria Corp	2,600,000	Simplified, low cost, 2x concentration flat plate module.
SolFocus	2,000,000	Reflective concentrating PV panels enabling large-scale, reliable energy generation.
SoloPower	2,370,000	CIGS technology based on electroplating.
DOE TOTAL	**27,240,000**	

University Funding Opportunities

DOE has released several University solicitations:

- one for universities and companies to perform research on post-2015 (post-SAI) photovoltaic topics
- one for university support of industry efforts to achieve the SAI 2015 goals
- 20% cost-share
- total DOE funding ~ $ 4 - 8 million per year per solicitation

SAI Market Transformation Efforts

- Support for the development of solar energy system and interconnection codes and standards by the Solar America Board for Codes and Standards through New Mexico State University
- Utility technical outreach through the SEPA to assist utilities with solar business information
- State technical outreach through the National Conference of State Legislatures, the Clean Energy Group, and the National Association of Regulatory Utility Commissioners to enable solar legislation and implement programs
- Solar America Cities partners with select cities to achieve a sustainable solar infrastructure—13 cities in 11 states
- Solar America Showcases provides technical assistance to large-scale high-visibility solar installations: Forest City Military Communities in Hawaii, Orange County (Florida) Convention Center, and an installation in San Jose, CA.
- Training of solar installers through the North American Board of Certified Energy Practitioners. NABCEP offers voluntary certification for PV and solar thermal installers: 421 PV installers and 56 solar thermal installers.
- DOE Solar Decathlon, a highly successful biannual solar home demonstration conducted by university students and home builders/suppliers on the National Mall in Washington, D.C. (October 2007).

Conclusions

- Solar, and photovoltaics (PV) in particular, is rapidly expanding
- Crystalline Si will be the dominant form of PV to at least 2015; however, thin films are expanding quickly in the United States
- DOE SAI will greatly lower $/Watt values, improve system reliability, and expand manufacturing capabilities, to allow PV to become an important part of the national energy mix by 2015
- The PV industry (along with other solar technologies) will soon demand huge quantities of specialized glass products

DOE Glass Program and Introduction to the Workshop

Workshop on Glass Needs of the Solar Industry

Golden, Colorado 2 - 3 April 2008

Glenn Strahs
Industrial Technologies Program
Office of Energy Efficiency and Renewable Energy

http://www.eere.energy.gov/industry

Planning the Glass-Solar Workshop

- Special thanks to the Steering Group members who planned this workshop, with DOE, in four conference calls from November ’07 through mid-March.
- The Steering Group gave very useful guidance and information on the content and organization of this Workshop, including where to hold it, the breakout sessions and other features. We believe this Workshop will reflect their valuable input.
- The afternoon of the second day, Thursday, April 3, is an optional tour of several solar laboratories at NREL

Background on the Glass-Solar Workshop

- DOE is very encouraged by the great interest in this workshop to bring together solar and glass industry principals & planners.
- The workshop has attracted significant attention by DOE upper management as well as the industries involved. There was a similar meeting in China in January and one very soon in Munich, Germany
- For over a decade, ITP has been engaged in reducing energy demand in the US glass industry. ITP worked collaboratively with the industry in sponsoring about 35 R&D projects, preparing a Glass Industry roadmap, performing key analyses and providing training and workshops on important technical topics. ITP helped with the commercial development of oxy-fuel technology which is now extensively used in the glass industry, received 2 R&D 100 awards and supported work culminating in significant intellectual property, including patents and copyrights.

Anti-Trust Considerations

- Since this workshop has business competitors as its participants, there are Anti-Trust requirements that have to be adhered to. I have discussed this issue with DOE General Counsel and the U.S. Department of Justice- Anti-Trust Division, who provided this language as appropriate to this Glass and Solar workshop. So, before we begin these discussions, there are some comments I need to make about the conduct of the meeting.
- "This meeting is subject to U.S. antitrust laws and communications among actual or potential competitors regarding competitively sensitive information, such as markets served, prices charged and marketing plans, could result in a violation of the antitrust laws and lead to civil or criminal liability. We therefore ask that you refrain from disclosing any proprietary company cost, supply or price information, or any proprietary company information."

Output from this Workshop

- We definitely plan to have a Workshop Report with all the presentations and other materials provided.
- Beyond the Workshop Report, do we want a Roadmap, Strategic Plan or some other document?
- What are our next steps or follow-on to this Workshop?
- Do we need another workshop or meeting, and what would be the purpose and who would be the suggested participants?
- Any interest in CRADAs?

Concentrating Solar Power

Solar Glass Workshop

April 2-3, 2008

Tommy Rueckert
Solar Program Systems Team Leader
U.S. Department of Energy
(202) 586-0942
thomas.rueckert@ee.doe.gov

Discussion

- CSP Technology Overview
- Solar Resource Potential in the Southwest U.S.
- U.S. and International Project Status
- Cost Targets and Market Penetration Analysis

CSP Technologies and Market Sectors

- CSP w/ Storage (Dispatchable)
  - Parabolic Trough
  - Central Receiver
  - Linear Fresnel
- CSP w/o Storage (Non-Dispatchable)
  - Dish/Engine
  - Concentrating PV

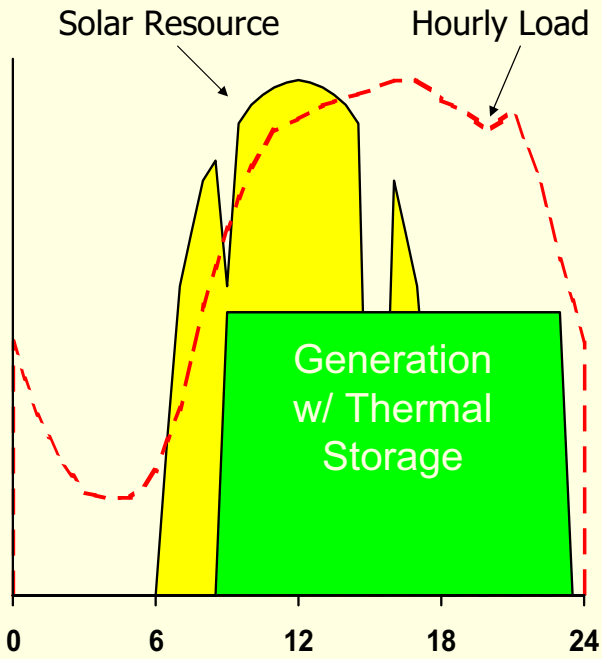
Concentrating Solar Power: Dispatchable Power

Parabolic Troughs: Commercial, utility-scale deployments

Central Receiver: Pre-commercial, pilot-scale deployments

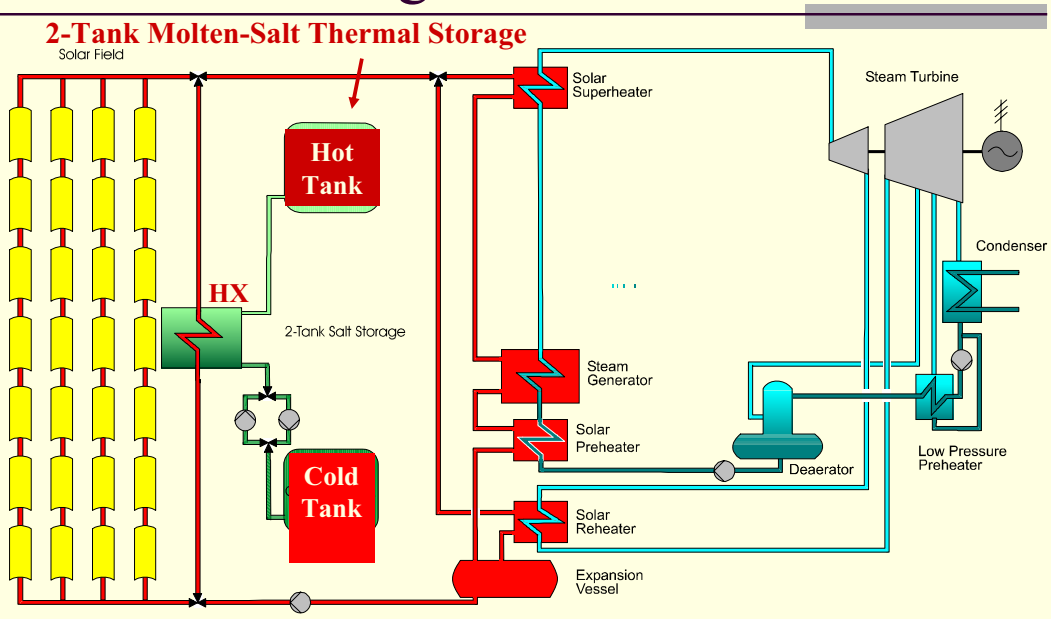
- Up to 250MW plants (or multiple plants in power parks) for peaking and bulk power
- Moderate solar-to-electric efficiency
- Thermal storage offers load following and capacity factors up to 70%

Value of Dispatchable Power? Meeting Utility Power Demands



- Storage provides
  - higher value because power production can match utility needs
  - lower costs because storage is cheaper than incremental turbine costs

Parabolic Trough Power Plant with Thermal Storage



Dish Systems without Storage
Central Station or Distributed Power

Dish/Stirling: Pre-commercial, pilot-scale deployments

Concentrating PV: Pre-commercial, pilot-scale deployments

- Modular (3-25kW)
- High solar-to-electric efficiency

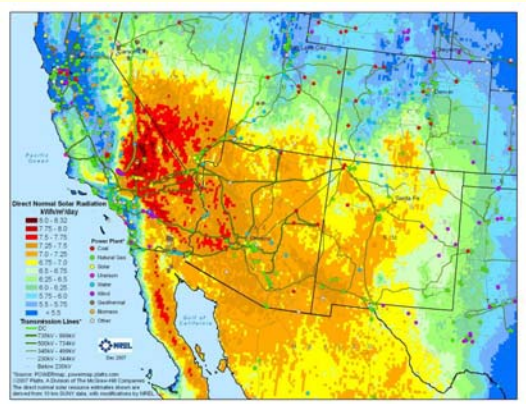
6-Dish Prototypes – SES/Sandia

Discussion

- DOE Laboratory and CSP Technology Overview
- Solar Resource Potential in the Southwest U.S.
- U.S. and International Project Development Current Projects
- Cost Targets and Market Penetration Analysis

U.S. Southwest GIS Screening Analysis for CSP Generation

- Initial GIS screening analysis used to identify regions most economically favorable to construction of large-scale CSP systems.
- GIS analysis used in conjunction with transmission and market analysis to identify favorable regions in the southwest



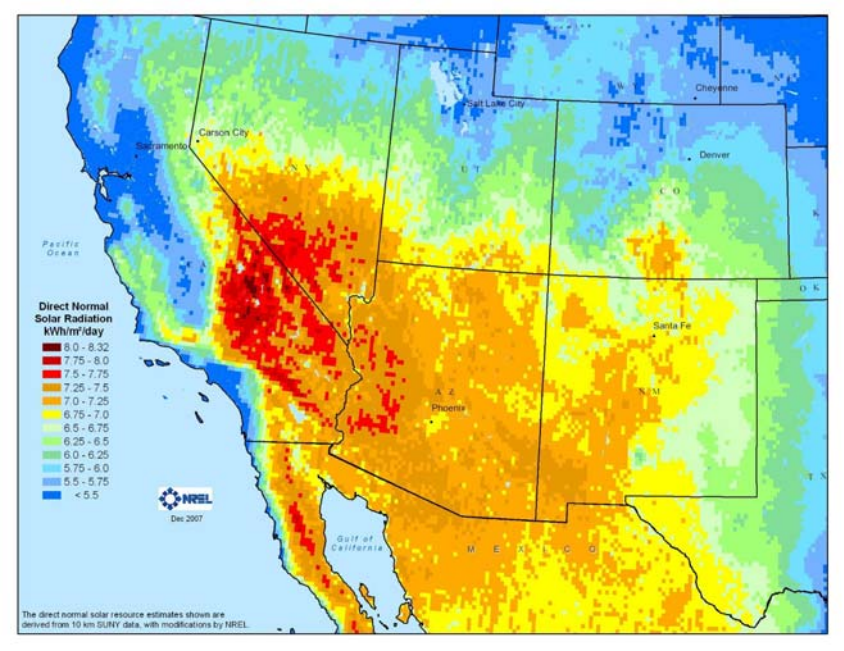
Solar Resource Screening Analysis

All Solar Resources

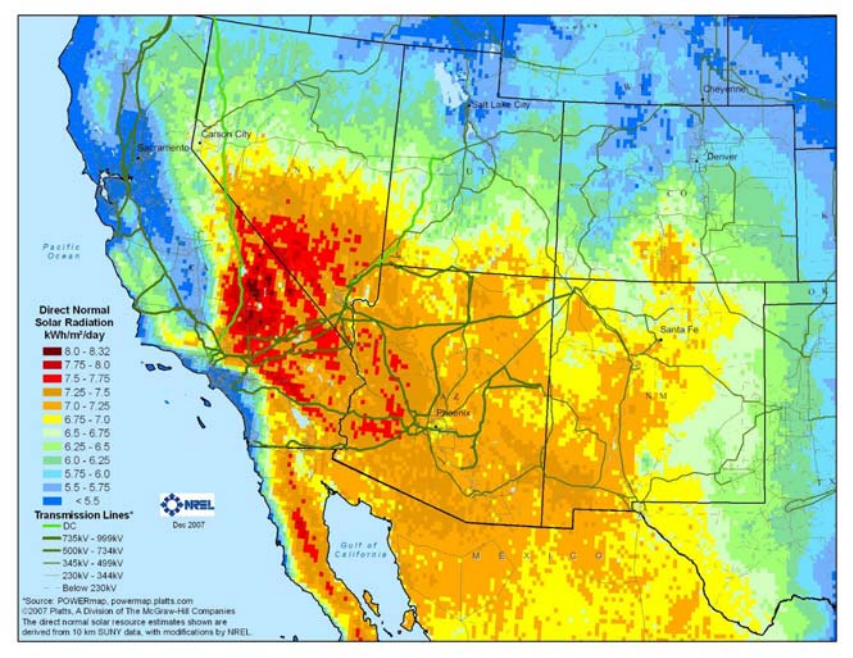
Locations Suitable for Development

1. Start with direct normal solar resource estimates derived from 10 km satellite data.
2. Eliminate locations with less than 6.0 kWh/m^2/day.
3. Exclude environmentally sensitive lands, major urban areas, and water features.
4. Remove land areas with greater than 1% (and 3%) average land slope.
5. Eliminate areas with a minimum contiguous area of less than 1 square kilometers.

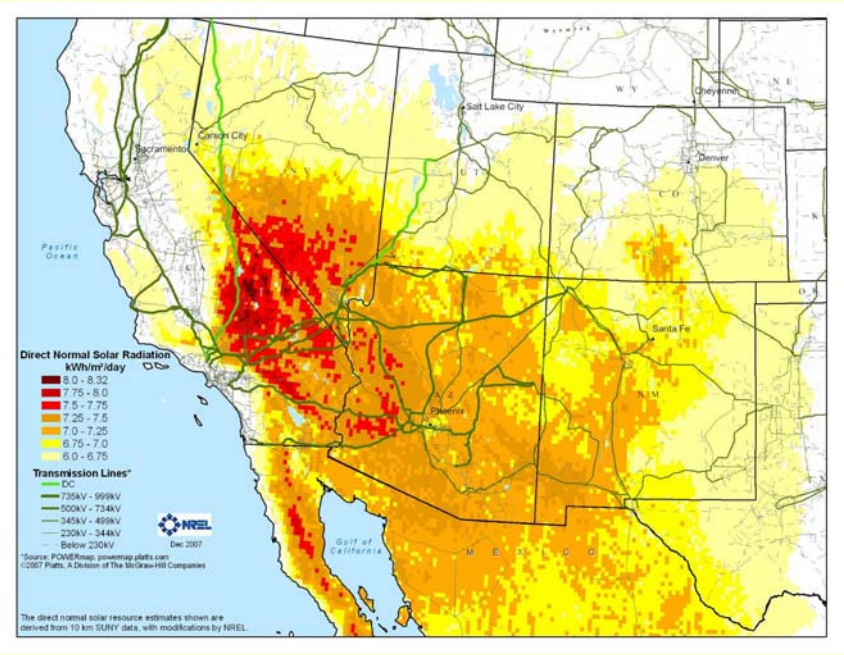
Southwest Solar Resources - Unfiltered Data



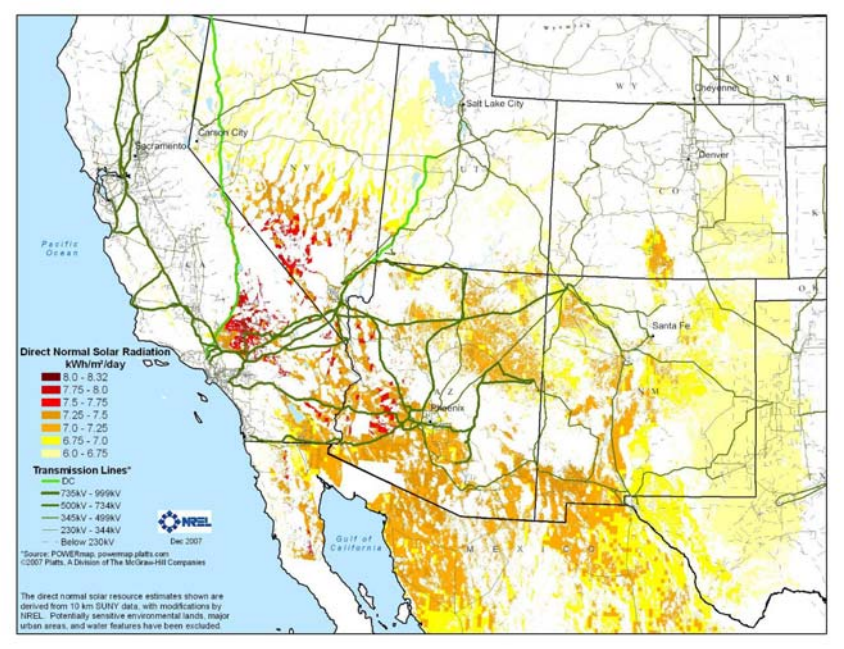
Southwest Solar Resources – Transmission Overlay



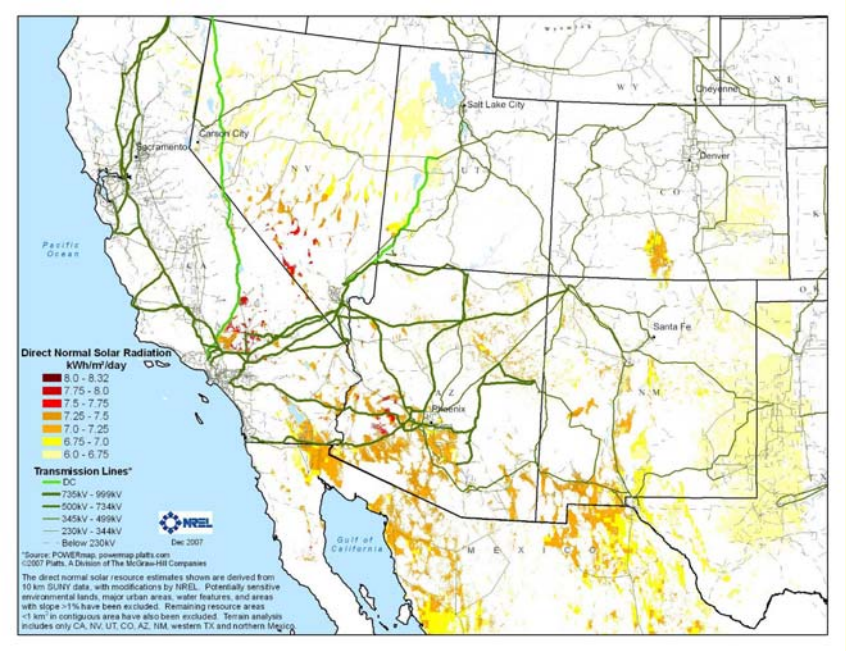
Southwest Solar Resources > 6.0 kWh/m^2/day



Southwest Solar Resources with Environmental and Land Use Exclusions

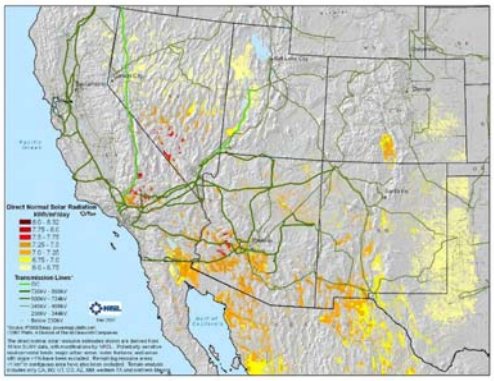


Southwest Solar Resources
Previous plus slope < 1%



Resulting CSP Resource Potential

State	Land Area (mi^2)	Solar Capacity (MW)	Solar Generation Capacity GWh
AZ	13,613	1,742,461	4,121,268
CA	6,278	803,647	1,900,786
CO	6,232	797,758	1,886,858
NV	11,090	1,419,480	3,357,355
NM	20,356	2,605,585	6,162,729
TX	6,374	815,880	1,929,719
UT	23,288	2,980,823	7,050,242
Total	87,232	11,165,633	26,408,956



The table and map represent land that has no primary use today, exclude land with slope > 1%, and do not count sensitive lands.
Solar Energy Resource ≥ 6.0
Capacity assumes 5 acres/MW
Generation assumes 27% annual capacity factor

Current total nameplate capacity in the U.S. is 1,000GW w/ resulting annual generation of 4,000,000 GWh

Discussion

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1-MW Arizona Trough Plant – near Tucson, AZ

64 MWe Solargenix Parabolic Trough Plant

50MW AndaSol-1 Trough Plant w/ 7-hr Storage Andalucia, Spain

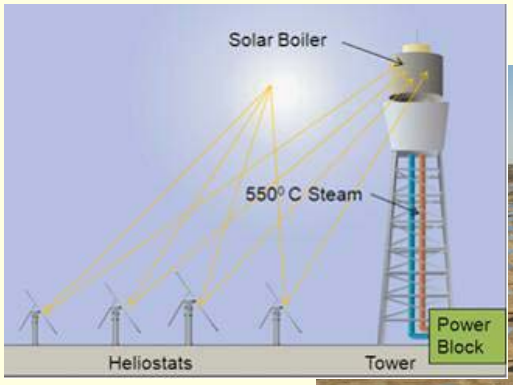
Solucar 50 MW Trough Project Sevilla, Spain

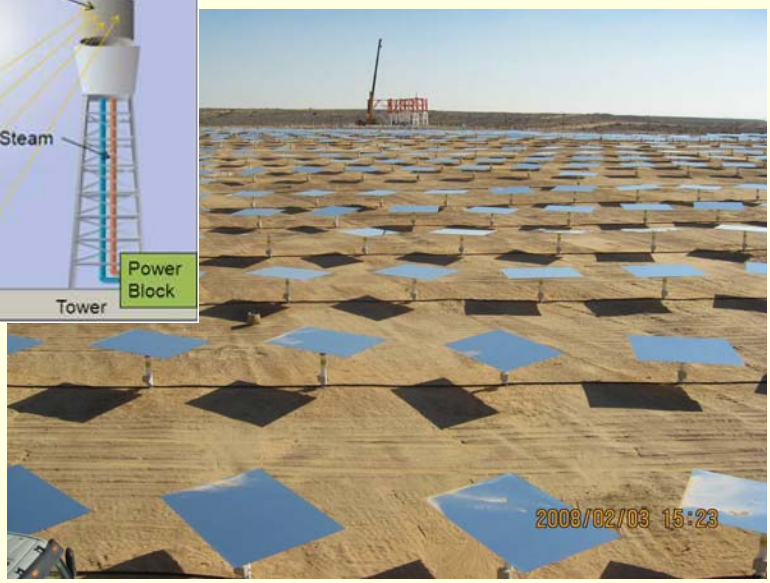
First of 5 x 50MW parabolic trough plants under construction by Solucar

Solucar PS10 Power Tower
Sevilla, Spain

Solucar PS20 Under Construction
Sevilla, Spain

BrightSource Distributed Power Tower





Ausra Linear Fresnel

CSP Projects – early 2008

U.S. projects: enabled by 30% investment tax credit and State renewable portfolio standards

State	RPS Requirement
Arizona	15% by 2025
California	20% by 2010
Colorado	20% by 2020
Nevada	20% by 2015, 5% Solar
New Mexico	20% by 2015
Texas	5,880MW (~4.2%) by 2015

Utility	Capacity (MW)	Technology -Status
Arizona Public Service (APS)	1	Trough – completed and in operation 2006 (Acciona)
Nevada Power	64	Trough – completed and in operation June 2007 (Acciona)
So. Cal Edison; San Diego G&E	500/300	Dish – signed power purchase agreement (SES)
Pacific Gas & Electric	550	Trough – signed power purchase agreement for four plants (Solel)
Pacific Gas & Electric	170	CLFR – signed power purchase agreement (Ausra)
Pacific Gas & Electric	500	Tower – MOU signed (Bright Source)
Florida Power and Light	250	Trough – Application for Certification with CEC
Arizona Public Service	280	Trough – signed power purchase agreement (Abengoa)
SW Utility joint venture (APS)	Est. 250	TBD – multiple expressions of interest submitted
New Mexico Utility Joint Venture	50-500	TBD – initial stages

CSP Projects – International

Country/Company	Capacity (MW)	Technology -Status
Spain: Solar Millenium	4 x 50MW with storage	Trough – Andosol 1 &2 under construction.
Spain: Abengoa/Solucar	5 x 50MW	Trough – 1st plant under construction
Spain: Abengoa/Solucar	11MW &20MW	Power Tower (saturated steam) – PS10 operational. PS20 under construction
Spain: SENER	17MW	Power Tower (molten salt) – contract terms under discussion
Spain: various	TBD	Projects under various stages of development due to tariff for 500MWs of CSP capacity. Cap likely to be raised to 1000MWs.
Algeria: Abener	150MW	Integrated Solar Combined Cycle System (ISCCS) – 25MW Solar Capacity
Egypt: TBD	140MW	ISCCS – 25MW Solar Capacity, negotiations in progress
Mexico: TBD	TBD	ISCCS – RFP issued
Morocco: TBD	230MW	ISCCS – 35 MW Solar Capacity
Israel: Solel	2 x 125MW	Trough – Northern Negev. Waiting approval from Interior Ministry
Australia: SHP	15MW,th	Linear Fresnel – under construction for integration into feed water heaters in existing coal plant
Greece: TBD	TBD	Tariff for CSP recently enacted. Similar in design to Spanish feed-in tariff

Discussion

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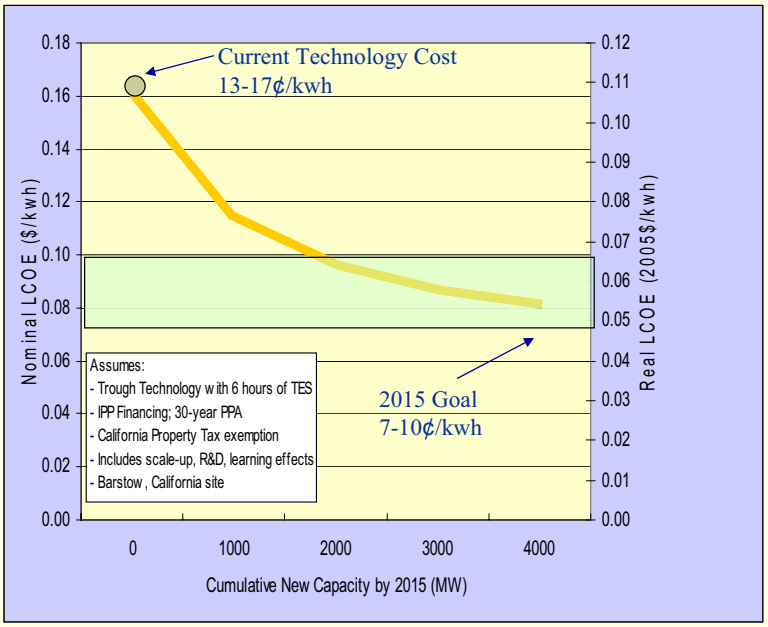
Bridging the Cost Gap



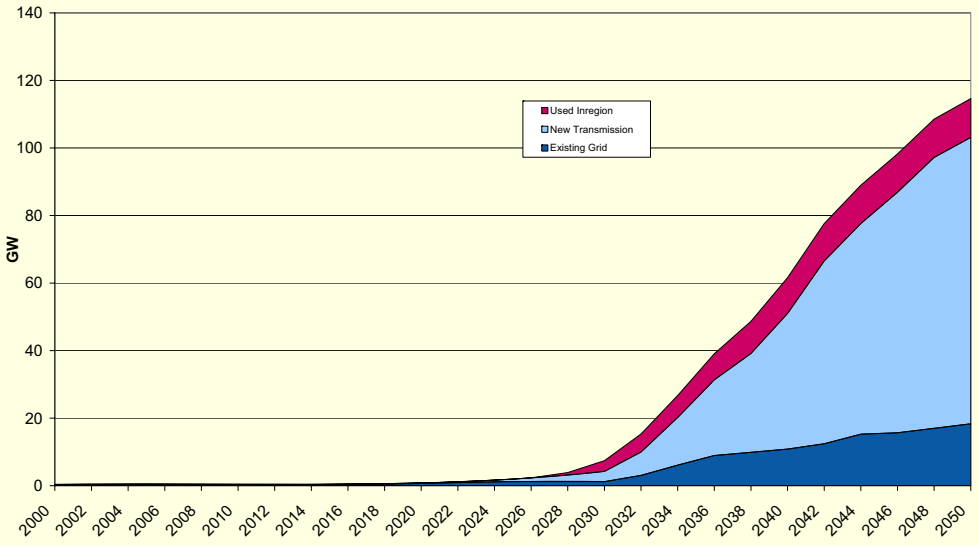
Source: WGA Solar Task Force Summary Report

Cost Reductions to Bridge the Gap

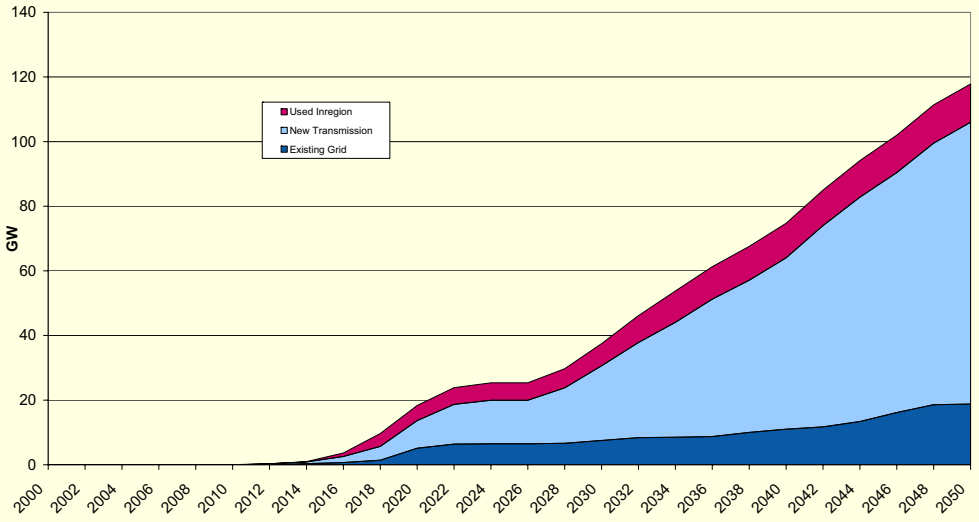
- Deployment
- Plant Size
- Financing
- R&D

Analysis does not include current 30% investment tax credit

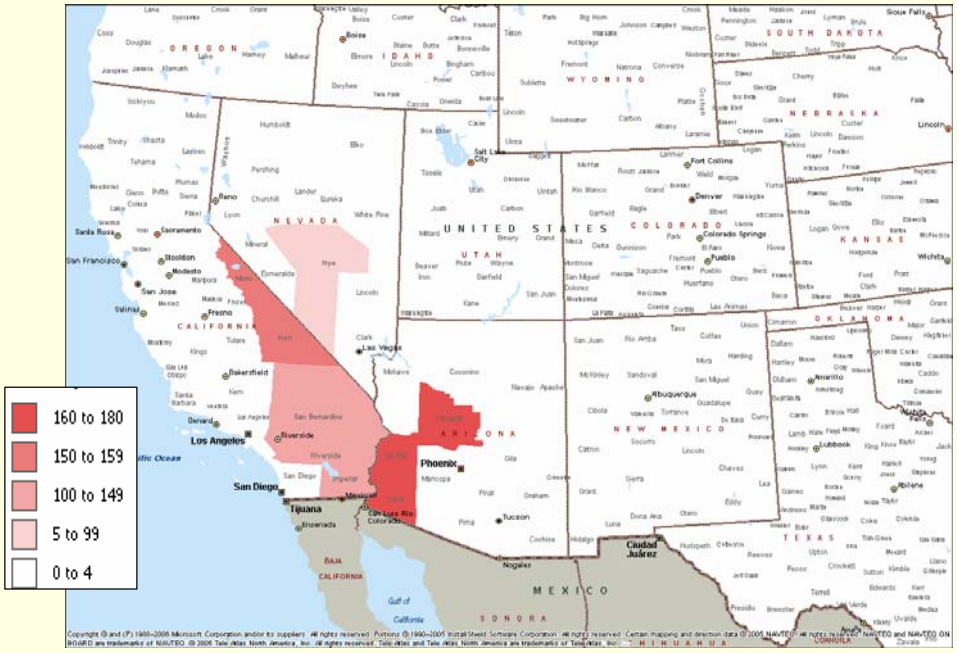
Cumulative CSP Capacity
No Extension of Solar ITC



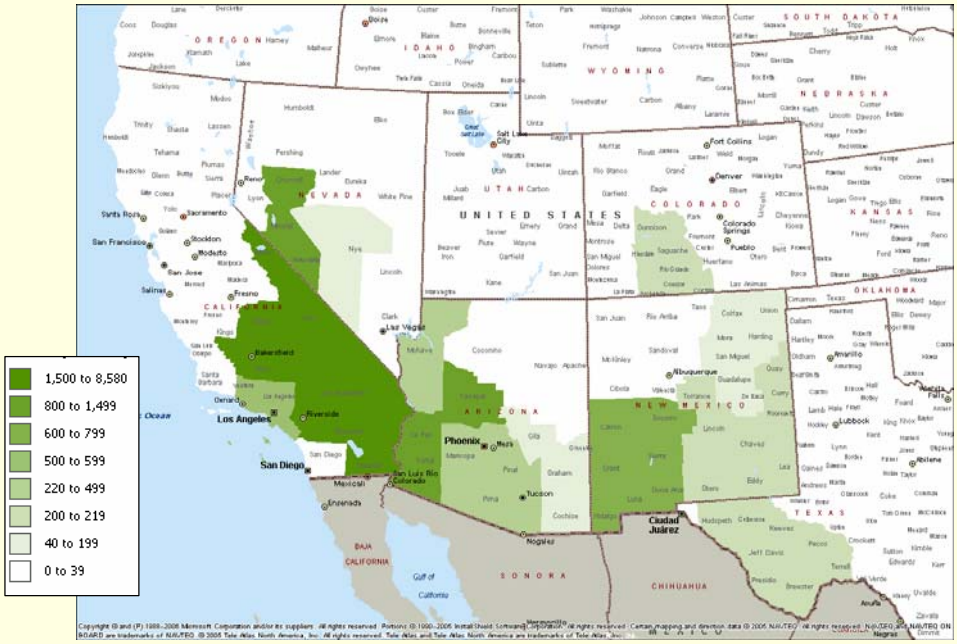
Cumulative CSP Capacity
8-year extension with declining ITC



CSP Capacity in 2020 with no ITC extension



CSP Capacity in 2020 with ITC extension



Glass Applications for CSP Industry

- **Mirrors**
  - Current Manufacturers
    - Pilkington - Germany
    - RIO - Spain
  - Related CSP Awards
    - 3M
    - Abengoa
    - Alcoa
    - PPG
- **Receivers**
  - Current Suppliers
    - Schott Glass - Germany
    - Solel - Israel

Summary

- CSP technologies, especially those with thermal storage, offer a low-cost high-value option for utility markets.
- The solar resource in the Southwest is immense resulting in generation potential of CSP greater than six times current U.S. demand.
- Suitable lands are located close to existing transmission, minimizing costs required to access high-value solar resources.
- U.S. market penetration is occurring and will continue with extension of the investment tax credit and current southwest state policies.
- The CSP industry is hungry for U.S. glass manufacturers to enter the CSP market to lower costs, improve reliability, and increase options.

Commercialization & Deployment

Energy Efficiency and Renewable Energy

U.S. Department of Energy

April 2008

Michael Bruce, Senior Advisor for Finance

National security, environmental and economic goals form the basis for a robust National Energy Policy…

National Security

- Diversify the U.S. energy portfolio and reduce dependence on petroleum

Environmental Stewardship

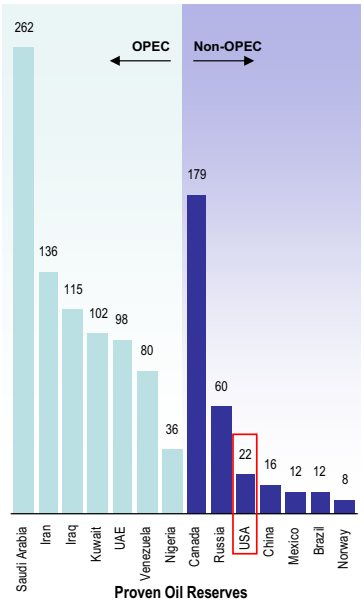
- Reduce greenhouse gas emissions and other negative environmental impacts

Global Economic Competitiveness

- Create more flexible, more reliable and higher capacity U.S. energy infrastructure
- Improve the energy productivity of the United States economy and industry

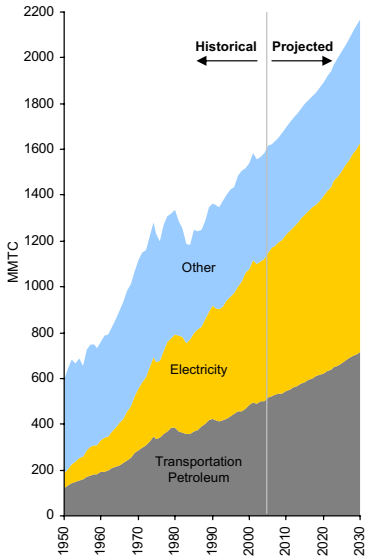
… but historical data demonstrates the magnitude and urgency of the challenge

Energy Security



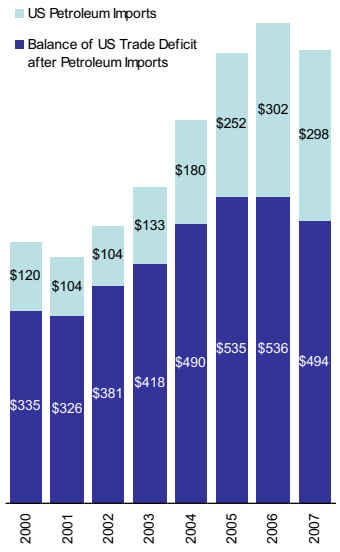
Proven Oil Reserves by Top Producing Countries in 2006[1]
(Billions of Barrels)

Environmental Stewardship



US Historical and Projected Greenhouse Gas Emissions by Source[2]
(Millions of Metric Tons of Carbon)

Global Economic Competitiveness



US Historical Trade Deficit[3]
(Billions of US Dollars)

(1) Source: PennWell Corp., Oil & Gas Journal, December 16, 2006. Includes 174BN barrels of Canadian oil sands.
(2) Source: American Energy Outlook 2007, Energy Information Agency.
(3) Source: US Department of Labor, Bureau of Economic Analysis, International Transactions Accounts. Note: 2007 trade deficit annual data extrapolated from the first three quarters of the calendar year.

Accelerating commercialization is Assistant Secretary Karsner's primary policy objective

"I believe that success will be defined by enabling commercial frameworks and free enterprise to **accelerate the development and deployment of new energy technologies** to address these challenges head on… I will seek to expand the efforts to **more rapidly commercialize** and deploy the under-harvested yield of decades of public sector investment..."

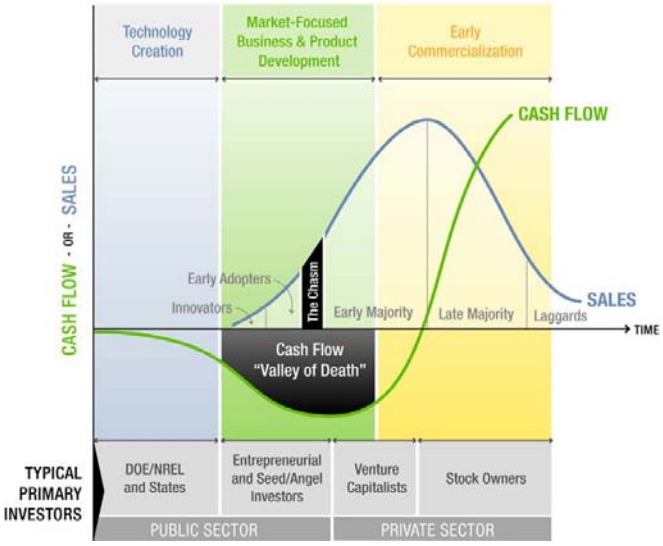
- Assistant Secretary Andy Karsner,
Senate Confirmation Testimony, March 6, 2006

Fall 2006 Question to DOE Program Managers:

"How has your program impacted the life of the American taxpayer?"

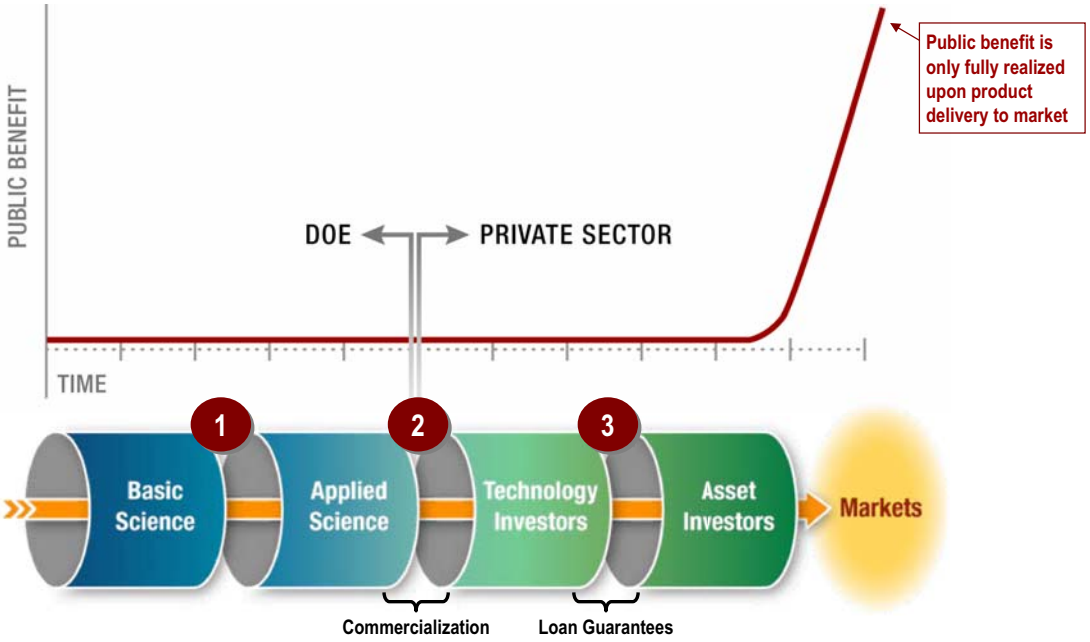
Answer:

"[Good Answer]…but the 'Commercialization Valley of Death' has prevented us from being as effective as we'd like."



The historical "Commercialization Valley of Death" refers to the quantitative challenge of transitioning between early adopters and mass market penetration

An innovation must overcome three qualitative transitions before reaching the market



The EERE Commercialization Team focus on building bridges between Applied Scientists and Technology Investors

EERE Commercialization Bridges are designed to overcome four primary gaps

Talent

- DOE traditionally hires scientists – not businessmen
- Commercializing technologies requires both technical & business skill set

Information

- Communication is a fundamental prerequisite of commercialization
- Technical language fails to resonate with the business community

Capital

- Competition is stiff for venture capital funding
- VCs more likely to fund business plans and prototypes than research papers

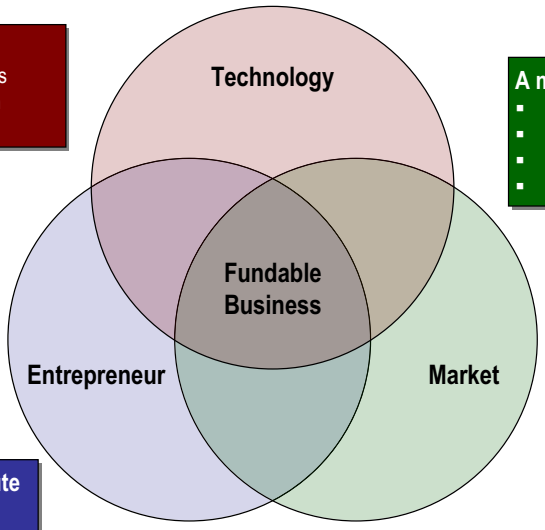
Strategy

- The Commercialization Valley of Death is not unique to national laboratories
- Best practices have been developed to foster a culture of innovation

Built off a proven venture capital model, the Entrepreneur in Residence (EIR) program forms the primary plank of the TALENT BRIDGE

A technology that works
- Readily available at national labs
- Under-deployed due to focus on scientific research

A market ripe to sell into
- Market ready for clean energy
- $100 oil
- Global climate change
- Sufficient degree of policy predictability



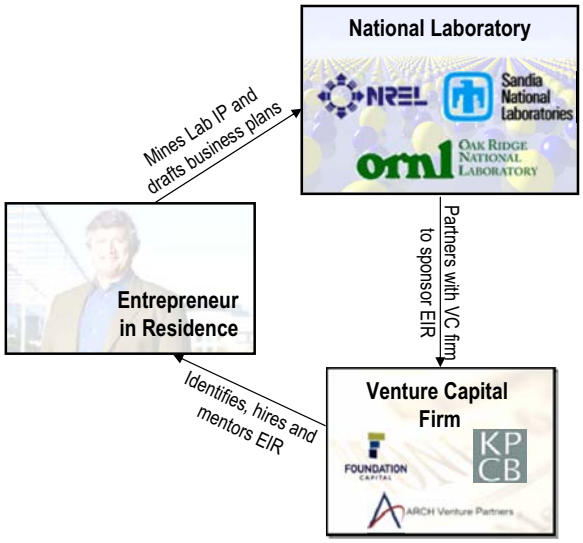
An entrepreneur who can execute
- Build business plan
- Assemble management team
- Raise capital

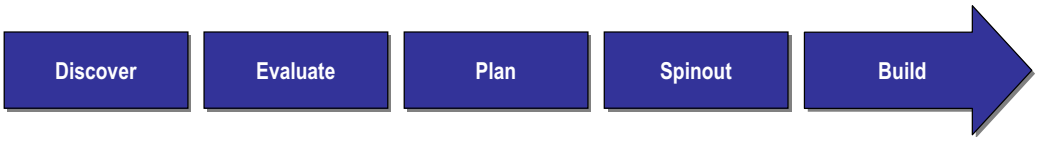
Venture Capitalists favor experienced entrepreneurs with a track record of identifying promising technologies and building markets

DOE's Entrepreneur in Residence program connects leading scientific and business talent

Structure

- DOE partnership with Venture Capital Firm
- EERE provides $100k matching-funds and full access to laboratory
- Venture Capital Firm identifies, hires and mentors EIRs
- Pre-Negotiated standard equity share license agreement





Tailored for entrepreneurs and small businesses, the Equity Share License agreement forms a primary plank of the **STRATEGY BRIDGE**

	Traditional License	Equity Share License
Laboratory Benefit	➢ Up-front license fee ➢ Royalties	➢ Equity share of company, royalties or combination
Points of Negotiation	➢ All terms	➢ Percent equity share
Length of Contract	➢ 30 pages	➢ 17 pages
Private Sector Preference	➢ Large companies with cash on hand	➢ Small businesses on tight budgets ➢ Entrepreneurial ventures

Built off the Stanford license, the Equity Share License has been pre-negotiated with venture capital general counsels, national laboratory general counsels and DOE general counsel

DOE's 2008 pilot EIR program attracted established agents of disruption

National Laboratory	Venture Capital Partner	Highlights
NREL	KPCB Kleiner, Perkins Caufield & Byers	▪ Silicon Valley Venture Capital Firm with investments in Amazon, Google, Netscape, Sun Microsystems and Genentech ▪ Created proprietary knowledge map of cleantech space ▪ Made over 500 investments across twelve funds since 1972
ornl Oak Ridge National Laboratory	FOUNDATION CAPITAL	▪ Recently ranked #4 out of 1,176 global venture capital firms based on returns ▪ Coined the term "Entrepreneur in Residence" in 1994 ▪ Currently manages $2BN across six active funds
Sandia National Laboratories	ARCH Venture Partners	▪ Spun out of Argonne National Laboratory in 1986 ▪ Currently manages nearly $1.5BN across seven funds

Following a strong response to the first solicitation, EERE plans to expand the program to additional laboratories in 2008

Designed to introduce investors to technology opportunities, the Venture Capital Technology Showcase forms the primary plank of the INFORMATION BRIDGE

Need

- Many EERE funded technologies stall in the "commercialization valley of death" simply because the innovation has not been clearly communicated to the business community

Structure

- Challenged EERE Program Managers to identify 8-10 most promising technologies in their portfolio
- Created simple, layman's descriptions of the innovation opportunity
- Invited prominent venture capital firms to a two day conference showcasing technologies

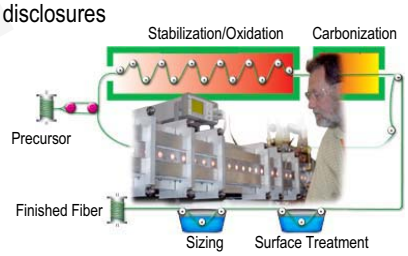
Venture Capital Firms Represented

NGP Energy Technology Partners
khosla ventures — venture assistance, strategic advice, venture capital
Pinnacle Ventures
KPCB
Nth Power — Energy | Vision | Capital
Massachusetts Green Energy Fund
RockPort Capital Partners
Matrix Partners
Good Energies
@Ventures
MDV — Mohr Davidow Ventures
Battelle Ventures
Flagship Ventures

DOE Venture Capital Technology Showcase Case Study:
Low-cost carbon fiber: increases fuel economy 25%

Simple, layman's description of technology

- **Problem:** Carbon fiber, a lightweight replacement for structural steel, is currently too expensive for broad application ($12–$30/lb vs. $5–$8/lb)
- **Description:** ORNL has developed technologies to reduce the cost of carbon fiber production by utilizing:
  - **Low costs feedstocks** (low-cost textiles and renewable lignin) and
  - **Advanced processing methods** (thermo-chemical stabilization, rapid oxidation, and microwave-assisted plasma carbonization)
- **Impact:**
  - **Automobiles:** Reduces vehicle mass by up to 40% which *increase fuel economy up to 25%*
  - **Wind:** Increases blade efficiency through superior properties
- **IP Position:** 3 patents issued, 5 patents filed, 7 invention disclosures
- **Technology Status:**
  - 4 processes reduced to practice:
    - Microwave-assisted plasma carbonization
    - Textile-based precursors
    - Thermo-chemical stabilization
    - Plasma oxidation
  - Time to availability: 3-5 years
  - Capital Needs: A 2-4MM lb/year carbon fiber plant is expected to cost $18M–$22M



Microwave-assisted plasma processing, shown in photograph, could replace conventional stabilization, oxidation, and carbonization processes represented in boxes at top of illustration

Direct contact to inventor

Dave Warren | ORNL | Phone: 865-574-9693 | WarrenCD@ORNL.GOV

Filling the gap between R&D and venture capital funding, the Technology Commercialization Fund forms the primary plank of the **CAPITAL BRIDGE**

Need

- Innovations struggle to find financing post-research and pre-venture capital funding as described by the "Commercialization Valley of Death"

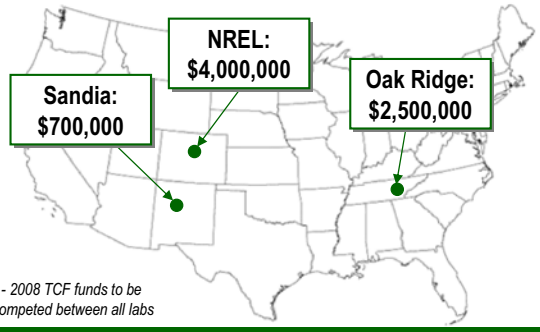
Structure

- 50-50 industry matched funds required to participate
- Funds restricted to prototype development, demonstration and deployment – not further scientific research
  Designed to complement angel investment or early stage corporate product development

Decision criteria

- Potential market opportunity
- Likelihood of commercial success
- Management team
- DOE priorities
- Private sector partners

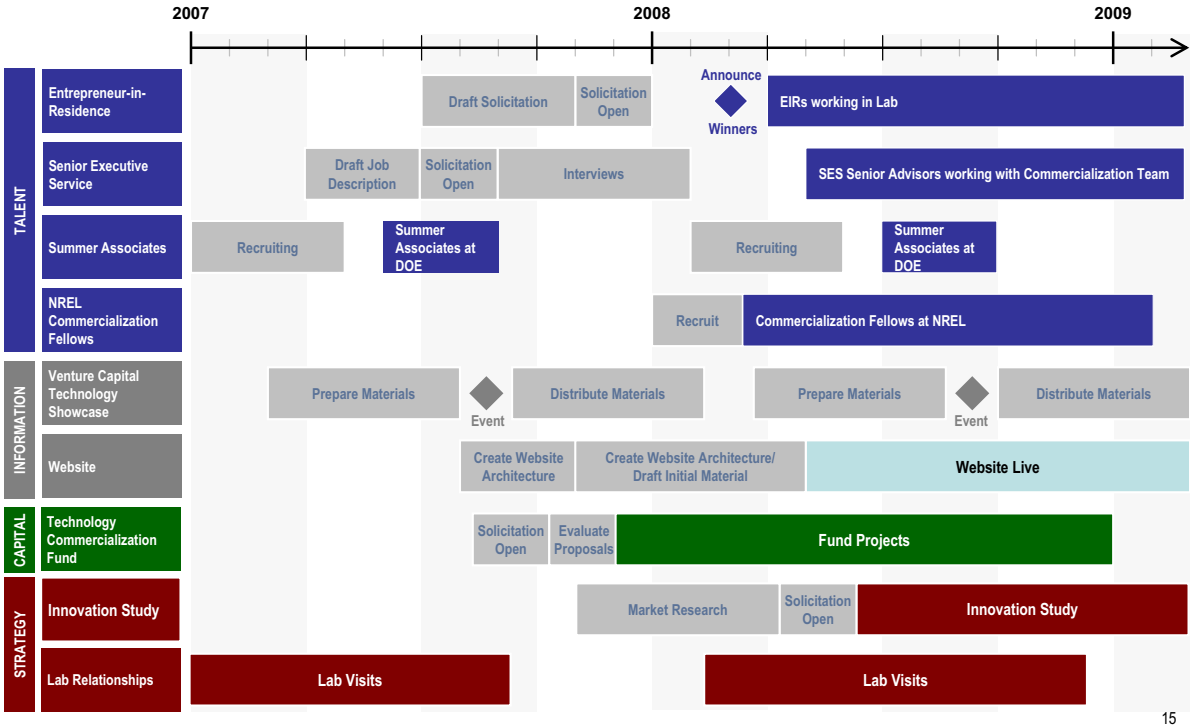
FY07* Technology Commercialization Fund



** - 2008 TCF funds to be competed between all labs*

The Technology Commercialization Fund is a carrot to attract private sector partners to examine the national laboratories' intellectual property portfolio

The Commercialization Team pursues an aggressive schedule to accelerate the deployment of advanced energy technologies



Rapidly Evolving Solar Technologies and Markets

Robert M. Margolis
National Renewable Energy Laboratory

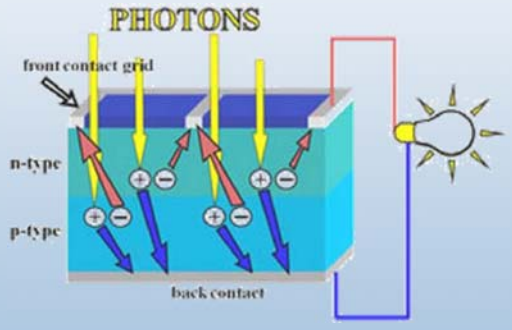
Presented at
DOE's Specialty Glass Needs for the
U.S. Solar Industry Workshop
Golden, CO

April 2, 2008

Converting the sun's radiation into electricity – two main pathways

Photovoltaics (PV)

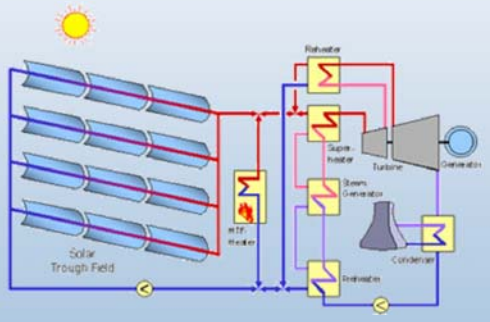
Cells of semi-conductors absorb photons and directly convert them into electrical current.



Can be used anywhere in the U.S.

Concentrating Solar Power (CSP)

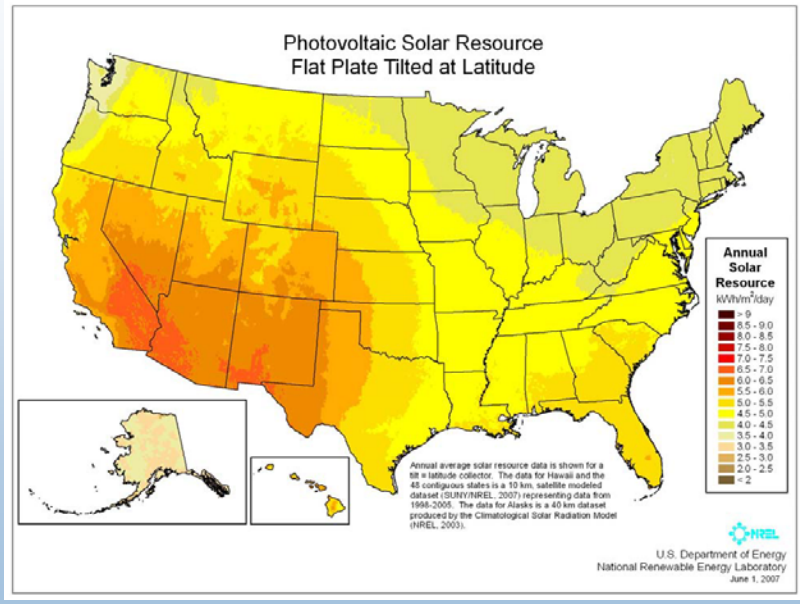
Mirrors focus solar radiation to heat fluids that are used to drive electric generators.



Predominantly in the Southwest U.S.
(requires direct sunlight)

U.S. solar resources significantly outweigh energy use

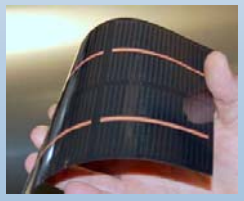
- Currently, solar provides less than 0.1% of the electricity used in the U.S.
- For the U.S., less than 2% of the land dedicated to cropland and grazing could provide all of our electricity.
- Covering less than 0.2% of the land on the earth with 10%-efficient solar cells would provide twice the power used by the world.



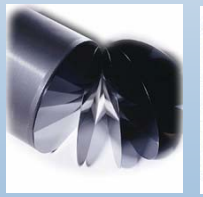
Government and industry are pursuing a range of promising PV technologies

20x-100x

500x



$Cu(In,Ga)Se_2$ ~ 1-2 um



c-Si ~ 180 um

Photovoltaic (PV) applications and markets are evolving very rapidly

Residential

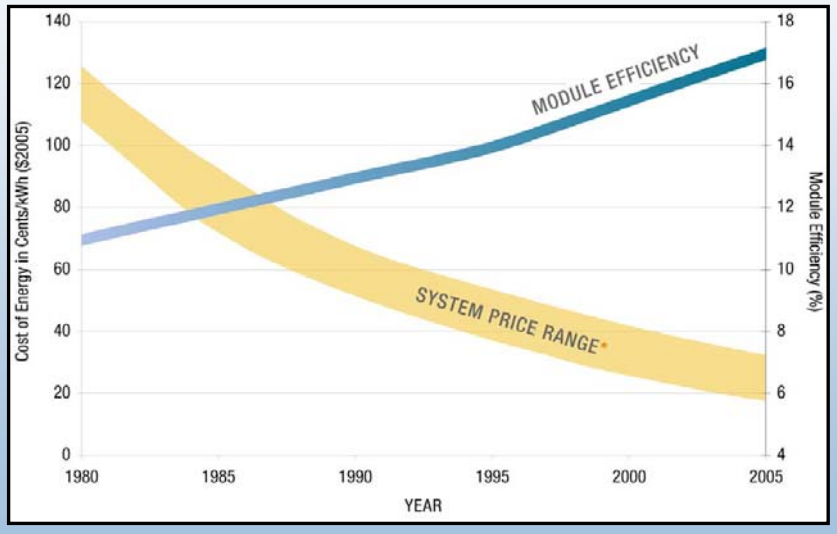
Commercial

Utility-scale

- PV is a growing source for distributed & centralized electricity generation

Dramatic reduction in cost and increase in efficiency of PV over past 25 years

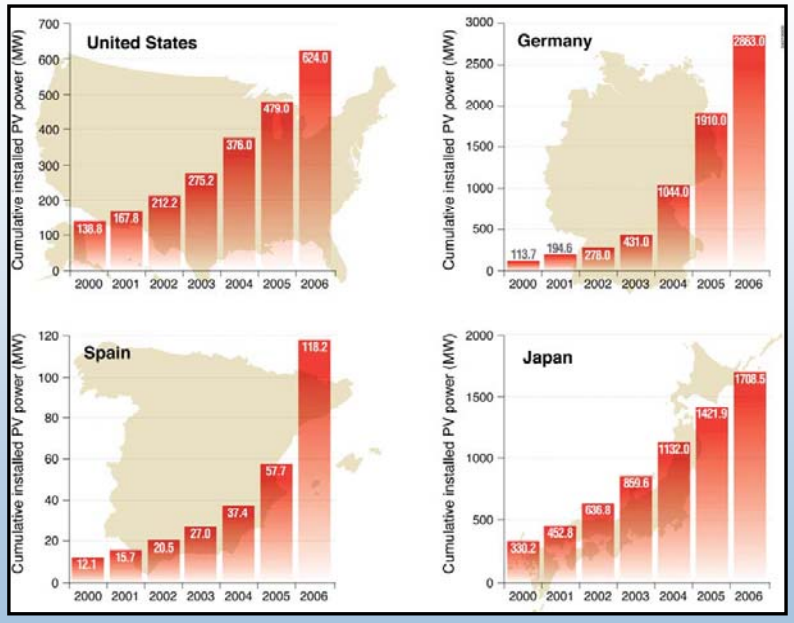
Historical PV Cost Curve (Silicon-based Technologies)



- Government investment in solar R&D has had a significant impact.
- System prices must come down another 50-70% to achieve grid-parity nationwide.

* System price is dependent upon location, application and variable financing options.
Source: NREL.

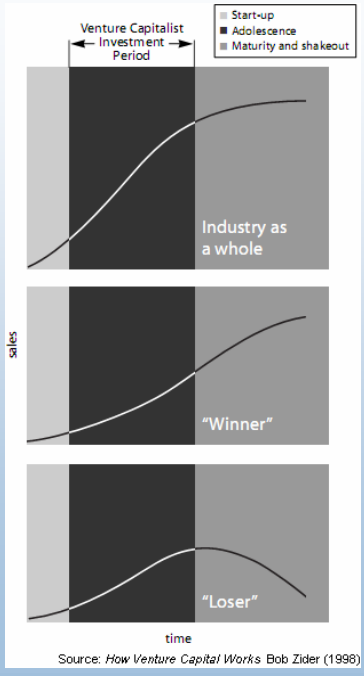
PV growing rapidly in key countries



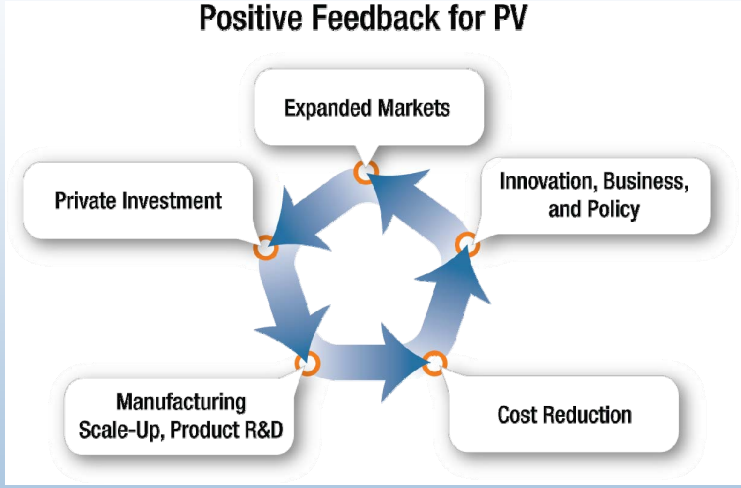
- Grid-connected PV is fastest growing market.
- Incentives have driven steep growth in installations.
- Average annual global growth rate has been 40+% for the past 5 years.
- PV could capture > 30% of market share for new capacity additions within next 5-10 years.

Source: International Energy Agency (2007).

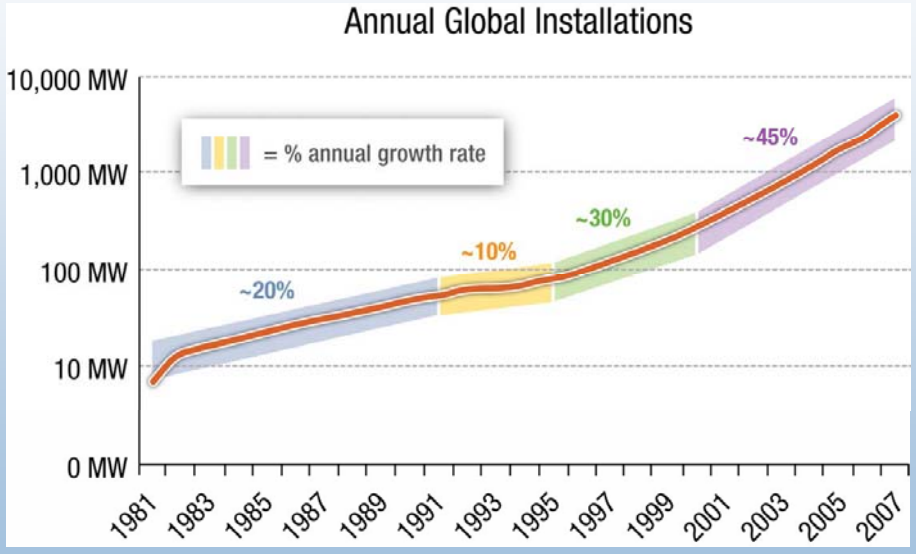
Solar's inflection point is still well off



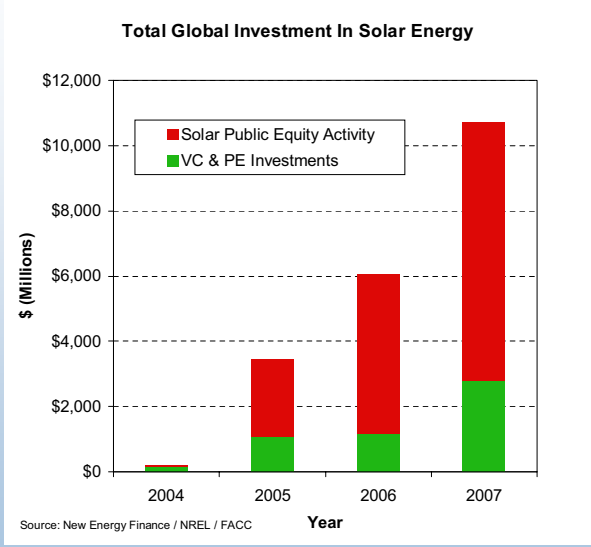
Source: *How Venture Capital Works* Bob Zider (1998)

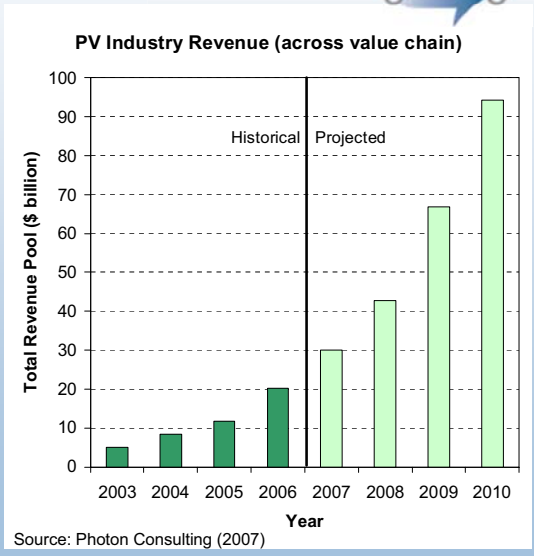


Market demand has produced super exponential growth

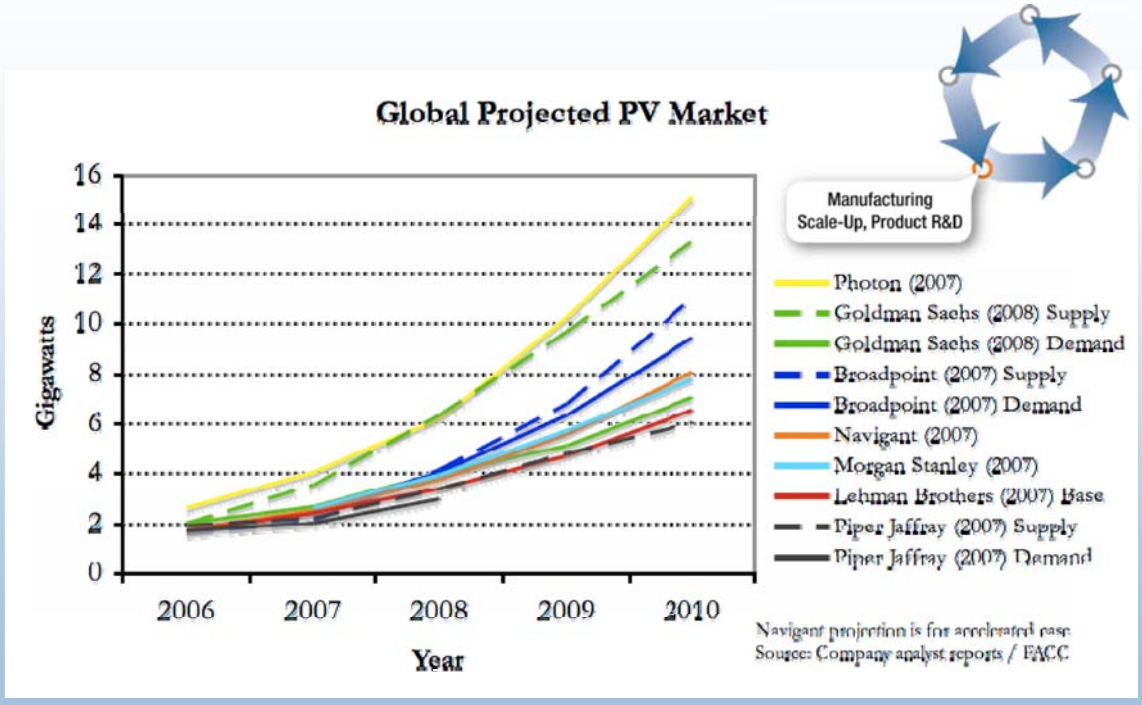


Which has stimulated investment in the solar sector

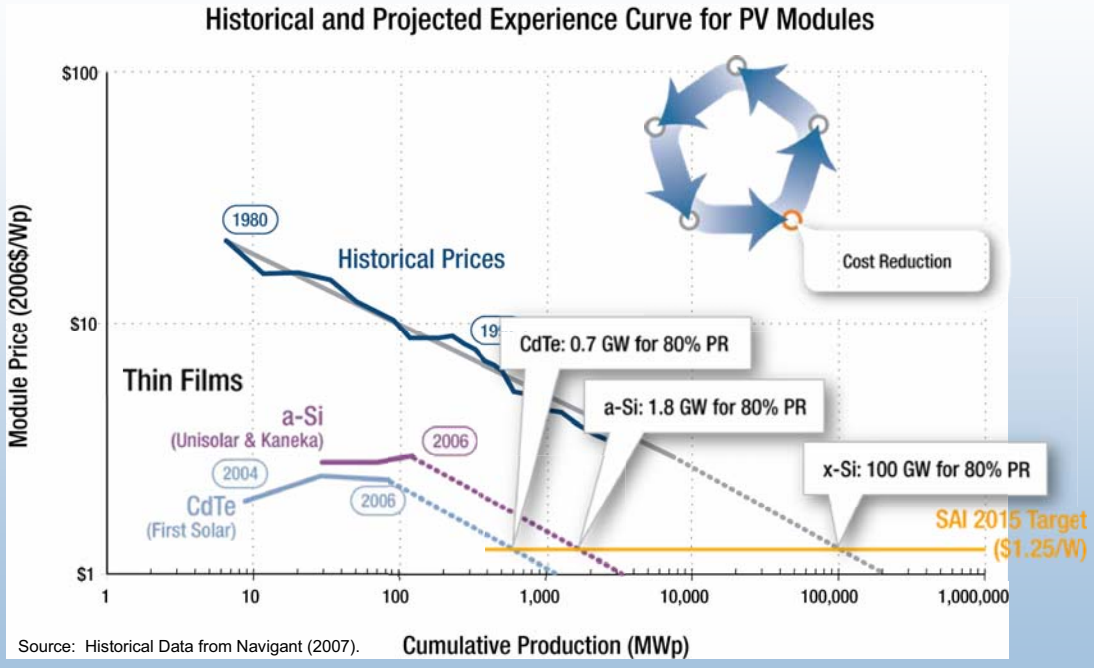




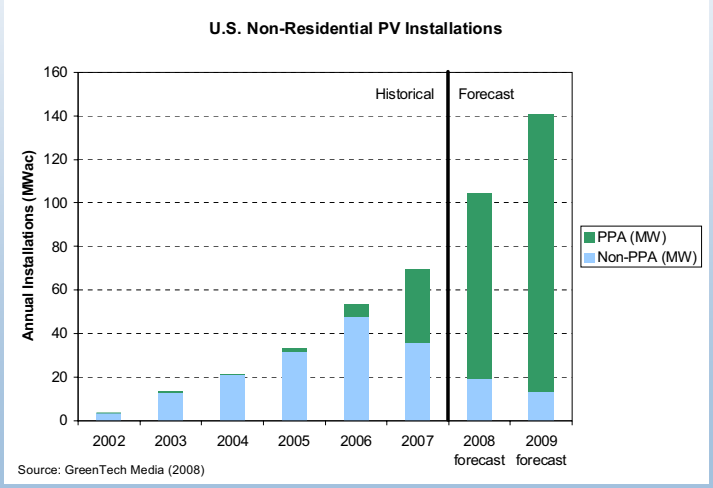
Leading to manufacturing scale-up, and…



… associated cost reductions



Driving innovation in business models and government policy



Concept:

- Power Purchase Agreements (PPA)
- Feed-In-Tariffs (with solar carve out)
- Investment and residential tax credits
- REC / Carbon Policy
- Creative Funding Vehicles

Implementation:

- Federal Installations
- LEED / E-Rating
- Clean Renewable Energy Bond
- Property Tax Assessment (no double dipping with ITC)

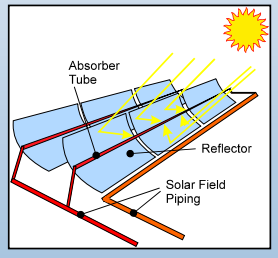
Also pursuing a range of promising Concentrating Solar Power (CSP) technologies

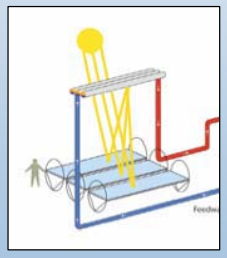
Trough

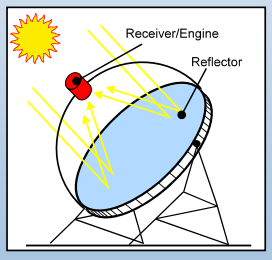
Linear Fresnel

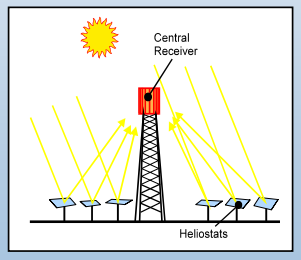
Dishes

Tower





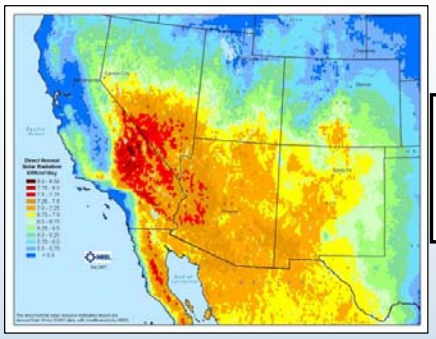




Utility scale power plants – intermediate and base load power

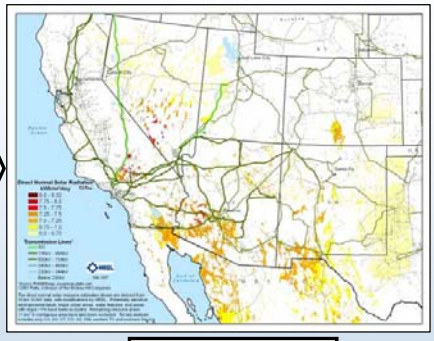
Southwest U.S. is ideal for CSP technology

Direct-Normal Solar Resource for the Southwest U.S.



Screening for:
> 6.0 kWh/m2/day,
Environment/urban/
water/etc land uses,
< 1% slope, > 5 km^2.

Screened Solar Resource for the Southwest U.S.



Potential Solar Generation Capacity by State

State	Land Area (mi^2)	Solar Capacity (MW)	Solar Generation Capacity GWh
AZ	13,613	1,742,461	4,121,268
CA	6,278	803,647	1,900,786
CO	6,232	797,758	1,886,858
NV	11,090	1,419,480	3,357,355
NM	20,356	2,605,585	6,162,729
TX	6,374	815,880	1,929,719
UT	23,288	2,980,823	7,050,242
Total	87,232	11,165,633	26,408,956

Source: NREL (2007).

- Very large technical potential
  - Could provide more than 10X current U.S. electricity capacity.
  - Need access to transmission.

Environment & population growth are key drivers for CSP

- Environment
  - AZ, CA, CO, NV, NM, TX all have RPS requirements.
- Population growth
  - 15 of the 20 fastest-growing metro areas in the country are in close proximity to solar resource.
- Currently > 3GW of projects in various stages of planning / development.

U.S. CSP in Planning/Development

Utility/State	Capacity (MW)	Company	Technology - Status
Southern Cal Edison	500-850	SES	Dish – signed power purchase agreement
San Diego Gas & Electric	300-900	SES	Dish – signed power purchase agreement
Pacific Gas & Electric	500	Bright Source	Tower – application for construction filed
Pacific Gas & Electric	553	Solel	Trough - signed power purchase agreement
Pacific Gas & Electric	177	Ausra	Linear fresnel - signed power purchase agreement
Florida Power and Light	300	Ausra	Trough - project announced
SW Utility joint venture (APS)*	Est. 250	TBD	TBD – multiple expressions of interest

A number of factors are driving strong growth in the solar industry

- Federal, state, and local policy incentives.
- Market volatility and high cost of natural gas and oil.
- Climate change and likely carbon regulations.
- Energy security issues.
- Need for increased energy production to meet growing demand (China, India, etc.).
- Interest from financial community in “next big thing”.
- Influx of talent from the IC industry.

NREL Solar and Glass Activities: Technology and Partnerships

Specialty Glass Needs for the U.S. Solar Industry
April 2, 2008

John Benner
Photovoltaics Center
National Renewable Energy Laboratory
Golden, Colorado, U.S.A.

National Center for Photovoltaics

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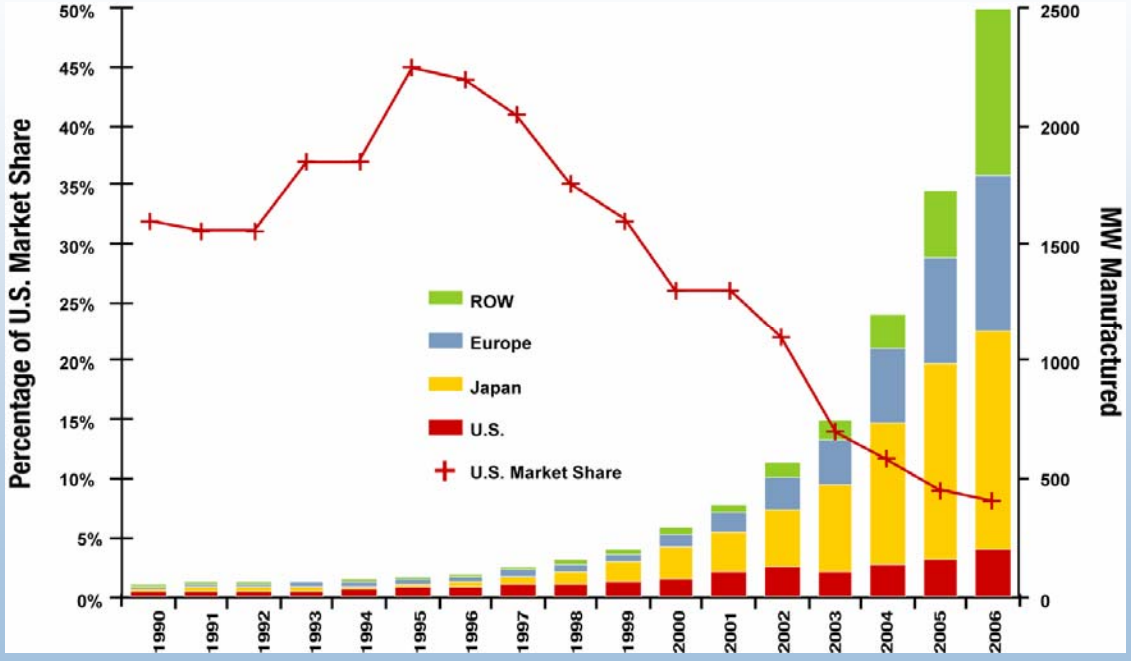
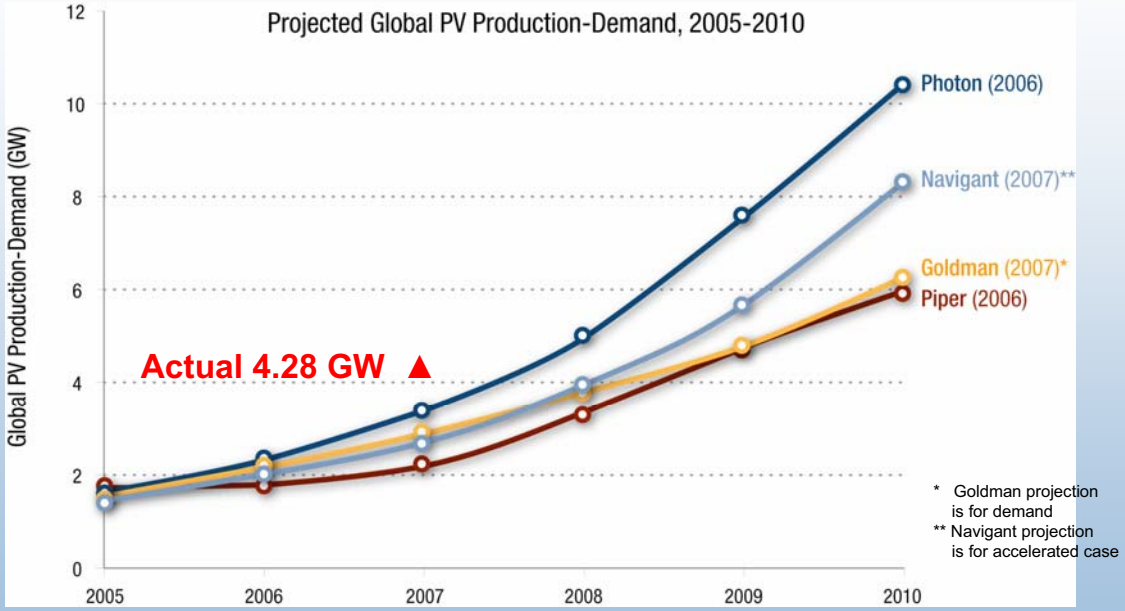
Foreign incentives and R&D programs have driven worldwide competition past U.S. producers



U.S. production now lags Japan and Germany, and China passed U.S. in 2006.

Production is expected to ramp quickly through 2010, as shipments catch up to capacity and new suppliers enter



Analyst forecasts for global production/demand vary based on different expectations on ramp-rate for polysilicon, thin films, and downstream channel evolution.

How large is the PV Roofing Market?

US Residential Roof Area = 16×10^9 m^2
US Commercial Roof Area = 5×10^9 m^2

Shading Factor
Residential = 78%
Commercial = 50%

Roof Area Appropriate for PV
US Residential = 3.6×10^9 m^2
Commercial = 2.5×10^9 m^2

How much energy would this produce?
Assume 1800 KWH/m^2/year (US Average)
10% efficient PV modules

Residential + Commercial = 11×10^{12} KWH/year
> 2X the U.S. Electricity Consumption in 2005!

Colorado=103,967 sq mile=270×10^9 m^2

Source: Ron Judkoff,
Director Buildings and Thermal Systems, NREL

Polycrystalline Thin Film PV Modules (Standard conditions, Aperture-area, *NREL Confirmed) Ranked by Power

Company	Device	Aperture Area (cm^2)	Efficiency (%)	Power(W)	Date
Global Solar	CIGS	8390	10.2*	88.9*	05/05
Shell Solar	CIGSS	7376	11.7*	86.1*	10/05
Würth Solar	CIGS	6500	13.0	84.6	06/04
First Solar	CdTe	6623	10.2*	67.5*	02/04
Shell Solar GmbH	CIGSS	4938	13.1	64.8	05/03
Antec Solar	CdTe	6633	7.3	52.3	06/04
Shell Solar	CIGSS	3626	12.8*	46.5*	03/03
United Solar	a-Si	4519	7.9	35.7	06/97

Sources: R. Noufi and K. Zweibel, Proc. 4th WCPEC, Waikola, Hawaii, 5/2006, Photon International October 2004.

Solar Specialty Glass

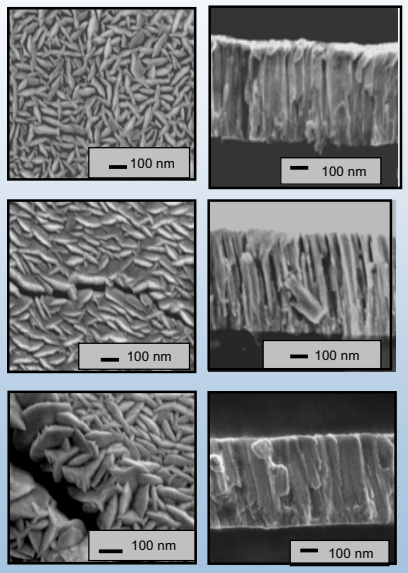
>600ºC could buy significant performance improvements

- Cost
- Impurity diffusion and other defect creation
- Thermal expansion
- Strength

Substrates don't need transparency and block the back contact

Copper Indium Di-Selenide (CIS) and related alloy (CIGS) Thin-film Solar Cells

Rate: 25Å/sec.



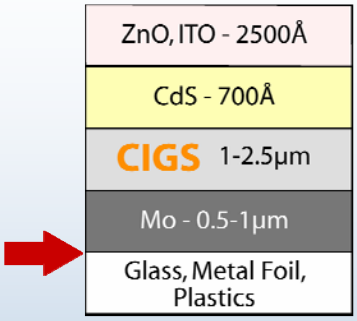
Pressure

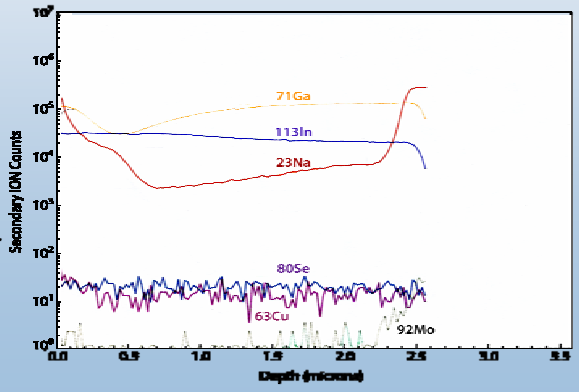
5 mTorr

8 mTorr

12 mTorr

H. Althani Thesis

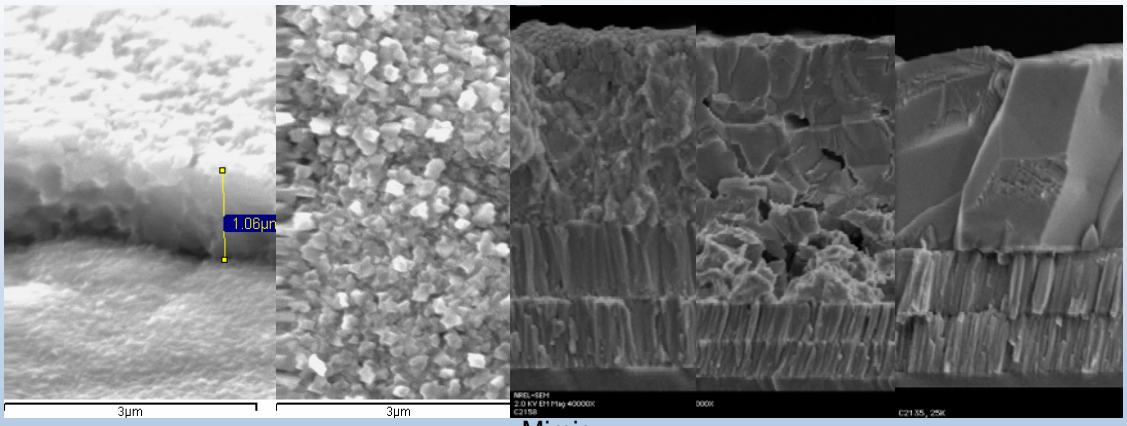




Source: R. Noufi and K. Zweibel, Proc. 4th WCPEC, Waikola, Hawaii, 5/2006,

Closing the Gap in Performance

Industrial Processes vs Laboratory Efficiency



5 minute deposition – Industry
3-5 % efficiency

Mimic Industrial Conditions
5%

Modified by 3-stage knowledge
15%

30 minute 3-stage
>19%
Record

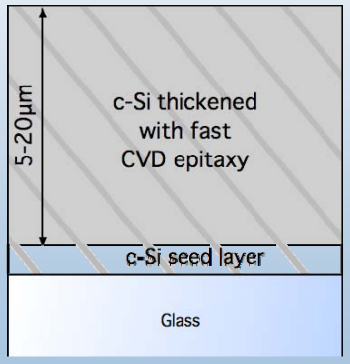
NREL 5 minute depositions

Avoid high wafer costs with film silicon

An ideal PV material would be 20 µm of crystal silicon on glass!

NREL approach to crystal silicon on glass

- Initial step: establish good crystal quality with a thin seed layer
- Second step: Quickly thicken the seed layer epitaxially



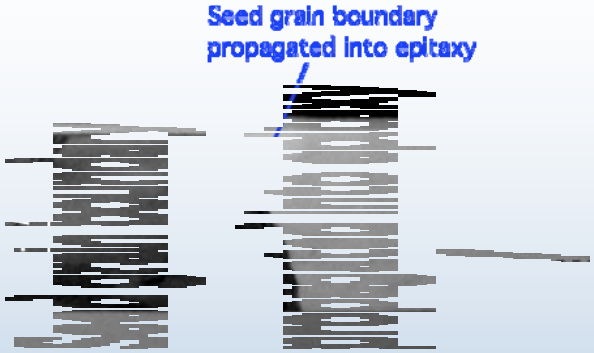
Research Challenges

- High quality epitaxy at glass-compatible temperatures
- Identification of high-quality, low-cost seed layers
- Final device designs
  (*p/n* junction, light trapping, electrical contacts)

Epitaxy on seed/glass demonstration

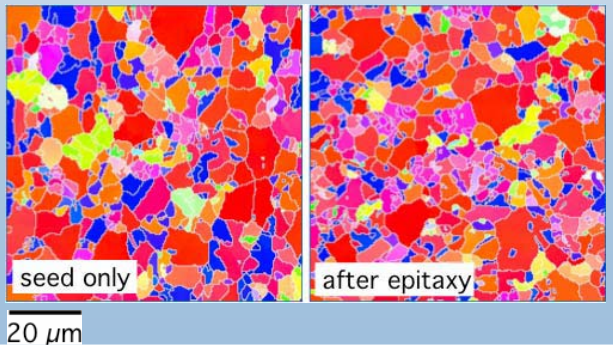
Teplin et al. MRS-Symp A, 2008

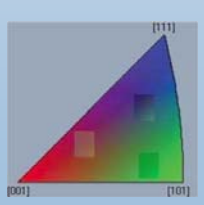
- HWCVD epitaxy at 650°C
- Al-induced layer exchange seed
  - from HMI Berlin (Gall)
  - 10 micron grains
  - 70% (100)-oriented grains

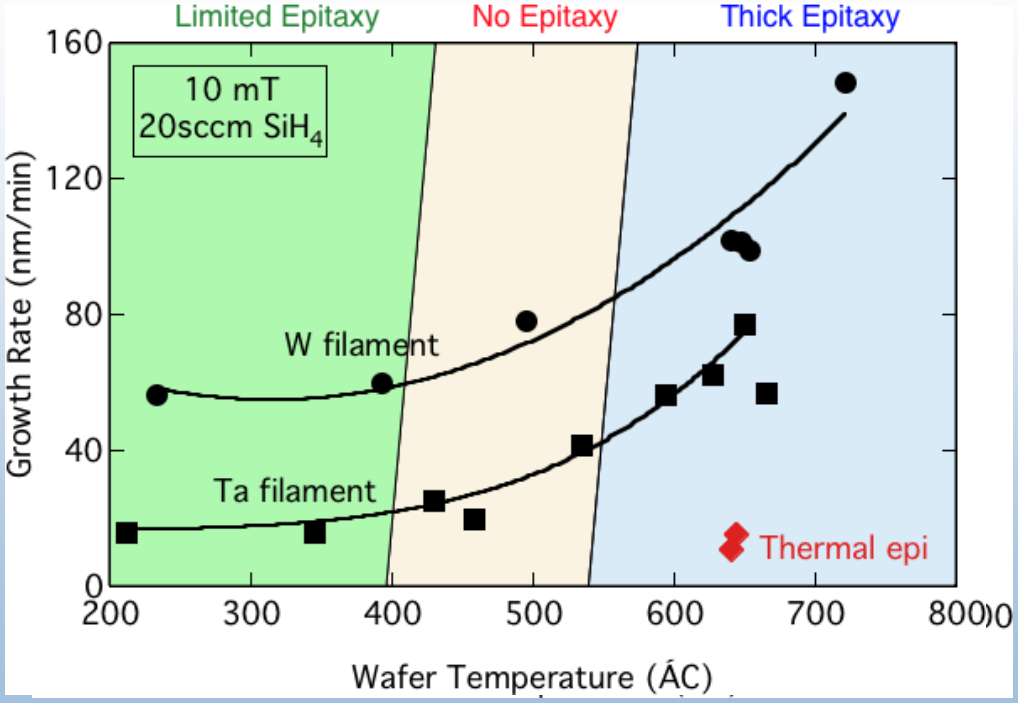


- Electron backscatter diffraction (EBSD)

HW epitaxy on all orientations





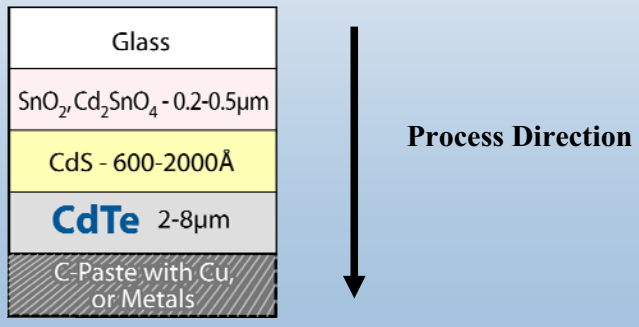


Solar Specialty Glass

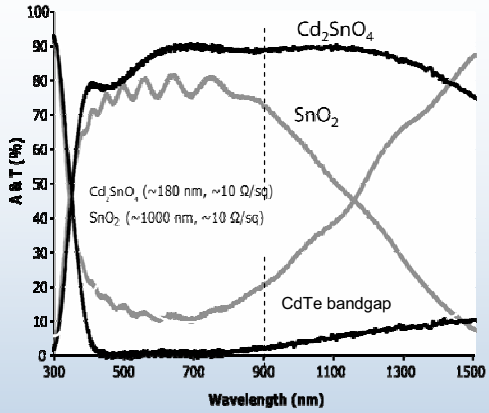
Low-iron glass for superstrate designs buys significant performance improvements

- Cost
- Impurity diffusion and other defect creation
- Thermal expansion
- Strength

CdTe Thin-Film Solar Cells



High Quality TCO – Cd_2SnO_4(CTO)

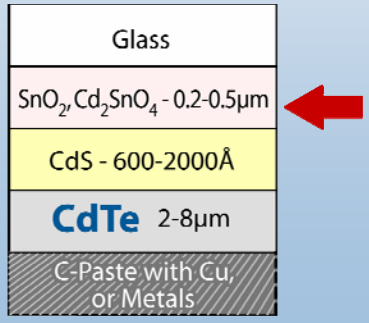


Sample	Cd_2SnO_4	SnO_2 ($SnCl_4$)	SnO_2 (TMT)
t (nm)	510	~1000	~1000
n (cm^{-3})	8.94×10^{20}	4.95×10^{20}	4.52×10^{20}
μ (cm_2/Vs)	54.5	15.4	42.-0
Resistivity (Ω cm)	1.28×10^{-4}	8.18×10^{-4}	3.29×10^{-4}
R_s (Ω/sq)	2.6	8.6	3.3

Alternate TCO Layers: In_2O_3:Sn/SnO, In_2O_3:Mo?

TCO layer typically combined with a "Buffer" layer between CdS and TCO

Buffer Layers: Undoped SnO_2, Zn_2SnO_4

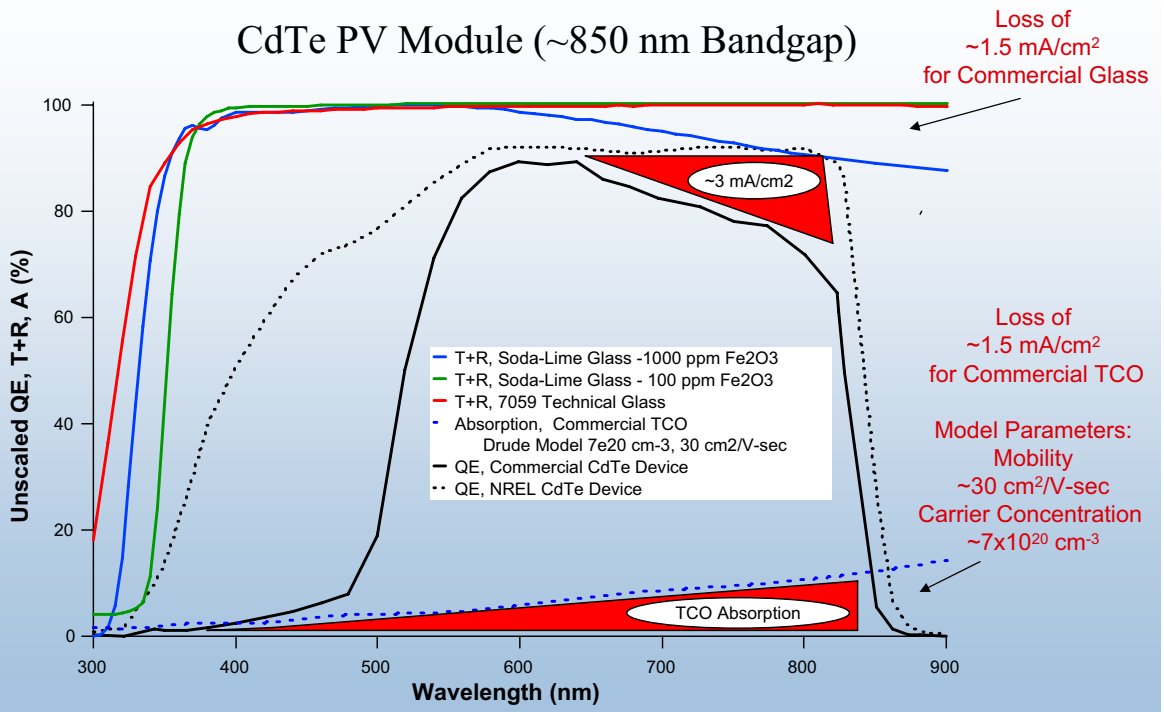


From X. Wu et. al, Proc. 28th Photovolt. Spec. Conf. pp. 470-474 (2000)

NREL National Renewable Energy Laboratory

Effect of TCO on PV Module Performance

CdTe PV Module (~850 nm Bandgap)



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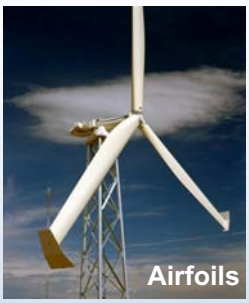
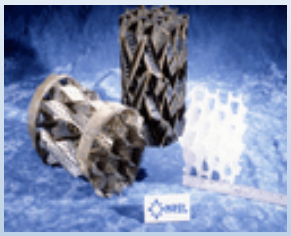
National Renewable Energy Laboratory

Making Partnerships Work

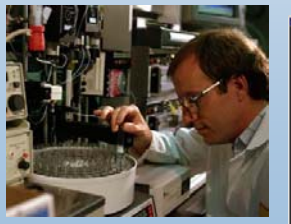
- Only national laboratory dedicated to renewable energy and energy efficiency R&D
- Research spans fundamental science to technology solutions
- Collaboration with industry and university partners is a hallmark
- Research is market relevant

Technology Transfer





Direct Contact Heat Exchanger



Fermentation Enzymes

Vehicle System Model

- Strategy focuses on fast transaction speed, transparency, being venture-capital friendly, enhancing the value of intellectual property (IP), and broad value proposition
- Intellectual property attracts partners that move technology toward commercialization
- Industry Growth Forum joins investors and entrepreneurs
- NREL has a portfolio of 278 patents, copyrights, and trademarks; and 47 active licenses

NREL Technology Transfer Mechanisms

NREL

Public Technology

- Scientific Publications
- Web Sites

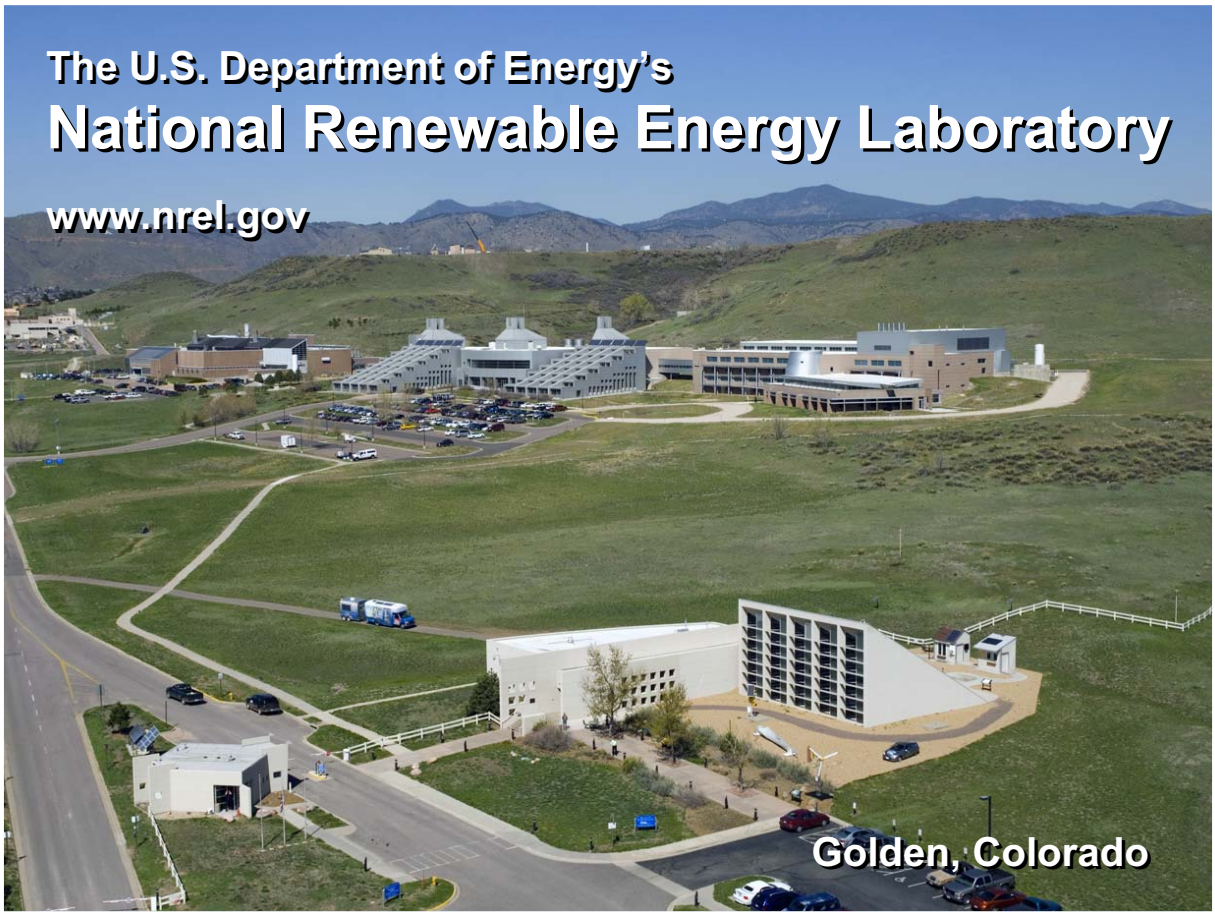
Protected Technology

- Patents
- Copyright
- Trademarks

- Conferences
- Staff Exchanges
- Technical Assistance
- Investor & Business Networks

- Cooperative Research & Development Agreements (CRADAs)
- Technical Service Agreements
- Cost-shared Subcontracts
- Technology Licenses

NREL in Partnership



A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

Glass Requirements for Concentrating Solar Power *Sector of the Solar Industry*: Mirrors and Solar Selective Coatings

C.E. Kennedy

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Solar Glass Workshop
April 2, 2008

NREL is operated by Midwest Research Institute • Battelle

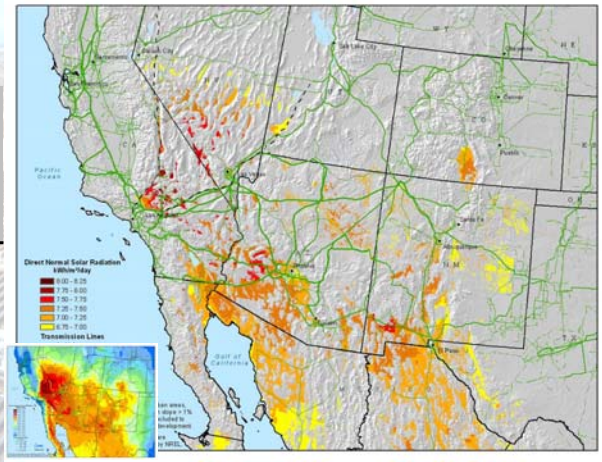
Outline

- Solar Market Potential
- Solar Reflectors
  - Thick & thin glass
  - Anodized aluminum
  - Silvered Polymer
  - Front surface IBAD alumina
- Solar Selective Coating
- Conclusion

Concentrating Solar Power Technologies

SW Solar Energy Potential

State	Land Area (mi^2)	Solar Capacity (MW)	Solar Generation Capacity GWh
AZ	19,279	2,467,663	5,836,517
CA	6,853	877,204	2,074,763
CO	2,124	271,903	643,105
NV	5,589	715,438	1,692,154
NM	15,156	1,939,970	4,588,417
TX	1,162	148,729	351,774
UT	3,564	456,147	1,078,879
Total	53,727	6,877,055	16,265,611

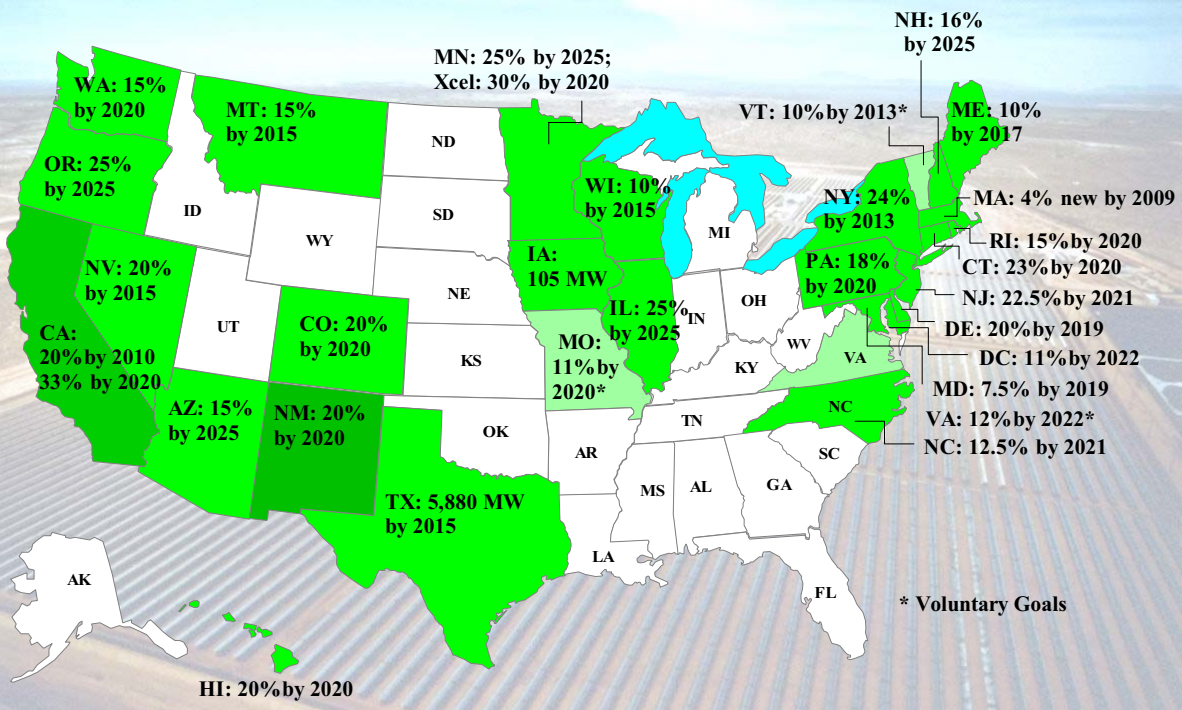


The table and map represent land that has no primary use today, exclude land with slope > 1%, <5 contiguous km^2, & sensitive lands.

Solar Energy Resource ≥ 6.75 $kwh/m^2/day$
Capacity assumes 5 acres/MW
Generation assumes 27% annual capacity factor

- **Current total generation in the U.S. is 1,000GW w/ generation approximately 3,800 TWh**

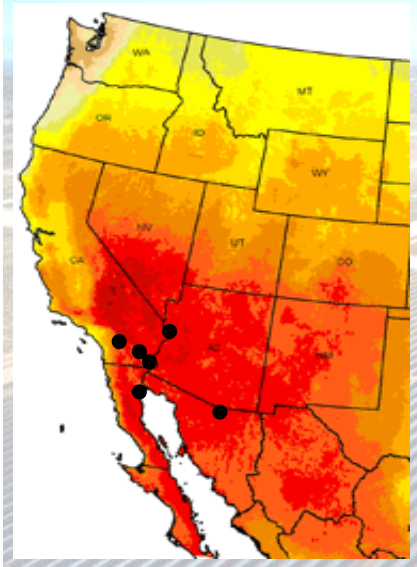
Renewable Portfolio Standards



State RPS mandates successfully jump-starting desirable growth

Market for Solar in US SW

10,000 MW of CSP by 2020



~36.4 M m² mirror

~0.53 M m² AR glass

~0.91 M HCE/receivers

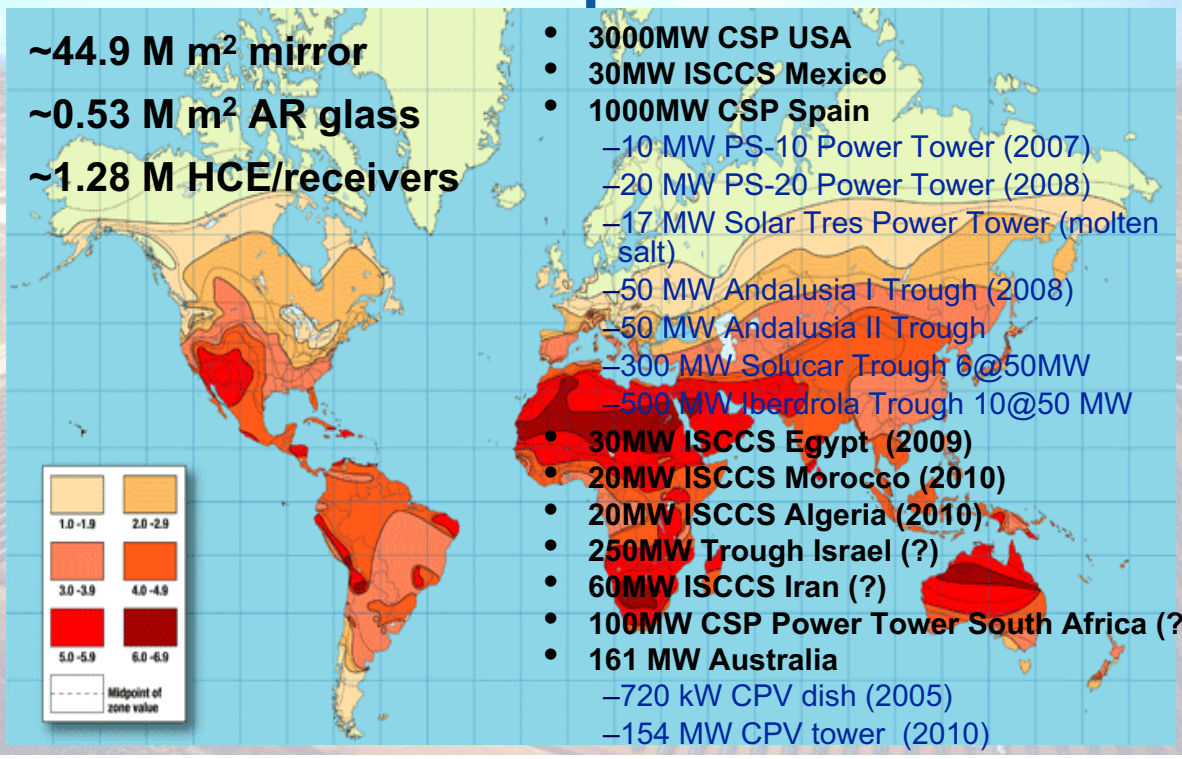
- California:
  - 500 MW by 2010
  - 8,000 MW by 2020 –peaking demand
    - **354 MW SEGS trough plants in CA**
    - **2 PPAs for 1.75 GW Dish Stirling plants in Southern CA**
      - 500 MW (option to expand to 850 MW) – Mojave Desert
      - 300 MW (two options to expand to 900 MW) – Imperial Valley
    - **553 MW PPA signed PGE, CA**
    - **300 MW PGE, CA Pending contractual announcement**
      - 2 - 100 MW Power Tower
      - 200 MW Power Tower
    - **175 MW PGE/FPL CLFR (commitment)**
    - **200 MW FPL CLFR (commitment)**
    - **1000 MW PGE (commitment) probably in CA**
- Arizona: 2,000 MW
  - **1 MW trough plant in AZ**
  - **280 MW trough plant PPA between APS & Abengoa**
  - **250 MW RFP multi-state SW utility consortium**
- Nevada: 1,500 MW
  - **64 MW trough project in NV**
- New Mexico: TBD
  - **Schott announced new receiver plant in NM**
- West Texas: 1,000 + MW
- Colorado:500 MW after 2010
  - **Numerous RFP's in CO, TX, AZ,**
- Florida: 300 MW CLFR (FPL Commitment)
  - **10 MW initial (w/ option to expand to 300 MW)**
  - **500 MW FPL (commitment) in CA, FL, & other states**

International CSP Project Developments

~44.9 M m² mirror

~0.53 M m² AR glass

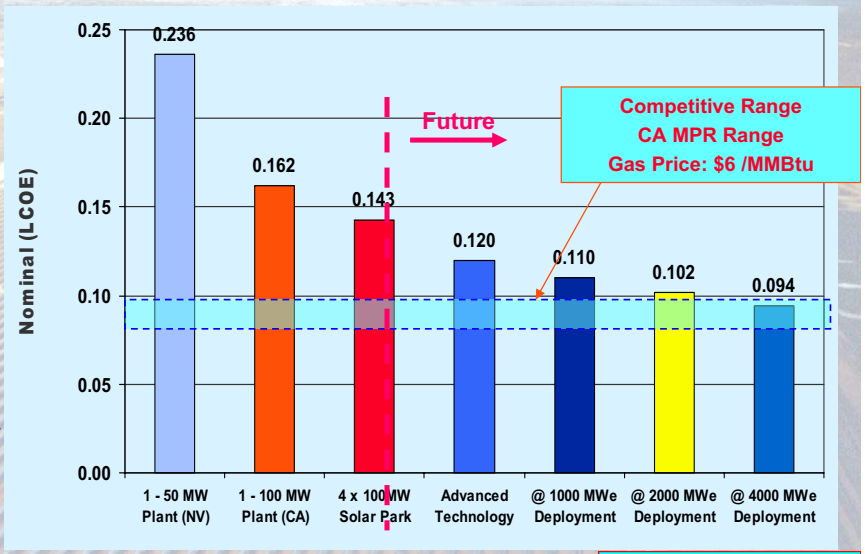
~1.28 M HCE/receivers



- 3000MW CSP USA
- 30MW ISCCS Mexico
- 1000MW CSP Spain
  - –10 MW PS-10 Power Tower (2007)
  - –20 MW PS-20 Power Tower (2008)
  - –17 MW Solar Tres Power Tower (molten salt)
  - –50 MW Andalusia I Trough (2008)
  - –50 MW Andalusia II Trough
  - –300 MW Solucar Trough 6@50MW
  - –500 MW Iberdrola Trough 10@50 MW
- 30MW ISCCS Egypt (2009)
- 20MW ISCCS Morocco (2010)
- 20MW ISCCS Algeria (2010)
- 250MW Trough Israel (?)
- 60MW ISCCS Iran (?)
- 100MW CSP Power Tower South Africa (?)
- 161 MW Australia
  - –720 kW CPV dish (2005)
  - –154 MW CPV tower (2010)

Parabolic Trough Cost Reduction Scenario

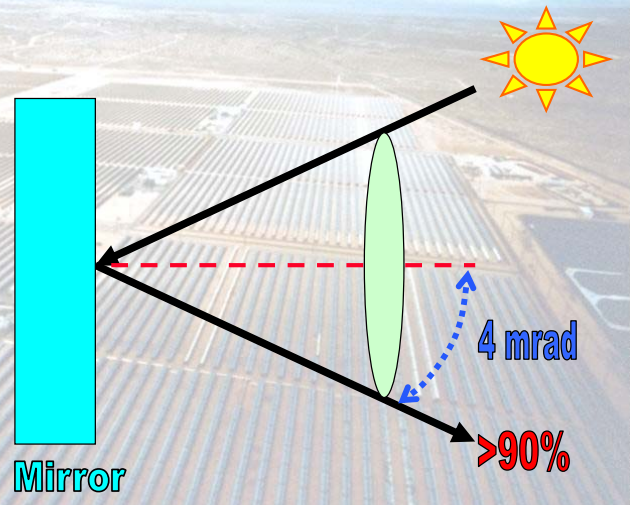
- Good Solar Resource Site
- Advanced Technology
- Learning & Competition
- Increasing Plant Size
- Alternative Financing
- Tax Neutrality for Solar Fuels
- Tax Incentives



Location: Barstow, CA
Incentives: Current California
Deployment Assumes:
- 90% PR in Solar Field
- 95% PR in Power Plant

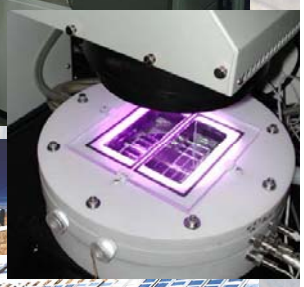
Goals for Improved Optical Materials

- >90% Specular reflectance into a 4-mrad cone angle
  - Unofficially 95%
- 10 - 30 year lifetime
  - Unofficially 30 y
- Manufacturing cost $10.76/m^2 ($1/ft^2)
  - 1992 Cost Goal
  - Adjusted for inflation to $15.46/m^2 ($1.44/ft^2)
  - Structural (self-supporting) mirror to $27/m^2 ($2.50/ft^2)



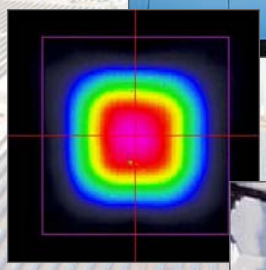
Technical Approach

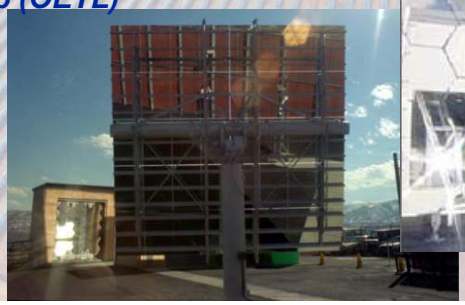
- ***Samples supplied by:***
  - ***Industry***
  - ***Subcontracts***
  - ***Developed in-house***
- ***Optical Characterization:***
  - **Perkin-Elmer (PE) Lambda 9 & 900 UV-VIS-NIR spectrophotometers (250-2500 nm) w/ integrating spheres**
  - **PE IR 883 IR spectrophotometer (2.5-50 µm)**
  - **Devices & Services (D&S) Field Portable Specular Reflectometer (7, 15, & 25-mrad cone angle at 660 nm)**
- **Outdoor (OET) & *Accelerated Exposure Testing (AET):***
  - **Atlas Ci65 & Ci5000 WeatherOmeters (WOM) (1X & 2X Xenon Arc/60ºC/60%RH)**
  - **QPanel QUV (UVA 340@ 290- 340 nm/ 4 h UV at 40º / 4 h dark at 100%RH)**
  - **1.4 kW Solar Simulators (SS) (≈5X Xenon 300-500 nm. 4-quadrants 2 RH &T, light /dark)**
  - **BlueM damp heat (85ºC/85%RH/dark)**
  - **3 meteorologically monitored sites at Golden, Colorado (NREL), Miami, Florida (FLA), and Phoenix, Arizona (APS)**
  - **Typically test until lose 10% of initial SWV**



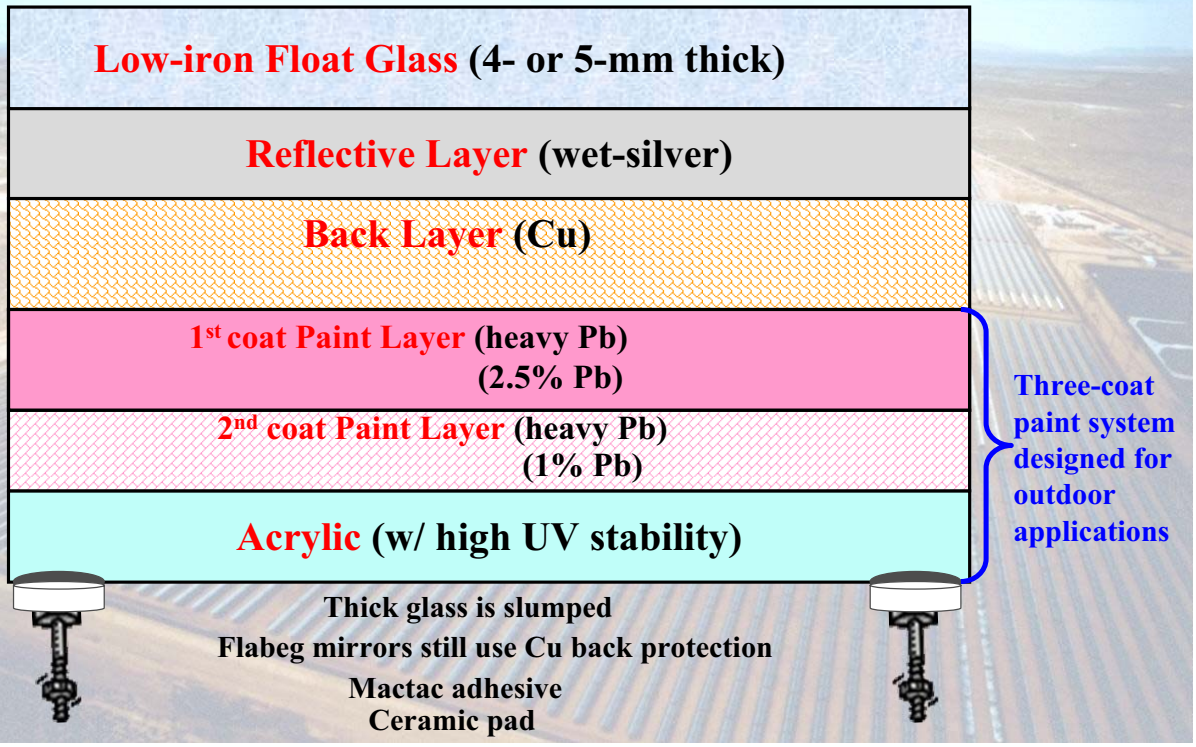
Additional Capabilities

- *Optical Characterization:*
  - VSHOT (Video Scanning Hartmann Optical Test)
  - Beam characterization system
- *Accelerated* Natural Sunlight *Exposure Testing:*
  - High-Flux Solar Furnace (HFSF) (2,500 to >20,000 suns)
  - Ultra-accelerated UV dish
  - EMMAQUA or ACCUVEX
- *Receiver Tube Characterization*
  - *Receiver test stand*
  - *IR survey of HCE glass temperature*
  - *Optical Efficiency Test Loop (OETL) facility*

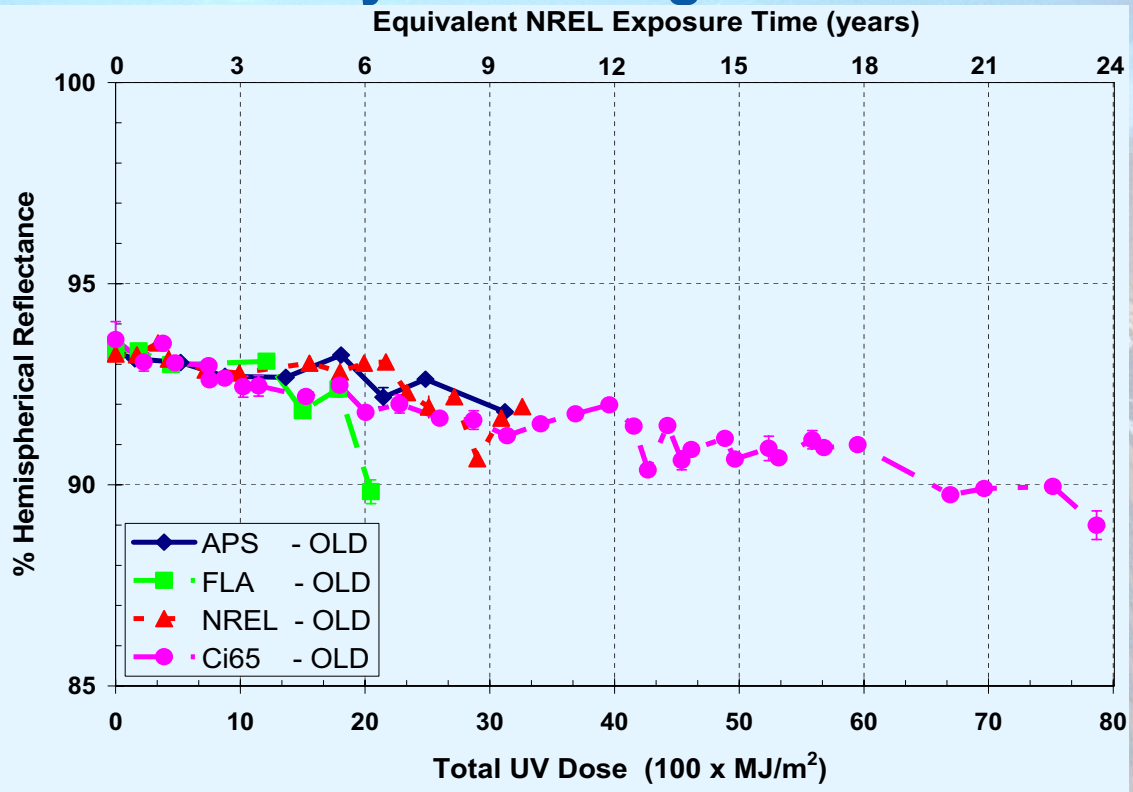




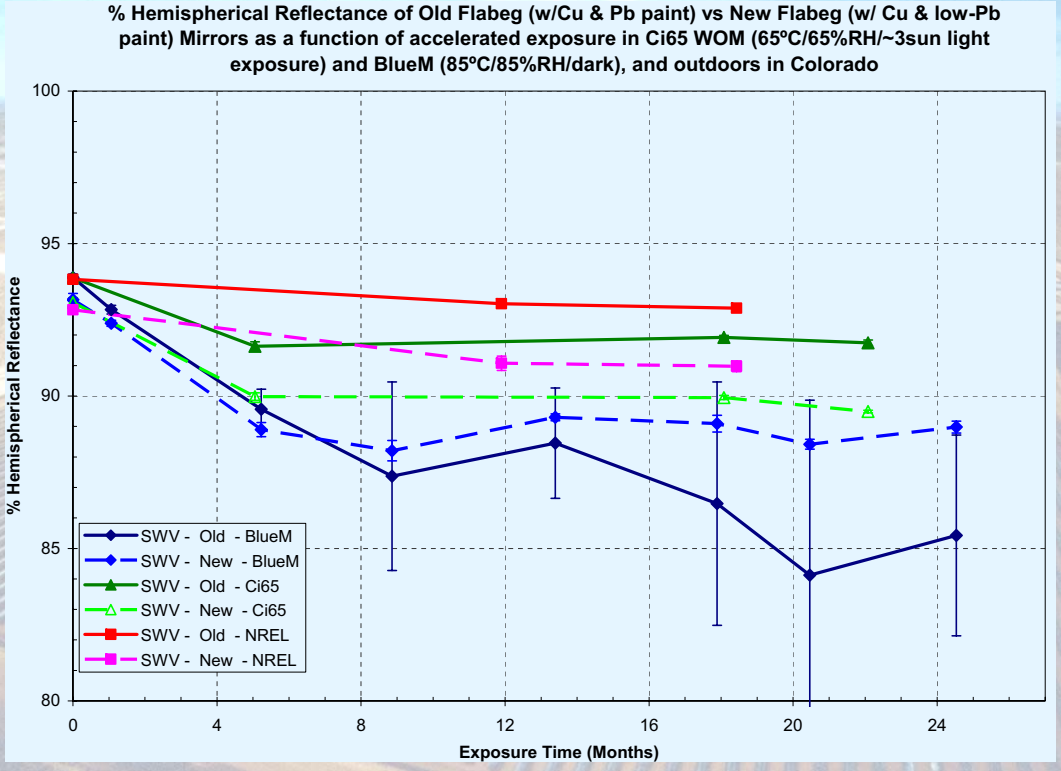
Parabolic Trough Glass Mirror Architecture



Heavy-Pb Flabeg Mirror



High-Pb vs. Reduced-Pb Flabeg



Alternate Thick Glass Mirror Architecture

Low-iron Float Glass (3- or 4-mm thick flat)

Reflective Layer (wet-silver)

Back Layer (Cu-less)

1st coat Paint Layer (lead-free)

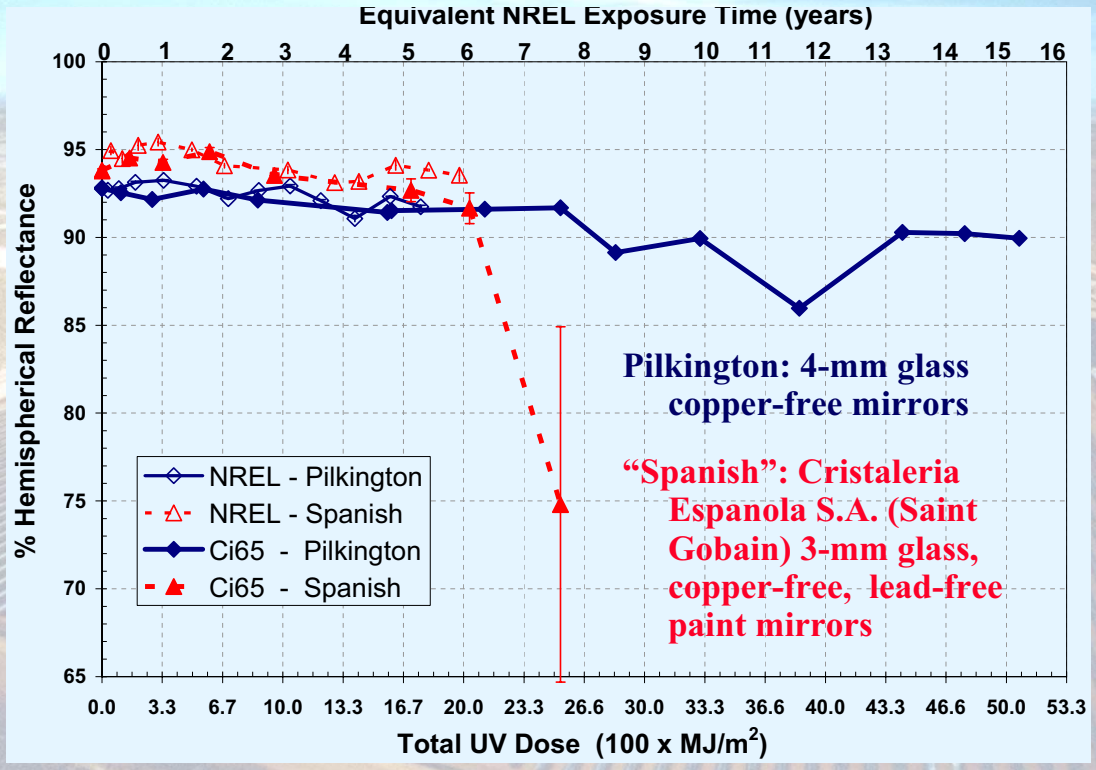
2nd coat Paint Layer (lead-free)

Adhesive (PS, spray)

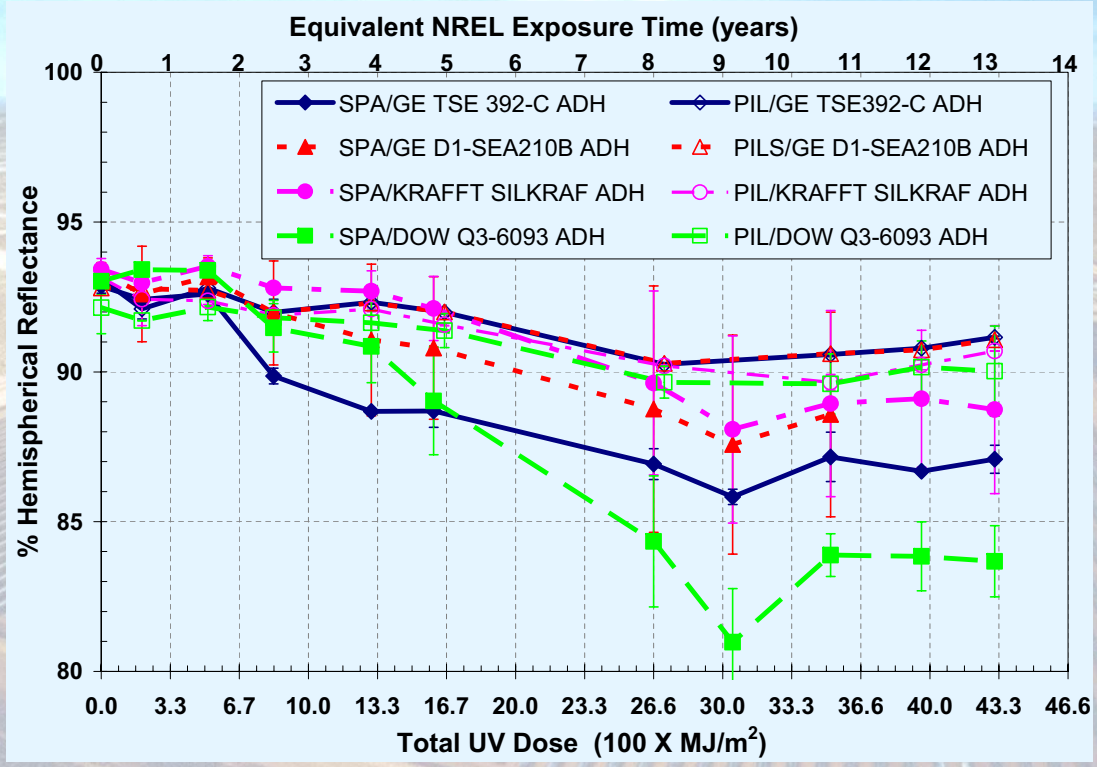
Substrate (SS, Al)

- Glaverbel vs. Valspar process
- Lead-free <0.15% Pb EU
  <1-5 PPM Pb US
- Valspar vs. Fenzi paint system
- Lead-free <0.15% Pb EU
  <1-5 PPM Pb US
- Valspar vs. Fenzi paint system
- Wax content in paint
- Chlorine-scrubbed
- Low bleed paths

Alternate Thick Glass Mirror



Effect of Adhesive on Thick Glass Mirror



Thin Glass Mirror Architecture

Low-iron Glass (~1 mm- thick)
Reflective Layer (wet-silver)
Back Layer (Cu) (Cu-less)
Paint Layer (Pb) (Pb-free)
Adhesive (PS, spray)
Substrate (SS, Al)

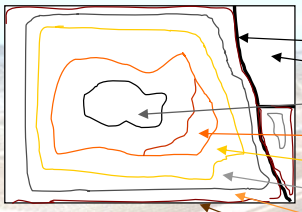
Thin glass mirrors have been designed for indoor applications.

"Mirror Graying"

Sample

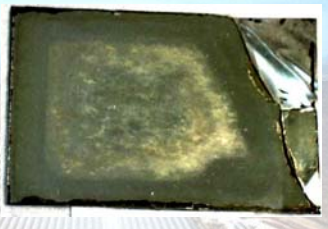
Ci65

25 Mo



Bands:

- Cracks
- Delaminated
- Mottled silver-white
- Golden-creamy yellow
- Creamy yellow
- Dark metallic
- Golden-brown
- Dark brown corrosion

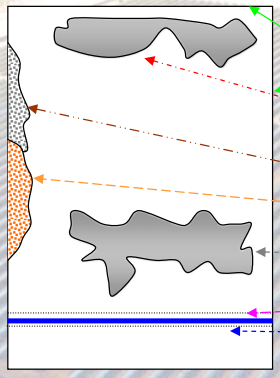


Facet

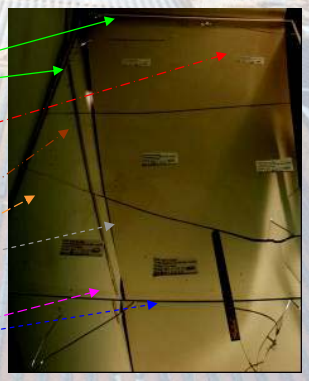
AZ

21

MO

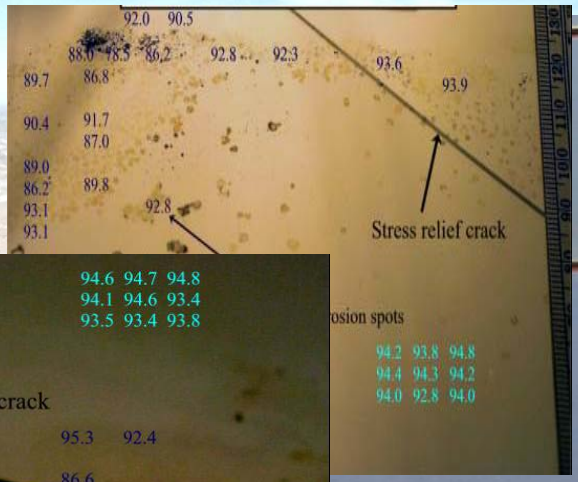


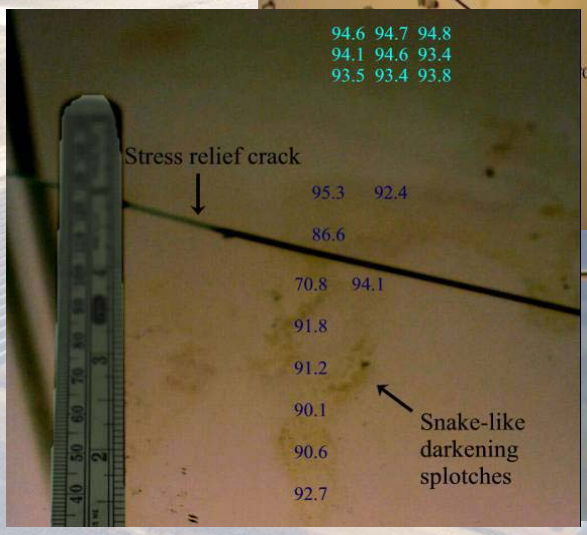
- Cut Edge
- Snake-like bands – internal
- Gray pit corrosion spots
- Brownish staining spots
- Snake-like bands – closer to edge joint
- Gray edge discoloration
- Glass joint

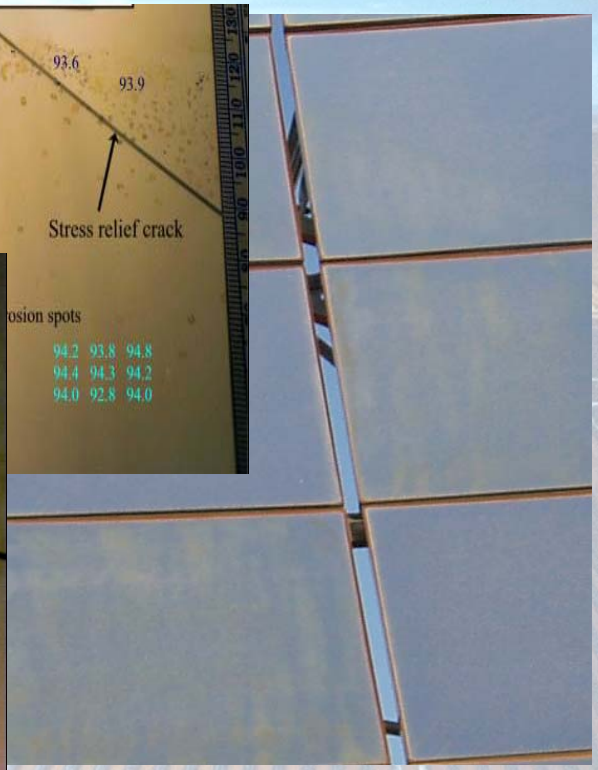


Mirror Corrosion

21 mo AZ







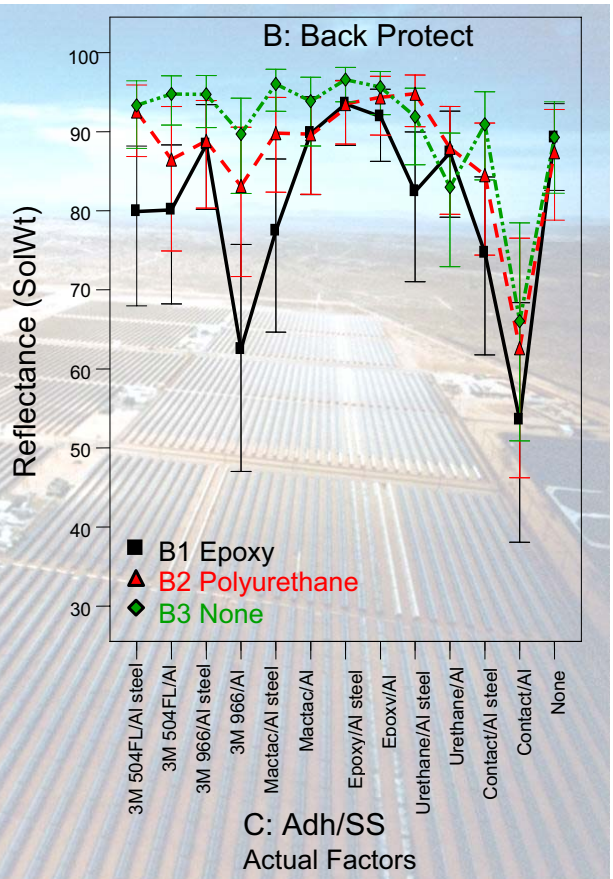
Thin Glass Mirror Matrix

D-optimal fractional factorial algorithm using Design-Expert® software

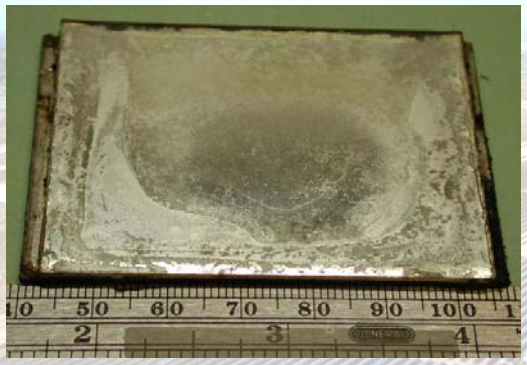
Levels	Factors					
	Mirror Type	Back Protection	Adhesive / Substrate	Edge Protection	Substrate Cleaning	Back Priming
1	Naugatuck/Cu	Epoxy	3M504FL/AL steel	None	SAIC	3M
2	Naugatuck/ No Cu	Polyurethane	3M504FL/AL	Exuded Adh.	SES	None
3	Glaverbel	None	3M966/AL steel	CPFilm		
4			3M966/AL			
5			Mactac/AL steel			
6			Mactac/AL			
7			Epoxy/AL steel			
8			Epoxy/AL			
9			Urethane /AL steel			
10			Urethane /AL			
11			Contact /AL steel			
12			Contact /AL			
13			None			

ANOVA Analysis

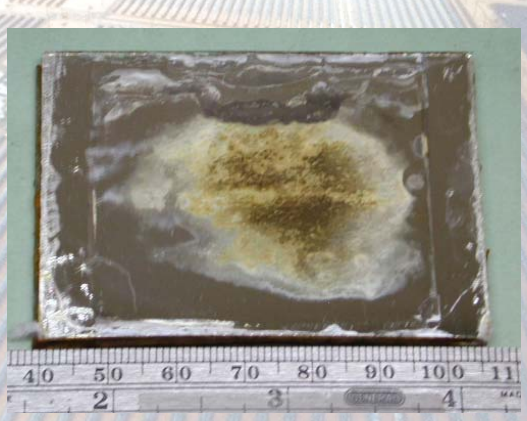
- Glaverbel - best overall mirror in Mirror matrix test
  - Commercial vs. prototype
  - 1- vs. 2-coat paint system
  - Difference in EU and US lead-free regulations
- Epoxy-based adhesive – probably good choice
- No additional back protection - survive the longest
- Polyurethane – poor choice
- BlueM - more accelerated exposure chamber



Damp-Heat results similar but ~5X faster than Ci5000 WOM

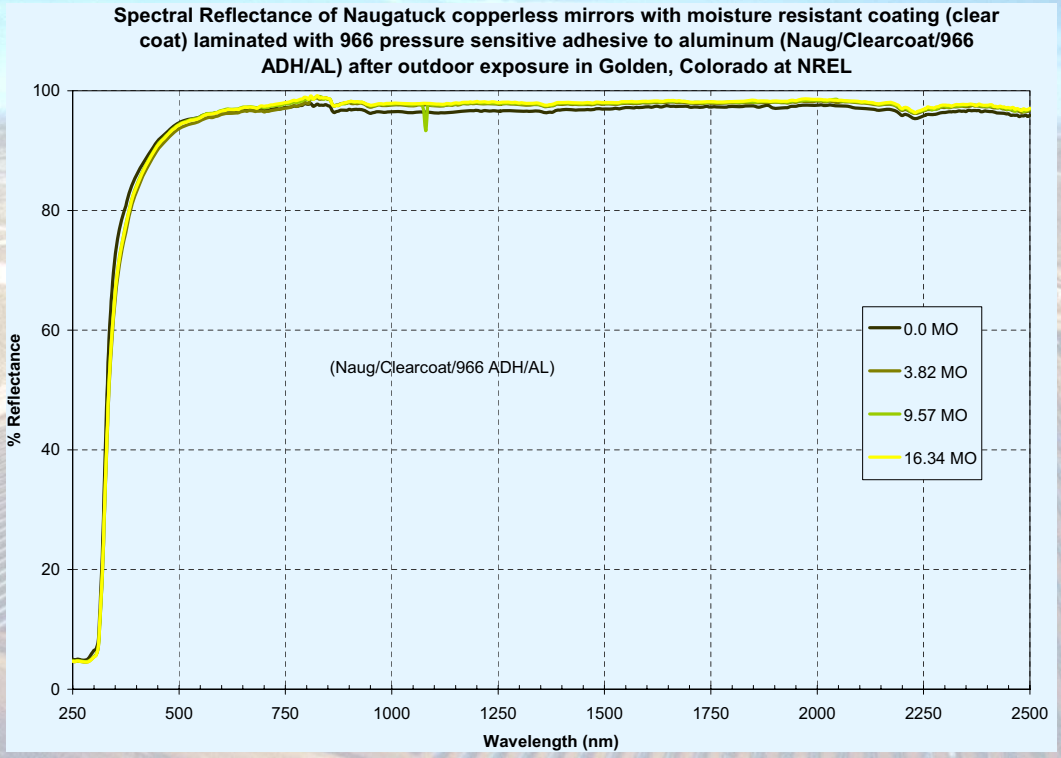


Discontinued in Damp-Heat 5.9 MO



Discontinued in Ci5000 18.9 MO

Thin Glass Mirror



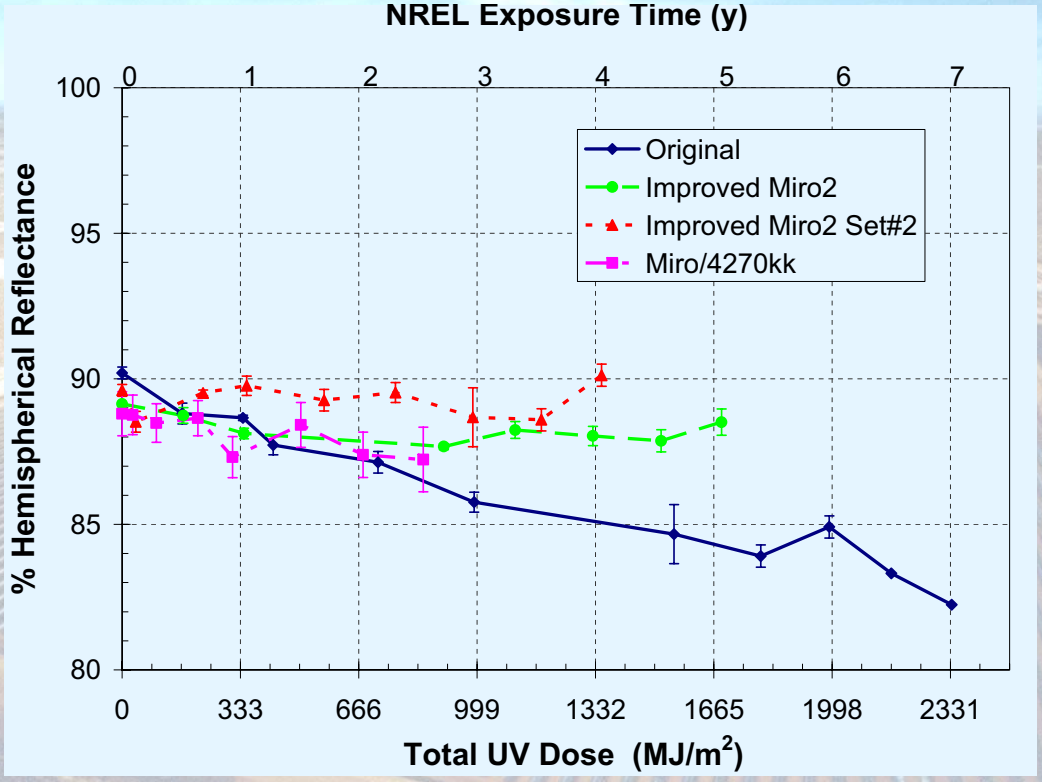
Glass Mirror

- Thick
  - RioSolar
  - Guardian
  - Saint-Gobain
  - NSG Pilkington
  - Pilkington Australia
  - PPG (CSP FOA)
  - Arch
  - Cardinal
- Thin
  - AGC Belgium, Thailand, Indonesia
    - (Asahi Glass Company formerly Glaverbel)
  - Naugatuck

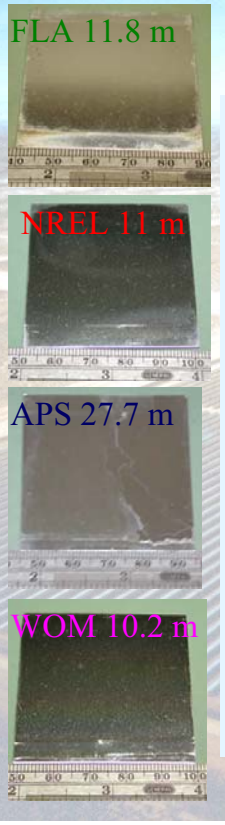
Aluminized Reflector Architecture

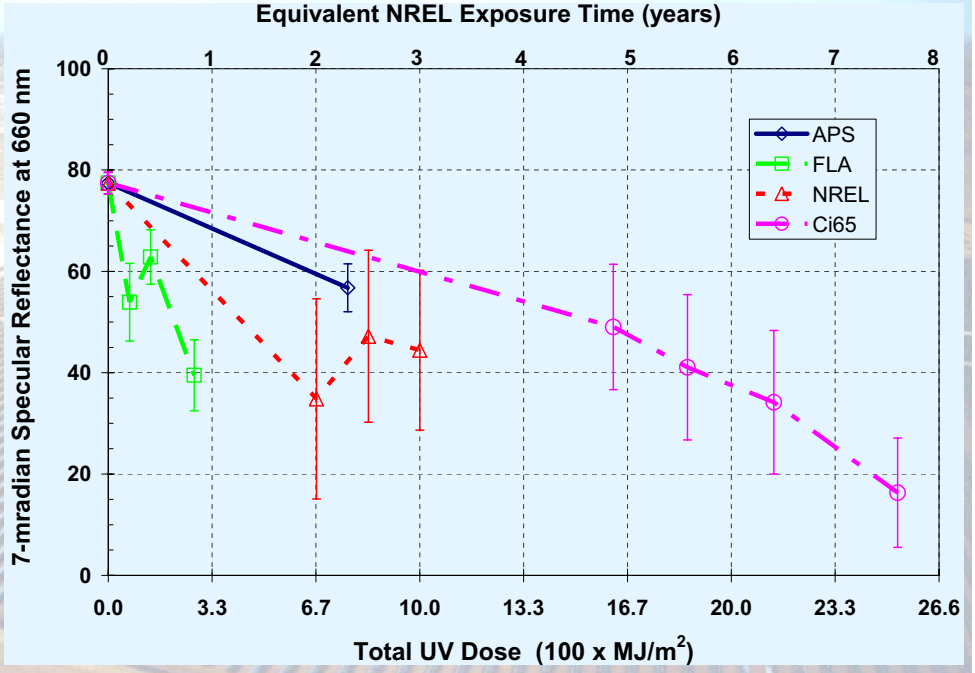
Protective Overcoat
Reflectivity - Enhancing Layer
PVD Al Reflective Layer
Polished Aluminum Substrate

Aluminized Reflectors

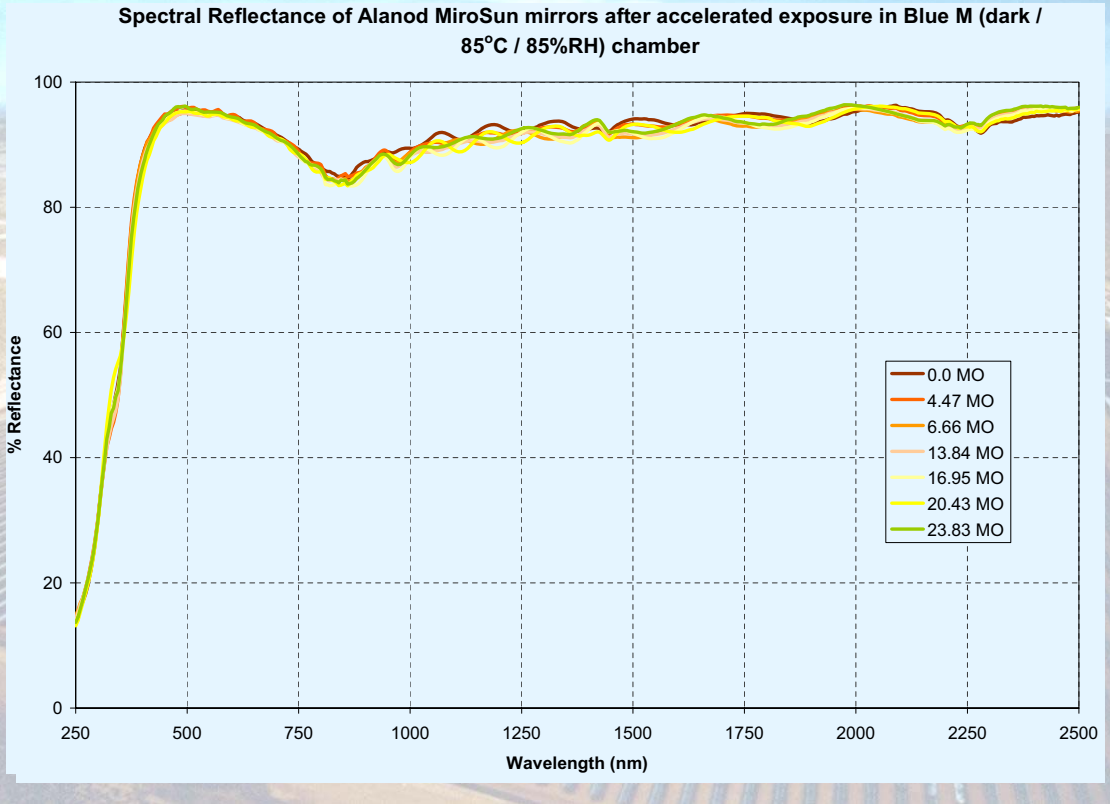


Aluminized Reflector Specularity

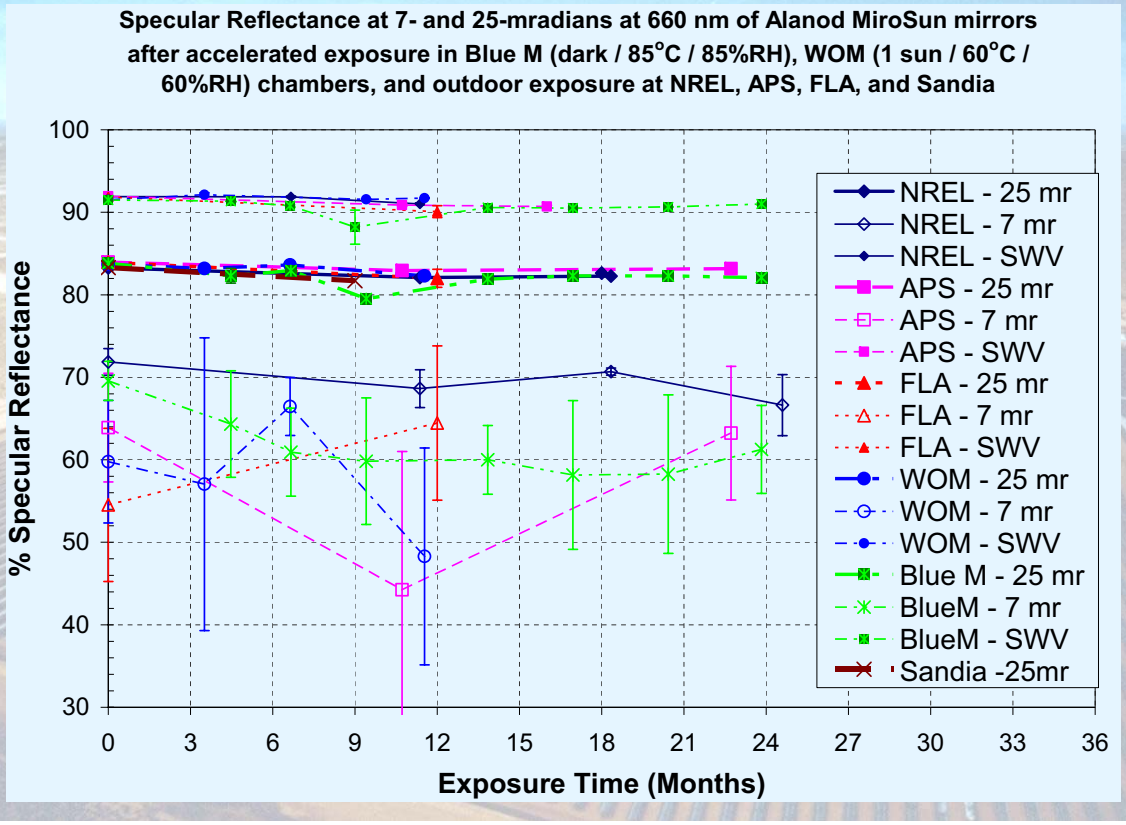




Aluminized Reflector



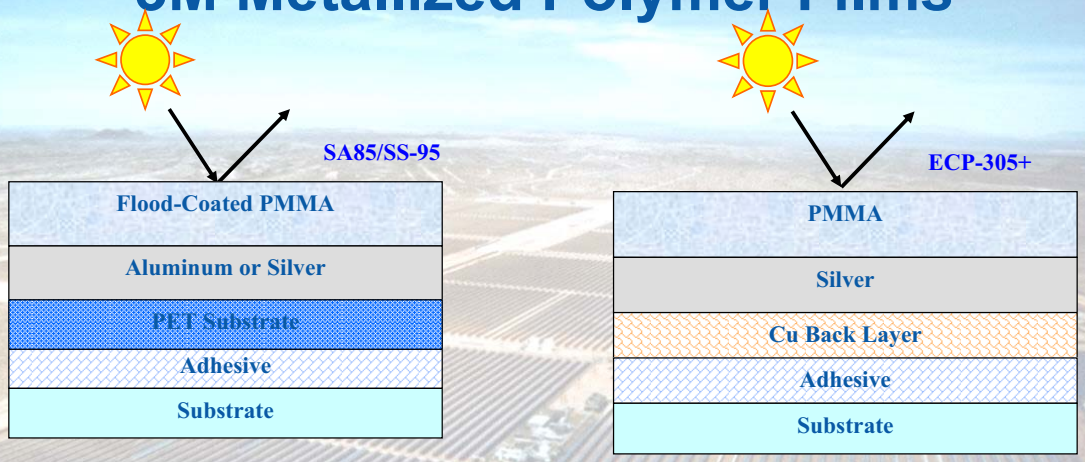
Aluminized Reflector



Aluminized Mirror

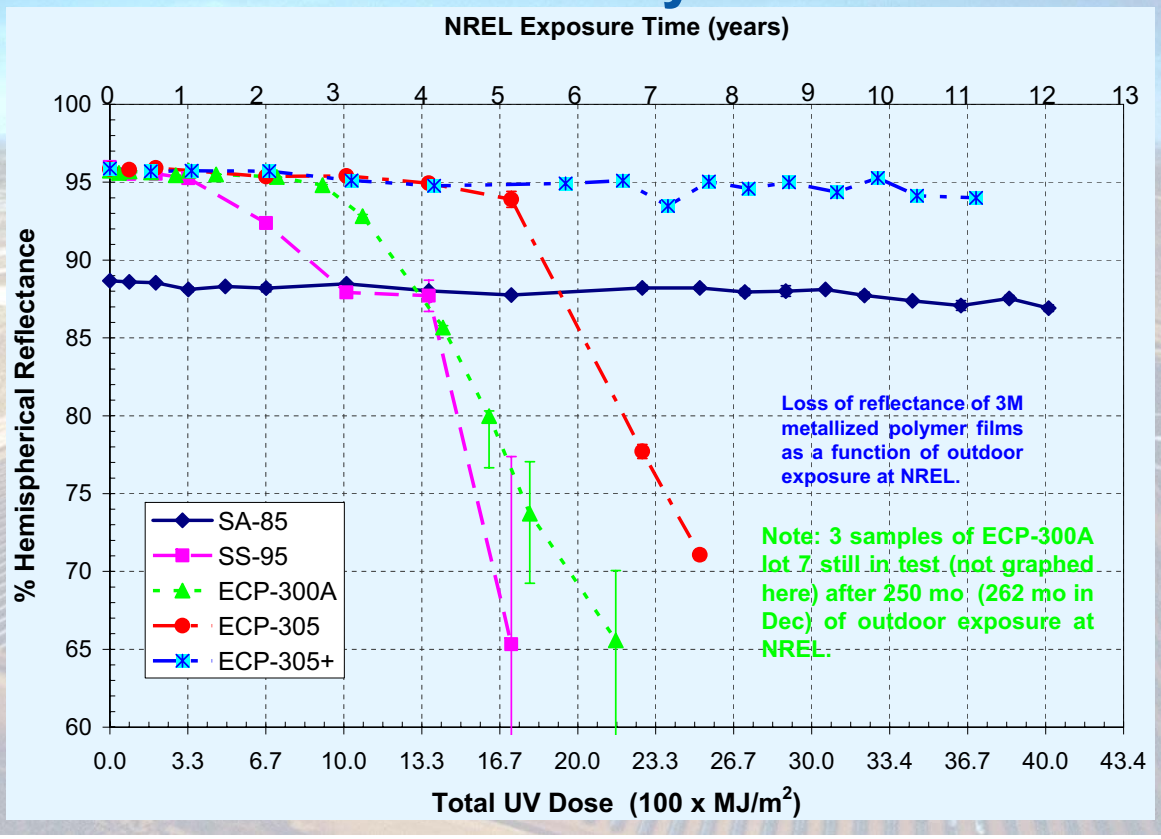
- Alanod
- Alcoa (CSP FOA)
- Alcan

3M Metallized Polymer Films



- **SA-85:** Aluminum-vapor-coated PET with acrylic coating. Initial reflectance ≈87%. Durable for more than 14 years of outdoor exposure. Outdoor exposure testing is continuing. 3M discontinued production in 1997.
- **SS-95:** Silvered PET with a thin acrylic flood coat. Manufactured as an indoor lighting product. Initial reflectance ≈95%. Durable for more than 4 years outdoors without additional UV screening layer. Outdoor exposure testing with and without an additional UV-screening layer continued until failure. 3M discontinued production in 2000.
- **ECP-305+:** Silvered acrylic reflector developed jointly under subcontract by 3M and NREL. Initial reflectance ≈94.5%. Durable for more than 12 years of outdoor exposure. Outdoor exposure testing is continuing until failure. 3M discontinued production in 1997. **3M restarted 305+ development in late 2007; received CSP FOA for hardcoat on 305+.**

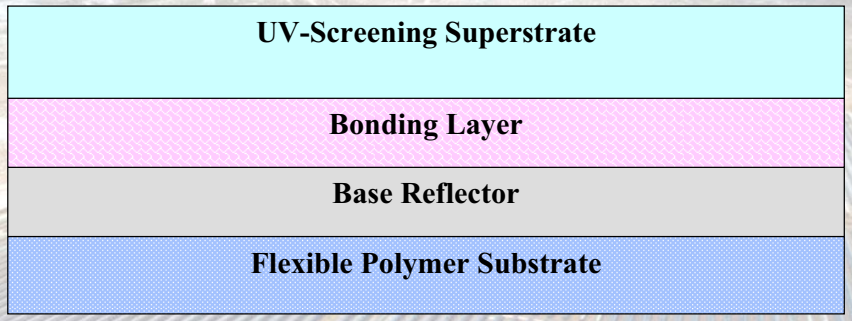
3M Metallized Polymer Films



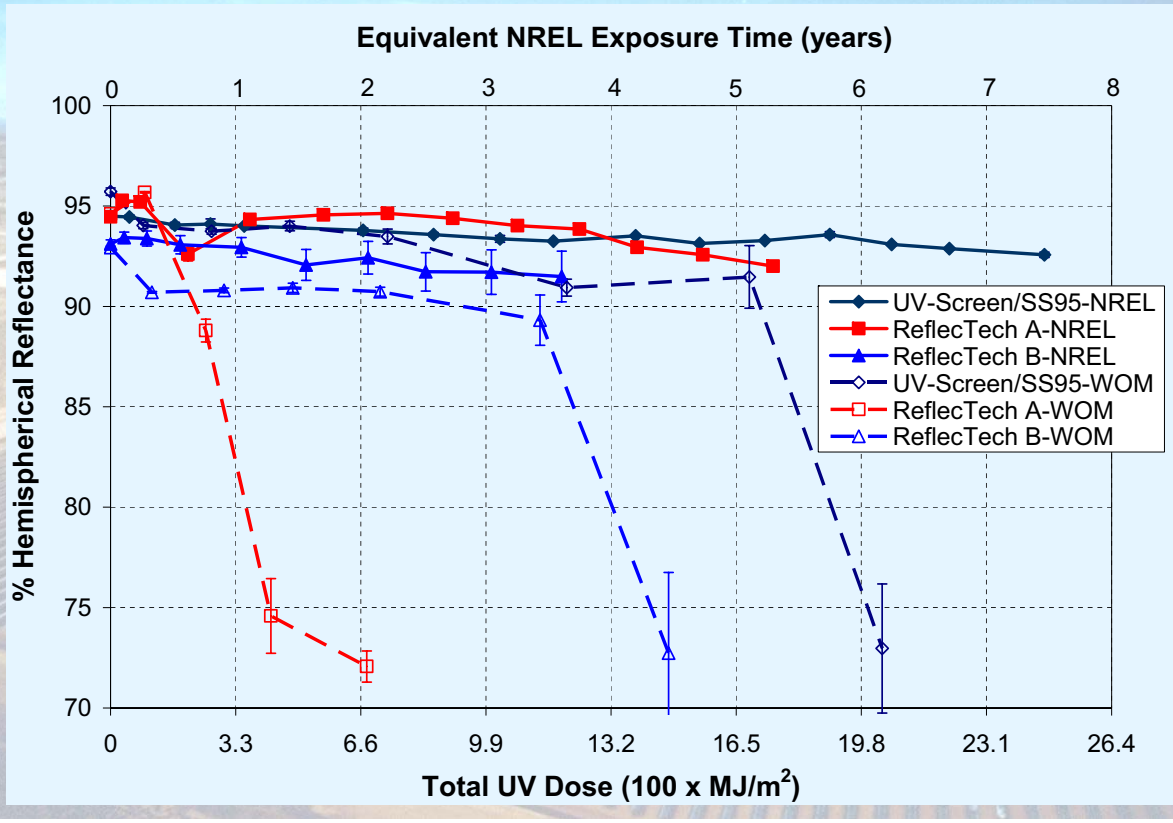
Delamination Failure of ECP-305+

NREL was able to prevent tunneling by annealing laminated substrate at 80°C for 4 hr or by adding adhesion promoting interlayers

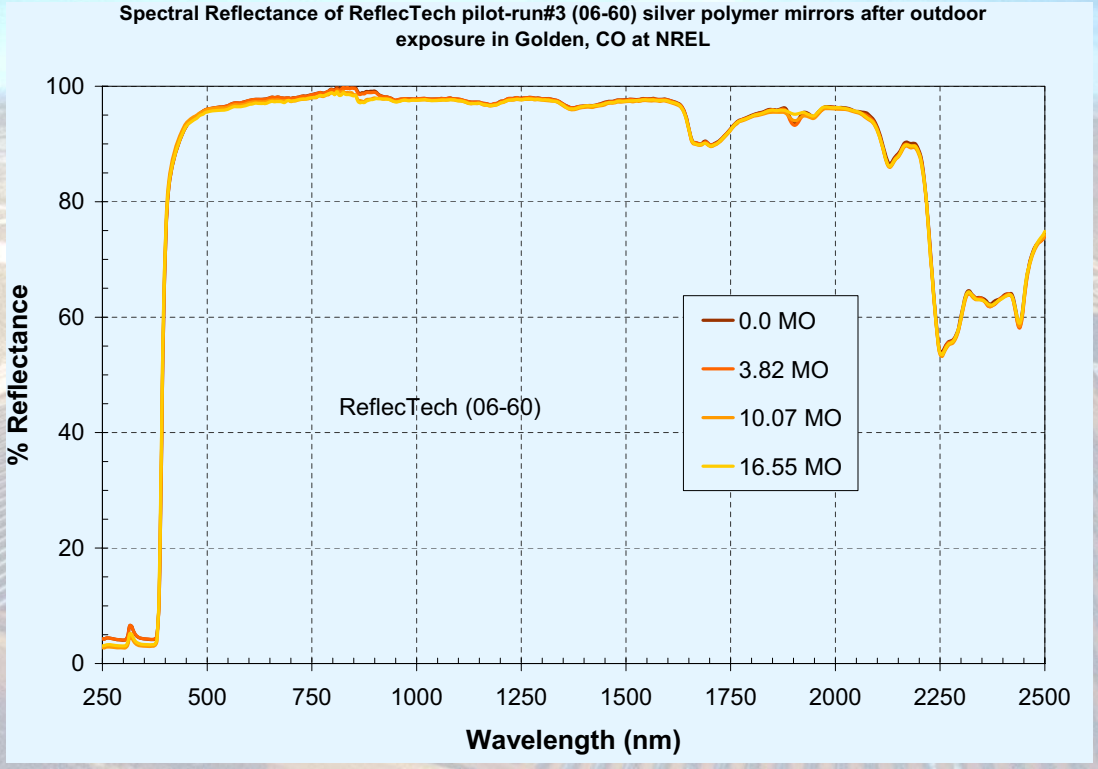
ReflecTech - Silvered Polymer Reflector Architecture



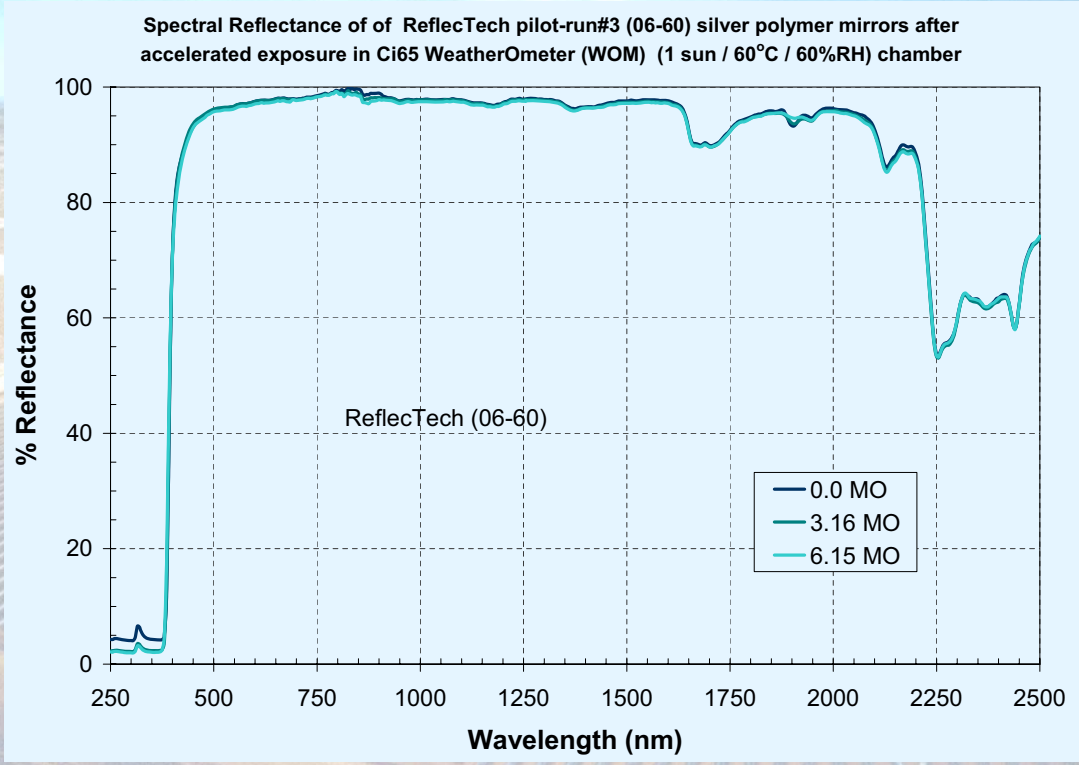
ReflecTech Prototypes



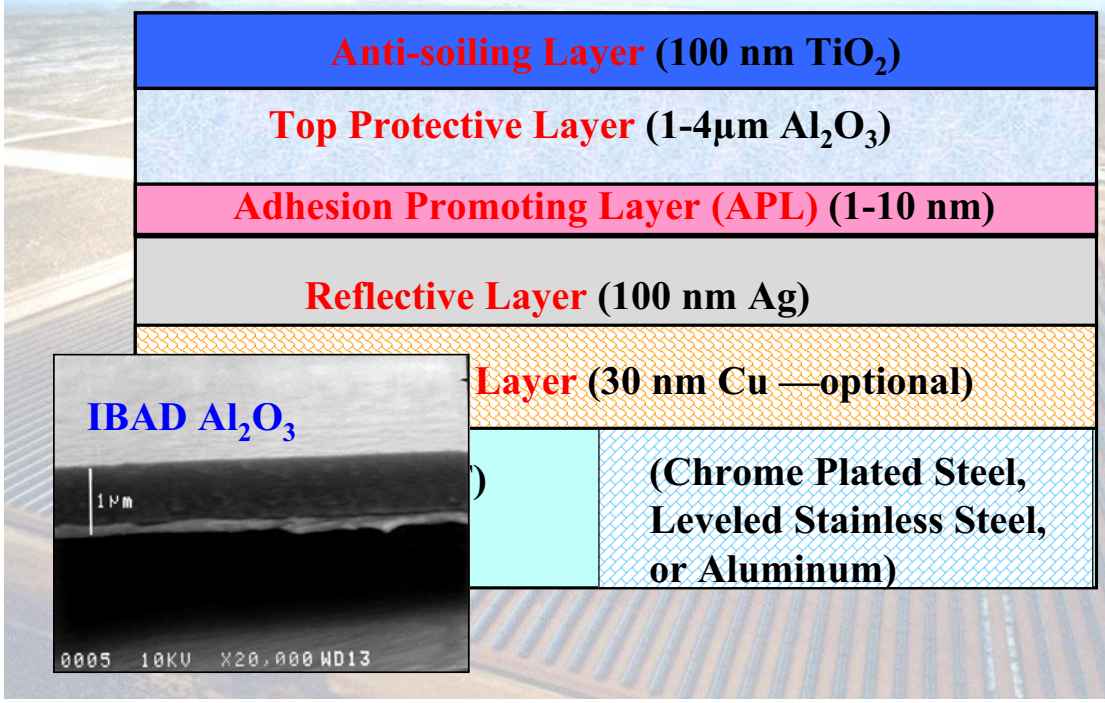
ReflecTech - Pilot Run III - NREL



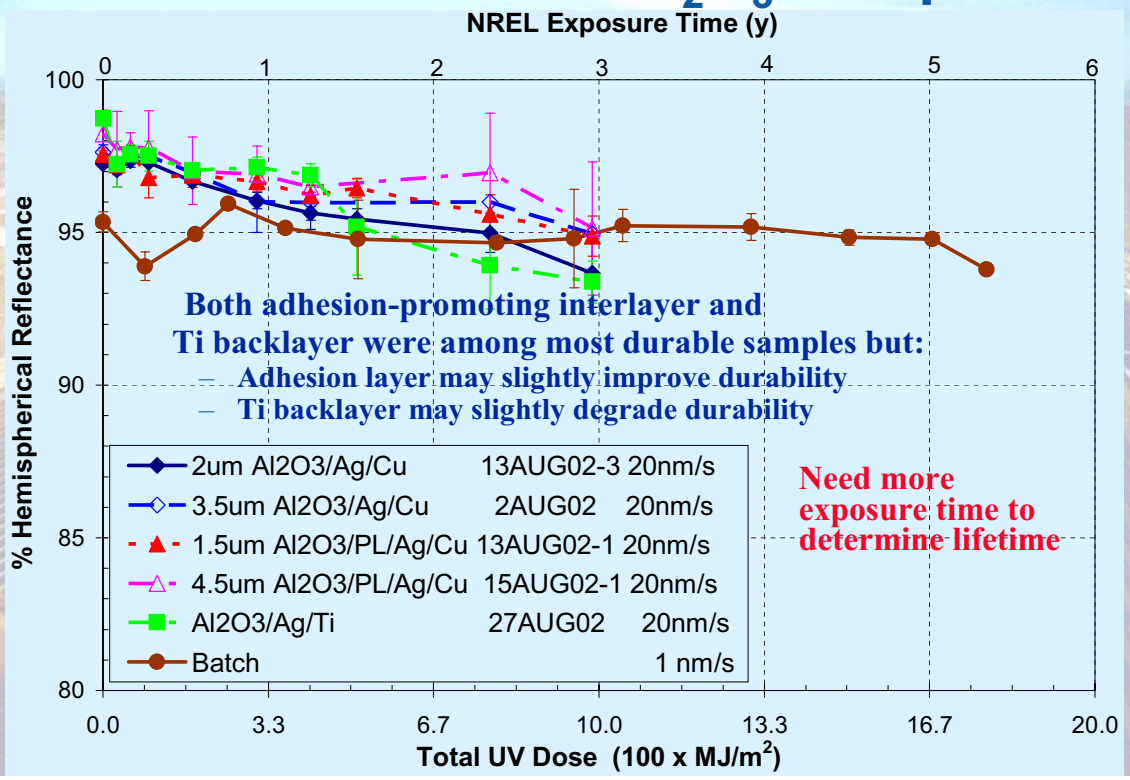
ReflecTech - Pilot Run III – Ci65 WOM



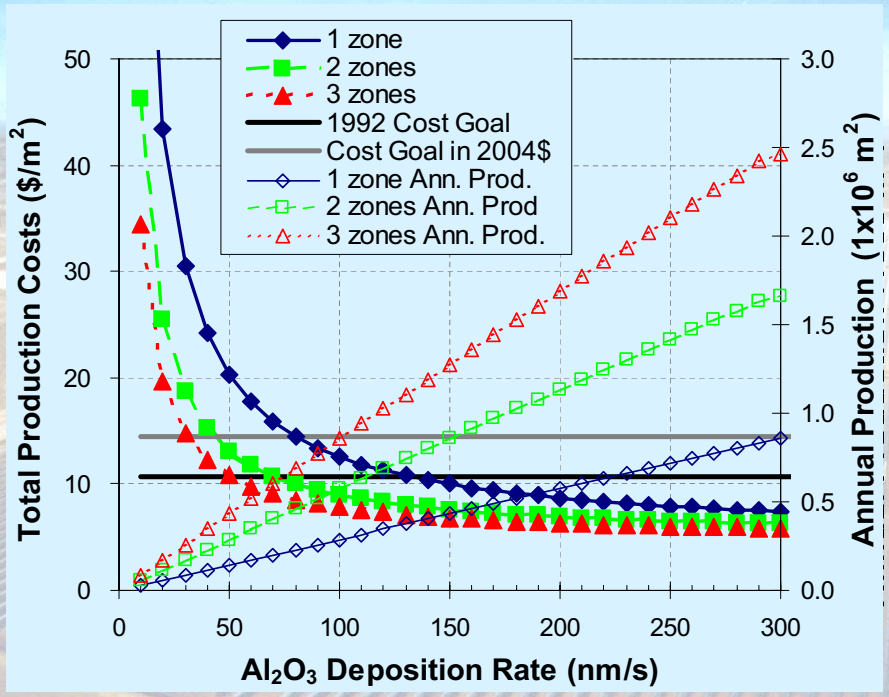
Front Surface Solar Reflector Architecture



Outdoor exposure at NREL of Roll-Coated IBAD Al_2O_3 Samples



Cost Analysis

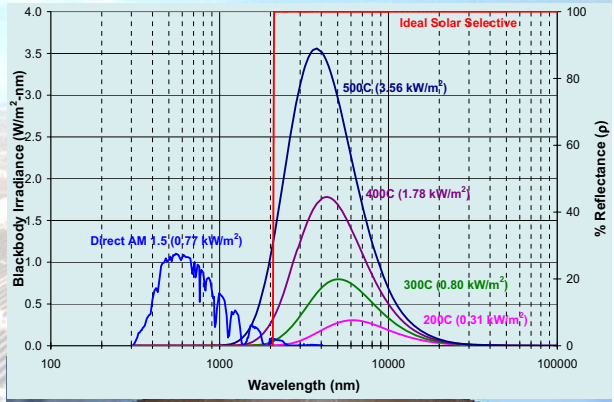


Abengoa Solar selected for a CSP FOA subcontract to develop ASRM

- 30% yield
- Coating 79% time
- 10 to 200 nm/s rate
- Machine cost: $2M-$4.1M
- Loan%/length: 12% for 5 yrs
- PET substrate
- 1-µm Al_2O_3
- Modified ASRM
- $200/h machine burden
- 1200-mm web
- High-purity High-volume (i.e.,$200/kg) Al_2O_3
- ✓ 1 vs. 2 vs. 3 zones in 1 machine

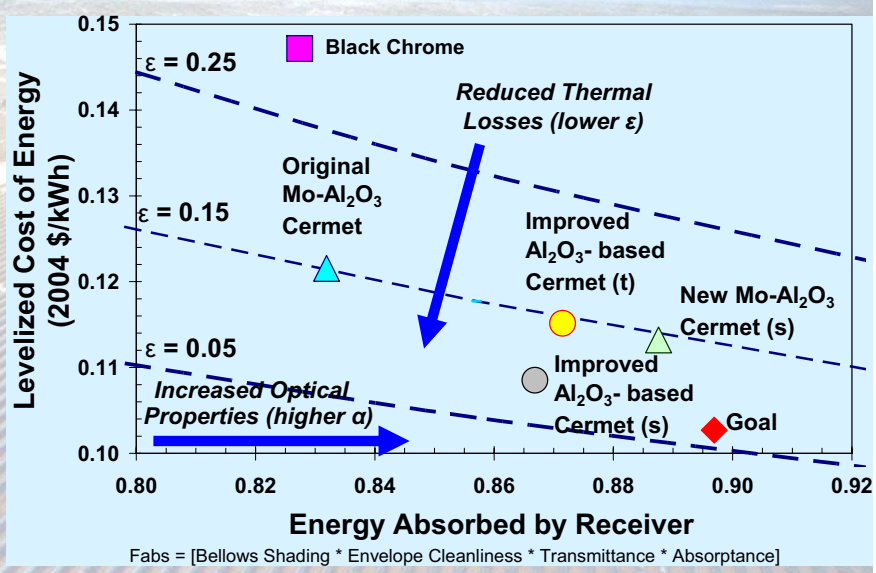
Advanced Selective Coating Goals

- Receivers:
  - 4 m long x 70 mm diameter
  - 64 MWe Nevada plant
    - 820 collectors with 24 (96 m) receivers each
    - 19,680 receivers
    - 82 km of receivers (50 mi)
  - 3-4%/yr Failure Rate
  - ~$1000/tube
- To develop receiver coatings that have:
  - Good optical and thermal performance: absorptance (α) ≥ 96%, & emittance (ε) ≤ 7% >450ºC
  - High temperature stability in air at temperatures ≥ 550ºC
  - Manufacturing processes with improved quality control
  - Lower cost



High Temperature Solar Selective Coating Development

- Selective coating properties impact collector optical performance and thermal losses.
- Improvements in the receiver can enhance collector efficiency & lower cost.
- The international community currently leads this area and there exists minimal US research & no US manufacturer of high-temperature selective coatings.

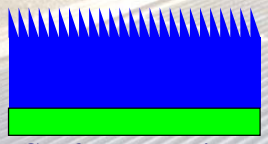


Fabs = [Bellows Shading * Envelope Cleanliness * Transmittance * Absorptance]

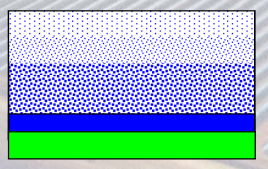
Types of Selective Coatings

Intrinsic absorber

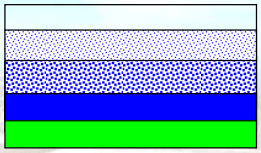
Multilayer absorbers



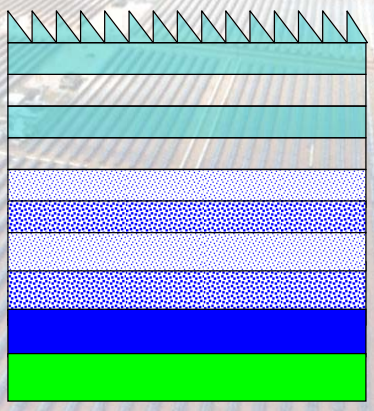
Surface texturing



Graded cermet



Double cermet



Multiple cermet

Literature Review of Candidate High-temperature (> 450°C) Solar Selective Materials

- Graded Mo,W, ZrB, Pt- Al_2O_3 cermets
- Si tandem absorber
- Black Co, Mo,W
- Double cermets- SS-AlN, AlN/Mo, or AlN/W
- 4-layer V-Al_2O_3, W-Al_2O_3, Cr-Al_2O_3, Co-SiO_2, Cr-SiO_2, Ni-SiO_2
- Double AR
- Multilayers; Al-AlN_x-AlN
- Au/TiO_2 cermet
- ZrC_xN_y/Ag
- $Ti_{1-x}Al_xN$
- Q*uasicrystals* multilayers & cermets
- Surface Texturing

Desirable Properties for Stable Coating in Air > 550°C

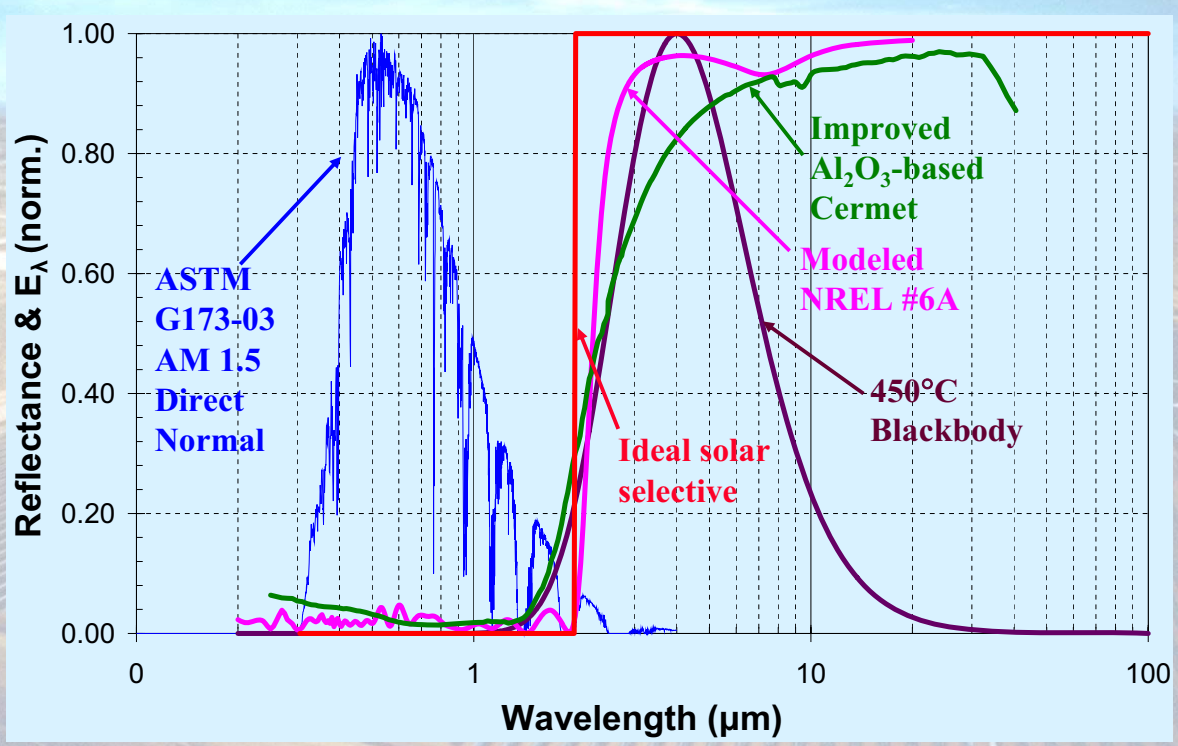
- High thermal & structural stabilities for combined & individual layers
  - Elevated melting points
  - Large negative free energies of formation
  - Materials that form a multicomponent oxide scale
  - Single-compound formation
  - Lack of phase transformations at elevated temperature
- Suitable texture to drive nucleation, subsequent growth of layers with suitable morphology
  - Stable nanocrystalline or amorphous materials
- Excellent adhesion between the substrate and the adjacent layers
- Enhanced resistance to thermal and mechanical stresses
  - Acceptable thermal and electrical conductivities
  - Higher-conductivity materials have improved thermal shock resistance
  - Some ductility at room temperature reduces thermal-stress failures
- Good continuity and conformability over the tube
- Compatibility with fabrication techniques

NREL Modeled Selective Coating

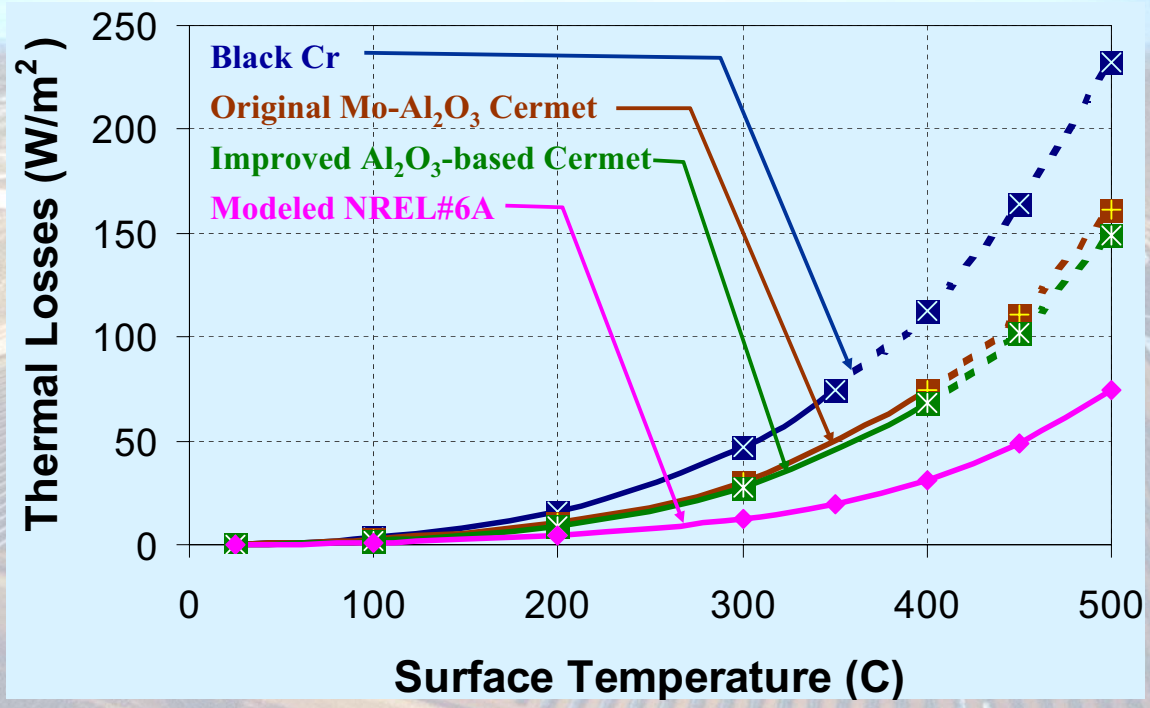
Comparison of theoretical optical properties for NREL's modeled prototype solar selective coating with actual optical properties of existing materials.

	Commercial (as tested)			Modeled NREL
	Black Cr	Mo-Al_2O_3 Cermet	Al_2O_3-based Cermet	# 6A
Solar Absorptance	0.916	0.938	0.954	0.959
Thermal Emittance@				
25°C	0.047	0.061	0.052	0.027
100°C	0.079	0.077	0.067	0.033
200°C	0.117	0.095	0.085	0.040
300°C	0.156	0.118	0.107	0.048
400°C	0.197	0.146	0.134	0.061
450°C	*0.218*	*0.162*	*0.149*	*0.070*
500°C	0.239	0.179	0.165	0.082

Modeled NREL Selective Coating



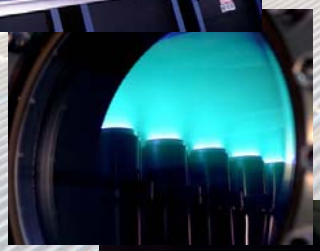
Modeled NREL Selective Coating Thermal Losses



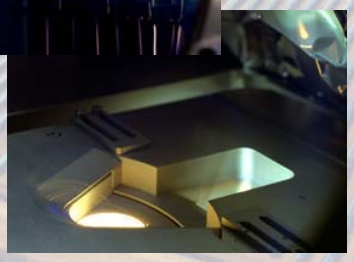
Modeling Key Results

- Solar Selective Coating Development
  - Modeled solar-selective coatings with α=0.959 and ε=0.070 at 450°C that meet CSP goals
  - Using materials that are oxidation resistance >800°C
  - Emittance excellent & absorptance of modeled coatings is very good and further improvements are expected. However, trade-off exists between low emittance and high absorptance

Deposition Capabilities



Sputtering Chamber



E-Beam Chamber

- Three-Chamber In-line System
  - Load-Lock Chamber
  - Pulsed DC Sputtering Chamber
    - 3 - linear arrays of 5 - 1.5" Mini-mak guns
    - 2 - 12" planar cathodes
  - Electron-Beam/IBAD Chamber
    - 6 multi-pocket e-beam source
    - Co-deposition bottom plate
    - IBAD w/ 12" Linear Ion Gun
  - System
    - 12"x12" ambient or heated substrate
    - 4 Reactive Gases
    - Turbo molecular drag pumps
      - $2x10^{-8}$ torr
    - Monitoring
      - RGA
      - Quartz Crystal Monitor
      - Pressure/Gas
      - Computer

Progress in Prototyping

- Key issue is making deposited coating
- XPS showed evaporation from compounds produced layered stoichiometry
  - Layers were deposited with over- and under-thickness and compound layered structure, the optical performance of the prototype NREL#6A was quite encouraging.
- Need to codeposit materials
  - Required significant upgrade to equipment
- Codeposit individual layers and modeled coating
  - Codeposition development
  - Optical performance lower than modeled but very encouraging
    - Need to improve thickness monitor and control; β-version thickness error was >>5% because of manual control.
    - Need to optimize stoichiometry and determine phase formation because compotion was not optimized in β-version
    - Need to optimize morphology with ion assist to give both high α and low ε, plus high oxidation resistance

Selective Coating Performance

- ε can be measured at higher temperatures but is typically reported based on calculations from reflectance measurements fitted to the black body curve
  - Actual performance of the absorber at high temperatures commonly does not correspond to the calculated ε
    - Small errors in ρ lead to large errors in ε
    - ε is a surface property & depends on surface condition of material and substrate
    - Selective coatings can degrade at high T
  - Therefore it is important that ρ is measured accurately and to measure ε of the selective coating at operating temperatures & conditions before using calculated ε
- Thermal stability is sometimes given based on the thermal properties of the individual materials or the processing temperature parameters
  - Actual durability data is uncommon for high temperature absorber coatings
  - Durability or thermal stability is typically tested by heating the selective coating, typically in a vacuum oven but sometimes in air, for a relatively short duration (100's of hours) compared with the desired lifetime (5-30 years)
    - IEA Task X performance criterion (PC) developed for flat plate collector absorber testing (i.e., non-concentrating, 1-2X sunlight intensity)
    - No analogous criterion known for testing high-temperature selective coatings for CSP applications
- NREL building capability for accurate optical measurements and long term testing of thermal stability
  - Round Robin & purchase Perkin Elmer 883 IR spectrophotometer
  - Purchased & installed high-temperature (600°C) inert gas oven

Selective Coating Development

- Identify requirements
- Identify oxidation resistant materials
- Design selective coating with optical software
- Deposit prototype selective coating
- Characterize deposited selective coatings
- Simplify manufacturing method
  - Detailed cost analysis
  - Multilayer → Cermet
  - EB-PVD → Sputtering → CVD?→ Thermal (Air?) Spray
  - Higher Temperature material systems

Conclusion

- DOE, the WGA, state RPS mandates, and feed-in tariffs have successfully jump-started growth in CSP technologies that would require 7 to 10 million square meters of reflector and more than 600,000 HCEs over the next 5 years.
- Commercial glass mirrors, Alanod, and ReflecTech may meet the 10-yr lifetime goals based on accelerated exposure testing. 3M ECP-305+ and alumina IBAD mirrors of interest.
- Predicting an outdoor lifetime based on accelerated exposure testing is risky because AET failure mechanisms must replicate those observed by OET.
- None of the solar reflectors available have been in test long enough to demonstrate the 10-year or more aggressive 30-year lifetime goal, outdoors in real-time
- Emittance excellent & absorptance of modeled solar selective coatings is very good. Further improvements are expected, but trade-off exists between low emittance, high absorptance, and excellent oxidation resistance. Optimizing prototype underway and looks very promising. NREL (recently) filed for patent and solicited business partners to help develop the advanced solar selective coatings.

Acknowledgments

3M, Alanod, Alcoa, AGC (i.e., Glaverbel), Naugatuck, Pilkington, ReflecTech, RioGlass, SAIC, Saint Gobain, SES, and Solar Systems for providing solar reflective samples.

Schott and Solel for providing solar selective samples.

AZ Technology and Surface Optics Corporation for high-temperature optical measurements .

Armstrong World Industries: Dr. J. S. Ross

Northeastern University: Dr. Jackie Isaacs

Penn State University: Prof. Singh, Tom Medill, and Dale Donner

SAIC: Dr. Russell Smilgys and Steve Wallace

Stat-Ease: Wayne F. Adams

Swisher and Associates: Dick Swisher

NREL:

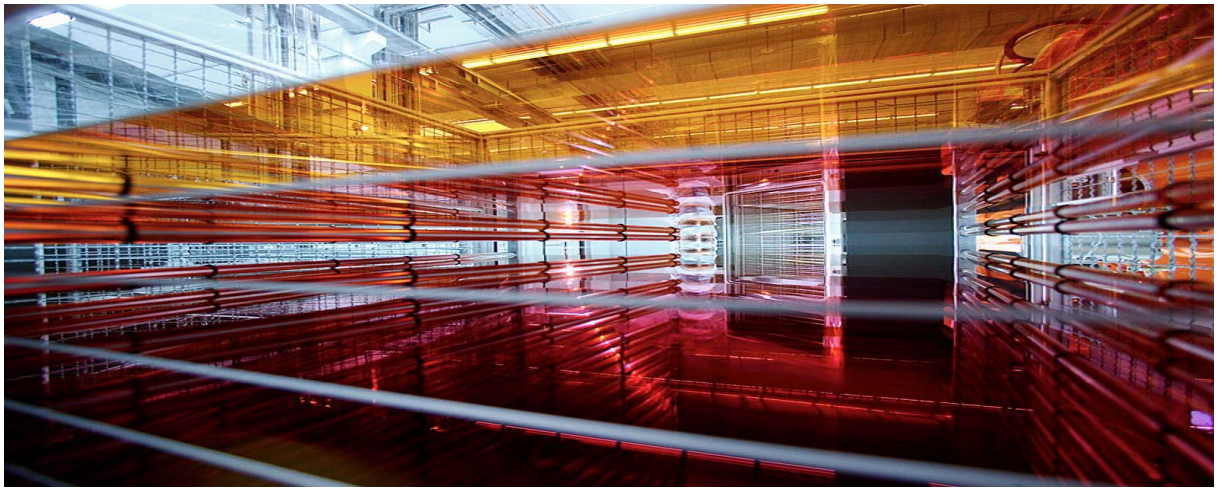
Lynn Gedvilas, Gary Jorgensen, Mark Mehos, Judy Netter, Craig Perkins, Hank Price, Kent Terwilliger, and Student interns: Micah Davidson, Anthony Nelson, Michael Milbourne, Christopher Lundquist, Andrea Warrick, and Marc Oddo.

DOE supported this work under Contract No. DE-AC36-99GO10337.

Welcome to Oerlikon Solar

Solar Glass Workshop, Denver, CO

Dr. Chris Constantine

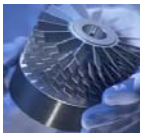


Agenda

- Oerlikon Overview
- Thin-Film PV, a High Growth Market
- Achieving Grid Parity
- Solar Glass

œrlikon

New Oerlikon Organization

Group »	œrlikon					
Segments »	Oerlikon Textile	Oerlikon Coating	Oerlikon Solar	Oerlikon Vacuum	Oerlikon Drive Systems	Oerlikon Components
						
Business » Units	œrlikon barmag œrlikon neumag œrlikon saurer œrlikon schlafhorst œrlikon textile components	œrlikon balzers œrlikon systems	œrlikon solar	œrlikon leybold vacuum	œrlikon graziano œrlikon fairfield	œrlikon esec œrlikon optics œrlikon space

07 Sales > $ 5 billion – 19,250 employees – 1,500 scientists – 35 countries – 170 locations

œrlikon
solar

Oerlikon – Supplier of Clean Technologies

Oerlikon Coating Systems

Coatings For Automotive and Advanced PV

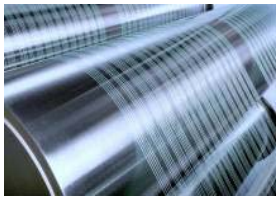
- 10 times longer life of components
- 4% less fuel consumption
- Multi-Junction Space PV

Oerlikon Vacuum

- Develops and builds vacuum solutions for the solar industry
  (wafer-based and thin film technology)

Oerlikon Textile

- Introduction of the e-save® program for sustainable energy savings in textile production machines



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Oerlikon – Supplier of Clean Technologies

Oerlikon Drive Systems

- Develops and builds transmission systems for leading manufacturers of wind power systems

Oerlikon Space

- Develop various satellite components for researching climate changes on our planet

Oerlikon Solar

- Develops and builds turnkey production solutions for thin film silicon solar modules
- Leading researcher and developer in thin film silicon solar technology

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Focused on Advanced Technologies

- Telecommunications
- Solid State Lighting
- MEMS
- Photovoltaics
- Photonics

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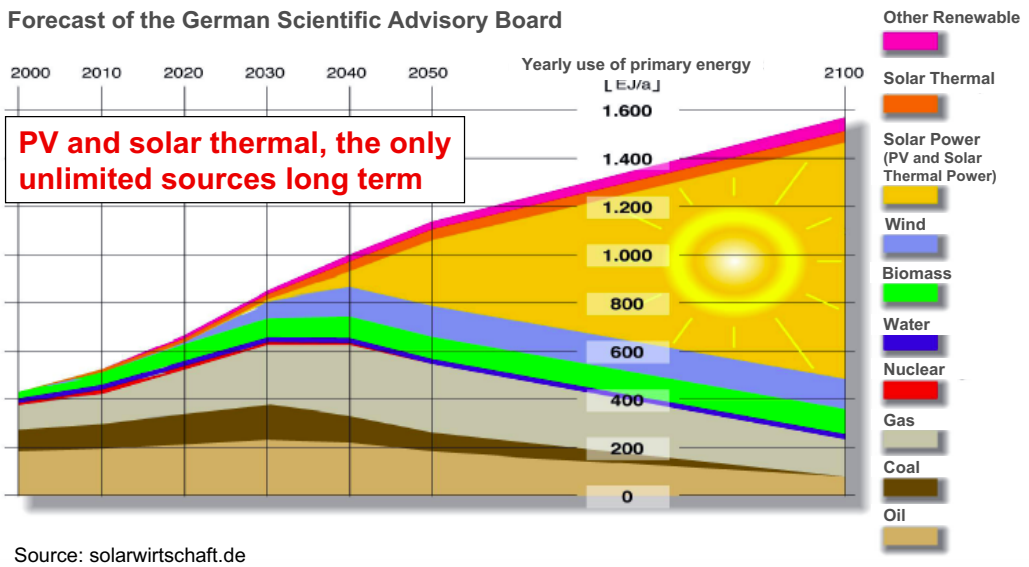
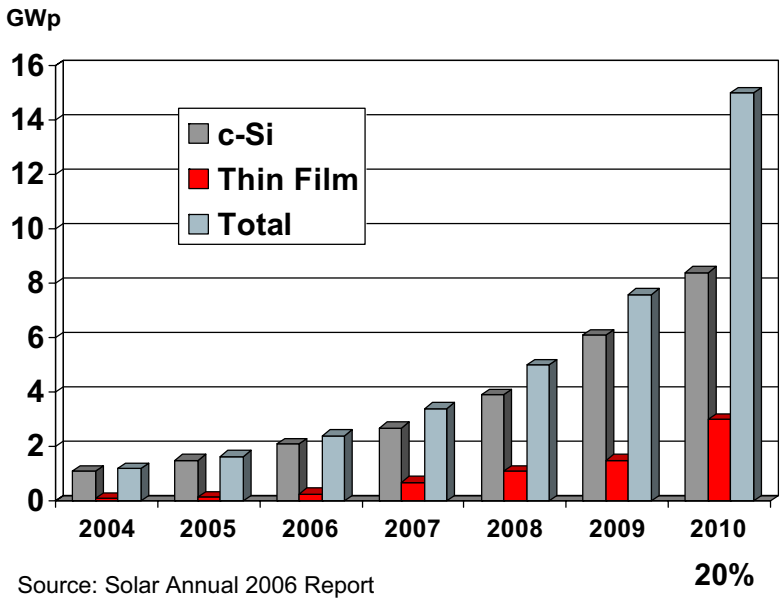
Global Energy Supply until 2100



Source: solarwirtschaft.de

PV Module Forecast and Growth Rates



Source: Solar Annual 2006 Report

2005-2010 CAGR	
Total market	44%
C-Si	41%
Thin Film	66%

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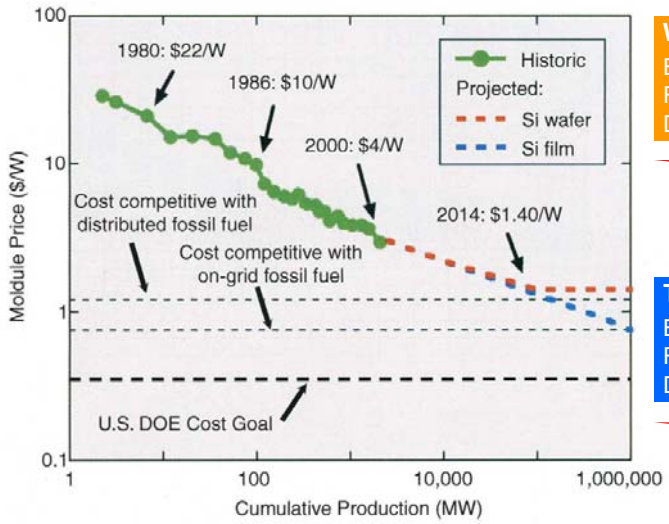
Different Technologies – Different Cost Saving Potential



Wafer based

Base material	Silicon wafer
Raw material	Silicon wafer
Differentiation	Higher efficiency

Low saving potential

Thin-Film

Base material	Glass
Raw material	Silane gas
Differentiation	Higher power per $

High saving potential

Source: MRS Bulletin, Vol. 30, No. 1, Jan 2005
„Distributed fossil fuel" refers to off-grid generation of power, using for instance gas-driven generators.

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Cost of Ownership Calculation

$$\frac{\$}{Wp} = \frac{Material\ Cost + Invest\ Cost + Labor\ Cost}{Throughput \bullet Yield \bullet Uptime \bullet Power}$$

Material Cost	⇔	Gas, glass, lamination foil, consumables, etc.
Investment Cost	⇔	Equipment, Line Automation, Back-end, etc.
Labor Cost	⇔	Operators, technicians, engineers, management, etc.
Throughput	⇔	Glasses per hour
Yield	⇔	% of sellable modules
Uptime	⇔	% of equipment availability
Power	⇔	Module power driven by conversion efficiency

Wright Williams Kelly

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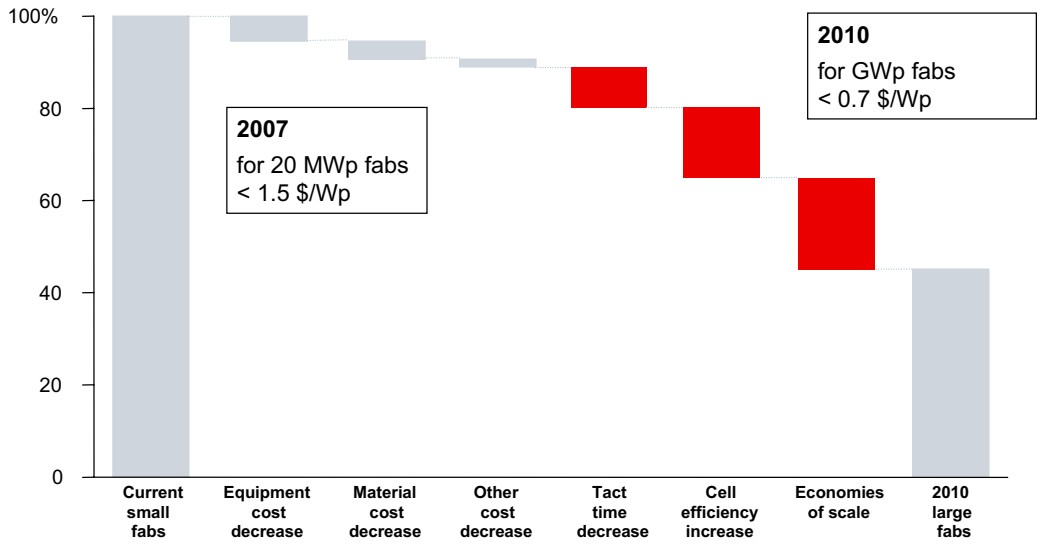
Cost of Ownership: Driving to Grid Parity…

Amorph 2007 to micromorph tandem 2010



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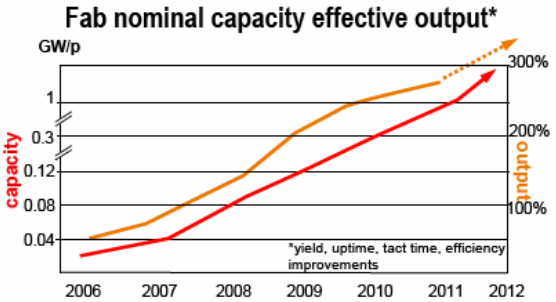
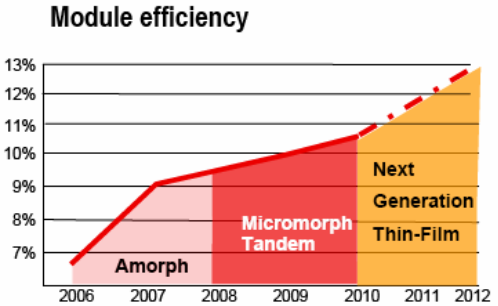
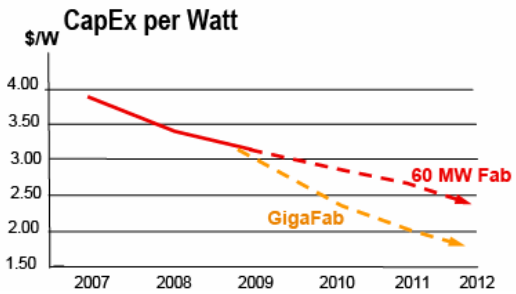
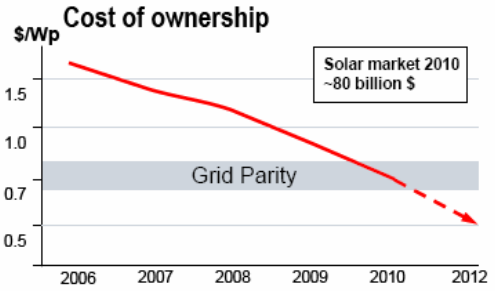
Achieving Grid Parity









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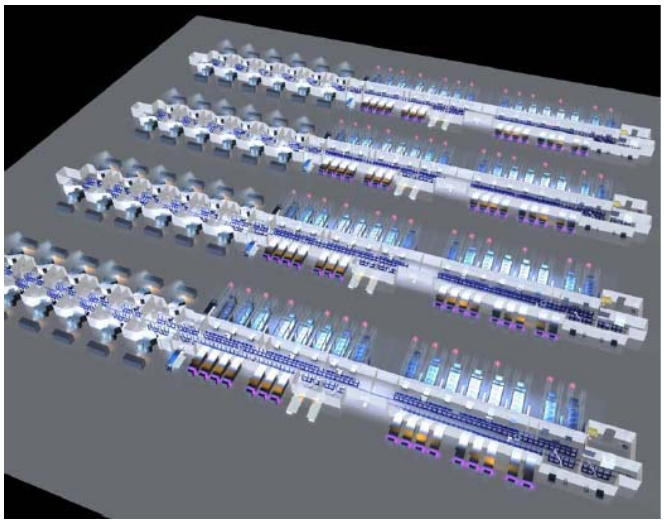
Driving Toward the Giga-Fab Era



Typical 120 MW Line

Floor Space

- 23.500 m^2

Manpower (5 Shifts)

- 240 staff

Production

- 4.1 modules/day
- 1,500 modules/year

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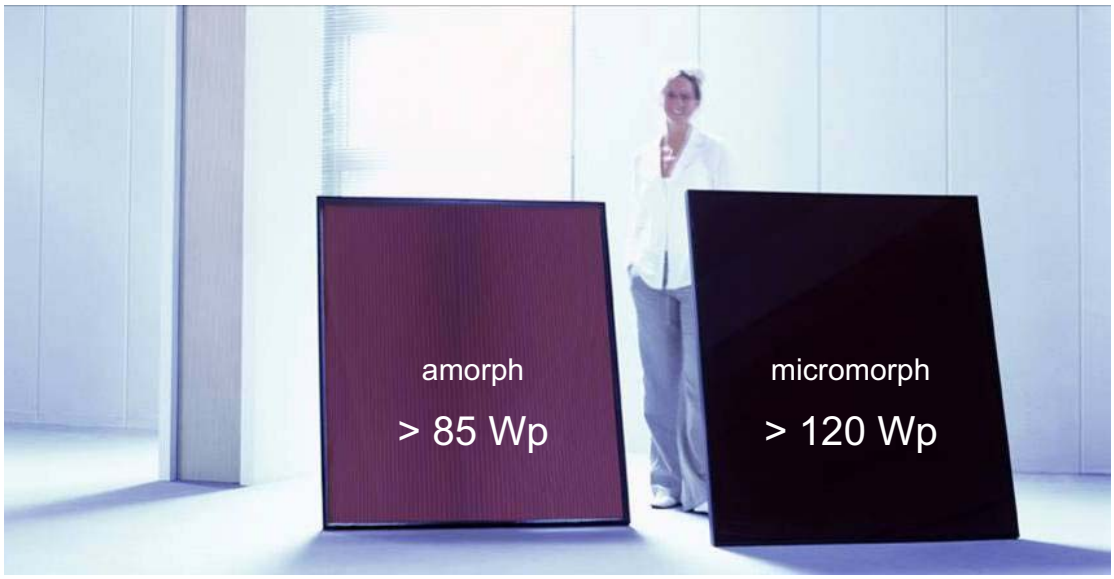
Technology Roadmap – From Amorph to Micromorph



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Strong Increasing Demand

GLASS
suitable for
photovoltaic and thermal
use of solar energy

concerns of

Availability

Price

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Selection Requirements for Photovoltaic use:

1. Optical properties
2. Mechanical properties
3. Chemical resistance
4. Electrical conductivity, Na-diffusion (substrates)
5. Low weight
6. Decreasing price

And for Thin Film:

7. TCO coated glass

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Thin Film Silicon 1 GWp Production:

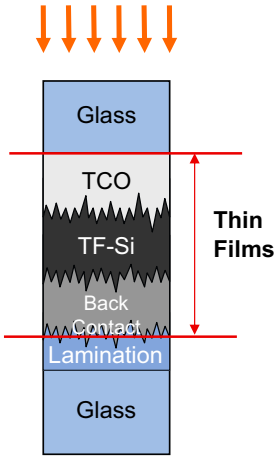
$10m^2 \approx 1$ kWp, 1 GWp $\Rightarrow 10 \times 10^6$ m^2 glass

with ≈ 2 x 3mm = 6mm thickness (glass-glass laminate)

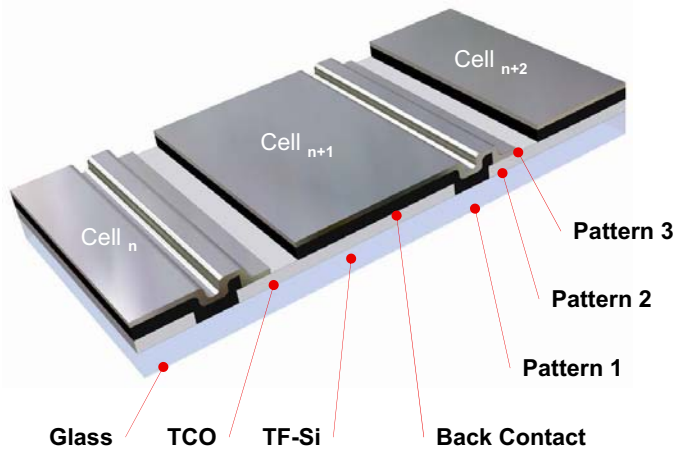
➢ 60,000 m^3 flat glass ≈ 150,000 tons of glass

Thin Film and Cell Technologies

Module Cross Section



Cell Structure



Module tests concerning the glass properties

DIN IEC 61215, DIN EN 61646

- Damp heat test (1000 h at 85°C, 85% rel. humidity)
- Mechanical: 3 cycles 2400 Pa 1 h front and back side, optional last front side 5400 Pa (snow)
- Hail: 25mm ice ball with 23M/s at 11 points

No visible defects, loss of efficiency max. 5%

No endurance tests, but time of use (amortisation): 20 – 25 years!

Optical Properties

Aim: maximum radiative intensity should reach the semiconductor material for a long period of time (→chemical resistance)

$$I_0 = I_{reflection} + I_{absorption} + I_{transmission}$$

$$I_{reflexion} \approx 8\ \%$$

$$I_{transmission} = (I_0 - I_{reflection}) \cdot e^{-\varepsilon c d}$$

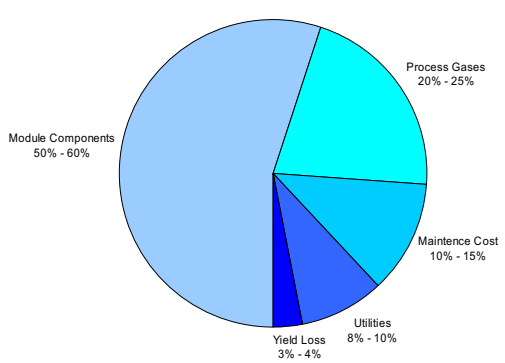
Concentration **c**: mainly Iron (Fe) is important

$$Fe_{total} = Fe^{2+} + Fe^{3+}$$

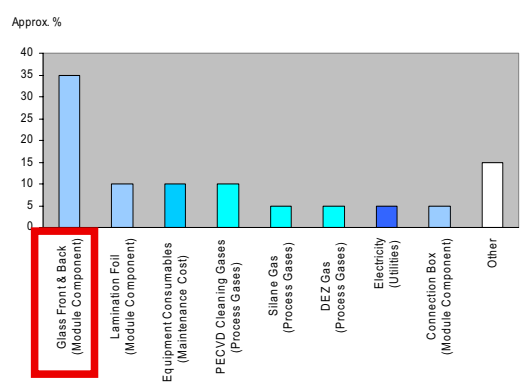
(deceisive cost factor for raw material)

Material Cost Breakdown

by Group



by biggest Cost Contributors (Pareto)



Glass the biggest contributor to Material Costs – 30%

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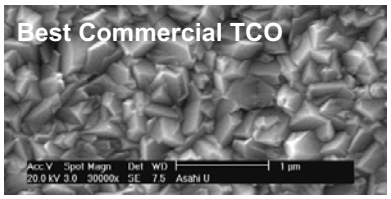
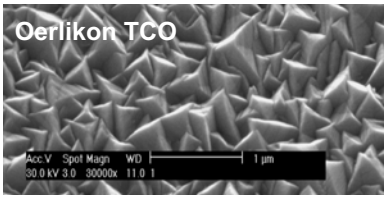
Added Value: High Quality TCO Enables Higher Efficiency

The principle of light trapping





TCO ▸ Laser ▸ PECVD ▸ Laser ▸ TCO ▸ Laser ▸ Assembly

oerlikon solar

input DOE conference Dr. I. Sinicco, A. Huegli, 27/03-08

Thin Film PV Glass: PV Manufacturer's View

Wish list:

- High transmission 400 – 1100nm: > 92.5%
- Mechanical Strength > 75N/mm2
- Waviness < 1mm/m
- Local Waviness <0.3mm/300mm
- minimized residual (thermal) stress: ensure high production yield and product reliability
- cost <6.5€/m2 by 2011
- PV glass size standards
  (width multiple of 1.3 or 1.1m & thickness 3mm)

Way to avoid bottlenecks for PV Glass:

- Utilize non-TCO glass for uninterrupted, reliable supply
- dedicated glass line for thin film PV?

œrlikon

CORNING

Science & Technology

Glass Industry Perspectives

Specialty Glass Needs for the U.S. Solar Industry
Golden, Colorado April 2, 2008

Doug Hall
Solar Portfolio Director
Strategic Growth

Glass (melting) industry segments

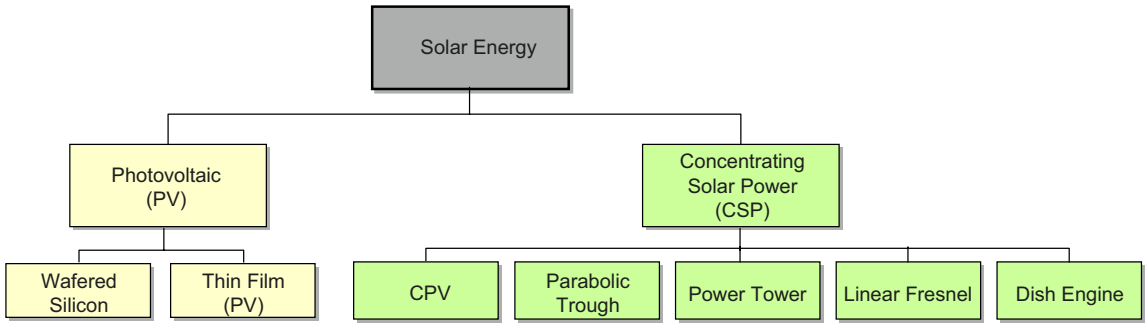
Flat Glass	Container Glass	Glass Fiber	Specialty Glass

- NSG Group (Pilkington)
- AGC Group
- Saint-Gobain
- Guardian
- PPG

70% of world capacity

Technical Glass
- Corning
- Hoya
- Schott
- ……..

Glass needs for solar energy

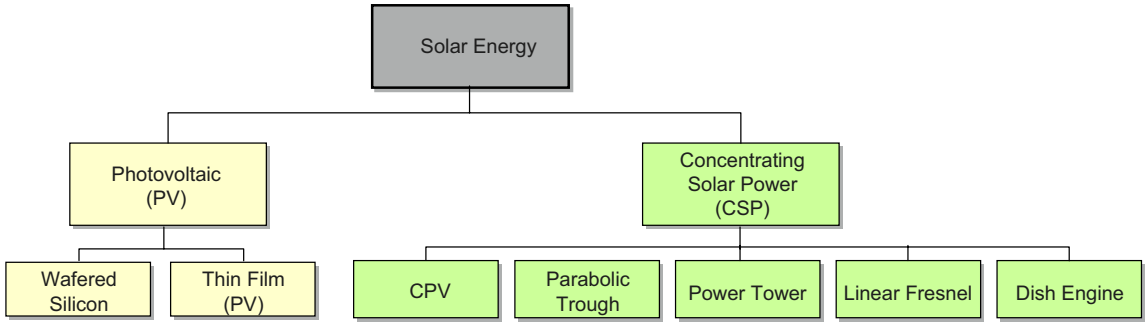


Possible products for
Specialty Glass companies

Current glass usage

Cover Glass	*Cover glass*	*Concentrating Optics*	*Mirrors*	*Mirrors*	*Mirrors*	*Mirrors*
	Sub/superstrate glass		*Borosilicate tubes*			*Tube cover glass*

Glass needs for solar energy



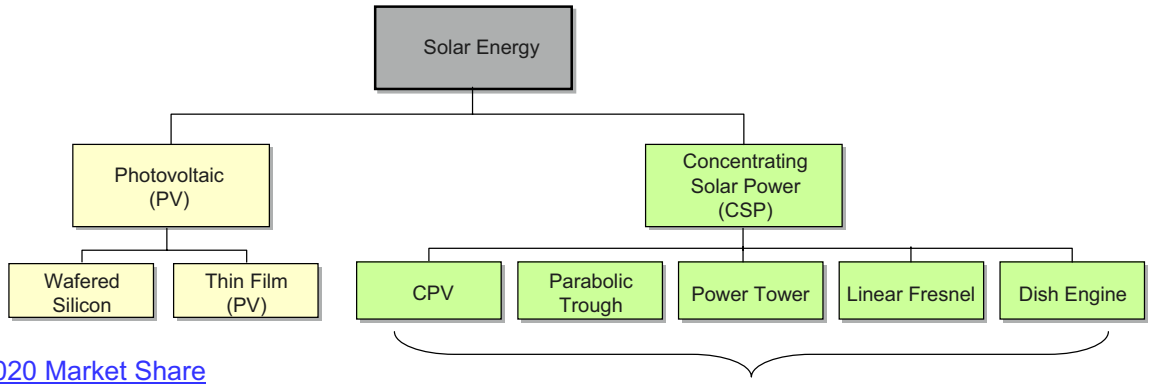
2008 Market Share
90% 5% 5%

2008 Market Size 3.5 GW

Current glass usage

Cover Glass	*Cover glass*	*Concentrating Optics*	*Mirrors*	*Mirrors*	*Mirrors*	*Mirrors*
	Sub/superstrate glass		*Borosilicate tubes*			*Tube cover glass*

Glass needs for solar energy



2020 Market Share

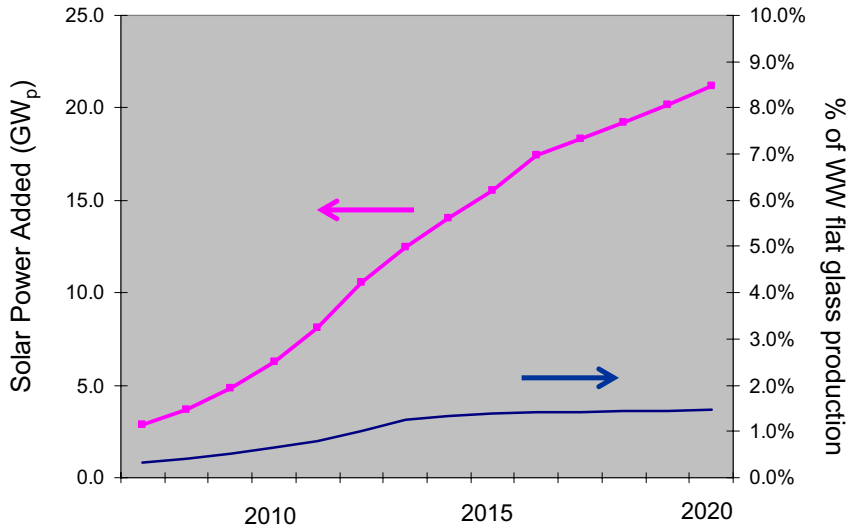
50% 25% 25%

2020 Market Size 21.2 GW_p ~ 10% of annual WW electricity capacity increase (150-200 GW/yr)

Current glass usage

Cover Glass	*Cover glass*	*Concentrating Optics*	*Mirrors*	*Mirrors*	*Mirrors*	*Mirrors*
	Sub/superstrate glass		*Borosilicate tubes*			*Tube cover glass*

Solar and Flat Glass Industries have an "impedance mismatch"



η_{solar} = 15%
t = 3.2 mm
ρ = 2.4 g-cm^{-3}
flat glass CAGR = 4%

# of tanks (500 tonne/day)	1	1	2	2	3	3	4	4	5	5	6	6	6	7

NSG GROUP

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NSG Group Flat Glass Business

NREL
Glass-Solar Workshop

Glass Industry overview

Stephen Weidner
Pilkington

April 2-3, 2008

Solar applications demanding glass

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- Solar Hot Water Systems and Conventional PV
  - Glass cover plate
    Maximum light transmittance, protection, often rolled glass

- Thin Film cells
  - Each technology has its own glass requirements, but usually requires transparent conductive coated e.g. TEC glass

- Solar Collectors
  - Mirrors with very high light transmittance

Why glass as a substrate?

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- Transparent
- Readily available
- Inexpensive (not cheap)
- TCO availability
- Fabrication is well defined
  - Cutting
  - Toughening standards – flatness is critical
  - Laminating
  - Silvering
  - Bending (CSP)

The Technologies

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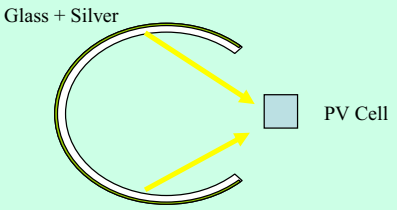
Conventional PV

Glass (Rolled)
+ Si
- Si
Foil

Solar Mirrors

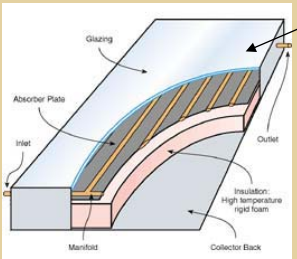


Thin Film PV

Glass (TCO)
+ junction
- junction
Glass (Toughened)
Coating
Foil

TCO Coated glass is on bottom surface for CIS

Flat Plate Water Heaters



The Technologies (Glass Requirements)

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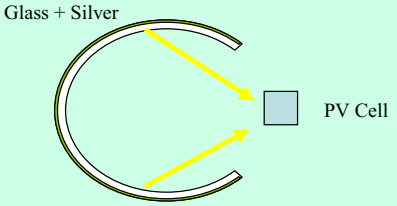
Conventional PV

Highest Light Transmittance Protective Cover Sheet (Low Iron, Rolled/AR, Toughened)

Glass (Rolled)
+ Si
- Si
Foil

Solar Mirrors



Highest Light Reflection

Thin Film PV

Highest Light Transmittance Conductive Coating (Low Iron Coated + AR)
Strong Backing Plate (Toughened)

Glass (TCO)
+ junction
- junction
Glass (Toughened)
Coating
Foil

TCO Coated glass is on bottom surface for CIS

Flat Plate Water Heaters

Highest Light Transmittance Protective Cover Sheet (Low Iron, Rolled/AR, Toughened)

TCO – Transparent Conductive Oxide

Glass substrates for PV

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- Clear or Low-Fe soda lime float
- Clear or Low-Fe soda lime patterned
  - Crystalline Silicon
- Clear or Low-Fe float w/ TCO
  - Thin film
- Borofloat
  - Higher T_{vis}
  - Low coefficient of expansion
  - Very expensive

Substrate Types

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1. Solar Hot Water Systems and Conventional PV
   - Glass cover plate
     - Maximum light transmission (AR, low Fe, diffuse pattern)
     - Withstand hail storms (toughened glass)
     - Rolled tends to be preferred over float at present (ER, WSW, Spring)
2. Thin Film cells
   - Each technology has its own requirements
     - a-Si: Rough TEC, ideally on low Fe and with AR on other side
     - CdTe: Smoother TEC ideally with buffer layer on low Fe with AR
     - CIS: Sputtered Mo coating, possibly on barrier layer. The back electrode can be on any glass (including waste transition glass)
3. Solar Collectors
   - Mirrors
     - maximum reflection
     - Low Fe glass to minimise absorption
     - Excellent durability for long life outdoors (paints and sealants)
     - Opportunity for low maintenance coating #1 surface

Solar Collectors

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- Mirrors
  - Maximum reflection
  - Low Fe glass to minimize absorption
  - Excellent durability for long outdoor life
  - Cleaning issues
- 4mm &/or 5mm Low Fe for troughs
- 1mm Low Fe for dishes
- Repetitive sizes
- Bent glass

PV Devices **(CIGS)**

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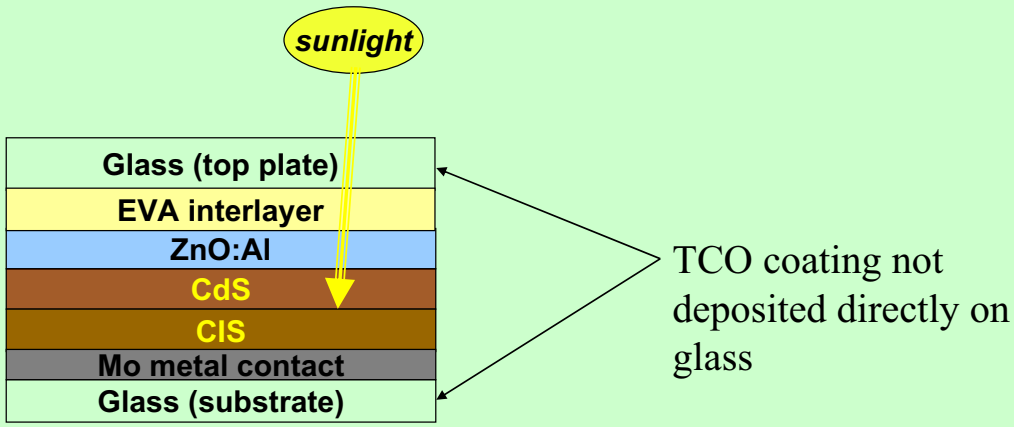
CIGS = Copper Indium Gallium diSelenide



PV Devices (*a*-Si and CdTe)

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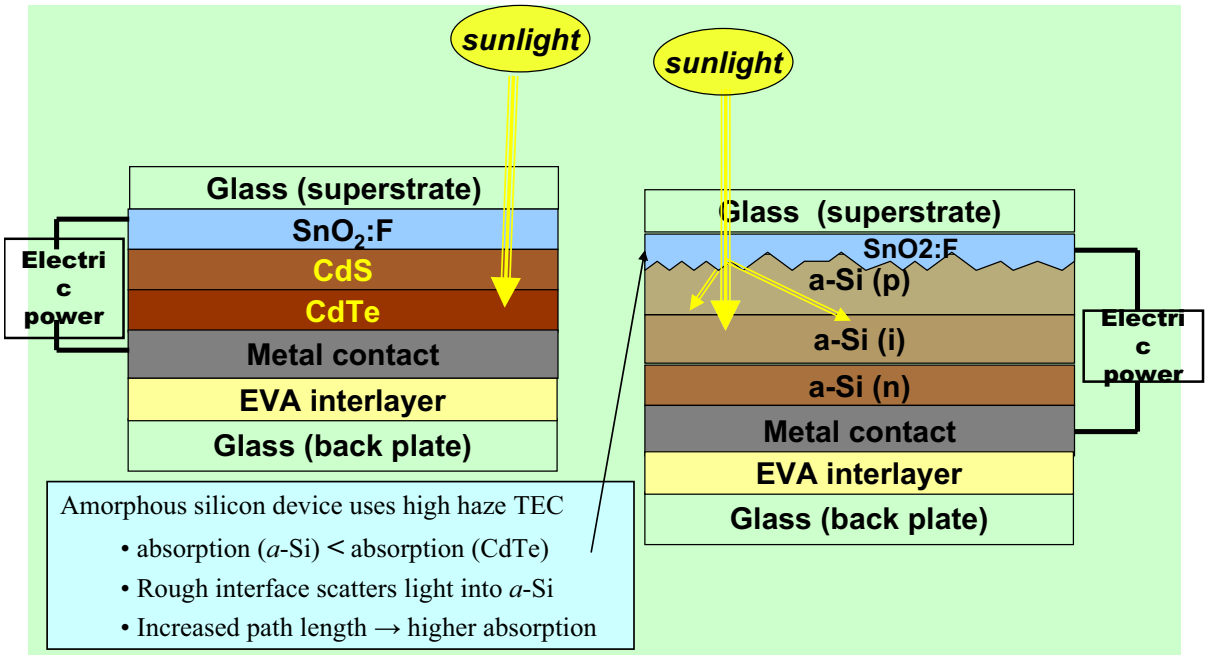

Amorphous silicon device uses high haze TEC

- absorption (*a*-Si) < absorption (CdTe)
- Rough interface scatters light into *a*-Si
- Increased path length → higher absorption

TCO Requirements: Haze

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- **Haze**
  - Thin film Si: high is good (10-15%)
    - Haze = diffusely transmitted light
    - Light is scattered by surface roughness
    - Scattered light increases absorption in PV layers
  - CdTe: as low as possible
    - CdTe has high absorption coefficient, so no need to increase path length
    - Roughness can produce electrical shorts
    - Smoother TCO enables thinner CdS layer

TCO Requirements: Other

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- Compatibility with downstream processes
  - Thin film Si deposition occurs at moderate temperature in a hydrogen plasma (~200-250°C)
  - CdTe deposition at high temperature (~600°C) in vacuum or at atmospheric pressure
- Long-term Durability
  - Must be unaffected by damp-heat tests

PV Capacity / Glass Production

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	***a*-Si**	**CdTe**	**Hybrid Si**
PV Efficiency*(%)	6	9	12
W / ft^2 (or MW / mil.ft^2)	5.6	8.3	11.1
kW / ton†	6.8	10.1	13.5
Annual float capacity† (GW)	0.50	0.75	1.0

***Average solar intensity = 1000 W / m^2.**

†Assumes 3.2mm glass thickness. Coat 50% of time.

Float Glass

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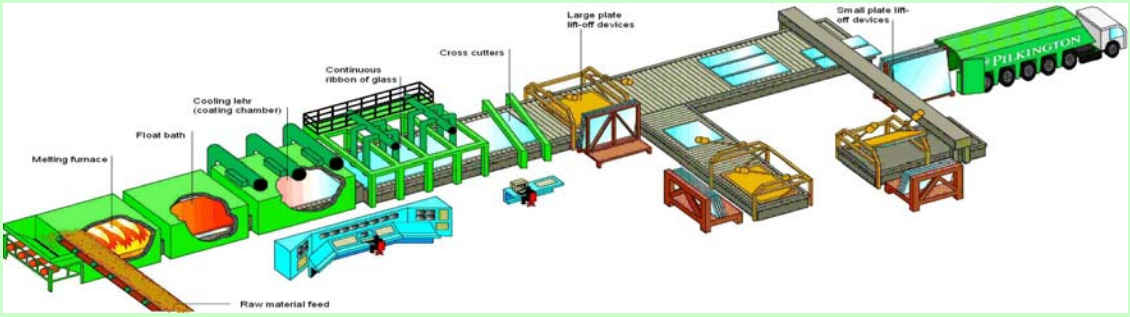

- Capital intensive ($120-$200 million)
- 2 year build cycle
- 24/7 operating cycle
- Size – 130-144" ribbon width

Glass – NA Macro view

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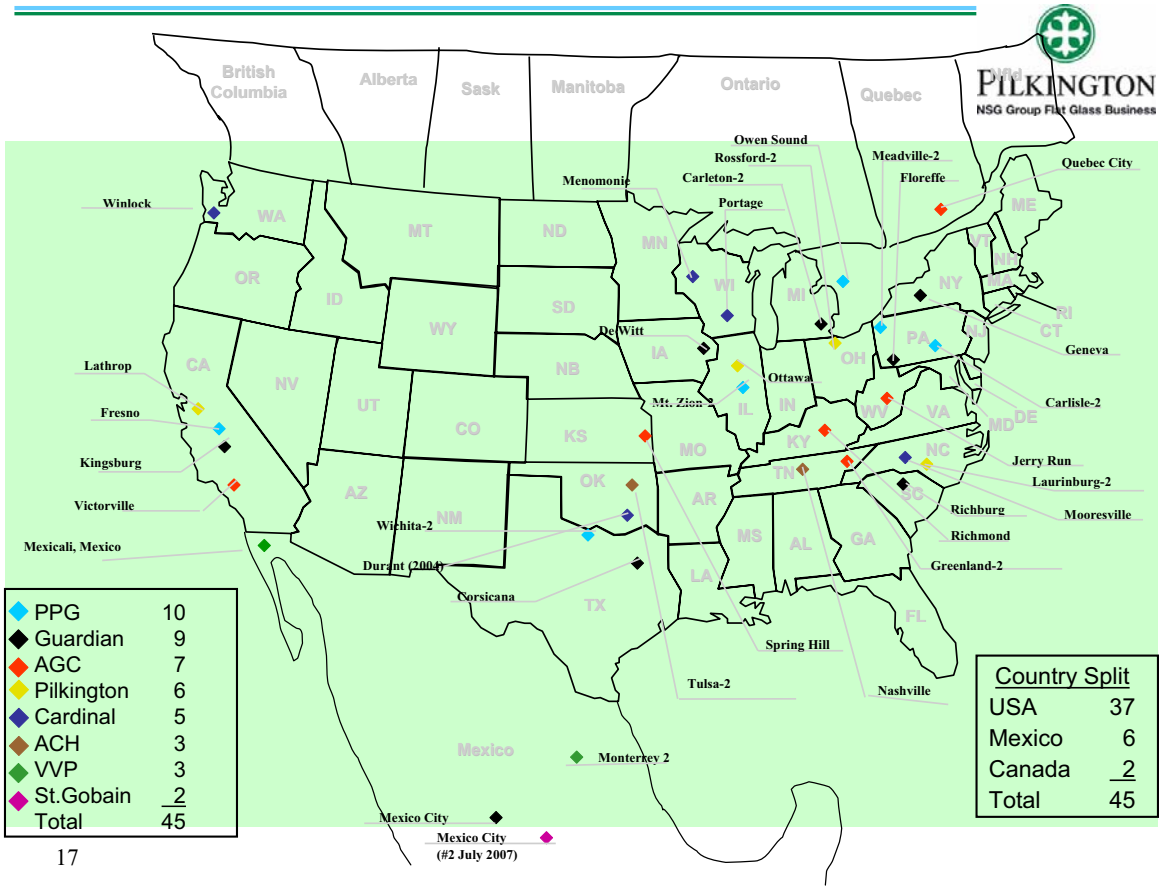
- Energy intensive
  - ➔Same driver increasing demand for PV also increases costs of manufacturing
- Logistics
  - – Transportation can be 10-15% of delivered costs
    - ➔Proximity of manufacturing is low tech opportunity to eliminate significant cost burdens



Glass – NA Macro view

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- TCO
  - availability
  - Cost
  - "Tuneability"
- Low iron sand
  - Availability
  - Cost

Glass fabrication requirements

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- Edge-working
- Laminated module
  - EVA interlayer used to prevent water ingression
- Drilled holes
  - Electrical connections
- Toughened/Tempered (Backplate and /or TCO)
  - Flat backplate →Low stress in laminate
- Silvering (concentrator reflectors)

Future

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- Need specifications for the industry to follow
  - Currently customer specific specs
    - Toughening
      - Flatness
    - T_{vis}
    - Laminating
- Equipment to facilitate measurements

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NSG Group Flat Glass Business

NSG
GROUP

Workshop Process and Logistics

Specialty Glass Needs for the U.S. Solar Industry Workshop

April 2-3, 2008
Golden, Colorado

Keith Jamison
Ross Brindle
Pamela de los Reyes

ENERGETICS

Agenda

- Two Sets of Concurrent Breakouts This Afternoon
  - Session 1: 1:30-3:10 PM
  - Session 2: 3:30-5:00 PM
- Please Join Us for Light Snacks and Cash Bar at 5:30 in the American Grill
- Thursday Morning: Summary Session
  - Review Breakout Session Results
  - Discussion and Next Steps

Breakout Sessions

- 1:30 – 3:10
  - Photovoltaics (Crystalline Silicon) - Salon A&B
  - Coatings - Salon D
- 3:30 – 5:00
  - Photovoltaics (Thin Films) - Salon A&B
  - Concentrating Solar Power - Salon D
- Attend the Two Sessions That Best Fit Your Interests

Breakout Sessions

- Identify and Discuss Technical Issues
- Identify and Discuss Market Issues
- Determine Priorities

Washington Update

Solar Glass Workshop
April 2, 2008

Scott Hennessey
Manager, Climate and Energy Markets

Overview

- Introduction to SEIA
- The Solar Market
  - Global
  - U.S. Market
- The Washington Update
  - ITC Extension
  - Climate Change Legislation
- SEIA Conferences
- Conclusion

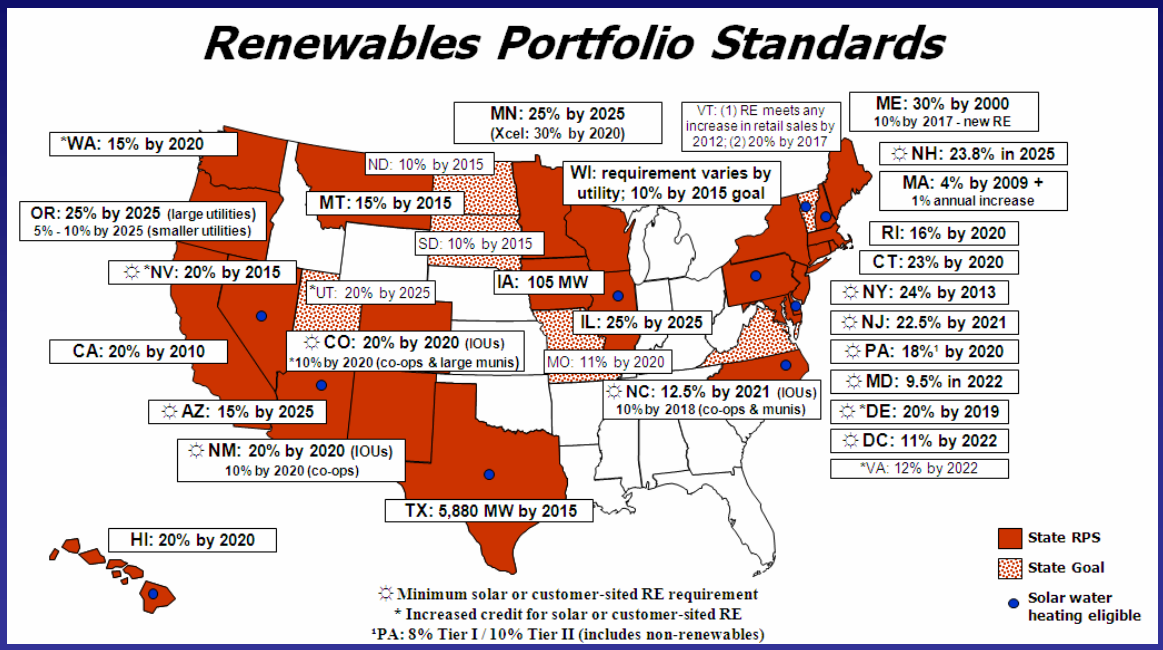
Introduction to SEIA

- National trade association for solar companies
  - » Over 550 member companies
  - » Members include all solar technologies
  - » Represent over 20,000 people employed by solar
  - » 14 state and regional chapters
- Mission

  To make solar energy a mainstream and significant energy source by expanding markets, strengthening the industry and educating the public on the benefits of solar energy
- Strategic Objectives
  - » Expand Markets
  - » Strengthen R&D
  - » Remove Market Barriers
  - » Improve Education and Outreach
- Members include manufacturers, installers, end users, financial and legal entities

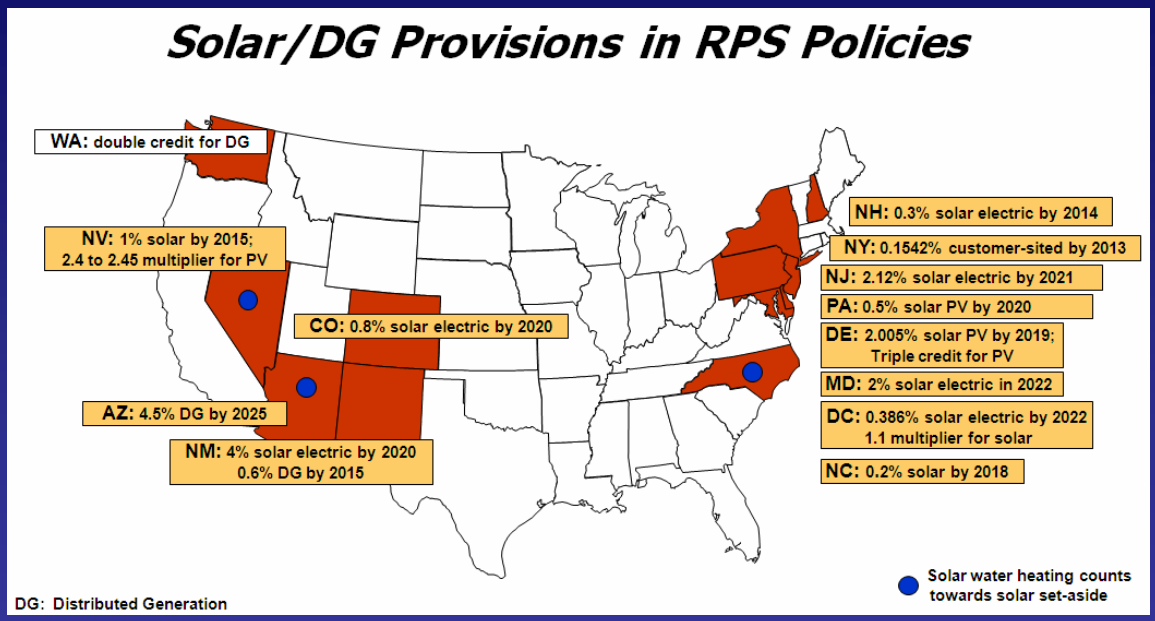
Creating a Solar Market in the US

Existing State RPS Requirements: 25 States and Washington D.C.



Source: DSIRE, www.dsireusa.org, March 2008

Solar/DG Provisions in RPS Policies 12 States and Washington D.C.



Source: DSIRE, www.dsireusa.org, March 2008

Why Solar? Why Now?

- Energy Independence
  - Displaces natural gas
  - Endless supply
- Energy Security
  - Stabilizes grid by reducing peak power demand
- Global Warming
- Electricity Prices
- We are a High Tech Society

Keeping the Lights On - 2007

Source GE Solar

Keeping the Lights On - 2030

Source GE Solar

The Washington Update

ITC - Recap

- Top Priority
  - 2008 Strategic Plan: long-term extension of the commercial and residential ITC is top priority
- SEIA Goals
  - Quick enactment of our "best outcome"
  - 8-year extension of the 30% business ITC
  - 6-year extension of the 30% residential ITC
  - Strike existing $2,000 limit on residential (except for SHW)
  - Alternative Minimum Tax (AMT) relief
  - Elimination of the public utility exception
- Broad bi-partisan and bicameral support and knowledge of our desired "Best Outcome"

Update

- Activities since December
  - 2007 Energy Bill passed with strong solar provisions but no tax title
  - Hundreds of Hill meetings
  - Company-to-Member writing & calling campaigns
  - Influential "grasstops" support from governors, Mayors, PUC's
  - Partnership with environmental community
    - ITC/PTC top energy priority
  - Dramatically expanded PAC contributions

Update

- Close Coordination with other Renewable Associations
  - Press event
  - Hill briefings
  - Hill reception
- Developing Broad Coalition of Support
  - Best Buy, Home Depot, Macy's, Target, Trane
  - Johnson & Johnson, Wall-Mart, Safeway
  - United Steelworkers, Moveon.org
  - Edison Electric Institute
  - NAHB, Realtors, Real Estate Roundtable, AIA
  - Dozens of Governors, NGA, WGA
  - Sierra Club, NRDC, Greenpeace, Audubon, UCS, National Wildlife Fund

Q-2 Campaign

Three options

- Cantwell/Ensign – next week ($5.8 billion)
  - 8 year ITC extension
  - Doubling of residential cap
  - AMT relief
  - Elimination of the utility exception
  - No payfors
- HR 5351 – end of April ($18 billion)
  - 8/6 year ITC extension
  - Doubling or residential cap
  - AMT relief
  - Elimination of the utility exception
  - Paid for by repeal of oil incentives
- "Back-stop" simple extender summer or later
  - 1-2 year extension, no modifications
- All three legislative options being pursued

Q-2 Campaign

1. Grassroots Pressure
   - Solar community: SEIA, ASES, State SEIA Chapters, Solar Nation, Vote Solar, Renewable Energy World
   - Environmental community: Broad & growing
   - Member action-alerts
     - In-state meetings, letters, calls
     - Phone banking
     - Paid media – Sierra, others
     - Earned media
   - We need your help!

Q-2 Campaign

Direct Lobbying to Hill

- SEIA, GAC members, SEIA Members, Coalition members, Washington Council Ernst & Young
- Large solar end-users (Best Buy, Wal-Mart)
- Other renewables (AWEA, NHPA)
- Other trade associations (e.g., AIA, NHBA, NGA)
- Environmental community (NRDC, Sierra, UCS)
- Utilities (APS, FP&L, PG&E, Xcel)
- Financial community (GS, Piper)
- Attendance at fundraisers
- State government, PUC support

Q-2 Campaign

Earned Media / Paid Media

- SEIA PR Committee leading effort
- Retention of specialty media firm
- Press briefings, outreach
- Advertorial in Politico (can be see at http://www.politico.com/seia)
- Opinion editorials in key target markets
- Targeted editorial board memos
- Targeted editorial board visits
- New media engagement, e.g. blogs
- Radio ads in select markets in run-up to key votes, e.g. stimulus effort by Sierra in 16 states
- Banner ads

Q-2 Campaign – SEIA PAC

Fundraising

- Raised $57k in ’07 (only 43 donors)
- Holding $25k cash on hand

Giving

- Held fundraisers for Ensign, Salazar
- PAC memberships in DSCC, DCCC, NRSC, NRCC
- Achieved multi-candidate committee status
- April 6th event for Rep. Camp at CA winery
- Future fundraisers for Reps. Pelosi, Giffords
- Attend party committee events 2-3x weekly
- Focus on W&M / Finance members & leadership

Future Fundraising

- Nationals game at July board meeting ($5k pp)
- Solar Power 2008 reception
- Increased participation critical
- $100,000 – 2008 annual goal must be met
- PAC – to – PAC transfers must begin

Q-2 Campaign

- Senate Obstacles Remain:
  - Opposition premised on "pay-fors"
  - Senate R's have broke all previous filibuster records
  - White House determined to stop democrats – veto threats now routine (150 and counting…)
  - Veto-dynamics very difficult to influence
- Goal:
  - Avoid Republican filibuster and veto threat on energy tax package through:
    - Bi-partisan compromise – Cantwell/Ensign Initiative

Back-up Plan: Extenders Legislation

- Short-term extension of existing law to insure against a lapse of ITC
- Well positioned for an extension:
  - ITC included in Senate 2008 economic stimulus package
  - Currently working on extender strategy
    - Finalize language
    - Coordinate with Pelosi, Reid, Baucus, Rangel & staff
  - Summer or later
  - Straight extension of current law likely, modifications strongly disfavored
- Will seek modifications and multi-year extension
- PAC mobilization crucial

Carbon Policy & Solar Energy

Why Should Solar Care?

- Solar energy production is carbon-free
- Federal / state incentives will expire
- Carbon controls can be optimized to maximize solar deployment and generation
- Carbon policy can recognize and monetize solar's carbon-free attributes
- Carbon policy can create a collateral "income stream" that surpasses current government support policies
- Carbon policy is happening now and solar is largely not at the table

Carbon Legislation Strategy

- SEIA Global Warming Task Force:
  - Quickly engage in debate
  - Seek equal treatment / equivalency with fossil
  - Exercise leadership in coordinating
    - Industry activity: pan-renewable caucus
    - Coalition building: enviro & efficiency groups
    - Information sharing
    - State, regional and stakeholder engagement
  - Develop talking points and fact sheets
  - Focus on key decision points that impact solar
  - Draft & introduce ***Solar Climate Response Act***

Carbon – Strategy, continued

- Develop detailed solar industry positions on:
  - Need for output-based standards
  - Inclusion in allowance allocation
  - Eligibility for auction proceeds, direct & indirect
  - Eligibility for new entrant set-aside allowances
  - Secure broad and consistent definition of solar
  - Inclusion of small energy systems
  - Reward public & private investments in solar technology and avoided emissions
  - Condition eligibility for allowances and auction proceeds on adoption of solar best practices
  - Non-pre-emption of more progressive state laws, programs

Solar Power 2008

- Network
  - America's largest business to business event
- Learn
  - One stop shop for the latest products, technological developments and market opportunities
- Expand your Business
  - Develop lucrative business contacts and partnerships
- San Diego, California
  - October 13-16

PV America 2009

- Mission:
  - To produce a vertically integrated tradeshow and conference on photovoltaics, designed to engage industry professionals and a wider spectrum of the population in expanding the U.S. solar energy market, ***with all show profits reinvested back into state and federal advocacy***.
  - The show will locate in emerging state and regional markets as identified by the PV industry.
- June, 2009 - Philadelphia

Moscone Center - SF CA - 675 kW

Source: SunPower

www.seia.org

FedEx - Oakland Hub, CA – 904 kW

Source: SunPower

www.seia.org

Lowe's - Union City, CA – 690 kW

2.4 MW on 4 stores

Source: SunPower

Bavaria Solar Park - 10 MW

Source: SunPower

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