

2008 Solar Annual Review Meeting

**Session: OPV, Sensitized, Seed
Company or Organization: NREL
Funding Opportunity: PV Conversion Technologies**

Dr. Arthur J. Frank
arthur_frank@nrel.gov
Ph: 303-384-6262



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Office of Energy Efficiency & Renewable Energy*



Innovation for Our Energy Future

Budget and Solar America Initiative Alignment



<i>NREL Sensitized Cells</i>			
Project Beginning Date	FY07 Budget	FY08 Budget	Total Budget
10/1/06	\$ 150k	\$ 698k	\$848k

- The **NREL Sensitized Solar Cell (SSC) Core Program** supports the Solar America Initiative by:
 - Targeting New Devices & Processes for commercialization by 2015 that are:
 - **Less expensive**
 - **More efficient**
 - **Highly reliable**
 - **Environmentally benign**
 - Collaborating with DOE OS/BES to conduct basic research targeting breakthroughs in key areas, such as ultra-high efficiency and/or ultra-low cost materials and devices

Budget and Solar America Initiative Alignment (cont'd)



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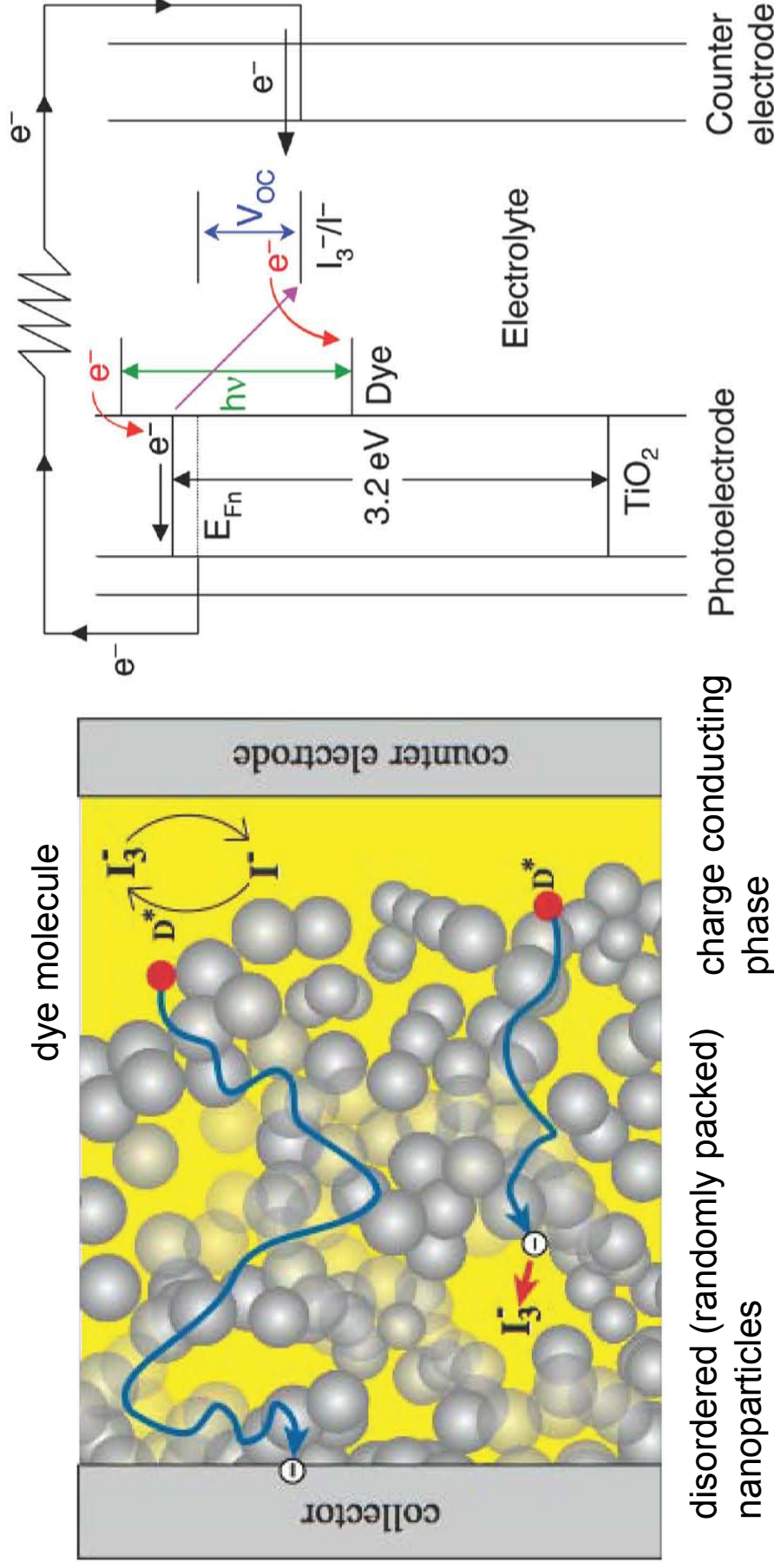
NREL SSC Program Research Efforts

- Develop prototype SSC devices and fabrication approaches for:
 - Polycrystalline metal chalcogenides and oxides
 - Nanocrystalline materials
 - Sensitized materials
 - Materials incorporating low-dimensional quantum structures
- Projects on SSC devices in the above areas address:
 - Material synthesis and processing concepts
 - Efficient and low-cost manufacturing techniques (unfunded FY08)
 - Materials and device characterization, including interface and contact studies (unfunded FY08)

Project Overview: Sensitized Solar Cells (SSCs)



Cell Operation: Traditional Dye-Sensitized Solar Cell



- Sensitized nanoparticle film sandwiched between conducting glass or plastic sheets
- Light absorption & charge separation occur at interface between two charge-conducting interpenetrating materials

Project Overview: Sensitized Solar Cells (SSCs)



- Technology/Industry Current Status

- **Sharp**

- Module efficiency 6.32% (26.5 cm² area; 2005)
 - Certified cell efficiency 11.1% (0.2 cm² area; 2006)



Courtesy of Dr. L. Han, Sharp Corp.

- **G24i**

- 1st commercial manufacturing plant (200 MW capacity by 2008)
 - Roll-to-roll technology
 - Nonvolatile electrolyte

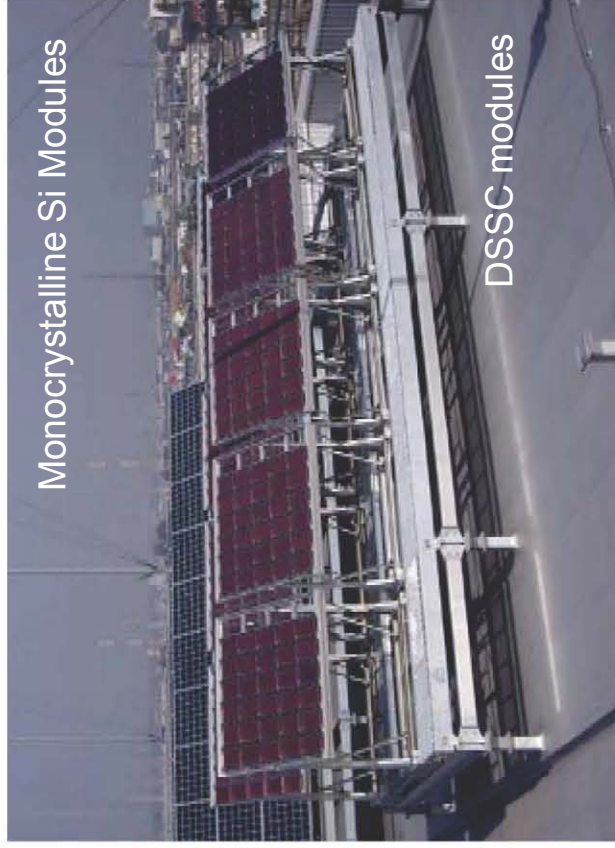


Project Overview: Sensitized Solar Cells (SSCs)



- Technology/Industry Current Status (cont'd)
- **Toyota/Aisin Seiki**
 - Modules undergoing multiyear outdoor testing
 - Building-integrated solar panels

Outdoor testing of DSSC and Si modules



Monocrystalline Si Modules

DSSC modules

Photo Aisin Seiki

Wall-integrated panel from
Toyota Dream House (PAPI)

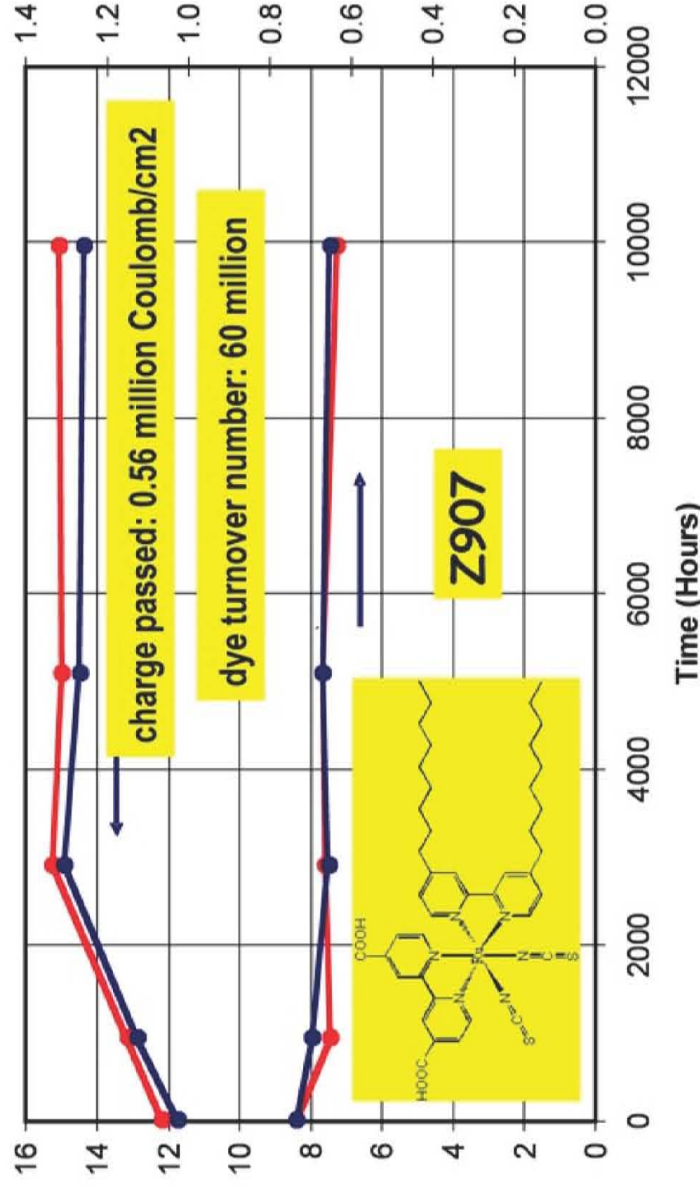


Project Overview: Sensitized Solar Cells (SSCs)

- Technology/Industry Current Status (cont'd)
- DyeSol (Australia)

The Z907 sensitizer sustains 60 million turnovers in full sunlight without decline in photocurrent generation

Short Circuit Current and Open Circuit Voltage vs. Time



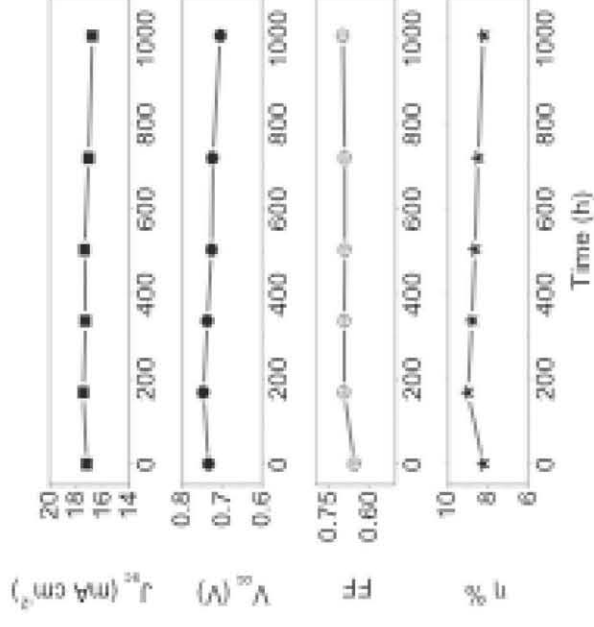
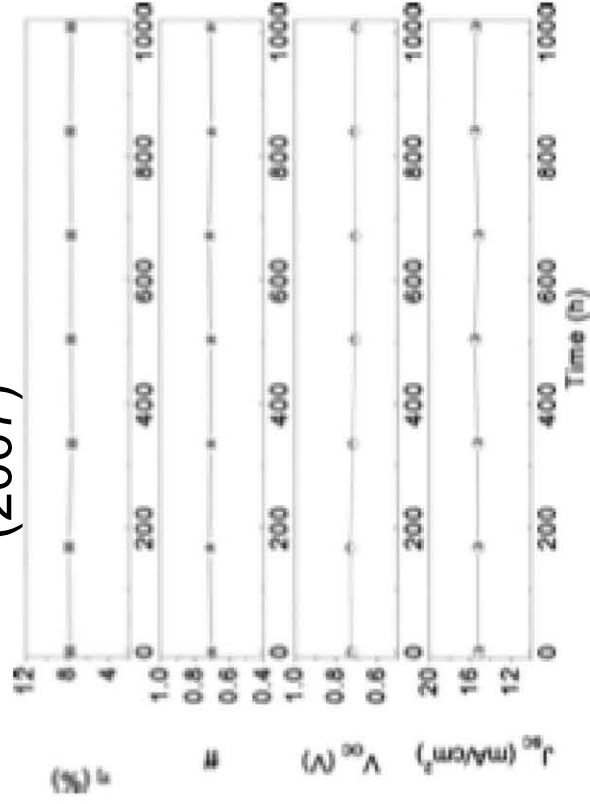
Courtesy: Dr.Ravi K. Harikisun Dyesol inc, Australia



Project Overview: Sensitized Solar Cells (SSCs)



- Technology/Industry Current Status (cont'd)
 - **Michael Grätzel (EPFL)**
 - $\geq 8\%$ cell efficiency with $< 5\%$ degradation at 80°C in the dark for 1000 h (2005)
 - $\geq 8\%$ cell efficiency with $< 5\%$ degradation at 60°C under continuous light soaking (2007)



P. Wang et al. *Appl. Phys. Lett.* **2005**, 86, 123508

D. Kuang et al. *Adv. Mater.* **2007**, 19, 1133v

Project Overview: Sensitized Solar Cells (SSCs)

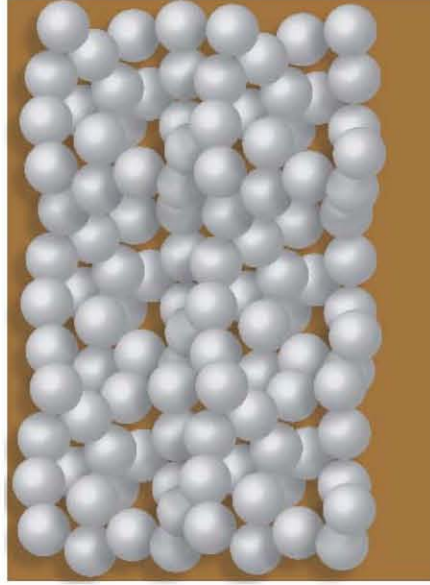


- NREL Research Activities
 - Foundational design, development & testing of materials and cell configurations for improved stability and performance
 - **(1) Sensitizers** (unfunded FY08)
 - **(2) Charge-Conducting Phases**
 - **(3A) Photoelectrode Architecture**
 - **(3B) Characterization and Stability Testing of new materials and cells** (collaboration with NREL Materials & Characterization Group)

Project Overview: Sensitized Solar Cells (SSCs)



- Research Activity 2: Design/Develop Improved Charge-Conducting Phases
 - Extend range of SSC thermal stability to -35°C to $+85^{\circ}\text{C}$ by investigating new ionic liquid and solid-state charge-conducting phases
 - Solid-state phases (e.g., PEDOT, P3HT, p-type CuI, CuSCN)
 - Manipulate ionic liquid viscosity by changing salt composition
 - Molecular voltage enhances (e.g., guanidinium) (BES collaboration)
 - Transparent charge-conducting plastic (BES collaboration)



e.g., PEDOT, P3HT, p-CuI, CuSCN

Liquid	Solid
-90°C	$+250^{\circ}\text{C}$



L. Moens, unpublished

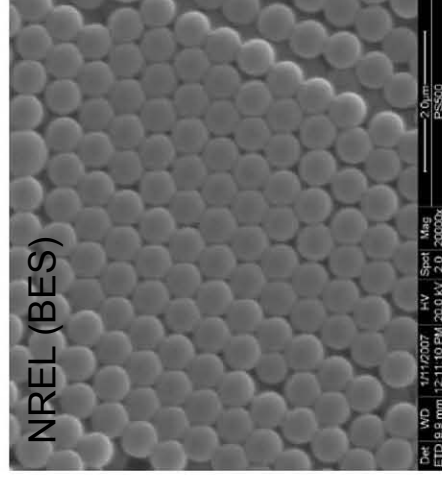
Project Overview: Sensitized Solar Cells (SSCs)



- Research Activity 3: Photoelectrode Architecture and Device Assembly & Characterization
 - Develop ordered nanomaterials with improved electrical/optical properties
 - Prepare ordered photoelectrodes (e.g., NTs, NWs, and 3D porous films)
 - Assemble laboratory devices
 - Materials characterization by M&C (Analytical Microscopy & Surface Analysis)
 - Assess new materials and cell configurations using accelerated aging tests (collaboration with NREL TERA team)

Polystyrene bead template

TiO₂ NT array



Templating routes to ordered nanomaterials

Improved light-harvesting & charge-collection using ordered nanomaterials

Project Alignment with Technology Roadmap



What needs in the Technology Roadmap are your project responding to?

What approaches are you using to address those needs?

Roadmap Need	Significance	Research Activity/Approaches
Conduct fundamental R&D relating material effects w/ their impact on device physics/chemical processes to the solar cell efficiency & stability. Identify the most promising cell materials and configurations (e.g., quantum dot, molecular dye, or inorganic sensitizers; conducting phase; and nanostructured architecture) for highest devices efficiency and durability	Understanding the fundamentals is the most efficient pathway to realizing the real potential of this technology.	RA 2&3: Collaborate with OS/BES SSC project to study: (a) charge-conducting phases (e.g., ionic liquids & inorganic conductors) & (b) ordered photoelectrodes (e.g., NTs, NWs, 3D porous films) for improved stability and performance over traditional device components (e.g., conducting phase & disordered nanoparticle films)
Develop next-generation sensitizers, nanostructured architectures, and charge-conducting phases	Improve efficiency and stability.	RA 2: Develop synthetic methods for preparing charge-conducting phases RA 3: Fabricate new ordered nanostructured architectures
Investigate materials for sealing cells containing liquid, quasi-solid, or solid conducting phases	Improve cell stability.	RA 3: Conduct accelerated aging tests to investigate effects of (a) new charge-conducting phases and photoelectrode architectures and (b) cell sealing procedures and packaging materials on device stability (in collaboration with NREL & TERA team)

Project Update: Sensitized Solar Cells (SSCs)

Past

Future



Planned work since last Program Review		Status
(1) Developed synthetic methodology for preparing TiO ₂ nanoparticles with controlled particle size and shape; (2) Showed that oriented TiO ₂ nanotube arrays markedly enhance charge-collection & light-harvesting efficiencies		Jun-07
(1) Identified cause of bundle & crack formation in oriented TiO ₂ nanotube arrays; (2) Developed a methodology to prevent such disorder; (3) Demonstrated improved photocurrent density and solar conversion efficiency in SSCs incorporating the more highly ordered electrodes		Jan-08
Maximize solar conversion efficiency for volatile liquid electrolyte SSC devices		Redirected efforts
Research Activity 1: Design/Develop Improved Sensitizers		Delayed until FY09
(1) Develop ordered electrode architectures with enhanced electrical and optical properties; (2) Preliminary device stability assessments in traditional TiO ₂ nanoparticle SSCs using stable dyes and electrolytes		Anticipated Sept 2008

Obstacle Discussion: Sensitized Solar Cells (SSCs)



- Barriers encountered or anticipated that may inhibit success of SSC program
 - Enhance sensitizer light-harvesting & injection properties
 - Extend device operating temperature range
 - Reduce carrier loss via recombination (esp., for solid-state devices)
 - Develop high-transmittance, low-cost, highly conducting substrates
 - Investigate materials for sealing & encapsulating cells
 - Evaluate module packaging schemes & interconnects
 - Modify manufacturing processes for low-temperature applications (e.g., plastic conducting substrates)