Bringing PV to Market
Want to make a Federal case of It?

An summary of the U.S. DOE and NREL support for growth of the PV industry

Presented to the Silicon Valley PV Society

John P. Benner
12/10/2008
Key Messages

• The Solar Energy Technology Program is focused on reducing the cost of solar energy to grid parity by 2015 working through a broad array of stakeholders.

• SETP funds a diversified and growing portfolio of photovoltaic and concentrated solar power technologies through both the national labs and directly to industry.

• Access to the expertise and facilities of the national labs can accelerate development.

• System Integration and Market Transformation are key sub-programs that address issues related to commercialization and wide-spread penetration of solar technology.

• The main challenge for the SETP going forward will be to adjust to dynamic industry conditions and changes in technology and market requirements to cost effectively reach program goals.
Presentation Outline

Review of DOE's Solar Electric Technology Program:
Highlights of NREL Research:
Capabilities of the Process Development and Integration Laboratory
Discussion of Program Structure and opportunities
The goal of the SAI is to reduce solar electricity to grid parity by 2015.
Policy analysis example: PV grid-parity analysis

2015 residential without incentives and moderate increase in electricity prices

- Attractive in about 250 of 1,000 largest utilities, which provide ~37% of U.S. residential electricity sales.
- 85% of sales (in nearly 870 utilities) are projected to have a price difference of less than 5 ¢/kWh.
Funding for the SETP has been increased in response to the Solar America Initiative Initiative.

*President's request for FY09 was $150M, current House mark is $220M, current Senate mark is $229M.
SETP Funding Breakout to Labs, Universities and Industry

Solar Program Funding by Recipient
The SETP is a critical part of the total funding available for solar technologies

**DOE Funding Advantages**

1. Non-dilutive to company financing
2. Maximum IP ownership
3. Preferential access to National Lab expertise and facilities

**DOE Funding Criteria**

- Impact Factor = ($/W savings) X (projected sales)
- Value = Impact ($) / DOE funding
- Uniqueness - risk to necessitate DOE funding
- Feasibility - likelihood of success
DOE’s Solar Energy Technologies Program (SETP) works along the whole Research, Development, and Deployment pipeline.
Solar America Board for Codes and Standards

Solar ABC

National Standards Coordination

Product Safety
Reconcile UL1703/IEC61730,
UL 1741/IEC32109

Interconnection,
Net Metering
Create Model Local Codes

Building and
Electrical Codes
Article 690 Guidance

National Standards
Coordination
Revise IEEE 1547

International Standards
Coordination
Monitor International
Codes and Standards;
Centralize U.S. participation

5-yr Award = $4,200,000
State Technical Outreach

Performers: National Conference of State Legislatures (NCSL)
Clean Energy Group (CEG)
National Association of Regulatory Utility Commissioners (NARUC)
Interstate Renewable Energy Council (IREC)

Activity Objectives:
- Build relationships with State decision-makers responsible for enacting policies, programs, and plans that are key drivers for solar technology market transformation.
- Provide state policymakers with best practice and current data about solar technology, so they can make informed solar policy decisions.

3-yr and 5-yr Awards = $7,000,000
Utility Technical Outreach

Performer: Solar Electric Power Association

Activity Objective:

- Deliver key technical and informational assistance to utilities to promote their acceptance and use of solar.

SEPA will assist their 175 member organizations and non-member utilities in the following ways:

- Develop new business cases for solar
- Provide current information on solar technologies
- Disseminate innovative solar program design information to utilities

3-yr Award = $990,000
Solar America Cities

www.SolarAmericaCities.org

Activity Objective
• Partner with cities committed to achieving a sustainable solar infrastructure through a comprehensive, city-wide approach. Cities serve as living laboratories to test methods to overcome barriers to solar commercialization.

Overview
• The 25 Solar America Cities receive $200,000 plus $250,000 in technical assistance from National Labs and other experts to:
  • Integrate solar technologies into city energy planning, zoning and facilities
  • Streamline city-level regulations and practices that affect solar adoption by residents and local businesses (e.g. permitting, inspections, local codes)
  • Promote solar technology among residents and local businesses (e.g., outreach, curriculum development and/or implementation, incentive programs, etc.)

New Activities
• Issue crosscutting studies and technical papers:
  • Interconnection in area/spot networks
  • Solar mapping
  • Creative financing
  • Rate structures

• Host 2nd Solar America Cities Annual Meeting in April 2009 in San Antonio
Distributed PV System Technology
Solar Energy Grid Integration Systems (SEGIS)
Phase I awards total ~$3M

- SEGIS is a “System” development program focused on new requirements for interconnecting PV to the electrical grid.
- SEGIS is the intelligent hardware that strengthens the ties of Smart Grids, Microgrids, PV, and other Distributed Generation.
Current status of SAI R&D solicitations for companies and universities

**Material & Device Concepts**

- **Solar Energy Utilization (BES) First Round**
  - Award duration: 3 years
  - 25 awards
  - Award amount: $0.15-$1.5 M/yr

- **Solar Energy Utilization (BES) Second Round**
  - Award duration: 3 years
  - Award amount: $0.15-$1.5 M/yr

- **Energy Frontier Research Centers (BES)**
  - Award duration: 5 years
  - Award amount: $2-$5 M/yr

**Device & Process Proof of Concept**

- **Next Generation PV Device and Process**
  - Award duration: 3 years
  - 25 awards
  - Total: Up to $21.7 M over 3 years

- **PV Incubators First Round**
  - Award duration: 18 months
  - 10 awards
  - Total: Up to $27 M over 18 months

- **Technology Pathway Partnerships**
  - Award duration: 3 years
  - 11 awards
  - Total: Up to $168 M over 3 years

**Component Prototype & Pilot Scale Production**

- **Solar Energy Grid Integration Systems (SEGIS) Program**
  - Award duration: 3 years
  - Award amount: Up to $6.25 M

- **University Product and Process Development Support**
  - Award duration: 3 years
  - 11 awards
  - Total: Up to $13.7 M over 3 years

- **PV Incubators Second Round**
  - Award duration: 18 months
  - Award amount: Up to $2-3 M

- **CSP FOA 2007**
  - Award duration: 3 years
  - Award amount: Up to $13 M

- **CSP Thermal Storage**
  - Award duration: 3 years
  - Award amount: Up to $6.25 M

- **Supply Chain**
  - Award duration: 1-3 years
  - Award amount: $0.3-2 M
  - Closing January 2009
DOE’s R&D programs span the entire investment pipeline and will evolve in response to changes in the market and our budget.

Current Annual Funding*:
- **Supply Chain and Cross Cutting Technologies**: $5-10 M
- **Future Cross-Cutting Programs**: $30-50 M
- **University Product & Process**: $4-5 M
- **Future System Focused Programs**: $20-30 M
- **Technology Pathway Partnerships**: $2-5 M
- **Future University Programs**: $6-10 M

*Subject to changes in out-year budgets.
PV module research balances various materials through joint industry R&D and long-term research

- **Thin Films (aSi) 5%**
  Advancing amorphous and wafer replacement crystal silicon film solar cells on low-cost substrates

- **Thin Films (CdTe) 5%**
  Simplifying deposition while retaining performance and transferring record device architecture to manufacturing processes

- **Thin Films (CIGS) 7%**
  Supporting the manufacture of non-vacuum processes and transferring record efficiency device performance into large area commercial modules

- **Organic PV 4%**
  Customizing molecules, substrates, and deposition techniques to yield ultra low-cost modules

- **Dye-Sensitized Cells 1%**
  Advancing the efficiency and stability of inexpensive dye-based solar cells with novel nanostructures

- **Next Generation 7%**
  Investigating advanced concepts aimed at delivering revolutionary performance improvements

- **Building Integrated PV 2%**
  Creating module form factors aimed at dramatically reducing or eliminating solar installation costs

- **Crystalline Silicon 23%**
  Developing higher efficiency devices and lower cost processing methods for traditional silicon cells

- **Concentrating PV 18%**
  Combining new, lower cost multi-junction cells and innovative optical packages

- **Crosscut 28%**
  Synergistic technologies, evaluation approaches, and process engineering approaches applicable across multiple absorber materials and processes
DOE’s industry R&D programs include diverse technologies for potentially diverse PV markets

- Second round of PV incubators announced September 26th, 2008
- Currently conducting stage gate reviews for TPP projects
- Announcement of supply chain funding opportunity due 1/28/2009
NREL’s Roles in Industry Interactions

-- Classifications crafted in support of SAI Technology Pathway Partnerships

• Support
  • Provide measurements, analysis, samples
  • No NREL intellectual property required
  • Level-of-effort dependant on total demands
  • Fully funded by PV Program

• Partner
  • Responsible for milestones and deliverables
  • Statement of Work and required resources specified up front
  • May require license to NREL background IP and agreements for ownership and licensing of subject IP
  • Negotiated costs 50:50 shared with Program
  • Contracted in a CRADA
Agreements for Interactions with Industry

- Cooperative Research and Development Agreement – CRADA
  - Cooperative
  - May be 100% funds-in or shared-resources (down to 0% funds-in)
  - Joint Statement of Work
  - Detailed IP development, protection and ownership
    - Partner may obtain an exclusive license for reasonable terms
  - Vastly more flexible terms for protecting information
    - “CRADA Protected”
  - Scope ranges from research to routine
  - No restrictions of funding or duration
  - 4-6 weeks process time
    - Unless complicated
NREL Intellectual Property

• Goals:
  • Protect potential investment and development for U.S. business
  • Provide revenue for protection of IP and transfer of technology
  • Provide incentive for inventors

• Strategy:
  • Foundational IP
    – Rarely licensed exclusively
      • Built from DOE PV Program resources
  • Product IP
    – Background IP
      • Non-exclusive usually preferred
      • Limited exclusive possible
    – Subject IP
      • Limited exclusive typical
      • Exclusive if essential and terms reasonable
Conversion Technology: “Wafer Silicon” (w-Si)

**PROBLEM:**
Materials waste in wafer is too high. About 45% raw material cannot be recycled. It is very difficult to achieve 1$/W modules using current technologies.

**DESCRIPTION:**
Si heterojunctions enable reduced costs by replacing 200 µm wafers with wafers <100 µm. Fabrication of high efficiency solar cell in thinner wafer at NREL.

**IMPACT/RELEVANCE:**
Reduce the cost through increasing material usage and efficiency. Heterojunction design provides low temperatures and symmetric processing for thin wafers. New technology could transform industry.

**TECHNOLOGY STATUS:**
- Thinner wafers (<100 µm) soon available in solar industry
- NREL demonstrated 19.3% Si Heterojunction Device - World best on p-type substrate
- Achieved open circuit voltage > 700mV
Conversion Technology:
“Film Silicon”

**PROBLEM:**
Costly energy & materials waste in wafer. Si feedstock alone currently > $0.5/W - need to achieve $1/W modules. Even when present feedstock crisis ends, cost is too high.

**DESCRIPTION:**
- Reduce costs by eliminating feedstock and melt, replacing 200 µm wafers with 2-10 µm films;
- Oriented seed layer is followed by epitaxial device growth;
- Grow devices over large areas with fast HWCVD.

**IMPACT/RELEVANCE:**
Crystal silicon efficiency, materials abundance at only slightly greater area cost than thin films. Transition to industry will leverage existing expertise and equipment from both thin-film and c-Si industry.

**TECHNOLOGY STATUS:**
- High-quality seeds in industry, collaborations underway with electronics, equipment, start-up and glass companies;
- 40 µm epitaxy at <700° C with low dislocations;
- First devices expected in FY09.
Conversion Technology: "CdTe"

**PROBLEM:**
- Short-term: CdTe module performance would benefit by glass/TCO-products tailored to CdTe
- Long-term: CdTe module performance limited by low p-doping and lifetime in CdTe absorber.

**DESCRIPTION:**
- Provide industrially relevant options for commercial-glass substrate designed for CdTe PV use.
- Understand defects that limit doping and lifetime.

**IMPACT/RELEVANCE:**
- Increase short circuit current density from ~19-21 mA/cm² toward 24-25 mA/cm².
- Dopant/lifetime control will improve voltage

**TECHNOLOGY STATUS:**
- Understand functionality of buffer layer to assist selection of commercial buffer-layer options.
- Increase dielectric permittivity of commercial (low-mobility) TCO processes to increase transmission
- Understand effects of various dopants on lifetime

---

**Graphs:**
- Improved TCO Options
- Improved Lifetime with Cu
Conversion Technology: “Organic Photovoltaics” (OPV)

PROBLEM:
The absorption of the industry standard P3HT only covers the visible spectrum and is not optimized for PV applications. Infrared absorbing materials with proper band edges are needed for improved light alignment of the absorption with the solar spectrum.

DESCRIPTION:
Combining molecular modeling, synthesis, and novel characterization will allow for the design of improved absorber materials.

IMPACT/RELEVANCE:
Current cells absorb poorly, but convert what they absorb efficiently, new molecules/polymers could improve efficiency dramatically through improved absorption and enhanced V_{oc}.

TECHNOLOGY STATUS:
- Successful synthesis of new dendrimers with improved red response.
- Collaboration with industry to improve devices
- Next generation of molecules being made by new synthetic team.

Conversion Technology:

“Organic Photovoltaics” (OPV)

PROBLEM:
The absorption of the industry standard P3HT only covers the visible spectrum and is not optimized for PV applications. Infrared absorbing materials with proper band edges are needed for improved light alignment of the absorption with the solar spectrum.

DESCRIPTION:
Combining molecular modeling, synthesis, and novel characterization will allow for the design of improved absorber materials.

IMPACT/RELEVANCE:
Current cells absorb poorly, but convert what they absorb efficiently, new molecules/polymers could improve efficiency dramatically through improved absorption and enhanced V_{oc}.

TECHNOLOGY STATUS:
- Successful synthesis of new dendrimers with improved red response.
- Collaboration with industry to improve devices
- Next generation of molecules being made by new synthetic team.
Cross-Cutting R&D Technology: “Reliability, Test & Evaluation”

Performance decreases by 0.4% per year

Inverter shows periodic failure

Long-term Performance and Reliability Testing
- Quantifies degradation/failure rates
- Validates energy models
- Provides samples for failure analysis
- Test bed for studying effects of mounting, shading, etc.
- Test bed for accelerating stress (high voltage, etc.)
Cross-Cutting R&D Technology: “Reliability, Test & Evaluation”

- Module Failure Analysis
- Accelerated Testing of Encapsulants
- Customized Stress Testing
- Measuring Adhesion Strength/Module Coring

Accelerated Stress Testing
Developing Alternative Test Procedures
Working with UL and industry

Graph showing lap shear strength (MPa) versus exposure time (hr)

Si cell
EVA
Glass
“Measurements & Characterization” (M&C)

- Analytical Microscopy
  - Utilize high-resolution techniques to obtain structural, chemical and morphological information of materials and devices on an atomic scale. Techniques include:
    - Scanning Electron Microscopy (SEM)
    - Transmission Electron Microscopy (TEM)
    - Cathodoluminescence (CL)
    - Electron Backscattered Diffraction (EBSD)
    - Scanning Probe Microscopy (AFM, STM, SKPM, C-AFM, etc.)
    - Electron Probe Microanalysis (EPMA)

- Electro-Optical Characterization
  - Utilize electro-optical techniques to relate PV device performance to the methods and materials used to produce them. Techniques include:
    - Photoluminescence Spectroscopy (PL)
    - Minority Carrier Lifetime (TRPL, RC-PCD, and µW-PCD)
    - Fourier Transform Infrared Spectroscopy (FTIR)
    - Spectroscopic Ellipsometry VASE and RTSE
    - Capacitance Techniques (C-V, DLTS, AS, and DlCP)
    - Computational Modeling

- Surface Analysis
  - Surface analytical techniques determine the chemical, elemental, and molecular composition and electronic structure of materials surfaces and interfaces. Techniques include:
    - Auger Electron Spectroscopy (AES)
    - X-ray Photoelectron Spectroscopy (XPS)
    - Ultra violet Photoelectron Spectroscopy (UPS)
    - Dynamic Secondary Ion Mass Spectrometry (SIMS)
    - Time-of-Flight SIMS

- Cell & Module Performance
  - Independent facility for verifying device and module performance for the entire PV community
  - ISO 17025 accredited for primary reference cell, secondary reference cell and secondary module calibrations
  - Provide the U.S. PV industry with a calibration traceability path (reference cell calibrations for the entire US terrestrial community)
  - Develop hardware, software and procedures to accommodate new cell and module technologies.
Process Integration Vision

• Provide a tool set that
  – facilitates both basic and applied science,
  – on commercially viable sample sizes,
  – with controlled ambient between process steps and measurements,
  – to answer previously inaccessible PV related research questions.

• Controlled ambient transfer between techniques emulates industrial processes with the added ability to
  – Interrupt processes at any point to perform a measurement
  – Mix material systems not fixed in a production line or technology
  – Control and characterize critical surfaces (interfaces) and investigate their impact on subsequent layers
  – Assess process-related source chemistry, surface chemistry and kinetics, and bulk reconstruction
  – Develop new techniques, methodologies, device structures, materials, and tools (growth, processing, and analytical)

• Provide a baseline of world-class cells and materials

• Improved collaborations with university and industry
The PDIL is a Collaborative Facility

Industry and universities work closely with NREL researchers via integrated….^ over 1800 person-years PV experience

<table>
<thead>
<tr>
<th>Equipment</th>
<th>PV Materials</th>
<th>Data Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Deposition</td>
<td>• CIGS, CdS, ZnO…</td>
<td>• Automation</td>
</tr>
<tr>
<td>- CVD, PVD</td>
<td>• CdTe, Cl₂ Tx’s…</td>
<td>- Reproducible</td>
</tr>
<tr>
<td>- Printing, Spray</td>
<td>• a-Si(Ge,N), nc-Si…</td>
<td>- “Recipes In”</td>
</tr>
<tr>
<td>- CBD</td>
<td>• Crystal Silicon Film</td>
<td>- High Throughput</td>
</tr>
<tr>
<td>• Processing</td>
<td>• Cross-Cutting</td>
<td>• PDIL Server/Network</td>
</tr>
<tr>
<td>- Etching</td>
<td>- TCO’s</td>
<td>- Relational database</td>
</tr>
<tr>
<td>- Annealing</td>
<td>- metal contacts</td>
<td>- IP &amp; Cyber Secure</td>
</tr>
<tr>
<td>• Measurement</td>
<td>• Organics</td>
<td>- Web-Based GUI</td>
</tr>
<tr>
<td>- Compositional</td>
<td>• Nano-Based</td>
<td>• Scientific Computing</td>
</tr>
<tr>
<td>- Electro-Optical</td>
<td></td>
<td>- Data Mining</td>
</tr>
<tr>
<td>- Structural</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PV Materials: 
- CIGS, CdS, ZnO…
- CdTe, Cl₂ Tx’s…
- a-Si(Ge,N), nc-Si…
- Crystal Silicon Film
- Cross-Cutting
  - TCO’s
  - metal contacts
- Organics
- Nano-Based

Data Products: 
- Automation
  - Reproducible
  - “Recipes In”
  - High Throughput
- PDIL Server/Network
  - Relational database
  - IP & Cyber Secure
  - Web-Based GUI
- Scientific Computing
  - Data Mining
Data Acquisition & Processing

Operators

Investigators

Feedback

Relational Database

File Archive

PDIL Central Server

Tool 1

Tool n

Data Mining, Modeling, and Simulations

SCC Cluster
Film Silicon Workstation

PECVD: a-Si (p)
PECVD: SiNx
PECVD: a-Si (n)
PECVD: µc-Si
PECVD: a-Si
PECVD: a-Si

Load Lock
Transport Pod
Etching
HWCVD: a-Si
VHF PECVD µc-Si

Sputtering: TCO
CIGS Workstation

- **CIGS**
- **TCO’s**
- **CdS, window layers**
- **Mo, back contacts**
- **Expansion Ports**
- **Movable AES**
DOE can have a unique leadership in the growth of the solar industry

The PV industry has the potential to enter a “virtuous cycle” of lower cost, new technology and expanded markets.

To reach its full potential, the PV industry requires close coordination between a number of public and private entities.
SETP will expand program activities in 2009 and beyond to address critical issues for grid parity

**Photovoltaics**
- Pre-incubator FOA
- Expanded Supply Chain FOA
- Industry Roadmapping

**CSP**
- Baseload Roadmap
- Improved mapping and forecasting
- Upgraded lab facilities
- Enhancement of supplier base

**Grid Integration**
- Energy Storage
  - Requirements Analysis
  - Technology Development
- High Penetration System Analysis

**Market Transformation**
- Workforce Development
- Expanded Solar America Showcases and Cities
- International Market Transformation
- Solar America Colleges and Universities
Key Messages

• The Solar Energy Technology Program is focused on reducing the cost of solar energy to grid parity by 2015 working through a broad array of stakeholders.

• SETP funds a diversified and growing portfolio of photovoltaic and concentrated solar power technologies through both the national labs and directly to industry.

• Access to the expertise and facilities of the national labs can accelerate development.

• System Integration and Market Transformation are key sub-programs that address issues related to commercialization and wide-spread penetration of solar technology.

• The main challenge for the SETP going forward will be to adjust to dynamic industry conditions and changes in technology and market requirements to cost effectively reach program goals.
DOE’s R&D programs span the entire investment pipeline and will evolve in response to changes in the market and our budget.
Thank You
Questions and Resources:

DOE Solar Program: http://www.eere.energy.gov/solar/
SNL PV Systems R&D: www.sandia.gov/pv
NREL Solar Research: www.nrel.gov/solar

Sign up for our Newsletter and Market Analysis: Send email to solar@ee.doe.gov

Questions & Follow-up:
John Benner – john_benner@nrel.gov – 303-384-6496