Technology to Market

Dramatic reductions in the cost of solar will enable the high penetration deployment of solar energy technologies. It is essential then, but insufficient, to discover new materials, build first-of-a-kind devices, or identify that we must simplify PV interconnection backlogs: to have real impact, we must also transition all of these solutions to the marketplace. As a taxpayer-funded program, the SunShot Initiative also aims to create domestic jobs through commercial activity in the solar sector. The Technology to Market subprogram builds on SunShot's record of enabling groundbreaking devices and concepts in earlier stage programs with follow-on funding. Technology to Market targets two known funding gaps in bringing new technologies to market: the ones that occur at the prototype commercialization and commercial scale-up stages, as illustrated in Figure 1.

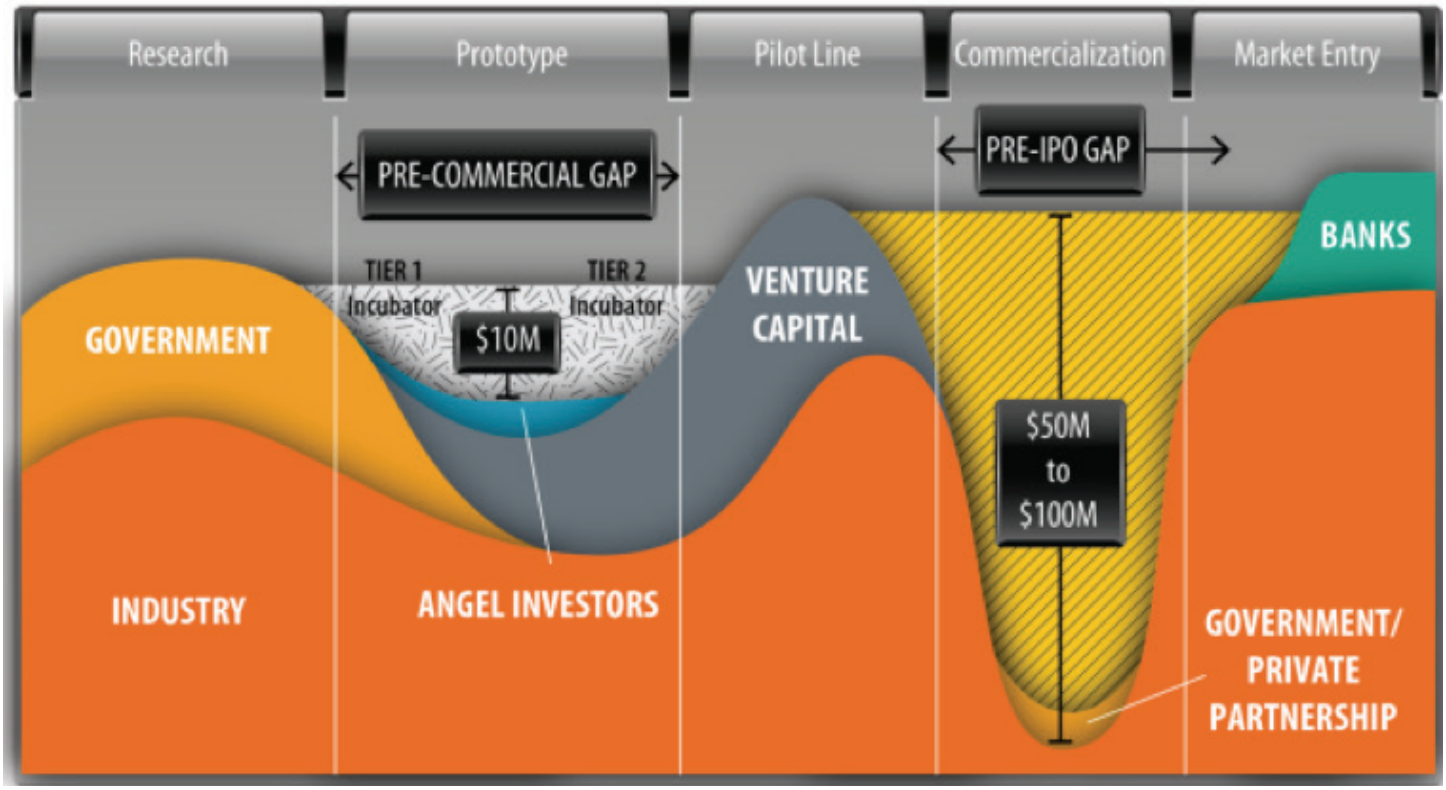

Figure 1. Commercialization and scale-up funding gaps addressed by SunShot's Technology to Market Program.

Commercially-focused technologies and business solutions in the SunShot portfolio are nurtured across varying stages in both the Incubator program and in the ongoing Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) programs. Businesses with later-stage technologies can apply for manufacturing programs such as Solar Manufacturing Technology (SolarMaT) and Scaling Up Nascent PV at Home (SUNPATH), both of which support cost-effective, domestic, manufacturing processes. If topically suitable, manufacturers and component suppliers can also join the consortia funded under the Photovoltaic Manufacturing Initiative (PVMI). All Technology to Market programs are tightly

structured to ensure that recipients commercialize the funded technology and achieve technical milestones. Through various other activities, SunShot's Technology to Market program also creates venues for helping the recipients find non-DOE follow-on funding and form strategic partnerships.

The flagship program in the Technology to Market portfolio is the SunShot Incubator program, currently in its ninth round. Past recipients have attracted more than $18 in follow-on funding for every $1 in federal investment. The Incubator program supports small businesses seeking to commercialize innovative PV and CSP device concepts and manufacturing pilot lines, as well as innovations in hardware installation, grid conversion technologies, and novel business models and software platforms for reducing soft costs.

Figure 2. Incubator awardee QBotix has developed a robotic tracking system that increases solar PV power plant production by up to 45% and delivers cost savings up to 20%.

In addition to funding commercialization-stage activities and beyond, Technology to Market tends to the internal compass of the SunShot Initiative by supporting market and cost analysis. This analysis informs SunShot's strategic direction and reveals the market barriers that can be addressed through solicitations. On an ongoing basis, SunShot closely scrutinizes the progress of its projects and programs and evaluates internal decision-making with reference to bottom-up cost analyses. These analyses, crucial to a rapidly-evolving industry, address conversion technologies and systems as well as supply chain- and location-specific competitive advantages.

The programs described below fall into three thematic areas across the Technology to Market portfolio: Technology Commercialization and Business Innovation, Manufacturing Innovation and Scale-Up, and Cost Analysis.

Dr. Lidija Sekaric
Technology to Market Program Manager
Solar Energy Technologies Office
U.S. Department of Energy

Technology Commercialization and Business Innovation

The SunShot Incubator program, which began in 2007, is now in its ninth round. Recipients, who graduate from the program within 12-18 months, have attracted outstanding levels of private follow-on funding relative to federal investment. Tightly formulated commercial and technical deliverables are the cornerstone of the program. The program also boasts breadth and permanence: the solicitation is open to a wide range of topics and recurs annually, subject to appropriations. The Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) are congressionally-mandated programs that, although not entirely managed from within SunShot, serve the purpose of piloting topics and concepts that complement the rest of the SunShot portfolio. SunShot aims to select and support Incubator and SBIR/STTR recipients whose innovative ideas will continue to benefit the solar market: the program goal is to have at least 50% of recipients and/or their business solutions survive and have impact in the marketplace beyond 2020.

SunShot Incubator Program

The SunShot Incubator Program provides early-stage assistance to help small businesses cross technological barriers and de-risk their products and services, while encouraging private sector investment to maximize impact. The program is focused on rapidly commercializing products and services with the potential to make solar more affordable. The SunShot Incubator Program partners with U.S. industry to accelerate innovation and meet aggressive cost and market penetration goals.

MOSAIC

Berkeley, CA | $2.0M | Incubator 6 | 06/2012–09/2014

Solar Mosaic is bringing much-needed capital to the solar industry by building a web platform for everyday Americans to create and fund solar projects. Mosaic's unique online crowdfunding platform will help reduce the soft costs of solar financing and customer acquisition while enabling thousands of Americans to own a piece of the growing clean energy economy.

ENKI TECHNOLOGY

San Jose, CA | $1.5M | Incubator 7 | 10/2012–09/2014

Enki Technology is working to improve PV module efficiencies and reduce the levelized cost of energy (LCOE) through development of low-cost high-performance functionalized anti-reflective coatings for PV cover glass. Enki's unique platform of products offer high-durability coatings for desert environments, anti-soiling coatings for arid and dusty environments and coatings optimized for world class optical performance. Enki offers coating processes on industry standard equipment with products that can be cured at low or high temperatures for compatibility with existing infrastructure. Enki is continuing to expand its product offerings to provide tailored anti-reflection coatings that solve customer problems.

Project Highlight: Solar Census

Awardee	Solar Census
Location	Walnut Creek, CA
Award Amount	$0.73M
Period of Performance	10/2013–11/2014
Primary Industry Area	Online Shade Tool

Solar Census will leverage its patented algorithms to produce the first commercial-grade online shade tool that enables salespeople and system designers to customize PV systems in 3D and create highly accurate quotes in minutes (Fig. 3). The software will streamline the sales and design process, reduce change orders and soft costs, and increase close rates and homeowner satisfaction.

How this Technology is Transformational

Solar Census Surveyor is the first commercial-grade online rooftop shade analysis tool. This fully automated software draws from 3D spatial databases and applies patented algorithms to model the shading effects on a particular roof on a 24/7/365 basis to determine exact solar access values. This software can be used by solar installers, financers, and other solar sales companies to qualify a house for solar in seconds and design a solar system to ensure optimal return on investment without leaving their desks.

This software truly revolutionizes the solar sales cycle. The National Renewable Energy Laboratory evaluated the accuracy of the online tool's shade values and determined that performing a virtual survey with Solar Census Surveyor is "scientifically equivalent" to using a handheld Solmetric SunEye. In addition to the instant shade analysis, the software provides an instant financial proposal and 3D CAD model. The need for a site visit is entirely eliminated with this software and companies can go directly from lead to install.

Why this Innovation is Important for the United States

This software connects solar to the web and can help to increase adoption of solar energy. By making buying and selling solar much simpler, Solar Census' online analyses can drastically reduce costs. This software eliminates the need for a physical site survey, reducing the cost of installers' workers compensation insurance, radically shortening the sales cycle, increaseing close rates, dramatically reducing change orders, ensuring optimal system placement and reducing installation labor. Further, enabling remote surveys allows companies, funds, governments and individual Americans to guarantee the security of their investments, helping to continue stability and confidence in the solar industry.

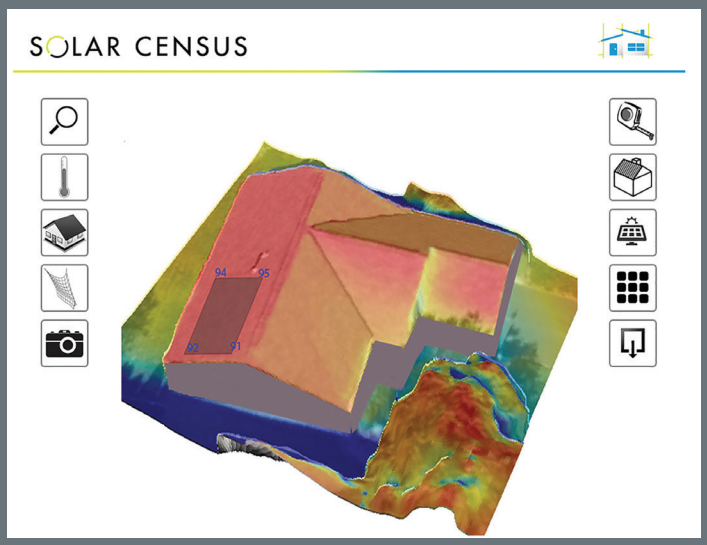

Figure 3. Incubator awardee Solar Census is producing the first commercial-grade online shade tool that enables salespeople and system designers to customize PV systems in 3D and create highly accurate quotes in minutes.

REhnu

Tuscon, AZ | $1.0M | Incubator 7 | 10/2012–05/2014

REhnu is transitioning a new concentrating photovoltaic (CPV) technology, already proven in a University of Arizona prototype, to a low-cost form ready for commercial production. The technology uses large glass dish reflectors, each with a compact array of CPV cells at its focus. This makes it economical to build systems with an extended 40-year lifetime and maintain high power output by swapping in new cells as multijunction technology improves.

SOLAFLECT

Norwich, VT | $1.0M | Incubator 7 | 02/2013–04/2015

Solaflect Energy has developed a low-cost Suspension Heliostat™ that dramatically reduces steel usage by utilizing steel cables instead of steel truss structures to stabilize mirror panels. The SunShot project will focus on continued development of the heliostat design, design for robotic manufacture, reduction of manufacturing and installation labor requirements, and the transition to high volume commercialization.

STION

San Jose, CA | $2.0M | Incubator 7 | 12/2012–06/2014

Stion has developed a disruptive technology based on a tandem copper indium gallium diselenide (CIGS) module that uses a revolutionary thin film design to enable broader and more effective harvesting of available light. The tandem module, which utilizes mechanically stacked top and bottom modules to avoid the design and manufacturing challenges associated with multijunction monolithic integration, enables 18% efficiency on full-size CIGS modules.

APPLIED NOVEL DEVICES, INC.

Austin, TX | $0.50M | Incubator 8 | 10/2013–09/2014

Applied Novel Devices is developing a low-cost, high-efficiency inter-digitated back contact (IBC) solar cell technology using a novel self-aligned direct patterned deposition system. The process for forming the cells eliminates the expensive multi-level patterning and alignment needed for conventional IBC cells. This technology is applicable to both implanted and heterojunction based IBC cells.

BRITTMORE GROUP, LLC

San Jose, CA | $0.68M | Incubator 8 | 10/2013–09/2014

The Brittmore Group will develop and demonstrate an automated system for pre-assembling frameless PV modules into larger panels using construction adhesives. This system will deploy panels across large-scale PV arrays by industrial robots that traverse the mounting rack. This technique promises a significant reduction in construction duration and cost. It is also expected to accelerate market acceptance of frameless PV modules, which further reduces structural materials and electrical installation costs.

CELLINK CORPORATION

Belmont, CA | $0.70M | Incubator 8 | 03/2014–03/2015

CelLink Corporation is creating an interconnect circuit that will be used to interconnect back-contact solar cells. The circuit is a standalone, simplified flex circuit that will be used in place of the back encapsulant in a back-contacted solar module. This product will reduce the costs of manufacturing silicon modules by 10%.

CLEAN POWER RESEARCH

Napa, CA | $0.94M | Incubator 8 | 10/2013–03/2015

Clean Power Research is developing the next PowerClerk® platform to significantly reduce soft costs associated with interconnecting distributed solar to the utility grid. By taking the interconnection process online and automating communications, application submission and review will be streamlined, and sophisticated solar retailers will be able to apply for interconnection directly from their proposal tools. Additionally, the platform leverages information collected in PowerClerk in a solar engagement tool that utilities can use to engage their customers early in the solar sales process. This interactive online tool will allow utility customers to see how many of their neighbors have gone solar, explore personalized economics of solar, and connect with installers and financing.

DEMETER POWER GROUP

West Palm Beach, FL | $0.50M | Incubator 8 | 10/2013–09/2014

Demeter will offer solar lease or services agreement financing collected as an assessment on the property tax bill via its web-based platform: PACE3P. By securing payments to the property, instead of the offtaker, PACE3P lowers the levelized cost of energy by 20%, makes more deals "bankable" without a corporate guarantee, and enables the first uniform, scalable financing for commercial solar.

ENERGYSAGE

Cambridge, MA | $1.2M | Incubator 8 | 10/2013–03/2015

The EnergySage Marketplace transforms the complex solar PV shopping process into a simple, online comparison-shopping experience. The unique, innovative platform provides unprecedented levels of choice, transparency, and information at no cost to consumers. Consumers can compare quotes from multiple, pre-screened installers in a consistent matrix format across all financing options. EnergySage reduces time and effort for both consumers and installers, significantly reducing customer acquisition costs, boosting consumer confidence, and accelerating mass market solar adoption.

FOLSOM LABS

San Francisco, CA | $0.35M | Incubator 8 | 01/2014–12/2014

Folsom Labs makes solar array design software that combines advanced performance modeling with cloud-based design tools. Under the SunShot award, Folsom Labs will extend its core HelioScope product to provide automatic evaluation of various system designs and component choices to quickly find the lowest LCOE approach for a given site.

GENABILITY

San Francisco, CA | $1.0M | Incubator 8 | 03/2014–09/2015

Genability is implementing an independent analysis of projected and actual solar savings and a monthly savings statement that automatically tracks actual savings, compares actual with projected savings, and determines the optimum rate plan for customers. The "Verified by Genability" mark will help to lower bid preparation costs and time and increase lead to customer conversions.

GEOSTELLAR

Martinsburg, WV | $0.75M | Incubator 8 | 10/2013–03/2015

Geostellar will streamline the procurement, financing, installation, and maintenance of solar arrays with the creation of a Solar Project Record. The Solar Record provides application developers with important data, including the estimated cost of solar energy production on a particular rooftop, utility rates, load profiles, incentives, property ownership, equipment configuration, installation, and permitting requirements for individual properties across the United States. This tool will be available to homeowners, installers, government agencies, and financing companies through Web and mobile applications.

INFINITE INVENTION, LLC

Philadelphia, PA | $0.50M | Incubator 8 | 10/2013–03/2015

Infinite Invention is developing the Solar Socket, a device for plugging in solar PV between the electric meter and meter case. It streamlines the installation process by reducing wiring costs, scheduling requirements, and site inspection time and allows for swapping in new technologies as they emerge. In addition, a version with onboard metering and communications lets power flow directly into the utility grid.

KWH ANALYTICS

Oakland, CA | $0.45M | Incubator 8 | 10/2013–09/2014

kWh Analytics aggregates historical data on PV system performance and financial credit. Combined with a cloud based storage system, parallel computing architecture and Bayesian statistics, kWh Analytics reduces third-party financing costs by offering highly-scalable investment risk analytics.

RENEWABLE POWER CONVERSION

San Luis Obispo, CA | $1.0M | Incubator 8 | 10/2013–03/2015

Renewable Power Conversion will produce an environmentally sealed inverter featuring plug-and-play installation/replacement and a maintenance-free lifetime equal to that of PV modules. The Macro-Micro is a modular 17 kW inverter enabling high system granularity and redundancy. Power is efficiently converted and collected with an inverter efficiency of 98.5% and system power collection at 600 Vac. This distributed multi-string inverter provides multi-megawatt PV projects with a low LCOE alternative to large central inverters.

SILICON SOLAR SOLUTIONS

Fayetteville, AR | $0.50M | Incubator 8 | 10/2013–09/2014

Silicon Solar Solutions, in partnership with Georgia Tech and Roth & Rau, is developing a hydrogen treatment to optimize the emitter of n-type solar cells resulting in improved conversion efficiency and reduced silver gridlines. The technology has shown 15% relative efficiency improvements while using 1/3 less silver grid lines in the lab. The goal of this project is to demonstrate the technology on commercial solar cells.

SIMPLY CIVIC

Parker, CO | $0.40M | Incubator 8 | 10/2013–03/2015

Simply Civic is developing an online solar project application that will be available to jurisdictions nationwide. The tool will seamlessly enable jurisdictions and installers to track the status of solar projects while making it faster and simpler to complete required paperwork.

SINEWATTS

Palo Alto, CA | $0.50M | Incubator 8 | 10/2013–09/2014

SineWatts is developing an inverter architecture that is 10X smaller, 100% siliconized and 70% lower in installed cost. The SineWatts Inverter Molecule™ is a single silicon IC based distributed inverter co-packaged with its PV panel and is of the footprint of an iPhone. SineWatts' patent pending architecture allows the molecules to utilize advanced silicon power switching technologies developed for mobile applications to be utilized for grid-supportive, highly reliable and dispatchable PV power plants.

SMASHSOLAR

El Cerrito, CA | $0.50M | Incubator 8 | 10/2013–09/2014

SMASHsolar is developing a scalable PV mounting system that installs in half the time with half the parts and allows an array to easily expand over time. This project will develop and test an integrated mounting system that shifts field work to the factory, resulting in a simplified installation process that drives down balance of systems costs.

SOLARNEXUS, INC.

Berkeley, CA | $0.50M | Incubator 8 | 03/2014–05/2015

SolarNexus and its partners will integrate a range of software used for customer acquisition, system design, permitting, and monitoring—resulting in the industry's first ecosystem of inter-operable software applications. The integration of key functionality from separate software vendors will significantly eliminate data re-entry and enhance the productivity of solar professionals with a simplified software experience. The ecosystem will leverage the Integrated Energy Project (IEP) Model (iepmodel.net), an existing, publicly available data standard for the transfer of solar project information.

SUN NUMBER

Deephaven, MN | $1.0M | Incubator 8 | 10/2013–03/2015

Sun Number is analyzing rooftops to determine the best roofs and the best locations of roofs for solar. This data is used to create Sun Number Scores – a tool to educate consumers about the solar potential of their homes. This data is combined with other information about the roof and the building to qualify properties and lower the cost of customer acquisition.

SUNRUN

San Francisco, CA | $1.6M | Incubator 8 | 10/2013–03/2015

Sunrun is creating an integrated system for automatic design, costing, simulation, proposal generation, pricing, permitting, and field change management for a PV system. This end-to-end platform will optimize system performance and greatly reduce project cost and lead-to-cash process time.

Supporting Innovation Research and Technology Transfer at Small Businesses

The DOE Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) Programs aim to stimulate technological innovation, use small businesses to help meet federal R&D needs, foster and encourage participation by socially and economically disadvantaged entrepreneurs, and increase private sector commercialization of innovations derived from federal R&D. SunShot SBIR/STTR Programs provide seed capital for early stage R&D with high commercialization potential. Active projects in the SunShot SBIR/STTR portfolio span a wide range of R&D topics, including: PV device fabrication and optimization, manufacturing metrology, diagnostics, and process control, corrosion-resistant sensors for high-temperature applications, and automation systems for large-scale PV installations.

TRANSPARENT, FLEXIBLE CdTe MODULES FOR HIGH EFFICIENCY TANDEM PV

Lucintech, LLC | Toledo, OH | $1.0M | STTR 2 | 08/2012–08/2014

Polycrystalline thin film cadmium telluride (CdTe) is a candidate material for a top cell in multijunction thin film solar cell structures, but its use is limited by the lack of high performance transparent back contacts to the CdTe. In this project Lucintech, LLC and its research partner, the University of Toledo, are adapting single-wall carbon nanotube structures for CdTe solar cell electrodes and scaling up toward the manufacturing of magnetron-sputtered CdS/CdTe devices with very thin and smooth CdTe layers ideal for applying transparent back contacts. The goal is to develop a top-cell structure for flexible tandem modules to match a low-bandgap bottom cell such as CIGS or Si, and to optimize a stand-alone, transparent top cell with less than 500 nm of CdTe for use in PV window applications.

REAL TIME PV MANUFACTURING DIAGNOSTIC SYSTEM

MicroXact, Inc. | Blacksburg, VA | $1.0M | SBIR 2 | 08/2013–08/2015

The application of in-line diagnostics to PV cell manufacturing lines with high production capacity (>10 MW/year) has the potential to significantly increase productivity and reduce costs by improving yield. In this Phase 2 project, MicroXact, Inc. is developing and demonstrating a high-throughput, in-line PV manufacturing diagnostic system that provides data on the spatial uniformity of thickness and refractive indices of thin films as they are processed in a roll-to-roll configuration. The retrieved information will provide the opportunity to detect a wide variety of processing errors, including but not limited to thickness/composition inhomogeneity, non-uniform scribing, thin film stress, cracking, and layer separation.

UTILITY-SCALE PV COST REDUCTION BY AUTOMATED PANEL INSTALLATION SYSTEM

Brittmore Group, LLC | San Jose, CA | $0.70M | SBIR 2 | 12/2013–12/2015

To reduce the costs of installing large-scale solar projects, Brittmore Group, LLC is developing and demonstrating a robotics-based automated installation system. The system consists of three key components: a mobile factory where individual modules are preassembled and wired into larger panels, a simplified, fixed-tilt, ground-mount support system that doubles as an above-ground transport track for panel installation, and an industrial robot that takes preassembled panels from a centralized logistics area and installs them at megawatts-per-day rates. In this SBIR Phase 2 project, Brittmore Group will fully productize their system by taking all three components from alpha-stage to full production. The anticipated public benefit of a fully productized Brittmore system is one of reduced large-scale PV installation costs and shorter time to power generation and revenue.

Project Highlight:
Apparatus for Optimizing Photovoltaic Solar Manufacturing Efficiency through Real-Time Process Feedback and Spectral Binning of Cells

Awardee	Tau Science Corporation
Location	Beaverton, OR
Award Amount	$0.98M
Period of Performance	08/2013–08/2015
Primary Industry Area	Metrology for PV Manufacturing

Tau Science is developing in-line metrology techniques to improve the quality and performance of solar cells and reduce manufacturing costs.

How this Technology is Transformational

Solar cell manufacturers lack immediate feedback on key process steps such as junction formation and film deposition. This gap is particularly impactful when an offline sampling plan cannot be easily implemented. Furthermore, manufacturers measure cell performance inline under white light conditions, but are unable to obtain cell response as a function of wavelength without extensive offline testing. Tau Science Corporation is developing non-contact, electro-optic techniques to extract semiconductor bandgap and full spectrum photoresponse. Expected commercial applications include module scanning for failure analysis, cell spectral sorting, inline monitoring for absorber/emitter quality, and substrate contamination and surface preparation control.

Why this Innovation is Important for the United States

The U.S. maintains a key presence in test and measurement equipment for PV, and this project aids in pushing the state of the art in this area. This project helps to support the nation's long-term energy goal of building higher performance, consistently robust solar devices at a lower cost.

ADVANCED CERAMIC MATERIALS AND PACKAGING TECHNOLOGIES FOR REALIZING SENSORS FOR CONCENTRATING SOLAR POWER SYSTEMS

Sporian Microsystems, Inc. | Lafayette, CO | $1.0M | SBIR 2 | 01/2014–01/2016

Advancements in current instrumentation technology are needed to improve and optimize the performance and reliability of existing and future CSP plants. A specific need has been identified for improved pressure, temperature, flow, and level sensors for emerging CSP heat transfer fluids and thermal energy storage fluids. Sporian Microsystems, Inc. is addressing this need by developing, testing, and demonstrating small, highly reliable, high-temperature-operable (600-1300°C), corrosion-resistant sensors. Sporian's sensor technology is based on the combination of advanced high temperature packaging, recently developed silicon carbide nitride (SiCN) based polymer derived ceramics, and advanced integrated electronics. The proposed sensors will improve the efficiency and economic viability of CSP systems, and may have a variety of additional applications for nuclear power generation, fossil fuel power generation, concentrating solar fuels, and transportation systems.

RELIABILITY IMPROVEMENT IN SOLUTION PROCESSABLE ROLL-TO-ROLL PHOTOVOLTAIC MODULES

Next Energy Technologies, Inc. | Santa Barbara, CA | $1.0M | SBIR 2 | 05/2014–05/2016

Limitations of conventional solar technologies in their form factor, weight, flexibility, color-tunability, transparency have impeded growth in flexible PV and large, building-integrated photovoltaic (BIPV) markets. Addressing this opportunity, Next Energy Technologies, Inc. is developing soluble small molecule organic semiconducting inks that can be coated onto conventional plastic rolls in high yields using roll-to-roll technology. The goal of this project is to demonstrate that the lifetime of encapsulated organic PV devices made using organic soluble small molecules is long enough to meet the needs of the markets (20–30 years for rigid encapsulation; 3–5 years for flexible encapsulation). The development of the technology is anticipated to achieve a price point that will compete with non-renewable energy sources and help the U.S. transition to a clean energy future.

SOFTWARE TOOL FOR CODE-COMPLIANT ASSESSMENT OF WIND LOADS ON SOLAR PHOTOVOLTAIC PANELS

TIAX, LLC | Lexington, MA | $0.22M | SBIR | 06/2013–03/2014

Presently, the proper installation of PV panels to withstand wind loads is conducted by licensed installers who use and individually interpret the relevant building codes and standards. These design calculations can be laborious requiring expertise in the applicable codes and looking up a multitude of parameters, an exercise that is subject to judgment and prone to human errors. TIAX is leveraging its expertise in structural analysis, software development, and building technologies, to develop an application that automates the calculation of wind loads and provides recommendations for the appropriate PV mounting systems. By creating a software tool, TIAX provides a way to standardize wind load calculation and minimize human errors in code-compliant installation.

DEVICE-PHYSICS-ACCURATE COST-EFFECTIVE CELL AND MODULE TEST INSTRUMENTS

Sinton Instruments | Boulder, CO | $0.17M | SBIR | 06/2013–03/2014

Sinton Instruments is changing the way that cells and modules are tested, in order to be faster, cheaper, and better. Detailed device physics testing are being integrated into test sequences so that the cell characteristics at cell test can be related back to the incoming material, substrate doping, and carrier recombination measurements done during the cell manufacture, as well as forward to the module characterization and reliability testing. This will contribute to lowering the cost of PV by enabling an

unbroken chain of detailed process control and optimization throughout the entire cell and module manufacturing process. After module manufacture, detailed characterization will enable better reliability testing for modules by tracking fundamental semiconductor parameters within the module.

MODULAR DISTRIBUTED CSP WITH STORAGE SYSTEM USING WATER/STEAM PHASE CHANGE FOR ENERGY STORAGE AND GENERATION

Terrajoule Corporation | Redwood City, CA | $0.22M | SBIR | 06/2013–03/2014

Core challenges for distributed CSP with storage include: the economic practicality of turbines at the sub-MW scale; the cost effectiveness of molten salt thermal electric storage; and poor turbine efficiency when engineered for variable power output. Terrajoule Corporation developed a proprietary solution to bypass these challenges, and is performing engineering designs and analyses for three closely-related system improvements that can be implemented in a demonstration of a modular distributed CSP with storage system at the 100 kW scale with 6 to 14 hours of thermal electric storage, using water/steam phase change for energy storage and generation.

NOVEL MODULE ARCHITECTURE DEVELOPMENT FOR INCREASED PV RELIABILITY AND REDUCED COSTS

Direct Solar, LLC | Fort Collins, CO | $0.22M | STTR | 06/2013–03/2014

Module reliability has a direct impact on the levelized cost of energy (LCOE), or the cost of the energy produced by the PV system. To improve the reliability of thin film PV modules, Direct Solar, LLC is developing a new module architecture and encapsulation technology, utilizing a specialized, two-part edge seal incorporating high-strength, UV-tolerant silicone, and low-moisture, vapor-transmission polymers in conjunction with a separate desiccant material. This technology is particularly suited for addressing the durability, adhesion and moisture performance concerns of thin film PV modules.

REAL-TIME POD-CFD WIND-LOAD CALCULATOR FOR PV SYSTEMS

Central Technological Corporation | Altamonte Springs, FL | $0.22M | SBIR | 06/2013–03/2014

Wind-loading calculations for structures do not necessarily take into account relevant characteristics, such as those from full 3D effects, end effects, turbulence generation and dissipation, as well as minor effects derived from shear forces on installation brackets and other accessories. Central Technological Corporation is developing a real-time response framework based on the Proper Orthogonal Decomposition method to calculate in real time the loads on PV modules that result from wind-induced drag and lift forces on rooftop-mounted PV systems.

Manufacturing: Innovation and Scale-Up

An integral part of EERE's Clean Energy Manufacturing Initiative, SunShot has supported manufacturing through programs that have adapted to the rapidly changing industry landscape. The Photovoltaic Manufacturing Initiative (PVMI), which started slightly before the SunShot Initiative was launched, supports consortia in university R&D with input from manufacturers, an industry supply chain consortium, and a unit-process service line. SunShot has also launched one round of a manufacturing scale-up program named SUNPATH. Another program that supports R&D and innovation in manufacturing, SolarMaT, recurs annually and funds PV and CSP supply chain improvements as well as innovation in system component manufacturing. Supply chain innovation, previously a stand-alone program, is now incorporated topically into SolarMaT. The Technology to Market subprogram supports innovation in manufacturing and aims to reverse the declining trend of U.S. market share in solar manufacturing before 2020 and enable the U.S. manufacturing industry to service the growing U.S. solar market.

Photovoltaic Manufacturing Initiative (PVMI)

The purpose of this funding is to support the development of the U.S. PV manufacturing industry. Two different approaches are taken: the first approach encourages universities to conduct industry-relevant R&D projects related to PV manufacturing. The second approach supports the industry in accelerating the development and implementation of PV manufacturing-related technologies through both collaborative and non-collaborative models, including the creation of manufacturing development centers.

U.S. PHOTOVOLTAIC MANUFACTURING CONSORTIUM

PVMC, Inc. | Albany, NY | $62.5M | PVMI | 09/2011–12/2017

The U.S. Photovoltaic Manufacturing Consortium (PVMC) is coordinating an industry-driven initiative to accelerate the development, manufacturing, and commercialization of next-generation, copper indium gallium diselenide (CIGS) thin film, PV manufacturing technologies, tools, and materials. PVMC seeks to drive down the cost and risk of bringing CIGS technologies to the marketplace. In partnership with the PV industry, PVMC has developed a PV Technology Roadmap as a guide for assessing R&D needs and opportunities for innovation. In addition, PVMC will operate complementary programs to foster new PV technologies and firms and develop the U.S. PV workforce. PVMC is also working with the University of Central Florida to develop cost-effective, in-line measurement and inspection tools to enable increased c-Si PV manufacturing yield.

Project Highlight:
Bay Area Photovoltaic Consortium

Awardee	Stanford University and University of California-Berkeley
Location	Palo Alto, CA
Award Amount	$25.0M
Period of Performance	08/2011–06/2016
Primary Industry Area	PV Technology

The Bay Area PV Consortium (BAPVC) funds industry-relevant R&D to impact high-volume PV manufacturing using a competitive selection process open to all universities. This project, managed by Stanford University and the University of California–Berkeley, develops and tests innovative new materials, device structures, and fabrication processes necessary to produce cost-effective PV modules in high volumes. The research advances technologies that bring down manufacturing costs and improve device performance characteristics to help achieve SunShot cost targets. Member companies determine the specific topics for R&D to ensure close alignment with industry and manufacturing needs and review individual project progress.

How This Activity is Transformational

Expertise and R&D tools available at universities can be critical for solving many of the difficult technical challenges of PV technology. However, it can be difficult for university researchers to directly connect their work to real world issues. Problems that need solutions are not well-articulated and opportunities that require solutions are missed.

The BAPVC forms direct connections between industry and universities by soliciting requests for proposals, its project review process, and its bi-annual meetings that link companies and leading university researchers.

Why This Innovation is Important for the United States

Universities are clearly one of the most important drivers of U.S. innovation. The BAPVC helps ensure that those assets are working on relevant problems and rapidly communicating their results to U.S. companies.

SOLAR ROCHESTER

College of NanoScale Science and Engineering, SUNY | Albany, NY | $26.0M | PVMI | 07/2011–09/2016

CNSE is creating a fee-for-service, PV Manufacturing Development Facility (MDF) accessible to PV companies. The facility will be able to accommodate a range of services and equipment, including access to advanced tools, manufacturing expertise, secure fabrication space for users' proprietary tools, and pilot production services — all in a secure intellectual-property environment. The MDF is focusing on the commercialization of silicon PV manufacturing processes and technologies. It aims to reduce the costs and development time for participating PV industry leaders to deliver innovative, emerging technologies from the laboratory to commercial manufacturing lines. These capabilities enable start-ups, materials suppliers, and other PV innovators to eliminate a major portion of their upfront capital costs and initial operating costs during product development and pilot production.

Scaling Up Nascent PV AT Home (SUNPATH)

This program supports the initial ramp towards domestic high-volume manufacturing of globally cost-competitive PV technologies. SUNPATH helps strengthen domestic manufacturing and demonstrates that innovative PV technologies can be cost-effectively made in the U.S. Targeted SUNPATH funding is enabling three innovative, high-tech companies to accelerate cost reductions and commercialization of their solar PVtechnologies. At capacity, SUNPATH is expected to support approximately 600 direct American manufacturing jobs and thousands more throughout the solar industry.

PROJECT SILICON: RECLAIMING U.S. SILICON PV LEADERSHIP

1366 Technologies | Bedford, MA | $7.0M | SUNPATH | 09/2012–09/2014

This award is assisting the industrial-scale demonstration of 1366's Direct Wafer process – an innovative, kerfless approach to forming multi-crystalline silicon wafers. Traditional silicon wafers are sawn from large silicon ingots, producing thousands of wafers per ingot. Sawing turns half of the ingot into sawdust, known as kerf-loss. Direct Wafers are made directly from molten silicon, circumventing the sawing process, which may reduce manufacturing costs by 50% compared to traditional processing. Furthermore, Direct Wafers have the same form factor as traditional wafers, allowing "drop in" compatibility with existing cell production lines. Approximately half of the current global PV shipments use multi-crystalline wafers, of which, the wafers themselves are a multi-billion dollar market. This project supports the design, build, and demonstration of 1366's industrial-scale Direct Wafer producing equipment; the layout, design and construction of a pilot-scale manufacturing facility; and commercial development activities.

LARGE-SCALE COMMERCIALIZATION OF DILUTE NITRIDE TRIPLE JUNCTION SOLAR CELLS

Solar Junction | San Jose, CA | $4.8M | SUNPATH | 09/2012–04/2014

Solar Junction is expanding its manufacturing capacity and reducing the costs of its high-efficiency (>40%) triple junction solar cells. Solar Junction's cells are suited for high-concentration photovoltaic (HCPV) applications, where sunlight is tightly focused onto a small-area cell. Driving down the cost of manufacturing and increasing cell efficiency is important for making HCPV technology cost competitive. Under this award, Solar Junction will progress towards SunShot's cost targets by a three-pronged approach. First, Solar Junction will make technology improvements to increase cell efficiency, which increases the power output per cell area. Second, cell processing will migrate to a larger substrate size, which increases manufacturing capacity and reduces scrap. Third, an asset-light strategy for wafer fabrication will be employed, where Solar Junction outsources its high-volume wafer growth to IQE, an epitaxy toll manufacturer. By award end, Solar Junction aims for an annual capacity of 40 MW with more efficient cells that cost 20% less.

Project Highlight:
Soitec Solar Industries

Awardee	Soitec Solar Industries
Location	San Diego, CA
Award Amount	$25.0M
Period of Performance	09/2012–09/2014
Primary Industry Area	Concentrating PV modules

Soitec is an international industrial manufacturing company that develops and manufactures semiconductor materials and concentrating photovoltaic (CPV) power plant technology. SUNPATH is assisting with building a highly-automated 280 MWp factory in San Diego (a.k.a., SANFAB) for the production of its concentrating PV modules, which have efficiencies of approximately 30%, compared to the 15–20% efficiency of non-concentrating flat-plate PV modules.

How This Activity is Transformational

To drive down costs of the modules, the factory is highly automated and integrates vertically the value chain of several production steps under one roof. Equipment from electronic and printed circuit board manufacturing as well as technologies using robots and gantry systems similar to automotive manufactures are utilized. Lean manufacturing principles and a certified quality management system are deployed.

The San Diego factory will manufacture the new Soitec CX-M500, Soitec's fifth generation CPV modules that feature enhanced performance characteristics specifically designed to benefit large-scale utility power plants. The modules will be used in a 28 kWp CPV system with over 1150 square feet of solar modules, a size that delivers high performance while significantly reducing the cost of installation and maintenance. This CPV system is designed to improve the levelized cost of electricity (LCOE) for very large solar power plants with a roadmap to SunShot's targeted LCOE.

Why This Innovation is Important for the United States

The CX-M500 modules will supply utility-scale CPV power plants throughout the U.S. Southwest and other sunny regions across the globe. The San Diego factory has already produced modules for the largest CPV power plant in the state of California (Newbery Solar 1) and has more than 300 MWp of project pipeline to fulfill. At full operational capacity, the factory is anticipated to create 450 direct jobs and more than 1,000 indirect jobs around San Diego.

Solar Manufacturing Technology (SolarMaT)

The Solar Manufacturing Technology program assists the development and demonstration of innovative manufacturing technologies in both the PV and CSP industries that will increase the U.S. share of the global solar market and create competitive advantage for domestic manufacturers. This program aims to create the next generation of solar industry-standard manufacturing technology.

IMPROVED LARGE APERTURE COLLECTOR MANUFACTURING

Abengoa Solar, LLC | Lakewood, CO | $1.9M | SolarMaT | 09/2013–09/2015

Abengoa Solar will demonstrate new manufacturing and assembly technologies for use in CSP parabolic trough systems to achieve cost reduction and enable innovative technology to quickly enter the market. This project will focus on highly-automated manufacture of trough components, onsite assembly of the troughs at the solar field and improved quality control using automated inspection.

RAPID, COMPACT C-Si MODULE MANUFACTURING

PPG Industries, Inc. | Allison Park, PA | $2.1M | SolarMaT | 09/2013–09/2016

PPG Industries, Inc. will partner with Flextronics International, Inc. to design and pilot a rapid PV module assembly process that replaces labor-intensive packaging steps with automation. The process uses an all-liquid encapsulation approach to completely eliminate lamination. The team will optimize encapsulation and backsheet formulations and develop the application processes required to rapidly and consistently dispense them, along with an automated system to place a 60- or 72-cell matrix into the encapsulant.

DEVELOPMENT OF MANUFACTURING TECHNOLOGY TO ACCELERATE COST REDUCTION OF LOW CONCENTRATION PV MODULES

Solaria Corporation | Fremont, CA | $2.0M | SolarMaT | 09/2013–09/2015

Solaria will cut costs for its low-concentration silicon PV module by automating a number of manufacturing process steps including the stringing and tabbing step that is used to assemble and align the c-Si strips that are placed under a lensing glass top sheet. This removes a primary barrier to enable Solaria to undertake high-volume PV module manufacturing in the United States.

HIGHLY AUTOMATED MODULE PRODUCTION UTILIZING ADVANCED LIGHT MANAGEMENT

SolarWorld Industries America, Inc.| Hillsboro, OR | $2.4M | SolarMaT | 09/2013–09/2015

SolarWorld will incorporate an advanced light management system into its PV modules that will achieve substantial efficiency improvements at little additional cost. The light management system reduces optical losses from tabbing ribbon and area between cells and represents a large, unrealized opportunity for module efficiency improvements. The proposed SolarWorld approach cost-effectively utilizes low-cost components implemented using highly automated robotic systems.

Project Highlight:
Road to Grid Parity through Deployment of Low-Cost 21.5% n-Type Si Solar Cells

Awardee	Suniva, Inc.
Location	Norcross, GA
Award Amount	$4.5M
Period of Performance	10/2014–09/2016
Primary Industry Area	PV Technology

Suniva, Inc., in partnership with the Georgia Institute of Technology, will develop a low-cost, highly-efficient silicon PV cell technology that will reach the marketplace within three years and meet the SunShot 2020 target of ≤$0.50/W module cost. This effort will overcome cost and efficiency barriers through advances in PV science and technology innovation involving new process tools and result in pilot production of 21.5% efficient cells.

How This Activity is Transformational

The majority of present c-Si PV cells are fabricated on p-type c-Si substrates that have limited minority carrier lifetime and therefore limited efficiencies. Moving to n-type silicon allows for longer lifetimes and more efficient cells. However, the movement toward n-type substrate material has been slow as changes in process and equipment require significant development. This is an important step on the ever moving PV roadmap.

Why This Innovation is Important for the United States

While differentiating technology is often proposed and demonstrated at companies in the U.S., the subsequent difficult and time-consuming manufacturing development has taken place at offshore manufacturing sites. Suniva's cell manufacturing is in the U.S. and the company has relied on innovation to keep its performance and cost profile competitive. This innovation will allow Suniva to continue on its current advantaged trajectory.

High Impact Supply Chain R&D for PV Technologies and Systems

The purpose of this funding opportunity is to identify and accelerate the development of cross-cutting and unique products or processes that are expected to have a disruptive impact on the PV industry.

ULTRA BARRIER TOP SHEET FOR FLEXIBLE PV

3M Company | St. Paul, MN | $4.3M | Supply Chain 2 | 04/2011–06/2014

3M's objective is to develop and commercialize a flexible, highly-transparent ultra-barrier top-sheet (UBT) that enables successful commercialization and growth of flexible solar modules manufactured from second- and third-generation PV technologies. This UBT is being manufactured with a proprietary high volume, low cost roll-to-roll process that has the potential to meet or exceed the technical requirements for these solar technologies. Successful commercialization of the UBT could have a dramatic impact on the solar industry by reducing total costs for installation in current markets such as commercial rooftop and residential building-integrated PVs.

GLASS INNOVATIONS FOR IMPROVED EFFICIENCY THIN FILM PV

PPG Industries, Inc. | Cheswick, PA | $2.8M | Supply Chain 2 | 04/2011–12/2014

The goal of this project is to develop the materials, coating designs, and manufacturing processes necessary to commercialize a new glass article for the cadmium telluride (CdTe) module manufacturing industry. This new glass article combines an improved transparent conductive oxide plus buffer layer, a high transmission glass substrate, and a low-soiling anti-reflective coating into one product offering. The combination of these various technologies into a single product results in performance gains and improvements in module cost. The cost reductions stem from the choice of deposition technology, scaling to high volume manufacturing, and systems integration of multiple coating operations.

Project Highlight:
Reduced Cost and Manufacturing Complexity of High Efficiency IBC Solar Cells using Ion Implantation and *in-situ* Patterning

Awardee	Applied Materials, Inc.
Location	Gloucester, MA
Award Amount	$4.8M
Period of Performance	04/2011–06/2014
Primary Industry Area	PV Manufacturing Equipment

Applied Materials is developing a patterning capability for a solar ion implant tool that enables the creation of patterned doped regions on an interdigitated back contact (IBC) solar cell in a single process.

How this Technology is Transformational

The majority of present c-Si PV cells are fabricated by diffusing an emitter junction into a doped wafer, with the emitter electrical contact formed by a metal grid screen printed on the front side of the cell. One established path toward increasing cell efficiency is to place both the emitter and base contacts on the back side of the PV cell, thereby increasing absorbed light by eliminating the front contact grid. Process steps to create this back contact structure are presently more expensive per wafer than the standard cell. A high throughput ion implantation tool that can pattern while implanting can reduce cost by creating emitter and base regions in a single process step while achieving higher efficiency.

Why this Innovation is Important for the United States

Manufacturing tools are an important component of the PV manufacturing supply chain. Developing and manufacturing advanced tools helps U.S. companies stay at the forefront of technology and allows companies to define the technology roadmap.

Cost Analysis: Technology, Competitiveness, Market Uncertainty

As a basis for strategic planning, competitiveness analysis, funding metrics and targets, SunShot supports analysis teams at national laboratories to assess technology costs, location-specific competitive advantages, and policy impacts on system financing, and to perform detailed levelized cost of energy (LCOE) analyses.

Project Highlight:
NREL Cost Analysis

Awardee	National Renewable Energy Laboratory
Location	Golden, Colorado
Award Amount	$1.0M per year
Period of Performance	Ongoing
Primary Industry Area	Cost Analysis

How This Analysis is Transformational

NREL researchers and analysts collect bottom-up data on a wide range of technologies: bulk and thin film crystalline silicon, CdTe/CIGS, multijunction, concentrating PV technologies, CSP heliostats, trackers, and overall PV system costs. This work helps the SunShot Initiative stay informed on current areas of focus, bottlenecks, and the opportunities for major innovation. The data also creates a sensitivity analysis of a variety of cost contributors to better understand decision-making in manufacturing competitiveness space. Most of the commercially-available data outside this program is not sufficiently backed up by diligence of the actual cost of solar technology manufacturing nor does it thoroughly analyze sustainable business models. Thus the internal analysis, vetted through peer-reviewed publications, when appropriate, is strategically important for SunShot Initiative and the U.S. solar industry in general.

Why This Innovation is Important for the United States

As the solar market grows, the importance of reclaiming parts of the manufacturing supply chain in the United States grows every day. In order for the SunShot Initiative to support manufacturing strategically with limited funds, the program needs to stay informed to decide how taxpayer investments can best translate into businesses taking root in the United States. In-house analysis capability allows for the flexibility in obtaining the needed data and the cost breakdown, helping the SunShot Initiative serve the community in a timely manner and support U.S. industry where it needs it most. In addition, this analysis work helps identify existing U.S. strengths in talent, innovation, and access to investment in a variety of sectors to help retain and regain U.S. competitiveness.

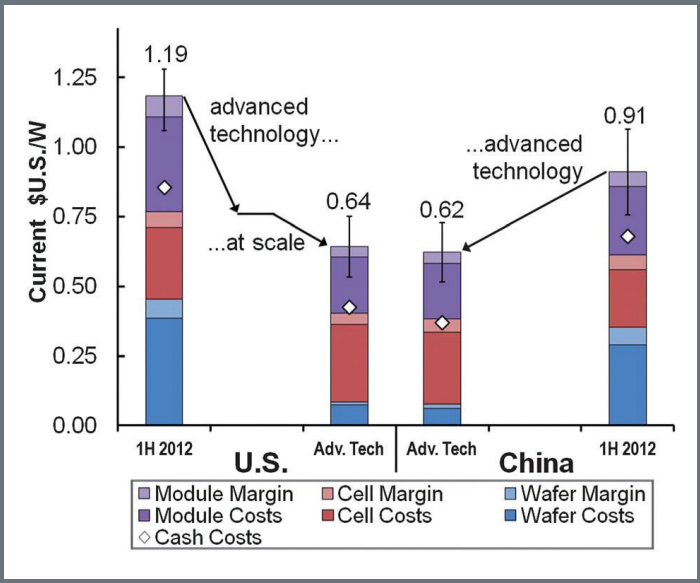

Figure 4. Cost-equalizing pathways for regional PV manufacturing.[9]

9. Goodrich et al. Assessing the Drivers of Regional Trends in Solar Photovoltaic Manufacturing. Energy and Environmental Sci. 6(10), 2811 (2013).