

# SOLAR ENERGY TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF  
**ENERGY** | Office of ENERGY EFFICIENCY  
& RENEWABLE ENERGY  
SOLAR ENERGY TECHNOLOGIES OFFICE



## 2018 PEER REVIEW REPORT

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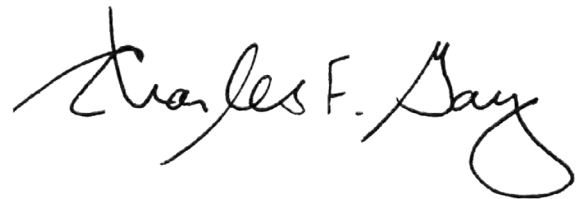
# List of Acronyms

<b>BAPVC</b>	Bay Area Photovoltaic Consortium	<b>kW</b>	kilowatt
<b>c-Si</b>	crystalline silicon	<b>kWh</b>	kilowatt-hour
<b>CdTe</b>	cadmium telluride	<b>LCOE</b>	levelized cost of electricity
<b>CO<sub>2</sub></b>	carbon dioxide	<b>LMI</b>	low- and moderate income
<b>CSP</b>	concentrating solar power	<b>NREL</b>	National Renewable Energy Laboratory
<b>DC</b>	direct current	<b>NSTTF</b>	National Solar Thermal Test Facility
<b>DER</b>	distributed energy resource	<b>O&amp;M</b>	operations and maintenance
<b>DG</b>	distributed generation	<b>PI</b>	principal investigator
<b>DOE</b>	U.S. Department of Energy	<b>PV</b>	photovoltaics
<b>DOT</b>	U.S. Department of Transportation	<b>R&amp;D</b>	research and development
<b>DuraMat</b>	durable module materials	<b>SETO</b>	Solar Energy Technologies Office
<b>EERE</b>	Office of Energy Efficiency and Renewable Energy	<b>Si</b>	silicon
<b>EV</b>	electric vehicles	<b>SNL</b>	Sandia National Laboratories
<b>Gas CC</b>	natural gas combined cycle	<b>T2M</b>	technology to market
<b>Gas CT</b>	natural gas combustion turbine	<b>TRL</b>	technology readiness level
<b>GW</b>	gigawatts	<b>U.S.</b>	United States
<b>IP</b>	intellectual property	<b>VC</b>	venture capital
		<b>Vdc</b>	voltage (direct current)

# Message from the Director

The 2018 Solar Energy Technologies Office (SETO) Portfolio Review convened hundreds of the brightest minds in the solar industry to share stories of progress and explore some of the most advanced solar energy technologies and solutions being developed across the country. We were honored to welcome more than 300 project teams, business leaders, and innovative researchers and scientists to Washington, D.C. to exchange ideas and identify the strategies that will shape our work over the next few years.

Just over 40 years ago, the idea that solar power could make the leap from powering satellites in space to powering the planet was the vision of only a few people, brought together by the shock of the first oil embargo. Today, solar power is everywhere. The exponential increase in applications powered by solar is directly tied to the predictable cost reduction experienced through economies of scale and continuous technology improvement. As the office looks ahead to defining strategies to achieve further scale in the solar industry, we will begin to explore a range of considerations appropriate for expanding every dimension of the value chain: how feedstocks are prepared, how modeling informs the panorama of possibilities, how factories consistently operate at high yield on the edges of new technology frontiers, how manufacturing environment, health, and safety is planned and audited, how life cycle benefits are quantified, and how to best use resources—all while ensuring that business prospers. Our teamwork will be critical for achieving this vision and I thank you for helping make a difference in accelerating the growth of the solar industry.



**Dr. Charles Gay**  
Director  
Solar Energy Technologies Office  
U.S. Department of Energy

# 2018 SETO Peer Review



Researchers mount a PV module for performance testing in Fraunhofer's Center for Sustainable Energy solar simulator dark tunnel.

*Photo by Lindsey Dillon.*

The 2018 SETO Peer Review was held February 12-14, 2018, at the Washington Marriott Wardman Park Hotel, Washington, DC. The review was attended by more than 530 participants and included poster presentations on the 260 active projects in the solar office's portfolio. Each day began with keynote presentations from the office's director, Charlie Gay, who provided a broad overview of the office's priorities. Following that, four parallel conference sessions discussed the research performed by each of the subprograms and detailed future research plans.

The 2018 Peer Review had three objectives:

1. Conduct an independent evaluation of current SETO projects and awardees, the efforts over the past year toward the programs' goals and future plans;
2. Provide a forum to promote collaborations and partnerships among awardees and other stakeholders; and
3. Communicate the value of SETO investments.

Independent reviewers were drawn from a variety of solar-related backgrounds and included experts from industry, academia, government, and other stakeholder groups. Each reviewer was screened for conflicts of interest and then assigned to projects based on their area of expertise and interests.

Reviewers evaluated each assigned project according to four criteria:

1. Relevance – the degree to which the project supports meeting SETO's goals.
2. Approach – how the project's design addresses technical/market challenges and how it is differentiated from current research.
3. Accomplishments/progress/impact – the project's progress relative to its own goals.
4. Project integration and collaborations – the degree that the project's staff is collaborating with relevant stakeholders.

The reviewers were provided project overviews prior to the event and were encouraged to visit each awardee during the poster sessions to discuss their projects. Afterwards, they provided a numerical score for each criterion and then substantiated these scores with additional comments.

The appendix provides a complete list of reviewers, as well as a detailed description of the evaluation criteria and scoring methodology.

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# Introduction

## SETO Mission and Programs

The mission of SETO is to support early-stage R&D to improve the affordability, reliability, and performance of solar technologies. The office invests in innovative research efforts to securely integrate more solar energy into the grid, enhance the use and storage of solar energy, and lower the cost of solar electricity. Toward these goals, SETO focuses on two different solar energy generation technologies: PV technologies that directly convert sunlight into electricity, typically via a semiconductor; and concentrating solar power (CSP) technologies that convert sunlight to heat, which can be stored until needed, and then used to generate electricity. As summarized below, the program is distributed across PV, CSP, systems integration, balance of systems soft cost reduction/market acceptance, and innovations in manufacturing competitiveness/technology to market (T2M) activities.

- **Photovoltaic Research and Development (PV):** Supports the early-stage R&D of technologies to drive down the cost of solar electricity and contribute to greater energy affordability by improving efficiency and reliability and lowering manufacturing costs.
- **Concentrating Solar Power (CSP):** Supports the development of novel CSP technologies that integrate thermal storage, lower cost, increase efficiency, and improve reliability beyond existing performance barriers.
- **Systems Integration (SI):** Works in partnership with the DOE Grid Modernization Initiative to enable the widespread deployment of safe, reliable, and cost effective solar energy on the nation's electricity grid by addressing the associated technical challenges and regulatory requirements.

- **Balance of Systems Soft Cost Reduction/Market Acceptance (BOS):** Addresses challenges associated with non-hardware costs of solar electricity, reducing the regulatory burden of adding solar to the grid, and identifying technology-neutral pathways that provide affordable and reliable solar electricity to American consumers.
- **Innovations in Manufacturing Competitiveness/Technology to Market (T2M):** Investigates and validates groundbreaking, early-stage technology and business models to strengthen concepts and move them toward readiness for greater private sector investment and scale-up to commercialization.

During the last five years, SETO has focused on supporting technologies that would allow solar to achieve the 2020 goals of \$0.06/kWh for utility-scale solar energy generation. During this time, the solar industry has substantially reduced the cost of solar electricity, which in part has enabled dramatic growth in the deployment of solar PV. Recently, SETO set 2030 goals to further reduce the cost of solar electricity across all market sectors.<sup>1</sup> The targets for the unsubsidized, levelized cost of energy (LCOE) at the point of grid connection in a location with average U.S. solar resource are \$0.03/kWh for utility-scale PV (with a path depicted in Figure 1), \$0.04/kWh for commercial rooftop PV, \$0.05/kWh for residential rooftop PV, \$0.05/kWh for CSP with a minimum of 12 hours of energy storage (with a path depicted in Figure 2), and \$0.10/kWh for CSP with six hours of energy storage.

<sup>1</sup> U.S. Dept. of Energy, The SunShot Initiative's 2030 Goal: 3¢ per Kilowatt Hour for Solar Electricity, 2016.

# Photovoltaics

The SETO's PV subprogram supports the early-stage R&D of technologies to drive down the cost of solar electricity and contribute to greater energy affordability by improving efficiency and reliability and lowering manufacturing costs. The project portfolio funds innovative concepts and experimental designs across a range of technology approaches that show promise to achieve dramatic cost reductions. The scope of the projects goes beyond the industry, focusing on non-proprietary innovations that have the potential to achieve commercial success in 10 to 20 years. This creates an innovation ecosystem in the United States, supporting the long-term growth of the solar industry.

The PV subprogram maintains U.S. leadership in photovoltaic R&D, with a strong record of impact over the past several decades. Nearly half of the world's solar cell efficiency records, which are tracked by NREL, were supported by the DOE, most through the PV subprogram and its predecessors. Projects in the portfolio target three main areas of improvement: (1) increasing efficiency and energy yield, (2) reducing material and process costs, and (3) understanding reliability and mitigating degradation.

**Increasing Efficiency and Energy Yield:** In order to make solar energy more affordable, projects are investigating the use of materials that will allow PV systems to produce more electricity from the same amount of sunlight. Current projects include the improvement of crystalline silicon (c-Si) cells—the most common type of solar cell on the market—by pioneering ultrathin c-Si absorber layers and passivated selective contacts, and developing module technologies that are more shade tolerant. Projects also target cadmium telluride (CdTe) cells, the second-most common type, by increasing the crystal quality, improving doping control, and increasing the minority carrier lifetime. Additionally, projects explore the use of tandem structures that combine two different types of solar cells into one, enabling record efficiencies.



Mojave Desert solar.  
*Photo by Reegan Moen.*

**Reducing Material and Process Costs:** Lowering the costs of solar panels through less expensive materials and more efficient processes enables savings for consumers. Projects include working to improve ultrathin perovskite-based solar cells, a relatively new material in the solar industry that can be deposited inexpensively from solution while attaining high efficiencies. Other projects are working to accelerate, and reduce the costs of, the materials growth processes that are used to manufacture solar cells of all types, including techniques to use flexible substrates and hydride vapor phase epitaxy.

**Understanding Reliability and Mitigating Degradation:** Increasing the lifetimes of solar panels is a significant lever to reduce solar electricity costs. SETO works on several initiatives that focus on improving panel reliability and lowering degradation rates. The Durable Module Materials (DuraMat) consortium brings together the national lab and university research infrastructure with the PV and supply-chain industries to develop and de-risk new materials with longer lifetimes. To provide better knowledge about real-life PV performance, SETO supports the Regional Test Centers across the country to test panel performance in a multitude of climates. SETO also supports national lab leadership in the Photovoltaic Module Quality Assurance



Task Force, which develops international test standards necessary to validate the quality of PV modules and determine service lifetimes, as well as smaller projects aiming to better understand degradation and develop better predictive testing.

PV projects have recently been selected through an annual PV R&D funding program (see table). The program focuses on both current and emerging technologies aimed at improving power conversion efficiency and energy output, while also enhancing service lifetime and decreasing hardware costs. In addition to traditional three-year projects, the program funds small, single-year projects focused on novel and/or emerging areas of PV research.



GRID Alternatives' volunteers, Jigeesha Upadhyaya and Raginee Yadav, from Arizona State University's professional science master's program installing a 5-kilowatt rooftop system in San Pasqual, California.

*Photo by Laksh Muchhal.*

## Active Funding Programs

Funding Program	Year Announced	Amount Awarded (million)
Photovoltaic Research and Development 2: Modules and Systems (PVRD2)	2017	\$20
Photovoltaic Research and Development (PVRD)	2016	\$17
Photovoltaic Research and Development: Small Innovative Projects in Solar (PVRD-SIPS)	2016	\$2
Physics of Reliability: Evaluating Design Insights for Component Technologies in Solar 2 (PREDICTS 2)	2015	\$7
SunShot National Laboratory Multiyear Partnership (SuNLaMP)	2015	\$110
Next Generation Photovoltaics 3 (NextGen3)	2014	\$14
Bridging Research Interactions through Collaborative Development Grants in Energy (BRIDGE)	2012	\$8

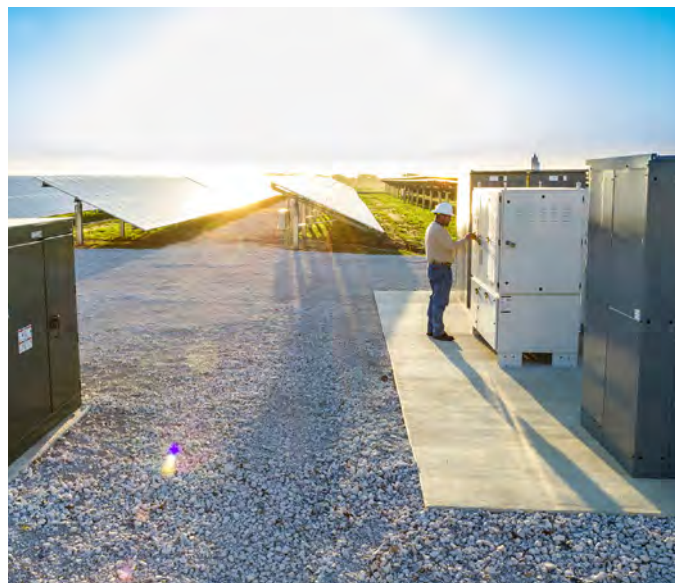
A panel consisting of 25 subject-matter experts reviewed the 94 active projects within the PV subprogram. The panel developed the following strengths, weaknesses, opportunities, and threats analysis to assist SETO in the future direction of the subprogram.

# Photovoltaics Strengths, Weaknesses, Opportunities, and Threats Analysis

*This list is compiled from all reviewer evaluations given at the 2018 Peer Review by the PV subprogram chairperson.*

## Strengths

1. SETO director Charlie Gay is deeply respected in the solar and energy communities, and has considerable expertise and experience in R&D, international collaborations, and industry.
2. SETO staff are highly knowledgeable and enthusiastic. Program managers have the technical background and expertise to discuss and share issues with the funded research groups.
3. Program priorities and organization are communicated well.
4. The PV R&D portfolio demonstrated good coverage and distribution of funding; e.g., fundamental versus applied R&D, research spanning fundamental materials, device development, and long-lifetime components and systems, and distribution between PV material technologies (c-Si, thin-film, etc.).
5. Compared to previous PV R&D program reviews:
  - a. PV R&D program addressed critical areas more effectively and efficiently.
  - b. PV R&D program showed better use of intellectual and funding resources within their portfolio.
  - c. PV R&D program is making more rapid technical progress.
6. The PV R&D program has relatively modest funding levels compared to international governmental support or to large private industry R&D. Nevertheless, SETO R&D portfolio remains active and relevant in worldwide solar R&D communities. This is particularly true for advanced cell materials and architectures.



A worker checks an inverter at the 2-megawatt CoServ Solar Station in Krugerville, Texas.

*Photo by Ken Oltmann/CoServ.*

7. Efforts are made to focus projects on industry-relevant materials and address key technical challenges or hurdles that are keeping advanced technologies from being commercialized.
8. The connection of the DOE SETO office to deep expertise in the national laboratories is beneficial for both SETO and the national laboratories.
9. The PV program shows strong research results; e.g., perovskite/Si and zinc CdTe/Si tandem work.
10. The PV program includes research at a low level in organic PV that shows good scientific progress.
11. The PV program has excellent young researchers.
12. The T2M panel was strong.
13. Many of the projects incorporate techno-economic analysis. This is highly valuable for focusing projects in relevant areas.

14. The PV R&D program includes excellent fundamental R&D in CdTe materials with strong industry (First Solar) participation.
15. The PV R&D program addressed a variety of module and system topics that address the overall program goal of lower LCOE. Such topics included improved thermal performance of modules and systems, in-field diagnostics, cell cracking tolerance and diagnostics, soiling, fail-safe module circuitry, bifacial module and system performance characterization, module anti-reflective coatings that can withstand the rigor of long-term exposure and multiple cleaning cycles, etc.
16. Projects addressing predictive models and accelerated tests for module electrical reliability and advanced material development (DuraMat) will help the United States stay at the forefront of materials development and deployment by improving industry's understanding of degradation mechanisms and learning how to test for them.
17. Most projects had strong technical execution and had excellent principal investigators (PI).
18. The traditional strength of DOE is innovative, early stage, next-generation technologies and this was evident in the program; e.g., perovskites, tandem cells.
19. Reliability research at the national labs is well documented and is a useful resource for the community.
20. The PV R&D program has a good track record for fostering new technologies and standards.
21. The PV R&D program has good ties to other stakeholders; e.g., other federal agencies, state and international programs, etc.

## Weaknesses

1. Solar PV contributions to energy security and economic vitality are not sufficiently recognized.
2. There appears to be growing interest and investment in soft sciences in the overall DOE PV program. Other portions of the SETO program (soft costs, systems integration, etc.) have fewer quantitative metrics, so progress and impact are more difficult to judge.
3. A strong need for investment in next-generation PV technologies still exists.
4. Some research groups resist sharing ideas.
5. Intellectual property (IP) ownership makes industry collaboration and technology transfer difficult.
6. DOE program managers could take a more proactive role.
7. There is competition between SETO and EERE organizations.
8. Industry has difficulty working with the national labs.
9. Existing competition from a large and rapidly improving Si industry may overwhelm any new PV technology (thin-film, concentrated photovoltaic, Si tandems, perovskites, etc.).
10. The DOE SETO could be better connected with solar wafer, cell, and module manufacturers. This would



A GRID Alternatives volunteer helps install solar on a roof in Loleta, California.

*Photo by Kate Costa.*

allow a more likely commercialization pathway for technology developed by SETO projects. It would also help inform calls for allocation of funding to new projects and calls for proposals.

11. The overall pathway for commercialization of DOE SETO-funded technology is challenging. Some of the technologies are intended to be long-term (~10 years), high-risk efforts and will take a long time to commercialize. Shorter term projects that could be adopted more quickly do not have a clear pathway to follow-on SETO funding after the initial DOE SETO investment, particularly if the T2M program is reduced or eliminated. The flow of technology out of a national laboratory or university into a company for commercialization faces many challenges, including the cost or availability of relevant expertise, equipment, and facilities, and/or the handling and availability of IP. Reducing barriers for national laboratory researchers to work more closely with companies, and benefit from the value creation of the commercialization process, would be very helpful.
12. The DOE SETO program is underfunded. The program supports the fastest growing energy source in the world. If the United States wants to be relevant in the future worldwide energy economy, it should be willing to invest the money now in solar R&D.
13. The III-V research was very strong, but economics will be difficult. The PIs, however, are aware of the techno-economic analysis and challenges.
14. Technology-specific projects that support advanced materials and higher efficiencies may be limited in their ability to directly enhance U.S. business. Without a strong domestic manufacturing base, from Si to materials, modules, and structures, the value of such technology projects may flow to foreign manufacturers.
15. SETO programs appear siloed in that the project opportunities continue to look at systems as discrete components. The module frame/structure interface will not be optimized if the component improvement opportunities are considered in isolation of each other.
16. Many of the funded projects appear interesting on the surface but appear lacking in understanding of field operations. Moreover, studies of reliability and defect modes tend to avoid consideration of variability in the upstream manufacturing process. Predictive and accelerated testing may assist with improving the performance of a properly manufactured product for purposes of certification. Unfortunately, at today's manufacturing scale, deviation in material quality, composition, and manufacturing processes may produce vast amounts of less-than-ideal products. Factory audits are intended to discover such deviation; however, the actual auditing processes typically are not sufficiently structured to identify such manufacturing excursions. Thus, reports of defects in fielded modules may not accurately identify the true contributing factors for the module failures.
17. System designs are rapidly evolving toward 1,500 voltage (direct current) ( $V_{DC}$ ) architecture. This migration is largely driven by system simplification, wiring, and inverter optimization. Current module designs have progressed little since their initial construction for 12 and 48  $V_{DC}$  systems. The financial and safety risks of 1,500  $V_{DC}$  implementation are significant without a more robust understanding of fielded module performance at such bias.



Solar installer lays a module on a California rooftop.  
Photo by Kate Costa.

18. Field conditions vary dramatically from site to site and are also dependent upon the quality of O&M. Actual site conditions are rarely ideal. A number of the projects may face significant challenges regarding implementation due to test and development conditions having little in common with fielded conditions.
19. The PV program's focus on funding individual PIs reduces collaboration and/or synergies.
20. The scientific progress in the PV program was stronger than the engineering progress.
21. Some of the work lacked enough innovation. The United States lacks resources to be a strong, fast follower and needs to be a leader in new areas.
22. Obstacles stand in the way of collaborating with foreign governments and foreign manufacturers.
23. The PV program lacks attention on seemingly simplistic yet important parts of solar projects like junction boxes and balance of system components.
24. The PV program continues to be distracted by technologies shown to be impractical.
25. The program seems to still have some hangover from the days when the goals were manufacturing jobs in cells and modules. There are a large number of jobs, economic impacts, and ample opportunities in many elements of the value chain.
26. SETO staff are stretched thin by the large number of projects, making it difficult to meaningfully monitor projects.

## Opportunities

1. Investment in next-generation technologies provides the best path for a revival of a large U.S. PV panel manufacturing base.
2. Investment in some areas (e.g., hybrid perovskites and their tandems) could leverage new startups in Si heterojunctions in the United States.
3. World leadership in next-generation PV is needed (including a balanced approach from materials and



Iron workers set the main wide flange beams 30 feet above the ground for one of the two PowerParasols at the KOA campsite in Tucson. Each structure is over 500 feet in length and combined, they provide over a megawatt of power and nearly 90% of the campground's electrical needs.

*Photo by Michael Nothum.*

- devices, through policy, markets, and analysis).
4. Leadership in some of the thin-film PV technologies provides opportunity for PV integrated with building architecture (building-integrated PV).
5. Enhanced collaborations with foreign organizations (industry, research institutes, or cross-government research consortia) could leverage U.S. PV research dollars and access strong international R&D teams and facilities.
6. Provide technical assistance to U.S. PV cell/module manufacturers (e.g., First Solar, Sunpower, Tesla/Panasonic).
7. Obtain and/or protect U.S. leadership in emerging technologies (perovskites, CdTe, Si tandems, etc.).
8. Commercial solar cells and modules are approaching the practical efficiency limit of single junction solar cells. Also, the cost has come down so much for

solar modules that even a 50% cost reduction in panel prices would only be a roughly 5% decrease in distributed rooftop solar system costs. However, a 50% efficiency increase (i.e., 20% to 30%) would result in a very significant cost savings for area-constrained distributed rooftop solar. This is an opportunity for manufacturers to enter the market with high-efficiency, dual-junction solar modules. DOE SETO investments in high-efficiency solar cells and modules are very important.

9. There is an opportunity for the United States to participate in solar module manufacturing indirectly by developing advanced tools to support the manufacturing of solar cells to reduce costs. There are opportunities around kerfless wafering, patterned implant, passivated contacts, and other technologies that could have an impact on manufacturing cost in the industry-dominant c-Si PV technology. Additional manufacturing tool opportunities exist for low-cost tandem cells.
10. Innovation opportunities for power electronics exist in a couple areas. First is tighter integration of power electronics with solar modules and solar cells.



Photo by Anirudh Ashok Pise.

By seeing the solar cells and power electronics as a system, there is the potential to unlock additional energy production and possibly cost savings. Greater integration of power electronics with solar cells and modules requires power electronics to have a similar lifetime as the modules (>25 years). This is not typically the case right now. Extending the life (and warranties) of power electronics to match solar modules would be a big benefit (especially for DG).

11. Improve technology transfer from the national labs.
12. Improve support of emerging technologies to industry (e.g., T2M).
13. Without a strong module manufacturing base, the U.S.-based development initiatives may benefit from focus on key aspects of integration and operation. Examination of the defects in fielded modules suggests much can be done to reduce defects and enhance longevity through introduction of designs that simplify installation and have reduced mean time to repair. This is especially true in consideration of 1,500 V<sub>DC</sub> systems.
14. Targeting the optimal integration of modules (framing) with structures and methods for installation may reduce costs through elimination of redundant metal. Integration of PV systems with loads provides an opportunity to reduce conditioning equipment (e.g., inverters) and optimize demand curves (improved “duck curve”). Typical PV system deployment and development activities (e.g., storage) seek PV power systems that mimic traditional peak and base power supplies. PV system output is inherently variable. Some loads can operate in a variable manner within defined parameters. The optimal integration of PV supply with such loads may offer further opportunities for LCOE reduction. Such work expands on current DC microgrid architectures and represents an area where the United States can lead.
15. Investigation of module/component recycling methods may present an opportunity as the life cycle of PV systems are optimized. Asset planning

generally appears inadequate as it relates to the life cycle of PV systems. Land lease agreements, ownership structure, and infrastructure costs must all be addressed when siting a PV plant. Once a power system has been sited, what prevents the site from remaining a power system for 30, 50, or 100 years? Distribution lines and ancillary equipment investments and infrastructure have already been commissioned. How systems are maintained and upgraded over their life to ensure performance well beyond the anticipated life of individual components may present a fertile area of investigation and development.

16. The four CdTe projects' synergy and diversity of investigative approach and tools of the trade, paint a critical and very significant resource funded by DOE to tackle the most critical challenge to thin film PV performance and reliability. It will be beneficial for the SETO programs to bring the four projects/teams into a quasi-alliance where some level of informal coordination and collaborative activities are designed to confirm and validate findings of each project. The expected impact is a universal defect model based on real experimental data with power to guide thin-film manufacturers and hopefully predict service lifetime of the module. Similar comments apply to perovskite R&D and other material technologies.



Solar Panels are installed at the 2-megawatt CoServ Solar Station in Krugerville, Texas.

*Photo by Ken Oltmann/CoServ.*

17. Some reviewers saw significant benefits to consortia. The Bay Area Photovoltaic Consortium (BAPVC) exhibited strong industry input on project selection and execution. Consortia (e.g., BAPVC and Quantum Energy and Sustainable Solar Technologies) generally hold more frequent meetings internally and with external partners than is typical with DOE PV program reviews. This led to good internal collaborations and an impact greater than the sum of the individual projects. The Institute of Electrical and Electronics Engineers Photovoltaic Specialist Conference does not provide the same environment for PIs to work across the aisle. There is concern that DOE does not value consortia. DuraMat was widely believed to be off to a good start in organization and execution. Other reviewers noted that consortia place a layer between PIs and DOE that reduces transparency and possibly responsiveness. The reviewers recommend that consortia have a well-defined vision and mission, strong business plan and organization chart, and have strong industry guidance.
18. Establish a program for smaller, rapid awards to better keep up with the pace of industry and the c-Si R&D community.
19. Support growth of solar in areas where the United States is strong: technology development (patents), tool making/industrial engineering for foreign manufacturers, project development, finance, construction, and operations.
20. Collaborate with state and other national government agencies with common goals to pool intellectual and financial resources, and implement common standards.
21. Collaborate with federal and state agencies to regulate the deployment of high quality solar modules and installations through periodic testing and inspections.
22. Match up industry stakeholders and project teams both in the United States and abroad.

23. Match up project teams and labs to foster synergies and promote shared resources.
  24. Pare down projects that appear to have little potential.
  25. Reach out directly to system owners. The present “audience” for DOE funding is the national labs and academia. Both are at least one step away from the market, and in some cases, many steps away. The focus on big data mining as a method to access system performance is an example of an academic answer to the problem of how systems are performing. The system owners know exactly how they are performing and have a wealth of very relevant field samples to share. A focused effort will be required to reach them and bring them into meaningful collaborations with the existing DOE-sponsored world. The overall goal of the effort would be a formal path to increasing the quality of products we largely buy from Asia, and eventually to lower cost solar energy.
  26. Convene C-level meetings with healthy U.S. corporations that show the opportunity for U.S.-based PV components and modules.
  27. The role of the national laboratories in management and technical leadership of the DOE PV program has been reduced—especially NREL and SNL. The expertise at the national labs, due to the large investment over time in facilities and people, could provide additional value to the program if a leadership role (“NCPV-lite”) could be identified.
  28. The PV program could help a reinvigoration of domestic PV cell/module manufacturing by targeted technical assistance for startups and new plant installations; e.g., Tesla/Panasonic.
- largest market for PV system installations, and has a rapidly improving R&D infrastructure.
  2. The U.S. PV program provides knowledge that benefits competitors in other countries.
  3. Perovskites is a very attractive new PV material. Perovskite threats include (a) Competition outside of the United States is proceeding faster because of the concentration and level of funding (non-U.S. leadership threat); (b) We need more coherence and collaboration between theory and experimental operations (this theory-experiment collaboration could be a huge advantage for the United States); and (c) Interest in China research groups is growing and their contributions are growing—direct interaction, for example, with China Si manufacturing for tandems might be beneficial.
  4. Reduction in funding and change in scope for the PV program due to lack of political support.
  5. China is showing increased interest and activities in thin-film and other next-generation technologies. Some U.S. experts have moved there already. Although thin-film PV has been a major part of the U.S. PV program in the past, there is inertia on considering reinvesting in this technology area.

## Threats

1. The U.S. PV program faces international competition with better financial resources and government and industry support. In particular, China is now the leading PV cell and module manufacturing base, the



Gorgeous evening on a solar array installation in Delran, New Jersey.

*Photo by Todd Baylson.*



6. The United States faces the threat that we will lose our leadership in advanced solar cell technology due to lack of investment in cell R&D. The United States is already becoming removed from the expertise around manufacturing of solar cells and modules, which is impacting the relevance of our R&D efforts.
7. Because the United States has little domestic manufacturing, any new technologies developed by the DOE SETO program will end up providing a bigger benefit to other countries that do manufacture solar panels.
8. The ability of foreign entities to rapidly scale and introduce new technologies represents a significant threat to U.S. manufacturing.
9. The PV program has a small c-Si emphasis. Continued investment into c-Si is recommended for the following reasons: (a) While c-Si cell and module manufacturing in the United States is small, we still have a large presence in other parts of the value stream (equipment, material, and IP) with large R&D requirements. (b) Startups need access to good facilities. (c) Funding is not adequate for c-Si labs, i.e., funding does not support continued investment to allow labs to maintain state-of-the-art capabilities.
10. The entry level today for wafer, cell, module, or any new PV panel technology is GW-scale, which is a very large barrier to entry. The industry needs to look for opportunities in other parts of the value chain.
11. Variable product quality due to manufacturing deviations and the high volume of imported solar modules could damage the reputation of solar PV energy.
12. Technical expertise is being lost to other nations.
13. Loss of national/political will to use solar as a method to achieve energy independence and reduce climate change will adversely affect the PV program.
14. Foreign patent infringement undermines return on investment.
15. As PV products are now fully mature, do we need a federal program to support them? Is there one for HVAC equipment? (The answer is yes, they do—to ensure the quality, reliability, and safety are present in products on the market, and that some semblance of the technology is maintained in order to continue to guide the product improvement effort.)
16. Cuts in DOE funding that cripple the national labs also threaten the PV program.
17. Loss of downstream tech-to-market-type projects due to budget cuts will have ripple effects upstream.



Students visit the 2-megawatt CoServ Solar Station in Krugerville, Texas.

*Photo by Ken Oltmann/CoServ.*

# Concentrating Solar Thermal Power

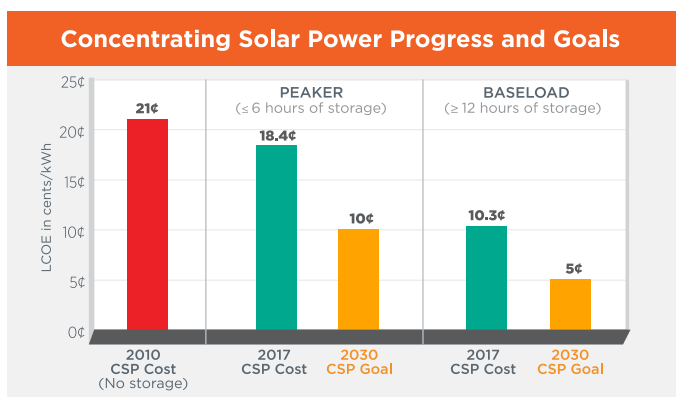
The SETO's CSP subprogram supports early-stage R&D of CSP technologies. Projects in the CSP portfolio focus on novel technologies that will integrate thermal storage, lower cost, increase efficiency, and improve reliability compared to current state-of-the-art technologies. This includes the exploration of new concepts for operations, system designs, and innovations in the collector, receiver, thermal storage, heat transfer fluids, and power block subsystems. Most of all, the CSP subprogram seeks out transformative concepts with the potential to break through existing performance barriers.

CSP is a unique form of solar energy because of its ability to incorporate storage and therein generate electricity on demand. By changing the relative sizes of the different CSP subsystems, plants can be configured as peaker systems, with 6 hours or less of storage, or baseload systems, with 12 hours or more of storage. Solar thermal technologies can also be used to generate heat for applications beyond electricity, such as water desalination, thermochemistry (including generation of fuels), and other industrial thermal processes.



Aerial photo of Ivanpah Solar Electric Generating System taken from a helicopter on March 23, 2015.  
*Photo by Cliff Ho.*

Since 2011, the LCOE for CSP has decreased significantly. Cost reductions have occurred throughout the various subsystems that exist within a CSP plant: the collector, where sunlight is first gathered and focused; the receiver, where concentrated sunlight is used to create thermal energy; the power block, which converts thermal energy into energy that can be used in our homes; thermal storage, which allows energy availability on demand; and the thermal transport subsystem, which moves heat from the solar receiver through thermal energy storage and delivers that heat to a power cycle. The office's 2030 cost targets for CSP peaker ( $\leq 6$  hours of storage) and baseload ( $\geq 12$  hours of storage) plants are 10 cents and 5 cents, respectively.





Dave, a solar installation supervisor working at GRID Alternatives Mid-Atlantic, inspects the solar panels after installing for a low-income family in Baltimore, Maryland.

*Photo by Kirsten Rumsey.*

## Active Funding Programs

Funding Program	Year Announced	Amount Awarded (million)
Concentrating Solar Power: Concentrating Optics for Lower Levelized Energy Costs (CSP: COLLECTS)	2016	\$9
CSP: Advanced Projects Offering Low LCOE Opportunities (CSP: APOLLO)	2015	\$32
CSP SunShot National Laboratory Multyear Partnership (SuNLaMP)	2015	\$29
Physics of Reliability: Evaluating Design Insights for Component Technologies in Solar (PREDICTS)	2013	\$4
Multidisciplinary University Research Initiative: High Operating Temperature Fluids (MURI HOT Fluids)	2012	\$10
Concentrating Solar PowerSunShot Research and Development (CSP R&D)	2012	\$56

A panel consisting of eight subject-matter experts reviewed the 35 active projects within the CSP subprogram. The panel developed the following strengths, weaknesses, opportunities, and threats analysis to assist SETO in the future direction of the subprogram.

## Concentration Solar Thermal Power Strengths, Weaknesses, Opportunities, and Threats Analysis

*This list is compiled from all reviewer evaluations given at the 2018 Peer Review by the Concentrating Solar Power subprogram Chairperson.*

### Strengths

1. The SETO director (Charlie Gay) is deeply respected in solar and energy communities with considerable expertise and experience in R&D, international collaborations, and industry.
2. SETO staff are highly knowledgeable and enthusiastic. Program managers have the technical background and expertise to discuss and share issues with the funded research groups.
3. Program priorities and organization were communicated well.
4. The CSP portfolio demonstrated good coverage and distribution of funding, e.g., fundamental versus applied R&D; research spanning fundamental materials, device development, and new Gen3 CSP components and systems.
5. Some of the current slate of CSP projects appeared to have efficient and comprehensive addressing of research critical areas like high temperature storage, receivers, and power conversion.
6. The CSP program had uniform programs with focused goals, attention to real needs, and sharing of technical ideas.
7. For very modest funding levels compared to international governmental support and large private industry R&D, SETO remains active and relevant in worldwide CSP R&D communities. This is particularly true for supercritical CO<sub>2</sub> power conversion technology.
8. Some of the projects are well focused on industry-relevant problems and efforts and/or to overcome the key technical challenges or hurdles that are keeping advanced technologies from being commercialized.
9. The connection of the DOE SETO office to deep expertise in the national laboratories is beneficial for both SETO and the national laboratories.
10. The CSP program showed strong research results, particularly with the falling particle receiver and supercritical CO<sub>2</sub> equipment work.
11. Some of the projects incorporated meaningful techno-economic analysis.
12. The CSP program includes excellent fundamental R&D in supercritical CO<sub>2</sub> power conversion equipment with excellent industry (General Electric, Solar Dynamics, Southwest Research Institute) and national lab participation.



A corporate volunteer for GRID Alternatives helps to prep panels for an installation on a Habitat for Humanity development in Novato, California.

*Photo by Kate Costa.*

13. Most projects were rated highly in technical execution and had excellent PIs.
14. The traditional strength of DOE is innovative, early stage, next-generation technologies, e.g., molten salt thermal storage and power tower technologies.
15. Analysis tool development and experimental research at the national labs is well documented and is very useful.
16. The CSP program has ties to other federal agencies.
17. The CSP program has ties to state and national governments.
18. The CSP program has access to experienced, world-class scientists and know-how at national labs and U.S. universities.
3. DOE is falling behind on creating innovative, early stage, and next-generation CSP technologies.
4. The CSP program lacks a vibrant U.S. CSP market.
5. U.S. political commitment to CSP is lacking, and CSP contributions in energy security and economic vitality are not recognized.
6. DOE program managers need to take a more proactive role in projects by taking on additional responsibilities like industry outreach and helping to inform policymakers.
7. Industry has difficulty working with the national labs due to slow and complex contract requirements and administration.
8. Existing competition from large and rapidly improving PV and battery industries may overwhelm any new CSP technology (supercritical CO<sub>2</sub> power cycles, improved selective surfaces, etc.).

## Weaknesses

1. The CSP program lacks sufficient funding.
2. The level of economic analysis in a number of the CSP portfolio projects is poor. Most PIs simply default to saying something like “and this work will help achieve the SETO LCOE target,” but the supporting financial analysis is often very weak.
9. The overall pathway for commercialization of DOE SETO-funded technology is challenging. Some of the technologies are intended to be long-term (~10 year), high-risk efforts and will take a long time to commercialize. Shorter term projects that could be adopted more quickly do not have a clear pathway to follow-on SETO funding after the initial DOE SETO investment, particularly if the Technology to Market program is reduced or eliminated. The flow of technology out of a national laboratory or university into a company for commercialization faces many challenges, including the cost or availability of relevant expertise, equipment, and facilities, and/or the handling and availability of IP. Reducing barriers for national laboratory researchers to work more closely with companies, and benefit from the value creation of the commercialization process, would be very helpful.
10. The DOE SETO program is underfunded.
11. The research projects related to a Gen3 CSP system were very strong, but economics will be challenging relative to PV and batteries, even if stated cost reduction and LCOE goals are met.



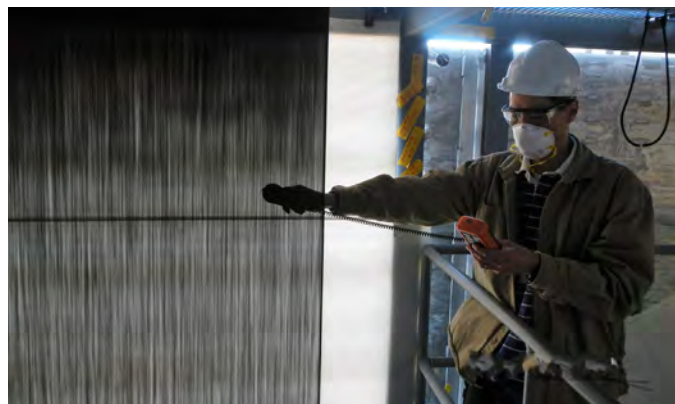
Early morning pattern of frost appears on the surfaces of these giant heliostat mirrors at Solar Reserve's Crescent Dunes facility in Tonopah, Nevada. The frost takes on the shape of the supports that hold each panel to the array, but quickly evaporates as the sun warms them.

*Photo by Ivan Boden.*

12. SETO CSP programs appear to be siloed in that a number of projects continue to look at systems as discrete components. There is a risk that the Gen3 CSP system will not be optimized if the component improvement opportunities are considered in isolation of each other.
13. Field conditions vary dramatically from site to site and are also dependent upon the quality of O&M. Actual site conditions are rarely ideal. A number of the projects may face significant challenges regarding implementation due to test and development conditions having little in common with fielded conditions.
14. Some of the work lacked enough innovation, or focused on old CSP technology like parabolic trough.
15. Obstacles stand in the way of collaborating with foreign governments and manufacturers.
16. Creating synergies across project teams is difficult.
17. The CSP program continues to be distracted by technologies that are either low technology readiness level (TRL) curiosities or have been shown to be impractical and that won't contribute to the SETO goal of lowering the LCOE for CSP systems—for example, anti-soiling mirror coatings and technologies (wires embedded in mirrors), marginal improvements to trough receiver intercept factors and wooden trough structures for process heat.
4. Investment in some areas (supercritical CO<sub>2</sub> turbomachinery, printed circuit heat exchangers) may leverage new start-ups in these areas in the United States.
5. World leadership in next-generation CSP and thermal storage systems is needed.
6. Enhance collaborations with foreign organizations (industry, research institutes, or cross-government research consortia).
7. Assist U.S. manufacturers (Echogen, GE) of supercritical CO<sub>2</sub> turbomachinery.
8. Obtain and/or protect our leadership position in emerging technologies (supercritical CO<sub>2</sub> turbomachinery, advanced CSP receivers and coatings, printed circuit heat exchangers).
9. Existing CSP technologies are at the temperature limits of existing power conversion and thermal storage equipment and materials. DOE SETO investment in high temperature materials and equipment are very important opportunities.
10. The United States has the opportunity to participate in the CSP market indirectly by developing advanced tools to support the design, construction, and operation of CSP plants to reduce costs and better

## Opportunities

1. A strong need for well-targeted investment in the present generation as well as in the next-generation CSP technologies still exists.
2. Lower temperature supercritical CO<sub>2</sub> cycles may be worth exploring further to eliminate the need for costly materials.
3. Investment in next-generation technologies may stimulate the revival of the U.S. CSP market and could foster the development of a U.S. manufacturing base of new Gen3 CSP system components.



This photo of a silhouetted falling particle curtain and engineer measuring light transmittance was taken on December 11, 2014, at the National Solar Thermal Test Facility in Albuquerque, New Mexico.

*Photo by Cliff Ho.*

integrate them with other parts of existing electricity and energy systems. There are opportunities around process heat, system integration (dispatching thermal storage), and forecasting.

11. Improve technology transfer from the national labs and utilization of existing tools and facilities at national labs.
12. Improve support of emerging technologies to industry (e.g., T2M).
13. Exert early influence over CSP and thermal storage before they become a critical portion of national energy infrastructure.
14. Support growth in areas of CSP where the United States is strong: technology development (patents), tool making/industrial engineering for foreign manufacturers, project development, finance, construction, and operations.
15. Collaborate with state and other national government agencies with common goals to pool intellectual and financial resources and implement common standards.
16. Match up industry stakeholders and project teams both in the United States and abroad.
17. Match up project teams and labs to foster synergies and promote shared resources.
18. Pare down projects that appear to have limited potential, such as higher temperature parabolic trough system development.

## Threats

1. The U.S. CSP program faces international competition with better financial, market, and industry support.
2. There is a very real possibility that the PV plus battery option may beat out Gen3's sophistication before a Gen3 prototype is even built.
3. The U.S. CSP program provides knowledge that benefits competitors in other countries because the

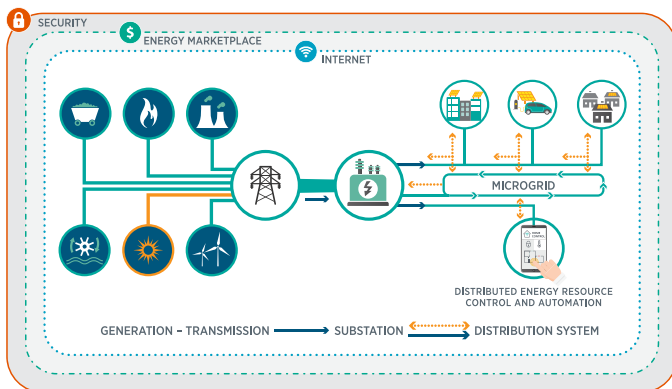
United States is shortsighted on the political side to make investments.

4. Because DOE shares responsibilities with subcontractors, the successes and failures of the subcontractors reflect the successes and failures of the DOE.
5. Funding for the CSP program is limited.
6. The amount of solar field component manufacturing in the United States is low and seemingly going lower.
7. The United States faces the threat of losing its leadership in advanced CSP technology due to lack of investment in cell R&D. The U.S. industry is beginning to lose its expertise around constructing new CSP power plants, which is impacting the relevance of R&D efforts.
8. DOE SETO programs in CSP may end up providing a bigger benefit to other countries that build CSP power plants and components.
9. The CSP program has little process heat emphasis. Continued investment in process heat, while controversial amongst the panel members, is recommended as industrial heat is still a large, albeit fragmented, amount of primary energy use.
10. Working with the national labs is difficult.
11. Technical expertise is being lost to other nations.
12. Increased or continued focus and funding for technologies shown to be impractical is counterproductive.
13. Loss of national/political will to use CSP as a method to achieve energy independence and reduce climate change will adversely affect the CSP program.
14. Cuts in DOE funding that cripple the national labs and shutter existing facilities like NSTTF or end support for and development of tools like the System Advisor Model threaten the CSP program.
15. Loss of downstream tech-to-market-type projects due to budget cuts will have ripple effects upstream.

# Systems Integration

The SETO's systems integration subprogram supports targeted technology R&D that addresses the technical challenges with achieving higher levels of solar penetration, while supporting a safe, reliable, secure, and cost-effective electric grid.

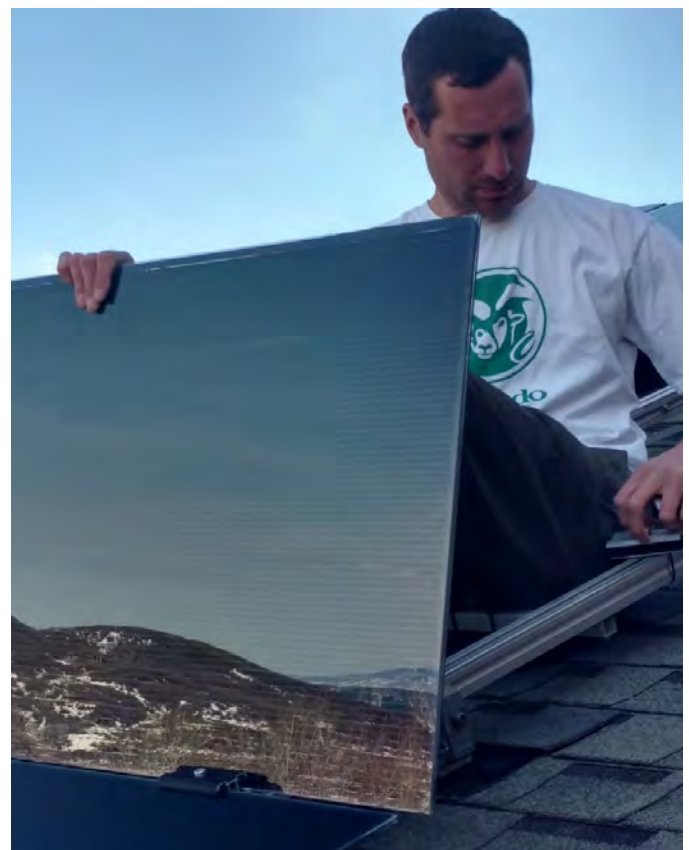
The installed cost of solar electricity has fallen significantly in recent years, spurring rapid and accelerating deployment of solar energy systems. Solar generation has gone from less than 0.1% of the U.S. electricity supply in 2010 to nearly 2% in 2017 with a total capacity of nearly 50 gigawatts. Furthermore, the penetration of solar is much higher in some states—reaching 13% of electricity in California in 2016, and more than 7% in Nevada, Vermont, and Arizona. The growth in solar power production emphasizes the need to develop timely and cost-effective technologies that ensure that solar energy contributes to enhancing the reliability, resilience, and security of the nation's electric grid.



The Systems Integration subprogram works to make solar energy more dispatchable, enabling its use regardless of whether the sun is shining. Projects are working to advance technology that integrates solar with energy storage, as well as building loads, to better match solar energy supply with demand. As the amount of grid-connected solar continues to increase, these solutions

will significantly contribute to cost effective and reliable integration of solar generation.

Systems integration projects also address challenges presented by increasing amounts of solar generation by improving general planning and operation for grid operators with high penetrations of solar. Two-way power flow, coordination of protection devices, transmission-distribution interaction, and reduction in system inertia related to high penetrations of solar electricity are all being addressed by projects in the portfolio.



An installer places thin film solar panels in Steamboat, Colorado.

*Photo by Ian Skor.*

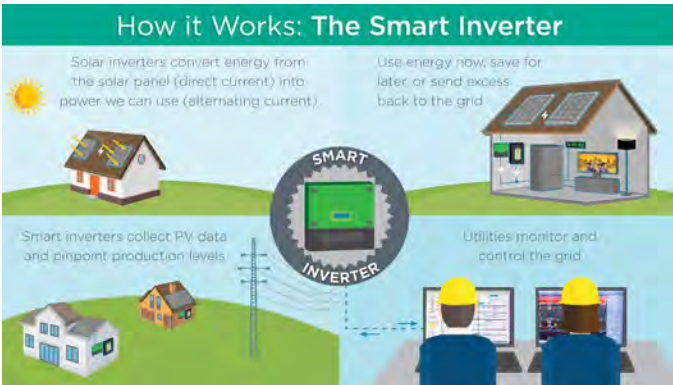




Solar installer installing a rooftop 36-kilowatt electrical PV installation for Reach Ashland Youth Center, a Leadership in Energy and Environmental Design (LEED) Platinum Certified building in Alameda County.

Photo by Ernesto Montenero.

Power electronics devices, such as inverters, serve as the critical link between solar photovoltaic arrays and the electric grid. Systems integration projects target advances in these technologies that will ultimately help the grid become more reliable, secure, and resilient, including projects that enable advanced grid services, such as the ability to detect and respond to fault events and help to efficiently recover from grid outages.



Active Funding Programs

Funding Program	Year Announced	Amount Awarded (million)
Solar Forecasting 2	2017	\$12
Resilient Distribution Systems Lab Call (RDS Lab Call)	2017	\$10
Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE)	2017	\$30
Grid Modernization Lab Consortium (GMLC)	2016	\$5
Sustainable and Holistic Integration of Energy Storage and Solar Photovoltaics (SHINES)	2016	\$18
SunShot National Laboratory Multiyear Partnership (SuNLAMP)	2015	\$59

A panel consisting of nine subject-matter experts reviewed the 37 active projects within the systems integration subprogram. The panel developed the following strengths, weaknesses, opportunities, and threats analysis to assist SETO in the future direction of the subprogram.

# Systems Integration Strengths, Weaknesses, Opportunities, and Threats Analysis

*This list is condensed from reviewer evaluations given at the 2018 Peer Review by the Systems Integration subprogram Chairperson.*

## Strengths

1. Some of the strengths of the program are also its weaknesses: Several of the projects overlapped in scope, duplicating work on the same issues, but differ in their proposed approaches. However, this diversity of thought is healthy in that it provides a number of possible solutions to the same questions.
2. The partnership with industry is key to providing meaningful guidance to the project work, and the effective engagement with end-users of the developed technology allows the work to be incorporated in the real world.
3. Most of the projects are guided by a larger roadmap with clear objectives and targeted performance metrics.



The newly constructed substation at the 43-megawatt Bladenboro, North Carolina, solar facility. The background shows sub-arrays that are feeding the substation. The foreground shows both the low-side and the high-side of the last part of the project before energy injects to the grid.

*Photo by Riley Harwood.*

4. Extensive use of open-source software and open data repositories for analytics can make the work extensible for future R&D.

## Weaknesses

1. Several of the projects overlap in scope and objectives. This is duplicative of efforts and should be discouraged when observed.
2. Several projects are aimed at optimization but lack the scope of vision to accomplish that goal on other than a distribution feeder basis.

## Opportunities

1. After initial findings, several projects could be encouraged to combine efforts, particularly the feeder optimization efforts and the optimization of communications and metering along the feeders. This combination could be very powerful, bringing the best efforts on the communications and metering together with the analytics. Only a couple of projects were of sufficient scope of vision across the electric system to realize that on their own.
2. Integration with existing transmission and distribution planning software, where practical, is highly desirable to ensure acceptance by the industry.

## Threats

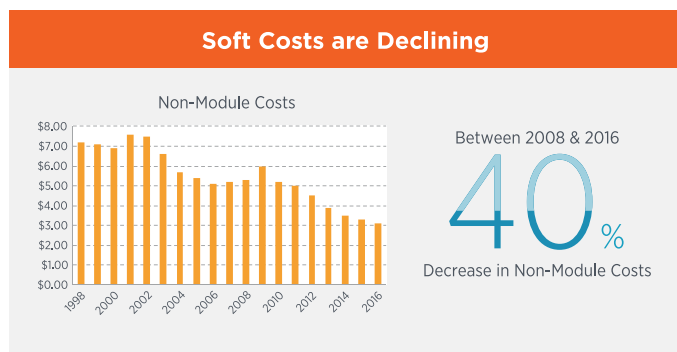
1. The cyber security threat of common access points and common-mode attacks is heightened by the assumption that all or most PV units need to be accountable on a per unit basis. Some additional thought should be given to cohesively designed, autonomous acting controls.

# Soft Costs

The SETO's balance of systems soft costs subprogram works to address challenges associated with non-hardware costs of solar electricity, reduce the regulatory burden of adding solar to the grid, and identify technology-neutral pathways that provide affordable and reliable solar electricity to American consumers. For residential systems, soft costs account for nearly 70% of the total cost of a new solar system. This includes financing, customer acquisition, supply chain costs, permitting, installation labor, and sales taxes, as well as developer overhead and profit.



The underlying causes of solar soft costs include the perceived risk associated with new technology, emerging business models, and the rapid introduction and growth of DERs. These challenges are layered into an energy market landscape with differing policies and regulations from state to state, many of which have not been updated and do not yet accommodate changes in resilience, reliability, consumer choice, digital and communications



functions, and increased coordination and competition among technologies. Many of these challenges can be effectively overcome by addressing information gaps.

Projects managed by the soft costs subprogram fall into three categories:

**Foundational research, data, and analysis:** This work aims to conduct high-impact analysis that can reduce soft costs for solar, while simultaneously creating new methods for conducting research and analysis, including agent-based modeling, machine learning, and other advanced data approaches. When possible and practical, real-world data is used to improve the quality and relevance of analyses. The tools and results of these analyses are used to inform activities across SETO.

**Institutional support:** Innovation in the solar industry happens at a fast pace. Soft cost programs integrate insights from studies of the science of innovation, as well as analysis of emerging business models and market impacts, to examine the results of ground-tested new program and policy strategies for state and local governments. These impacts cross the boundaries of utility, business, financial, policy, and regulatory issues. This work supports the exchange of new insights and lessons learned that continue to help the energy sector adapt in a period of rapid change.

**Training:** More than 250,000 people are employed by the solar industry, a number that has nearly tripled since 2010. More training opportunities are required to ensure a technically skilled workforce that is capable of modernizing our electric grid to handle increasing amounts of solar energy. SETO has supported the development of new certifications to fill the need for third-party validation of the skills and competence of the workforce. As more utilities add solar energy and require employees who have the knowledge of renewable energy integration, SETO has supported training programs at universities to train the next generation of engineers to

handle a rapidly changing grid. SETO also supports solar training for professionals in related fields like design, real estate, and finance. These training opportunities will ensure that solar energy has a stable supply of qualified professionals and supports American competitiveness.



Silicon solar wafers move down a conveyor belt following a quality check.

*Photo by Laureen Sanderson.*

## Active Funding Programs

Funding Program	Year Announced	Amount Awarded (million)
Solar in Your Community Challenge	2017	\$5
Solar Energy Evolution and Diffusion Studies 2 – State Energy Strategies (SEEDS2-SES)	2016	\$21
Solar Training and Education for Professionals (STEP)	2016	\$10
Orange Button <sup>SM</sup> - Solar Bankability Data to Advance Transactions and Access (SB-DATA)	2016	\$3.6
Solar Powering America by Recognizing Communities (SPARC)	2015	\$13
Solar Market Pathways	2015	\$16.5
SunShot National Laboratory Multiyear Partnership (SuNLaMP)	2015	\$24
Grid Engineering for Accelerated Renewable Energy Deployment (GEARED)	2013	\$15
Solar Utility Networks: Replicable Innovations in Solar Energy (SUNRISE)	2013	\$8

A panel consisting of 21 subject-matter experts reviewed the 56 active projects within the balance of systems soft costs subprogram. The panel developed the following strengths, weaknesses, opportunities, and threats analysis to assist SETO in the future direction of the subprogram.

# Soft Costs Strengths, Weaknesses, Opportunities, and Threats Analysis

*This list is condensed from reviewer evaluations given at the 2018 Peer Review by the Soft Costs subprogram Chairperson.*

## Strengths

1. Some current project awards support educating the public about the benefits of solar.
2. SETO provides funding for projects that industry will not support or that cut across too many constituents for individual companies to support (such as expedited permitting and interconnections). SETO should invest more in these types of projects.
3. SETO has awarded projects to regions, cities, or states that could serve as model programs to others. Such funding provides good role models for others to learn from and emulate.

## Weaknesses

1. There is an opportunity for much greater knowledge transfer of SETO-funded projects, both lab research and private projects (many of which are focused on deliverables but not on public outreach and communication of results).
2. In some cases, similar projects are funded in different geographic areas. There would be value in linking similar projects and/or requiring them to communicate and compare results.
3. Funding awards often seem not to take into account the viability and sustainability of projects without future or ongoing funding.
4. Clear dollars per watt reduction metrics for project awards have not been established.
5. Current projects are often funded without sufficient focus on their social science aspects. It is difficult to reduce complex, human-related issues like soft costs without such a focus.



Final connections and troubleshooting are addressed on the 123-kilowatt solar electric system at the Wayne Aspinall Federal Building in Grand Junction, Colorado.

*Photo by Scott Ely.*

6. National labs are not required to bear a significant enough cost-share portion of their funding, which leads to their over-reliance on theoretical research as opposed to practical results.

## Opportunities

1. Encourage much greater use of social media to communicate outcomes and results of funded projects. This is the preferred communications mechanism for the president and increasingly, all aspects of public life. SETO should be less reticent to use it.
2. SETO needs better assessments of the value delivered from funded projects. For instance, SETO should require projects to confirm quantitatively how their project and budget was worth SETO's investment and benefited the public trust.
3. Cross-link similar projects in different geographies and communicate lessons learned and other knowledge gained so that all geographies can benefit from what was learned.

4. SETO should publish a public catalog with hyperlinks to the results of all projects. Many of the lab projects were especially more focused on dry research vs. communication of results.
5. Give funding preference to projects that have the potential to become self-sustaining vs. those that will not be without ongoing support (however, projects do not have to be profitable to meet this bar).
6. Establish clear metrics for the contribution each project will make in reducing costs per watt since that is the overall objective.
7. Focus on reducing solar payback costs to reach a larger proportion of the population and counter the view that “solar is for rich people.”
8. Provide greater future support for broad, cross-functional efforts such as expedited permitting and streamlined utility interconnections that benefit all stakeholders and for which the government is really the only vehicle that can mandate change.
9. Ensure that DOE/SETO’s perceptions of project awardee benefits are aligned with those of the projects themselves and establish clear metrics for measuring and ensuring this alignment.
10. Be more proactive in funding projects that target simplification of regulations and policies that stand in the way of expedited processes (such as permitting and interconnections). This would seem to be very much in keeping with the administration’s objectives to reduce regulation.
11. Increase future funding for projects that work to integrate all the many complex interactions of the “new” grid: distributed resources, increased resiliency, energy storage, electric vehicles (EV), and American made. Invest in the technical depth necessary to integrate and synthesize these resources.
12. When funding projects targeted at the low- and moderate-income (LMI) community, be cognizant that those communities are not monolithic—it’s urban vs. rural, young vs. seniors, multifamily vs. single-family homes, etc. Require awardees to be clearer about the benefits to these constituent groups if they are targeting a segment of the LMI community.
13. Support future projects targeted at elementary schools, middle schools, high schools, and technical schools in addition to universities (which seems to have been the focus of prior awardees). Consider targeting projects that educate or work with school board officials as they are enormously influential in their communities and have relationships with other public officials who can enact change to reduce soft costs.
14. Support future projects focused on community solar, one of the best ways to provide benefits to all constituents including the low- and moderate-income community.
15. Require all projects (especially lab research projects) to include a social scientist or quantitative social science results. Social scientists and their quantitative methods (control groups, comparatives, quantitatively designed surveys, clear metrics,



Sunsense solar technicians wire string inverters at the 234-kilowatt solar PV array powering the water treatment facility for the Town of Silt, Colorado.

*Photo by Scott Ely.*



Five crews are installing solar modules on a new 75,000 square-foot PowerParasol for a Fry's Food Store in Phoenix. The patented PowerParasol provides both clean power and nearly two acres of shaded parking plus signage opportunity for the customer.

*Photo by Michael Nothum.*

and results measurement) are crucial to reducing complex, “human-touch” issues like soft costs.

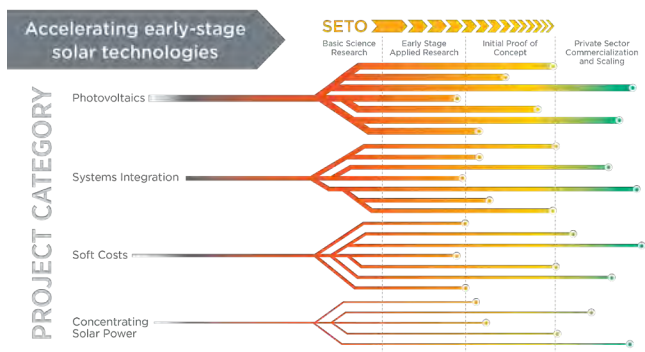
16. Since soft costs by their nature are bedrock, close-to-the-public issues, more project funding for soft costs should be directed to local and regional efforts and less to laboratory research.
17. Require all projects to conduct stakeholder surveys or interviews at the outset (and establish metrics they must meet in their milestones) to have a benchmark against which to measure the results of the project later. It's difficult to measure progress if you don't know where you started from.
18. Fund some “long thread” ideas or projects that will require multiyear or even multi-cycle funding efforts to become established. Government is in the best position to fund such efforts, and there should be a clear idea at the start of each project, both of its horizon (how long it will take to achieve meaningful results) and its sunset (when those results can be measured and quantified).
19. Fund future projects focused on solar plus storage because it is clear this capability is one of the most important mechanisms to support grid resilience, dispatchable renewable power, and energy independence. The soft costs in this new combined PV+EV world are even more complex and expensive than they are for PV alone. SETO should get ahead of the curve.
20. Fund future projects that bring together elements of solar and EV. EVs will eventually provide two-way resources (vehicles to grid) and therefore, will become a static resource to the grid as opposed to just an element of transportation infrastructure alone (this may require linking some efforts with the U.S. Department of Transportation).
21. Fund future projects in workforce development, especially for electricians (one of the highest paid jobs in construction but also one that is in the shortest supply), fire marshals and fire officials, and building code officials. All of these personnel are at the core of reducing soft costs in permitting, inspections, and installation.
22. Emphasize the benefits of soft cost reduction as reduced regulation and costs, improved grid resiliency, and improved job prospects and employment.
23. Increase opportunities for competition among awardees (for instance, hold contests in soft cost reduction among awardees) to create a competitive landscape that encourages everyone to get better faster (similar to how the competitive landscape functions in industry).

## Threats

1. The political climate and gridlock in Washington creates discontinuity of public policy.
2. The United States is the only country in the world not to participate in the Paris Climate Accords.
3. Solar could be adversely affected by increased tariffs on key elements of the solar value chain (modules, steel, aluminum).

# Technology to Market

The SETO's T2M subprogram funds projects that develop and validate groundbreaking, early-stage technology and business models to strengthen concepts and develop a path to accelerate innovations to the market. Also known as Innovations in Manufacturing Competitiveness, the T2M subprogram targets funding gaps that occur at the pre-prototype and pre-commercial stages of industry R&D. Historically, projects have focused on photovoltaics, photovoltaics system components, CSP and power electronics technologies, as well as innovations to reduce soft costs such as financing, interconnection, and O&M.



Technological innovation in the solar industry can lower the cost of solar energy for more consumers. However, it's not always easy for new ideas to surmount the barriers to commercialization. That's where the T2M subprogram has been helping, providing technical assistance and financial resources that allow companies to conduct research, develop practical applications for their concepts, then conduct testing and validation of their models with the long-term goal of creating a commercially viable product.

T2M projects that work to improve solar hardware cover a wide range of technologies: individual components of a solar panel or concentrating solar power plant, inverters that allow solar panels to feed energy back into the electricity grid, and the racking structures found on rooftops and utility-scale solar installations. Over



Solar installer laying out conduit after solar panels have been installed on a home.

*Photo by Kristelle Batucal.*

the course of a project, awardees determine the best applications for specific hardware, develop it from a concept into a prototype, test its ability to function in representative real-world settings, and define a potential path to the market so the hardware can play a critical role in reducing the cost of solar-generated electricity.

Cutting-edge R&D also helps the solar industry to reduce the cost of manufacturing solar technologies. T2M projects de-risk both near- and long-term innovations that can build a strong solar energy manufacturing sector and supply chain in America, while producing cost-competitive solar products that keep pace with the rising domestic and global demand for affordable solar energy.

Through fiscal year 2017, one annual funding program under T2M encompassed projects at all stages of technology development with the goal of developing pathways to commercialization for disruptive innovation.





A GRID Alternatives volunteer helps with a solar installation on the Bishop Paiute reservation in California.  
Photo by Kate Costa.

In addition, the subprogram provides funding for solar projects in other program offices throughout the DOE:

- The Small Business Innovation Research and Small Business Technology Transfer program encourages U.S.-based small businesses to engage in high-risk, innovative research and technology development with the potential for future commercialization.
- The Small Business Vouchers pilot program gives small businesses access to support from national lab researchers in a draw down voucher format, which helps companies overcome critical technology and commercialization challenges by leveraging lab expertise and capabilities.
- The Technology Commercialization Fund is designed to increase the number of energy technologies developed at DOE's national labs that graduate to commercial development and achieve commercial impact by pairing lab innovators with the private

sector in order to facilitate technology transition to the private sector.

- The Innovative Pathways program is developing new means by which to attract private capital earlier in the technology development cycle to reduce needs for government funding.

## Active Funding Programs

Funding Program	Year Announced	Amount Awarded (million)
Innovative Pathways	2017	\$3.5
SunShot Technology to Market 3 (T2M3)	2017	\$25
Small Business Voucher Pilot (SBV)	2016-2017	\$1
Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR)	2009-2017	\$39
Technology Commercialization Fund	2016-2017	\$2
SunShot Technology to Market 2: Incubator 11, SolarMat 4 (T2M2)	2016	\$25
SunShot Technology to Market: Incubator 10, SolarMat 3, SunPath 2 (T2M1)	2015	\$23
SunShot National Laboratory Multiyear Partnership (SuNLAMP)	2015	\$3
Solar Manufacturing Technology 2 (SolarMat 2)	2014	\$24
Photovoltaic Manufacturing Initiative (PVMI)	2011	\$110

A panel consisting of 13 subject-matter experts reviewed the 48 active projects within the T2M subprogram. The panel developed the following strengths, weaknesses, opportunities, and threats analysis to assist SETO in the future direction of the subprogram.

# Technology to Market Strengths, Weaknesses, Opportunities, and Threats Analysis

*This list is condensed from reviewer evaluations given at the 2018 Peer Review by the Technology to Market subprogram Chairperson.*

## Strengths

1. Photovoltaics – The T2M team felt the focus on cost reduction was very evident.
2. Systems Integration – All projects appeared to address one or all of the reliability, resilience, and recovery themes.
3. Soft Costs – This set of projects appeared to enable reduction in regulatory barriers as well as reduce cost.
4. U.S. jobs and manufacturing looked likely in many projects.
5. A SETO project award, particularly a successful one, is viewed as a conduit for other angel/venture capital (VC)/private equity investment.
6. Strong collaboration and stakeholder involvement is evident in certain projects.
7. Strong market adoption opportunities exist in some projects.

## Weaknesses

1. TRLs and project commercialization details are not articulated well in most cases.
2. In many cases, the PIs can't adequately explain the deliverables or the connection to a market need or opportunity.
3. Lack of progress towards project goals is not assessed well. Sometimes it looks like PIs changed direction without bringing the goals back to the original deliverables.
4. Concentrating Solar Thermal Power – While the T2M reviewers acknowledged the potential for storage



An investor checks out a mobile solar array at Powerhouse Circle, a speed dating event for clean energy startups and investors. Taken in San Francisco, California. Photo by Anna Cheyette.

solutions here, the fit for market reliability, resilience, and recovery is difficult to grasp. The T2M reviewers do not understand how the technology-to-market planning is being done in this portion of the portfolio.

5. The PIs' connections to other resources such as state-level help in entrepreneurial resource centers, pilot sites, logistics planning, and supply chain isn't clear.

## Opportunities

1. The teams could use specific mentorship for the PIs.
2. Project mentorship and resource brokering for the teams similar to those used in incubator facilitation might be helpful. T2M is best deployed when interpreted as T2M validation. As the work progresses on each project, the idea is to continually

“check in” that the project has commercial merit and is contributing to grid reliability, resilience, and recovery.

3. In Soft Costs, a continued overall look at cost and regulatory reduction is also important, as the project needs to “fit in” ultimately to a better contribution of renewables to the national energy supply.
4. Where significant project redundancy or overlap exists, the SETO teams should consider using project rankings to justify less spending on lower ranked projects.
5. Reaching out to Department of Transportation or to DOE’s Building Technologies Office may help some teams understand how their target market segment is realized.

6. International collaboration probably makes sense on the PV portion of the program, if only to keep the technology roadmap current.
7. Regarding market deployment, more could be done to get the PIs and teams in front of VCs to help spur interest on further funding of the projects after and during project execution of the DOE-specific goals. It may take the form of some project monies being spent on commercialization training of the PIs, such as presentation skills, knowledge of entrepreneurial resource centers, pilot sites, logistics planning, and supply chain.
8. The emphasis on validation of technology in the marketplace is extremely important in the latter stages of the individual projects. Demonstrating that technologies are marketable provides the performance, cost, and critical application information needed to inform decision makers. Market barriers can in most cases be identified earlier in the project.

### Threats

1. Rapid maturation of the incumbent technologies makes it hard to break into the market with new ideas or projects.
2. The barriers of reliability proof or bankability continue to be a challenge for many of the projects and can kill them before market entry.
3. International trade conditions can make it hard for industry to collaborate and optimize supply chains for raw goods.
4. The changing market relevance for parts of the value chain presents an ongoing challenge, particularly in soft costs, which comprise many components of the value chain.



The clouds perfectly frame this New Hampshire solar PV install.

*Photo by Sue McConnell.*

The background of the page is a vibrant orange color. On the left side, there are several diagonal, overlapping bands of a lighter yellow-orange hue, creating a sense of depth and movement. Scattered across the orange background are several semi-transparent, circular shapes in various shades of yellow and orange, resembling bokeh or light effects. The word "Appendix" is written in a clean, white, sans-serif font in the upper right quadrant of the page.

# Appendix

# List of Reviewers

**Acharya, Sumanta**

Illinois Institute of Technology

**Arfin, David**

First Energy Finance

**Asgeirsson, Haukur**

IEEE

**Attanasio, Donna**

George Washington University

**Bailey, Chris**

38 Degrees North

**Bartholomeusz, Brian**

Stanford University

**Bartholomy, Obadiah**

Sacramento Municipal

Utility District

**Bergemann, Crystal**

U.S. Department of Energy

**Bernfeld, Gary**

Wells Fargo

**Bobruk, Jason**

SolarEdge

**Brandt, Yann**

Consultant

**Branz, Howard**

Consultant

**Burkholder, Frank**

Galvanize, Inc.

**Buzzell, Greg**

New Resource Solutions

**Carlson, Dave**

Consultant

**Ching, Colton**

Hawaiian Electric Company

**Cinnamon, Barry**

Cinnamon Solar

**Conejo, Antonio**

The Ohio State University

**Cummings, Bob**

North American Electric

Reliability Corporation

**Cunningham, Danny**

Advanced Research Projects

Agency-Energy

**Daniels, Eric**

SunCycle

**De Ceuster, Denis**

First Solar

**DiFelice, Ronald**

Energy Intelligence Partners

**Du, Pengwei**

Electric Reliability Council

of Texas

**East, Daniel**

Solar City

**Ebong, Aba**

University of

North Carolina Charlotte

**Forbess, Jessica**

Sunshine Analytics

**Fredric, Chris**

Consultant

**Fu, Jianming**

Enova Technology

**Gee, James**

JMG Solar

**Good, Ethan**

SunEdison

**Gould, Bill**

SolarReserve

**Hall, Doug**

Hall Solar Consulting

**Hamadani, Behrang**

National Institute of

Standards and Technology

**Healey, Ben**

Clean Energy Finance at

Connecticut Green Bank

**Hemmeline, Charlie**

Texas Solar Power Association

**Jaramillo, Rafael**

Massachusetts Institute

of Technology

**Kazmerski, Larry**

University of Colorado Boulder

**Kohli, Pranay**

Amidus, LLC

**Koza, Frank**

Retired

**Kriz, Sarah**

Consultant

**Lior, Noam**

University of Pennsylvania

**Mattson, Brad**

Siva Power

**Mazur-Stommen, Susan**  
India Consulting

**Meydbray, Jenya**  
Cypress Creek Renewables

**Mints, Paula**  
SPV Market Research

**Nielson, Greg**  
Vivint Solar

**Norris, Chris**  
Aurinko Group

**Noufi, Rommel**  
Consultant

**Palmquist, Michael**  
SolarNexus

**Passow, Kendra**  
First Solar

**Pereira, Joseph**  
Colorado Energy Office

**Phillips, Nancy**  
DuPont

**Previtali, Jon**  
Wells Fargo

**Rajendran, Veera**  
Equipment Technologies

**Rand, Jim**  
Consultant

**Reichert, Emily**  
Greentown Labs

**Sachs, Ely**  
Massachusetts Institute  
of Technology

**Schwabe, Ulrich**  
Schneider Electric

**Sharps, Paul**  
SolAero

**Shisler, William**  
NRG

**Siegel, Nathan**  
Bucknell University

**Sklar, Scott**  
Consultant

**Stephens, Scott**  
NRG

**Thurlow, Aaron**  
SolFuture, LLC

**Tong, James**  
Advanced Grid Consulting

**Venetos, Milt**  
Wyatt, LLC

**Walton, Marsha**  
New York State Energy  
Research and Development  
Authority

**Walz, Ken**  
Madison College

**Wayne, Gary**  
Consultant

**Weiss, Dirk**  
First Solar

**Wentworth, Claudia**  
Quick Mount PV

**Widergren, Steve**  
Pacific Northwest  
National Laboratory

**Yuhas, Frances**  
TurningPoint Energy

**Zhao, JC**  
The Ohio State University

# Analysis Methodology

For all projects, reviewers were given four evaluation criteria and asked to score criterion 1–4 on a 1–4 scale, with four being the highest. In addition to numeric scores, reviewers were asked to provide qualitative comments and feedback regarding the project’s strengths and weaknesses, and any suggestions relating to the scope of the work. Reviewers were also asked to evaluate the value of the deliverables to the target audience/market and whether the key research areas/deployment activities relevant to the project scope are receiving sufficient emphasis. Please refer to the Project Evaluation Form on page 48 for full evaluation criteria.

Scores were based on the following criteria and weights:

**Score 1:** Relevance (stand-alone metric) - Degree to which the project supports SETO’s goals to drive down the costs of PV and CSP electricity toward 2030 cost targets and support the reliability and resilience of the U.S. electric grid. (*Note: this metric is not included in the weighted score for each project, as it does not reflect on the performer of the work.*)

**Score 2:** Approach (40%) – Degree to which the project’s design addresses the technical or market challenges identified. (20%), and degree to which the project is differentiated from current research performed outside of DOE Support. (20%).

**Score 3:** Accomplishments/Progress/Impact (40%) – Degree to which the project has supported the achievement of the stated *SETO performance goals* (provided in supplemental document).

**Score 4:** Project Integration and Collaborations (20%) - Degree to which the project staff collaborates or coordinates with relevant industry or other stakeholders.

For each project, relevance was assessed as a standalone metric. The other four criteria were used to calculate a weighted average.

# Project Evaluation Form

This evaluation form was used by reviewers to provide ratings and comments for projects showcased at the 2018 Solar Energy Technologies Peer Review.

## **A. Relevance (stand-alone metric):**

**Degree to which the project supports SETO's goals to drive down the costs of PV and CSP electricity toward 2030 cost targets and support the reliability and resilience of the U.S. electric grid.**

1. Poor - Project provides little or no support to SETO's goals.
2. Fair - Project provides some support to SETO's goals.
3. Good - Most project aspects align with SETO's goals.
4. Outstanding - Project is critical to SETO and fully supports SETO's goals.

*Comments on Relevance:*

## **B. Approach (40%):**

**Degree to which the project's design addresses the technical or market challenges identified. (20%)**

1. Poor - Project is unlikely to contribute to overcoming the challenges.
2. Fair - Has significant weaknesses; but may have some impact on overcoming challenges.
3. Good - Generally effective but could be improved; contributes to overcoming most challenges.
4. Outstanding - Clear focus on overcoming critical challenges; difficult to improve the project approach.

**Degree to which the project is differentiated from current research performed outside of DOE Support. (20%)**

1. Poor - Project is repeating efforts performed by other institutions.
2. Fair - Project is addressing unsolved research questions with an approach moderately distinct from previous approaches.
3. Good - Project is expanding efforts started by other organizations in new directions.
4. Outstanding - Project has an innovative approach that is substantially distinct from work by other organizations

*Comments on Approach:*



## **C. Accomplishments/Progress/Impact (40%):**

Degree to which the project has supported the achievement of the stated *SETO performance goals* (provided in supplemental document). Note: New projects should be scored in relation to the length of time the project has been active.

1. Poor - Little or no demonstrated support, either quantitative or qualitative, for the achievement of the SETO performance goals.
2. Fair - Modest qualitative support for the project's contribution to the stated SETO performance goals.
3. Good - Strong qualitative and some quantitative support of the project's contribution to the stated SETO performance goals.
4. Outstanding - Excellent, Strong qualitative and quantitative support for the project's contribution to the SETO performance goals.

*Comments on Accomplishments/Progress/Impact:*

## **D. Project Integration and Collaborations (20%):**

Degree to which the project staff collaborates or coordinates with relevant industry or other stakeholders.

1. Poor - Most work is done at the sponsoring organization with little outside collaboration or coordination.
2. Fair - Collaboration and coordination exist, but could be significantly improved.
3. Good - Good collaboration exists; partners are fairly well coordinated.
4. Outstanding - Close, appropriate collaboration with industry and/or other institutions; partners are full participants and are well coordinated.

*Comments on Project Integration and Collaborations:*

Please substantiate your score with comments about the project's strengths:

Please substantiate your score with comments about the project's weaknesses:

Please offer any additional recommendations you have for the project:

How would you rate the value of the project outputs produced by the project to the key target audience(s)/market(s) of the program?

High  Average  Low

*Explain:*

Are the key research areas/deployment activities relevant to the project's and program's objectives receiving sufficient emphasis?

Yes  No

*Explain:*

# Reviewer Evaluation

## on Projects' Impact on SETO Goals

SETO solicits input on its projects via an annual peer review process to ensure projects are relevant, effective, and productively assisting the Office in meeting its goals. Independent review is an important part of SETO's overall portfolio management process, as it provides alternative viewpoints from leaders in industry and academia on current project activities and strategies. Reviewers that participate in peer review evaluate projects and provide crucial, targeted feedback on progress-to-date as well as proposed future work. This feedback informs SETO's understanding of its portfolio's approach, effectiveness, and potential impact from current investments in technology research and development, validation and verification, and other related activities.

# Photovoltaics

**Project Title:** Collaborative Atomic-Scale Design, Analysis, and Nanofabrication for Record Breaking, Single-Crystal Cells

**Award Number:** 05958

**Principal Investigator:** Zubia, David, University of Texas at El Paso

**Project Description:**

This project allows researchers to use Los Alamos National Laboratory's Center for Integrated Nanotechnologies facility to create a molecular dynamics simulation capability to address fundamental barriers to achieving high open-circuit voltages in cadmium telluride or cadmium sulfide solar cells.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is a fundamental study that supports a major need established by First Solar--relating to CdTe Solar Cells. The study links a university with a national laboratory to address these grain boundary studies in a novel manner. Though the First Solar PV cells have been demonstrated by them in the efficiency range of 22%, there is a gap between that and commercial (and champion) modules of about 6%. This work on grain boundary material issues is aimed to address this gap.

*Reviewer 2:*

The ability to model and simulate grain boundary growth and conditions has applicability to a wide range of PV crystalline growth challenges. Beyond the direct focus on CdTe-based heterostructures in the project, it's also applicable to III-Vs and perhaps metallization technology.

*Reviewer 3:*

The project is focused on providing a simulation tool, the utility of which is verified by experimental data, to guide polycrystalline and epitaxial growth of CdTe films with minimized mobile defects, detrimental grain boundaries, and crystal orientation. In principle, the simulation tool will enable the engineering of grain bulk and benign grain boundaries, influence high symmetry planar defects by the substrate, in order to control the film defect morphology. Knowing the mechanisms of how defects are created in CdTe during growth and quantifying their mobility will enable the control of growth of these defects. The latter will lead to control of the defects and hence character of grain boundaries, hopefully leading to high efficiency. This thrust is aligned with at least one of the SETo Performance goals.

**Project Title:** Reliable and Large Organic Solar Cells on Flexible Foil Substrates

**Award Number:** 06708

**Principal Investigator:** Forrest, Stephen, University of Michigan

**Project Description:**

This project is advancing the practical viability of organic photovoltaics by demonstrating reliable, large area, and high-efficiency organic multi-junction cells based on small molecule materials systems. The project aims to demonstrate multi-junction organic solar cells with efficiencies of higher than 18 percent, extrapolated cell lifetimes exceeding 20 years, ultra-rapid organic film deposition on continuous rolls of foil substrates, and roll-to-roll application of package encapsulation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The potential for inexpensive semi-transparent organic PV based upon small molecules is strong, based upon this work. The project is also addressing the critical encapsulation problem to ensure long enough lifetimes for such applications.

*Reviewer 2:*

The work is fantastic, and may have commercial impact. The PI is actively commercializing the technology for building-integrated PV. In the context of this review, it must be pointed out that OPV - even world-beating technology such as that developed here - is not of clear relevance to the SETO goals. Hence the low Relevance score.

*Reviewer 3:*

Organic PV had extremely high promise and a wealth of research groups and industry involved with the technology hope. This has been the best-of-the-best on the R&D side--and DOE has kept a focus on the technology and possible rebirth by investment in this very good program. Although the interest has shifted to other emerging materials, there is a danger of abandoning OPV too early. Thus, the continued support of this high-level program has relevance. The "last bastion of excellence" in organic solar cell research in the U.S.

**Project Title:** Developing Efficient Perovskite and Silicon Tandem Devices

**Award Number:** 06709

**Principal Investigator:** Huang, Jinsong, University of Nebraska

**Project Description:**

This project is developing tandem junction solar cells with organo-lead trihalide perovskites, using high-efficiency perovskite cells as the top cell and crystalline silicon cells as the bottom cell. Project investigators are creating a novel top cell system that is compatible to the bottom high-efficiency crystalline silicon solar cell. The original design will boost the power conversion efficiency of silicon solar cells with minimal cost increases.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The goal of increasing Si PV efficiency with a low-cost tandem coating is clearly relevant to SETO goals. The PI on the project is a leader in halide perovskite PV, and the work of this project is important to the PV research community worldwide.

The lack of emphasis on device stability is a concern. This dilutes somewhat the relevance of this work to SETO goals.

*Reviewer 2:*

Perovskites are among the high priority materials for the DOE SunShot--and tandems provide some important attributes for bringing this technology on board more quickly. This program is aimed at demonstrating efficient tandems that are among the goals of SETO.

*Reviewer 3:*

This is an excellent program, quite relevant to SETO's goals. Terrific!

**Project Title:** Rapid Development of Hybrid Perovskites and Novel Tandem Architectures

**Award Number:** 06710

**Principal Investigator:** Hillhouse, Hugh, University of Washington

**Project Description:**

This project is developing high-bandgap hybrid perovskite materials and a novel two-terminal monolithic tandem device architecture that are capable of reaching power conversion efficiencies of higher than 25 percent. Researchers are rapidly discovering compositions and processing conditions that yield high-optoelectronic-quality hybrid perovskite films with the ideal bandgap to pair with record efficiency copper indium gallium selenide and copper zinc tin sulfide selenide absorbers. In addition, the team is engineering stable and efficient electron transport materials, hole transport materials, and interfaces to achieve better band alignment and passive interfaces for the hybrid perovskite top cell, as well as developing alternative structures and recombination layers to facilitate the fabrication of a tandem structure.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Halide perovskites (HP) offer the chance to improve the efficiency of established PV technologies by several percent - absolute - with low-cost coating to make two-terminal tandems. This is a high-risk, high-reward research direction that is clearly relevant to SETO goals. This project is one of several that are supported by SETO in pursuit of this goal.

*Reviewer 2:*

Tandem cell has proven over decades to not be cost effective. There is not a single surviving tandem cell company that has survived with the exception of perhaps satellite applications. Therefore, this project is very unlikely to meet SETO goals. In addition, since the main problem with tandems is the added efficiency over single junction has never compensated for the added cost, the focus is all wrong. It should be on determining the cost first before building the cells. Saying, "it's solution-based therefore it will be cheap" is a fallacy. Just look at all the failed roll-to-roll companies that used the same logic.

*Reviewer 3:*

The project objectives and breadth of scope are ambitious. The technical work plan (tasks) emphasizes development of high quality materials for the perovskite (top cell) and the chalcogenide/Si (bottom cell) in order to achieve very high efficiency for the integrated tandem structure. The PI expects that lowering the cost of the anticipated PV solar cell will come from the efficiency factor. As such, the project supports one element of the SETO goals. The work plan does not include some level of cost-benefit analyses, scalability potential, and strategy to insure that at the end of the project, it is shown that stability of the achieved efficiency is competitive with the commercial state of the art product. The latter statement relates to the other SETO goals.

The project strategy does not include outside collaboration or coordination with an external audience that might be interested in the outcome.



**Project Title:** High-Efficiency, Inexpensive Thin Film III-V Photovoltaics Using Single-Crystalline-Like, Flexible Substrates

**Award Number:** 06711

**Principal Investigator:** Selvamanickam, Venkat, University of Houston

**Project Description:**

This project is working to achieve a drastic reduction in the cost of III-V solar cells through a combination of high efficiency and low manufacturing costs. Researchers are depositing III-V thin films on flexible metal substrates that have been textured via ion beam assisted deposition using roll-to-roll processing.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

A high (e.g. 24-30%) single junction solar cell that could be cheaply deposited on a metal substrate is unlikely to supplant Si and Si tandems as the leading PV technology, but multijunction III-V cells are now over 40% efficiency. If costs remain within a factor of 3 of silicon, low concentration could be used in areas of direct sunlight. While risky, this is important research to be undertaken --- in parallel with projects seeking high-rate, high-quality cells like the HVPE project described by Ptak (NREL). There are 2 problems to solve without compromising efficiency too much: the substrate and the deposition rate. High efficiency is the key to reducing many of the other costs (BOS, etc.) involved in PV. The big prize would be III-V multijunction cells on metal, but first things first. This is a very long-range project.

*Reviewer 2:*

This project directly addresses the "substrate" issue for III-V, therefore is aligned with the goal of high efficiency at lower cost.

**Project Title:** High-Performance Perovskite-Based Solar Cells

**Award Number:** 06712

**Principal Investigator:** Mitzi, David, Duke University

**Project Description:**

This project supports the development of lead-halide-based perovskites in order to make these devices more suitable for commercialization. Researchers are optimizing the device efficiency at the cell level in order for the promise of an ultra-low-cost technology to be realized, pursuing a lead replacement, and improving the stability of the materials and devices towards moisture, air, and temperature.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Perovskites are probably the best hope of increasing the efficiency of PV modules above 24%, without greatly increasing the areal cost. This work is important to that effort. It would be good to avoid using Pb since these perovskites solubilize in water.

*Reviewer 2:*

The search for new thin film PV absorbers is a high-risk, high-reward activity. I support SETO pursuing such efforts at some level, because given the cost structure of silicon PV manufacturing and the drawbacks of established thin film PV technologies, there are still opportunities for disruptive new technologies to impact the SETO goals. However, even the most well-executed project in materials exploration and discovery could not be rated higher than Fair on relevance to SETO goals, in my opinion.

*Reviewer 3:*

This combined experimental and theoretical project has already improved the fundamental understanding of perovskite PV materials.

**Project Title:** Novel Accelerated Aging Protocols for Photovoltaic Modules

**Award Number:** 07137

**Principal Investigator:** Libby, Cara, Electric Power Research Institute

**Project Description:**

This project is advancing the state of the art of module certification and degradation certainty. The project is also advancing the knowledge base of on-site plant monitoring and proactive maintenance in order to maximize energy production and profitability of photovoltaic power plants.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Improved understanding of degradation rates, as well as leveraging existing standards while developing some new complementary methods, aligns well with SETO's goals.

*Reviewer 2:*

The connection between accelerated tests and 'real-world' performance has been difficult to establish in many industries and notably PV. Using results from fielded modules with significant deployment time and their spares for accelerate tests is a clever idea and should be fruitful.

*Reviewer 3:*

The project started with the goal of evaluating the Qualification Plus set of extended testing - a good target. A number of logistical issues made this more difficult than expected; and a surprise that modules thought to be the same BOM were not. With hindsight, the goals were overly ambitious.

**Project Title:** Plant and Module Designs for Uniform and Reduced Operating Temperature

**Award Number:** 07138

**Principal Investigator:** Tamizhmani, Govindasamy, Arizona State University

**Project Description:**

This project intends to identify and evaluate thermally conductive and radiative but electrically insulating backsheets, which can be used by module manufacturers to reduce future solar levelized cost of energy values. Based on the typical temperature coefficients of standard multicrystalline modules, it is possible for conventional rooftop crystalline silicon modules to lose as much as 30 percent of power and the open rack crystalline silicon modules to lose as much as 20 percent power on hot summer days in sunny and/or desert locations. This project intends to reduce the levelized cost of solar energy by lowering module operating temperatures, reducing reliability failures, and reducing degradation rates to improve system lifetimes.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reducing operating temperatures for a module in order to raise power output is a good goal, but this approach seems to be in violation of established models.

*Reviewer 2:*

Refining degradation rates for PV modules is a very good goal. Analyzing field-based data and accelerated-aging data is good to help understand these known degradation areas.

**Project Title:** Predictive Models and Novel Accelerated Tests for the Reliability of Cell Metallization and Solder Joint Failures

**Award Number:** 07139

**Principal Investigator:** Westerberg, Staffan, SunPower Corporation

**Project Description:**

This project examines two key failure modes of metallization interconnect reliability: metallization corrosion and solder joint failures. The key outcomes will be predictive models for metallization corrosion and solder joint failures to aid in the design of reliable interconnects and predictive and faster accelerated tests useful for qualification, certification, and ongoing reliability.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project is relevant to SETO's goals in regard to improving reliability and potentially lowering costs. In this particular example, the lowering of costs is most likely achieved by providing the industry with accelerated thermal cycling as a means to study solder joint integrity and understanding of internal module corrosion mechanisms. The intent has been to mimic field conditions, develop more relevant accelerated testing and improved predictive models for field performance. The work has yielded interesting findings regarding decreases in conductivity later in the day and over time.

Though there is likely benefit to the industry through adoption of accelerated testing, any reduction in lowered LCOE and improvements in reliability is not well established through the reported work. Moreover, field observations suggest a multitude of contributing factors to loss of solder joint integrity and internal module corrosion. Such factors include use of improper solder fluxes and high interconnect stresses stemming from module twisting, non-flat installation and oscillation during elevated winds.

This work appears to capture a portion of factors contributing to lower solder joint integrity and increased internal corrosion. The scope of this work seems limited given the breadth of the original proposal. Results seem limited in progress and understanding of field conditions affecting solder joint integrity and corrosion.

*Reviewer 2:*

Degradation related to stress of thermal cycling is well established as a reliability issue. Improved testing will help in development of new module designs, increased reliability, and speed to market.

**Project Title:** Module-Level Exposure and Evaluation Test for Outdoor and Indoor Photovoltaic Modules

**Award Number:** 07140

**Principal Investigator:** French, Roger, Case Western Reserve University

**Project Description:**

This project is correlating photovoltaic module degradation from accelerated tests and fielded module data to develop models with chemical and physical mechanistic detail in order to improve prediction of photovoltaic lifetime performance. Understanding and quantifying degradation can reduce the final cost of the system by reducing financing costs and uncertainty.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Developing our understanding of PV module degradation rates in different environmental conditions is valuable to the industry.

*Reviewer 2:*

Performance and reliability of the PV fleet is an important issue. Identifying issues, and refining degradation rates are very relevant for the industry today.

*Reviewer 3:*

This project uses machine learning in an attempt to correlate environmental stress tests to real world outdoor field failures. The use of massive amounts of data enables the research team to find equipment issues and determine degradation rates without filtering the data sets - according to the paper. This allows the users - primarily power plant owners/operators and developers - to better design equipment for higher energy yield and to predict failures for optimal use of O&M.

**Project Title:** Generalizable Mechanistic Understanding of Module-Level Light-, Heat- and Humidity-Induced Instability

**Award Number:** 07141

**Principal Investigator:** Rockett, Angus, Colorado School of Mines

**Project Description:**

This project is working to eliminate detrimental changes in copper indium gallium selenide solar modules and better characterize the expected performance of a given product by studying degradation processes.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Metastability is not the reason CIGS has had limited success, so this project is not the highest priority in CIGS. Cost has been CIGS major downfall. Stability is a second order effect, but still relevant at this lower priority level.

*Reviewer 2:*

The project is focused on supporting a critical SETO goal: the stability/reliability of the CIGS thin film PV module. In CIGS the performance in terms of power output (efficiency) and output stability (whether in a transient mode or permanent) are interlinked and hence the criticality of the problem at hand. This impacts directly the predictability of the module rating and its output in the field.

The project output has already shown significant progress following the investigation approach, and in collaboration with industry. The results are very much relevant to the SETO program especially in the way integration and coordination by the team is carried out.

**Project Title:** Backsheets: Correlation of Long-Term Field Reliability with Accelerated Laboratory Testing

**Award Number:** 07143

**Principal Investigator:** Boyce, Ken, Underwriters Laboratories

**Project Description:**

This project is advancing the mechanistic understanding of photovoltaic module backsheet degradation in fielded modules and developing improved laboratory weathering exposures with results correlated to field performance.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Improving industry's understanding of module backsheet performance is vital to the safety and optimal long-term system performance. This work establishes a critical link between fielded module performance and lab testing techniques, and for a variety of materials. This work also improves industry's understanding of environmental forces and their impact on fielded modules in a variety of conditions and installations.

*Reviewer 2:*

Real world degradation mechanisms of polymeric component materials used in PV are not well understood, particularly as relevant to safe operation and performance. This is a good attempt to identify degradation modes and identify the stresses causing failure and build a degradation model which can be tested in the laboratory.

There are many pieces to this work in terms of stress test development, evaluation test method development, etc. All is worthwhile.



**Project Title:** Enabling Efficiencies Greater than 22.5 Percent with Metal Oxide Passivated Contacts Using Low-Cost, In-Line, Atmospheric Pressure Chemical Vapor Deposition

**Award Number:** 07533

**Principal Investigator:** Davis, Kris, University of Central Florida

**Project Description:**

This project aims to increase module efficiency and reduce manufacturing costs by transferring lab-scale heterojunction passivated contact technology into the high-volume manufacturing of industrial-scale crystalline silicon cells. The target efficiency for these cells is 22.5 percent, which will create a lower cost alternative to cells currently on the market by reducing the wafer-to-cell conversion cost by 13 percent compared to current manufacturing methods.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This research effort of developing a low-cost, high-performance carrier selective contact that could be used as the back contact of a PERC cell has significant merit. The research is addressing several key issues such as the stability of MoOx at temperatures > 200°C and the development of a low-cost deposition method to create the metal oxide passivated contact. However, one challenge is to demonstrate that a stable, high work function can be formed using a thin passivating layer such as SiOx with sALD MoOx. Moreover, it may be necessary to deposit a thicker TCO over the thin SiOx and MoOx layers to obtain high reflection of the weakly absorbed IR light at the rear contact. It may also be a significant challenge to deposit all these layers cost effectively.

*Reviewer 2:*

Appropriate topical area for PERC cell lines around the world, all of whom are seeking improved rear contacting schemes that are both passivate and are solderable. Well positioned to deliver immediate stimulus to the target audience.

*Reviewer 3:*

The project is investigating a passivated oxide using metal oxides. The industry has now widely adopted PERC structures where the front and rear surfaces are passivated. The remaining interface for improvement is the contact -- i.e., passivated contacts. A manufacturable process for passivated contacts would be commercially relevant.

**Project Title:** Rapid Patterning and Advanced Device Structures for Low-Cost Manufacturable Crystalline Silicon Interdigitated Back Contact Cells

**Award Number:** 07534

**Principal Investigator:** Hegedus, Steven, University of Delaware

**Project Description:**

This project is developing a new method for the manufacturing of interdigitated back contact solar cells with metal contacts on the backside of the wafer, which allows for greater light harvesting on the front surface due to the absence of grid shadowing. The new process will use direct laser patterning of the metal electrodes to isolate the positive and negative contacts, as well as laser firing of dopants to create localized contacts regions between the metal and the silicon wafer. The result will be a lower-cost silicon manufacturing process and device structure that will lead to an interdigitated back contact solar cell with 25 percent efficiency.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

There is high efficiency potential. Ag-free metallization and low-cost patterning is relevant to achieving low \$/kWh. However, because of the inclusion of several additional vacuum steps in the process flow, total CoO and CapEx might ultimately make this device noncompetitive with high-efficiency mainstream PERC.

*Reviewer 2:*

This project is applicable to existing and emerging IBC process flows in search of cost reduction avenues to lower the cost of Cu plating.

**Project Title:** Low-Cost Tool Design for Cell and Module Fabrication with Thin, Free-Standing Silicon Wafers

**Award Number:** 07535

**Principal Investigator:** Buonassisi, Tonio, Massachusetts Institute of Technology

**Project Description:**

This project aims to reduce the barriers to inexpensive photovoltaic module manufacturing by de-risking key technology elements necessary to enable manufacturing with lower capital costs. The project team is focusing its efforts on crack detection and metallization techniques to enable high yield wafer, cell, and module fabrication with thin, free-standing silicon wafers. Thin wafers dramatically reduce the amount of polysilicon required and increase growth-system productivity, thereby reducing the capital expenditures associated with silicon refining and wafer fabrication, which together are more than half of the total capital costs of silicon module manufacturing.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Crystalline silicon solar cells comprise > 90% of PV shipments, and silicon is the single largest cost component in the cost of a silicon solar cell. Thus, this project to enable the manufacturing of thin silicon solar cells can have a large impact on the total cell cost by reducing the capital expenditures associated with the manufacturing of silicon solar cells as well as lead to a reduction in material costs. This effort will help to enable the use of thin silicon wafers by developing new technology to detect micro-cracks in thin Si wafers and by developing new methods of low-stress interconnection of thin Si wafers in PV modules.

*Reviewer 2:*

It is unclear without a yield improvement estimate if the project's aims are in keeping with SETO cost targets.

*Reviewer 3:*

This project is focused on reducing the amount of silicon required for each wafer and reducing the cost impact of yield and machine downtime due to wafers fracturing during manufacturing. The cost of silicon is a primary cost driver for solar PV systems. Reducing the wafer thickness is a primary mechanism for reducing costs. One of the primary concerns holding back thinner wafers is manufacturers concerns about yield. This project is designed to reduce manufacturers' concerns about thin wafers to result in silicon material usage reduction and cost savings.

**Project Title:** Solution for Predictive Physical Modeling in Cadmium Telluride and Other Thin-Film Photovoltaic Technologies

**Award Number:** 7536

**Principal Investigator:** Vasileska, Dragica, Arizona State University

**Project Description:**

This project aims to develop a software tool to enable a more accurate interpretation of thin-film photovoltaic device performance and material properties, with the goal of enabling predictive device design. The software includes a modeling tool that connects atomic diffusion and drift to device performance. This model will allow researchers to simulate recombination losses over time in II-VI absorber materials, such as cadmium telluride, using different doping profiles, process and stress conditions, and grain boundary or interface geometries.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Thin-film CdTe PV (and CIGS, also) has relied for too long on empirical correlation and trial and error. With so many different atoms, defects, and various crucial processing steps, it is very hard to learn quickly and improve. This kind of serious modeling, based upon formation energies, reaction rates, diffusion coefficients, etc., can be very important in speeding progress toward higher efficiency and perhaps even reduced costs.

*Reviewer 2:*

This project is very relevant to SETO goals as it attempts to develop a numerical instrument for modeling metastability and reliability of CdTe and other II-VI thin-film solar cells by solving diffusion-reaction equations. It hopes to improve the probability of empirical experimentation by modeling doping scenarios before lab work is performed. This should help likelihood of success and improve device performance, ultimately reducing the degradation rate for CdTe.

*Reviewer 3:*

I'm not a big fan of modelling. Once met the CTO of GM. They have spent 100's \$M on modeling. He doesn't think it's very useful. What is this program likely to achieve? Still, there is way too much unknown about PV semiconductors, and you have to start somewhere. So I think this is a decent idea, as it will at least drive asking questions and attempting to answer them. Just do not think it will have much impact.

**Project Title:** Developing a Low-Cost, High-Volume and Scalable Manufacturing Technology for Cadmium Telluride Feedstock Materials

**Award Number:** 07537

**Principal Investigator:** Lynn, Kelvin, Washington State University

**Project Description:**

This project is developing low-cost, high-volume, scalable cadmium telluride feedstock production technology, which can be commercialized to deliver high quality feedstocks to industry at a reduced cost with rapid production rate. The material quality of feedstocks will be optimized to the needs of high efficiency solar panel production. A novel cadmium telluride synthesis and growth process will be developed and scaled up, and the grown material will be evaluated with respect to defect structure, carrier lifetime, and unintentional impurities.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The team is trying to develop a low-cost source of feedstock for closed space sublimation and other methods of forming CdTe solar cell films. The importance is in allowing various Column V and other dopants to be used without creating inclusions in the grown crystal or other forms of phase decomposition. This could benefit the U.S. Company, First Solar strongly if successful.

*Reviewer 2:*

This project is focused specifically on improving the quality of CdTe feedstock, and also providing ways to dope the feedstock with a p-type dopant as part of the feedstock manufacturing process. A claim is also made that the Bridgman approach is lower cost than incumbent methods, but that claim was not substantiated in the materials I reviewed. For manufacturers of CdTe PV products, the approach studied in this project could deliver feedstock with better doping profiles, and therefore enable PV cells with higher VOC and efficiency. However, the approach is not broadly applicable beyond CdTe (or is already being done, as in the case of sX-GaAs or Si).

*Reviewer 3:*

This work targets higher efficiency in CdTe films for PV by addressing a) impurity content and b) alloying with group-V elements C11:E11 through improved crystallization techniques. Those techniques are currently not applied by state-of-the-art CdTe crystal manufacturers and therefore represent an opportunity for new learnings.

**Project Title:** Monolithic Silicon Module Manufacturing at Under \$0.40 per Watt

**Award Number:** 07538

**Principal Investigator:** Holman, Zachary, Arizona State University

**Project Description:**

This project aims to lower the cost of photovoltaic (PV) electricity generation in fewer than five years to \$0.04 per kilowatt hour through the development of a photovoltaic module that is based on back-contact silicon solar cells, which have interdigitated metal fingers on their rear sides and no metal on their front sides. The cells in this project will not have any metal; instead, they will be interconnected with a “flex-circuit” consisting of two layers of aluminum foil separated by an insulating spacer layer. This design reduces the amount of silver or copper used in modules and eliminates solder points that are prone to failure. Researchers will focus on cell interconnection, module assembly, module reliability testing, and techno-economic analysis.

**Reviewer Evaluation on Projects’ Impact on SETO Goals:**

*Reviewer 1:*

SETO goals of cost and performance are clearly addressed. However, as stated by the investigator in the report, it is likely that the \$0.40/W goal will not be competitive as the cost of mainstream PERC technology cost is dropping faster than expected.

*Reviewer 2:*

An improved back interconnection scheme is needed for advanced devices, and this approach attempts a low-cost solution that holds promise.

**Project Title:** Tandem Solar Cells: Pathway to Low-Cost, High-Efficiency Photovoltaics

**Award Number:** 07539

**Principal Investigator:** Grassman, Tyler, Ohio State University

**Project Description:**

This project is developing a monolithic tandem solar cell with gallium arsenide phosphide on silicon wafer substrates aimed at an efficiency of at least 30 percent. The cell will be produced using scalable and manufacturable processes, which will be accomplished through optimization of the current prototype cell, including the demonstration of structures that are ideally suited for maximized silicon-based tandem manufacturing. A mature tandem cell could then be manufactured at scale via existing silicon and III-V tooling and infrastructure, greatly reducing capital expenditures and revitalizing existing manufacturing industries.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is aimed at developing a Si-based tandem cell technology using a GaAsP/Si architecture with a target efficiency of > 30%, which would enable module efficiencies in the mid/high-20% range. Moreover, since this technology has the potential to eventually produce cell of ~ 35%, module efficiencies of ~ 30% might be attainable in the future. This performance is well beyond the potential of single junction crystalline Si where the theoretical cell efficiency is about 29.6% and module efficiencies are likely not to exceed ~ 25%. Thus, this project is a pathway to higher module efficiencies, but it remains to be seen if this approach will be cost competitive against the dominant single-junction crystalline silicon PV technology. Moreover, it appears that other approaches to high performance Si-based tandems such as with perovskite top cells may eventually be more cost effective.

*Reviewer 2:*

Focus on high efficiency is part of SETO plan, but weak emphasis on the other key aspects (cost and durability).

*Reviewer 3:*

Most modeling has shown this architecture to be a candidate for quickly increasing the performance of a typical Si solar cell; however, most groups are far from obtaining the modeling results. This project will hopefully shed light on that reason.

**Project Title:** Pushing the Limits of Silicon Heterojunction Solar Cells: Demonstration of 26 Percent Efficiency and Improving Electrical Yield

**Award Number:** 07540

**Principal Investigator:** Bowden, Stuart, Arizona State University

**Project Description:**

This project examines the manufacturability of n-type industrial silicon heterojunction cells and develops methods to improve energy yield and increase the appeal of this type of cell to manufacturers. The research performed will help to improve cell efficiency by two percent and reduce the cost of the cells by improving electrical yield based on a range of new processing improvements. The project also aims to demonstrate the feasibility of using thinner cells to increase the lifetime of the wafer and achieve a 26 percent record efficiency. The knowledge gleaned from this research is expected to help improve the manufacturing of silicon heterojunction cells in the next five years.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project addresses both efficiency and cost of SHJ cell technology.

*Reviewer 2:*

This is a highly relevant project to push the HJT performance with iterative improvements to existing processes and toolsets.

*Reviewer 3:*

High efficiency is the key to SETO goals to lower levelized cost of elect. This project focuses on silicon heterojunction technology (HIT) - which is an important high efficiency structure, in production in a number of companies around the world. Of particular relevance to SETO is the Tesla/Panasonic factory being built in Buffalo that will be a HIT factory. HIT cells are fabricated on n-type wafers and these typically vary widely in resistivity along the length of the ingot. This project seeks to develop approaches and process tools to mitigate this variability. Appropriate goals for SETO.



**Project Title:** Crosscutting Recombination Metrology for Expediting Open-Circuit Voltage Engineering

**Award Number:** 07541

**Principal Investigator:** Holtz, Mark, Texas State University

**Project Description:**

This project is developing a comprehensive characterization methodology for extracting recombination rates in thin-film solar cells as a function of depth into the device. The advanced metrology methods developed as part of this project will ideally allow researchers and manufacturers to identify problem areas in their materials to a depth resolution of a few dozen nanometers and correct their procedures accordingly. The proposed methodology will also allow for the viability of certain interfaces and contact structures to be examined at a greater level of detail than has previously been available based on existing optoelectronic methods.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project is an ambitious attempt to quantify the amounts of both SRH and radiative recombination as a function of depth (50 nm resolution) in CdTe and CIGS solar cells. If successful, it could complement depth-sensitive probes of structure and composition to provide insight into the growth changes needed to improve these thin-film solar cell technologies. Efficiency, yield and reliability could be addressed.

*Reviewer 2:*

The problems identified in this project are all important technical issues that need to be resolved in order to improve the performance and reliability of thin film photovoltaics.

*Reviewer 3:*

This project is one that is extremely complex, complicated in equipment and analysis, and requiring extremely high precision and the ability to separate and identify effects and differences. All these thin film, polycrystalline materials have considerable chemistry, morphology, and physical changes over small distances, at surfaces, across interfaces, etc. (One might wonder how they even can function!) Despite this, the project is highly relevant--and poses high impact for future technology development for thin-film PV. The PI and collaborators are brave to undertake this--but they do have sufficient background, understanding, and experience. This is the "Holy Grail" of characterization tools for thin film PV technology.

**Project Title:** Improved Performance and Reliability of Photovoltaic Modules using the Reaction of Metal Precursors

**Award Number:** 07542

**Principal Investigator:** Shafarman, William, University of Delaware

**Project Description:**

This project is working to improve the performance and reliability of thin-film copper indium gallium sulfide selenide cells. The team is developing innovative approaches to improve the deposition and device fabrication to provide a pathway to significant reduction in solar costs. By focusing on processes and materials with low manufacturing cost and that are already used in commercial production, the project expects to directly impact the market and advance copper indium gallium sulfide selenide technology toward a levelized cost of energy of \$0.06 per kilowatt-hour.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is a hold-over from the past when Stion was one of the few remaining U.S. PV companies. Stion has since ceased operations and almost no one uses the two-step process that is the subject of this project. No one uses it in the U.S. for sure. This project is no longer relevant.

*Reviewer 2:*

The design of the project was fairly specific to addressing the needs of a commercial partner that ultimately ceased operations. While the approach addresses a real problem with efficiency and processing temperatures, the lack of commercial relevance in the U.S. makes it somewhat less compelling.

*Reviewer 3:*

It is a difficult decision to make whether the SETO office should continue supporting CIGS research given that U.S. CIGS manufacturers have not been successful.

**Project Title:** Device Architecture for Next-Generation Cadmium Telluride Photovoltaics

**Award Number:** 07543

**Principal Investigator:** Sites, James, Colorado State University

**Project Description:**

This project is developing a novel solar cell architecture that will increase the voltage and energy output of thin-film polycrystalline cadmium telluride solar cells and address the short lifetimes of photo-excited electrons in the cells. This new architecture should give the cadmium telluride manufacturing community a novel, but highly realistic, approach for solving the voltage limitations of the technology. The resulting product will be compatible with solar panel manufacturing at or below current cost structures.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The team is working to change the CdTe architecture through a fully-depleted collection area with electric field driven transport of both electrons and holes, which is extremely relevant to improving CdTe cells. They also incorporate about 20% Se into CdSeTe to reduce the bandgap of the most of the active layer and thereby increase the current. By putting Se in the front half of the cell only, they illuminate why Se has been a successful strategy for First Solar and others, recently. If they are successful in increasing CdTe cell efficiency by these methods, the costs of CdTe cells would change little. The higher efficiency supports the SETO goal of lower BOS costs.

*Reviewer 2:*

This project is aimed at optimizing the CdTe cell structure, increasing VOC and efficiency, and potentially offsetting cost increases with a thinner absorber layer. The effort is specific to CdTe and is not directly applicable to other technologies. However, the approach the team is taking is well thought out, methodical and tested against real solar cells at each milestone. The experimental process could be replicated to make similar improvements in other technologies.

*Reviewer 3:*

Despite decades of research in CdTe material and devices, there remain several areas that are still not well understood. One goal of Dr. Sites' research agenda is the creation of PIN structures with fully depleted absorbers, similar to silicon HIT cells. This approach is novel and of interest.

**Project Title:** Improving Reliability and Reducing Cost in Cadmium Telluride Photovoltaics via Grain Boundary Engineering

**Award Number:** 07545

**Principal Investigator:** Klie, Robert, University of Chicago

**Project Description:**

This project is developing an innovative approach to understand and eliminate the detrimental effects of grain boundaries in poly-crystalline thin-film cadmium telluride solar cells. The project team will examine how grain boundaries play a role in limiting the open circuit voltage, performance, and reliability and leverage insight from fundamental atomic and electronic studies.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is relevant as the PI and his collaborators plan to model and grow/produce individual grain boundaries in CdTe to identify the best possible passivating compounds to increase device efficiency and with improved stability. Increasing the knowledge and design parameters for CdTe should have relevance to CdTe growers and module producers. These improvements will have a direct contribution to lowering LCOE by improving device performance.

*Reviewer 2:*

The open-circuit voltage is an issue limiting the performance of CdTe thin-film PV devices--and possibly relating to some reliability issues. This project addresses the relevant issue of determining the effect of grain boundaries on these issues, from some fundamental specimen and characterization aspects.

*Reviewer 3:*

Grain-boundaries in multi-crystalline CdTe films are among the least-understood defects in these films. Dr. Klie's work addresses grain boundary defects using a difficult, unique capability of STEM microscopy combined with computer simulations on bicrystals. This technique allows for imaging with atomic resolution of two adjacent crystals.

**Project Title:** Correlation of Qualification Testing with Field Degradation

**Award Number:** 07548

**Principal Investigator:** Tamizhmani, Govindasamy, Arizona State University

**Project Description:**

This project aims to obtain the correlation for the degradation modes typically observed in hot-dry, hot-humid, and cold-dry climates. The major degradation modes in these climates include: encapsulant discoloration, delamination at interfaces, metallization, solder bond and interconnect fatigue, cracks and corrosion. In the qualification testing, the primary environmental accelerated tests, which are related to the above climates and degradation modes, are: thermal cycling, damp heat, and humidity freeze. Therefore, the correlative study focuses only on these three environmental tests of the qualification testing programs. The potential impact of the proposed project is to obtain climate-specific and construction-specific acceleration factors for the current accelerate qualification tests.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The 20-30% power loss from elevated field temperature (~ 60 C vs. STC) is unlikely to be addressed by a 2-6C reduction.

*Reviewer 2:*

Understanding observed field degradation and how this relates to module qualification testing is important as the industry tries to develop a means to evaluate/analyze long term reliability.

**Project Title:** Research and Development of Architectures for Photovoltaic Cell-Level Power Balancing Using Diffusion Charge Redistribution

**Award Number:** 07549

**Principal Investigator:** Avestruz, Al-Thaddeus, University of Michigan

**Project Description:**

This project is conducting photovoltaic cell-level power balancing using diffusion charge redistribution to increase efficiency, lower manufacturing costs, and improve reliability. This work will examine the use of on-module power electronics to enable cell-level power optimization and transform the often complex J-V characteristics a string of solar cells into a well-behaved “super-cell” that eliminates cell power imbalances, mismatches, and partial failures.

**Reviewer Evaluation on Projects’ Impact on SETO Goals:**

*Reviewer 1:*

Improving existing module performance is critical. Looking at technologies other than cell efficiency is the key. This technology has the potential to increase the utilization of existing cell technology by building a PV module with better shade and mismatch tolerance.

*Reviewer 2:*

This project will lead to increased energy generation from solar panels. The impact could be seen in both rooftop solar, where shading from trees and other obstructions can reduce power production, as well as, utility scale systems where inter-row shading can reduce power production. By generating more energy at the same cost, the LCOE goes down, which directly impacts SETO’s goals for 2030.

*Reviewer 3:*

This project intends to address LCOE and reliability of PV modules by minimizing the impact on cells due to partial shading. This is particularly beneficial to the commercial/industrial and residential market.

**Project Title:** Continuous Silicon Reduction and Consolidation

**Award Number:** 07550

**Principal Investigator:** Hornbostel, Marc, SRI International

**Project Description:**

This project investigates a continuous silicon reduction and consolidation process to reduce the capital, material, and energy costs associated with producing high-purity polysilicon. The new method will use low-cost precursors and has the capability to recycle silicon fines, which are a common waste product of fluidized bed reactors and wafer sawing. This technology has the capability of reducing module costs by up to 10 percent based on reducing the cost of the polysilicon feedstock used to grow silicon bricks and ingots.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Decreasing the cost of silicon based solar cells is in line with SETO goals. A total projected savings of \$0.04/W is very meaningful. It must be done with no loss in efficiency and, in fact, must support growing efficiencies in the future. This is a challenge.

*Reviewer 2:*

This project has the potential to allow for recovery of 1/3 of the silicon refined for fabrication of silicon wafers for PV. As such, it has the potential for reducing the cost of PV and therefore aiding in reaching SETO goals or LCOE. While it is true that poly Si is currently low in cost, it still accounts for a significant portion of total cost and the price seems to be trending up at this time.

This is a unique effort and deserves credit for this. However, the project does not support the thrust to higher efficiency also required for lower LCOE.

*Reviewer 3:*

Recovery of Si from the wafering waste stream (KERF loss) would not improve the economics through reduced cost, but also reduce the environmental cost for producing Si PV.

**Project Title:** Post-growth Recrystallization by Halides for High Throughput CIGS Photovoltaics

**Award Number:** 07551

**Principal Investigator:** Rockett, Angus, Colorado School of Mines

**Project Description:**

This project will use a combination of a highly adaptable multi-source deposition system and a wide range of post-deposition treatments to in an effort to identify successful routes of improving the structural and electronic properties of CIGS films that are compatible with high-throughput manufacturing. If successful, new treatments that use alkali metals, halides, and other extrinsic dopants may be identified that could either improve the performance of CIGS produced using two step production methods and/or reduce the manufacturing costs of CIGS production using single step production methods.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is relevant to SETO goals as it will develop a high rate self-correcting process for CIGS synthesis resulting in high performance devices. This hopes to address a problem with CIGS photovoltaics, the high capital expense per unit produced. However, there has been little significant growth in the domestic CIGS manufacturing space. Therefore, it is not clear what the magnitude of the impact/relevance for SETO will be by end of the project this year while manufacturing volumes remain low compared to the silicon and CdTe market.

*Reviewer 2:*

This is another dated project. The 2-step CIGS process is basically obsolete. Stion is out of business, and Solar Frontier is not competitive. Basically no one will use this technology even if the project meets it's goals.

*Reviewer 3:*

This project is attempting to bring learning from the CdTe world to CIGS manufacturing by implementing a vapor transport version of deposition and finding an appropriate promoter for recrystallization at relatively low temperatures. If successful, this project could uncover approaches to reducing the capital expense associated with traditional CIGS deposition technology while maintaining high efficiencies.



**Project Title:** Fifteen Percent Efficient (Magnesium, Zinc) Cadmium Telluride Solar Cells with 1.7 eV Bandgap for Tandem Applications

**Award Number:** 07552

**Principal Investigator:** Holman, Zachary, Arizona State University

**Project Description:**

This project aims to demonstrate solar cells based on wide bandgap cadmium telluride alloys that will eventually enable the fabrication of highly efficient tandem photovoltaic cells in combination with a silicon bottom cell. The photovoltaic market is dominated by silicon and cadmium telluride technologies, which have become low-cost and reliable in the last decade but are nearing their individual efficiency limits. This project works to boost the eventual efficiency of photovoltaic systems by beginning the process of allowing cadmium telluride and silicon to function together to efficiently harvest the solar spectrum, potentially enabling a 20 percent decrease in the cost of installed systems.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is relevant as it works towards developing a wide band gap top cell for a potential CdTe tandem device. This would enable a technical pathway to extend the CdTe stack to beyond 22%, the current CdTe max efficiency with a single 1.5eV junction.

*Reviewer 2:*

The project goals are clearly stated and the authors make a great case for the value of the project. There are some "loose ends" that need to be addressed, such as how the CdTe based cell will be integrated with a Si cell, but they are outside of the scope of this program but should be part of a follow on. Because of the program's relevance and the progress that has been made, I recommend that there be a follow on program for this team.

*Reviewer 3:*

Dr. Holman's work on II-VI compound semiconductors with a bandgap of 1.7 eV or larger is valuable, although for different reasons as outlined in the research proposal. Such films can be used within a CdTe device to improve the band structure of the device. The main obstacle to achieving high-quality films is the incompatibility of Zn and Mg alloying, necessary for achieving higher bandgaps, with the cadmium chloride passivation process. Dr. Holman's motivation of using 1.7eV top cells for tandems with silicon cannot be followed easily, as such a tandem would naturally be a mechanical stack. Here, a 1.5eV unalloyed CdTe film would be sufficient to achieving high efficiencies. The energy yield of 4T tandems with 1.5eV top cell has been modeled by First Solar (Mailoa et al, DOI: 10.1039/c6ee01778a).

**Project Title:** New Approaches to Low-Cost Scalable Doping for Interdigitated Back Contact Crystalline Silicon Solar Cells

**Award Number:** 07553

**Principal Investigator:** Agarwal, Sumit, Colorado School of Mines

**Project Description:**

This project lowers the cost and reduces the complexity of manufacturing interdigitated back contact mono-crystalline silicon solar cells, which provide a promising pathway to achieve a levelized cost of energy of \$0.02 to 0.03 per kilowatt-hour by 2030. Currently, these types of cells require patterned doping of the back contacts, which adds several additional steps compared to the more traditional front-grid architecture. The research team will develop a photo-assisted, area-selective patterning method that produces high-quality devices and is highly scalable for large-area manufacturing at reduced cost.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The development of a low-cost fabrication process for IBC solar cells could have significant impact since IBC cells are currently the most efficient Si solar cells in the lab and in production, but they comprise only a small fraction of the total PV market due to the high manufacturing costs. As pointed out in the project report, current IBC cells require complex processing to produce interdigitated emitter and base contacts on the rear surface. The goal of the current project is to develop a simplified patterning technique for the interdigitated contacts of high performance Si solar cells by using shadow or contact masks and selective deposition or etching using plasmas. Successful implementation of this approach could lower the cost of high efficiency IBC cells leading to reduction in PV system costs and the LCOE.

*Reviewer 2:*

If successful, this project would result in a low-cost process for a back-contact cell with fully passivated contacts. This could enable a low-cost pathway to > 25% efficient c-Si solar cells. This is directly in line with SETO's goals for 2030 by achieving high-efficiency, low-cost solar cells and modules.

*Reviewer 3:*

This work is focused on reducing the manufacturing cost of back contact solar cells. Back contact cells are an important option for reducing LCOE because they are high efficiency. The impediment to their proliferation has been manufacturing cost. Thus, the basic thrust of the work is highly relevant.

**Project Title:** Pushing the Efficiency Limit of Low-Cost, Industrially-Relevant Silicon Solar Cells by Advancing Cell Structures and Technology Innovations

**Award Number:** 07554

**Principal Investigator:** Rohatgi, Ajeet, Georgia Tech Research Corporation

**Project Description:**

This project aims to advance manufacturable silicon cell technologies to above 22 percent efficiency through the use of passivated selective emitter and selective back surface field contact geometries. The improved contact and metallization methods investigated during the course of the project will reduce recombination and improve cell performance by up to two percent absolute efficiency. Multiple fabrication methodologies will be investigated to determine the most cost-effective method for producing the laterally patterned doping profiles needed to realize this high performance cell technology.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Stated LCOE target is \$0.06/kWh, but SETO goal is now at \$0.03/kWh. The successful completion of this project will not, alone, be sufficient to support the SETO goals.

*Reviewer 2:*

Increasing the efficiency of solar cells while reducing cost goes after SETO goals in two complimentary ways. PERC and PERT cell architectures are two important approaches to this goal. Thus, the project is highly relevant.

*Reviewer 3:*

Passivated contacts are the next technology node for crystalline-silicon solar cells after the current adoption of PERC is completed. Basic research on passivated contacts has demonstrated the fundamentals of the technology. The remaining work is to develop a manufacturable process, preferably using established production technologies.

**Project Title:** Metastability, Potential Induced Degradation, Damp Heat Degradation and Recovery in Copper Indium Gallium Selenide Devices: Effect of Alkali

**Award Number:** 07750

**Principal Investigator:** Bansal, Shubhra, University of Nevada, Las Vegas

**Project Description:**

This project is working to understand degradation that occurs in copper indium gallium selenide solar cells. These devices can suffer from degradation due to high temperatures, damp heat, or high system voltage. Developing a further understanding of why degradation occurs in these environments will allow scientists and engineers to develop copper indium gallium selenide products that are able to withstand these elements and have lower degradation rates, leading to a lower cost of solar energy.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is relevant to SETO goals as it has addressed CIGS meta-stability, potential-induced degradation, and damp heat stability. However, there has been no significant growth in the domestic CIGS manufacturing space in recent years. Therefore, it is not clear what the magnitude of the impact/relevance for SETO will be by end of the project if manufacturing volumes remain low compared to the silicon and CdTe market. The PI does show good appreciation of the impact of degradation on the module price efficiency relationship (ref SETO).

*Reviewer 2:*

The project goals and objectives are well aligned with the SETO primary goals: drive down the cost of PV. In CIGS, the metastability behavior and performance degradation (recoverable or otherwise) are the major barrier for high volume manufacturing and hence competing market costs as well as confidence in reliability in the field. This project addresses the above challenge directly with a synergetic team and coordination with industry, reliable cell fabricator, and modeling.

The project, if successful, will impact the SETO performance goals and the market audience of thin film PV.

*Reviewer 3:*

It is a difficult decision to make whether the SETO office should continue supporting CIGS research given that U.S. CIGS manufacturers have not been successful.

**Project Title:** Defect Kinetics and Control for Module Reliability

**Award Number:** 07751

**Principal Investigator:** Bertoni, Mariana, Arizona State University

**Project Description:**

This project is improving photovoltaic module reliability by developing a model to predict silicon module degradation. Once finalized, the modeling tool will evaluate the effects of sodium-induced degradation on materials in different operating conditions. The model will be able to evaluate the impact of a variety of contaminants, including potassium, though sodium is widely known to be responsible for major potential-induced degradation losses. The goal is to assist the selection and engineering of better encapsulation materials, dielectrics, contacting schemes, and device architectures based on the reliable performance of the device.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project aims to investigate the impact of Na and K on silicon wafers/cells in packages. It also will investigate the impact of copper on wafers for the technology of plated copper contacts. The former will have a larger impact than the latter on SETO goals and relevance.

*Reviewer 2:*

Module reliability is a key to SETO goals as the impact on LCOE is well known. This might not be the highest impact area for LCOE, but it is important nonetheless.

*Reviewer 3:*

The project is focused on modeling and predicting the reliability and performance of single crystal silicon solar cells and modules. This represents a large chunk of the commercial market. Success in this project will be well leveraged.

**Project Title:** Quantum Energy and Sustainable Solar Technologies (QESST)

**Award Number:** 07758

**Principal Investigator:** Honsberg, Christiana, Arizona State University

**Project Description:**

QESST is an Engineering Research Center sponsored by the National Science Foundation and the Solar Energy Technologies Office. Launched in 2011 and based out of Arizona State University, QESST focuses on advancing photovoltaic science, technology, and education in order to transform the existing electricity generation system. The center's primary research areas are silicon cells and modules, tandem PV cell architectures on traditional silicon utilizing thin-film or III-V absorbers, and improving the performance of PV using test beds that can demonstrate manufacturability, integration, and sustainability of solar technologies. In addition to this research, QESST develops solar and PV education programs for graduate and undergraduate students, K-12 students and teachers, as well as outreach programs for the general public. QESST is designed to set the solar industry on a path to terawatt levels of installed PV generation in 15 to 20 years.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

QESST is extremely diverse, and the reporting framework provides little detail on any one task area. It is difficult to evaluate. The educational impact appears to be high, and it is excellent to bring in NSF funding in support of PV. While some of the research described appears valuable (like the PERC Si work and the development of the 'pilot' c-Si facility), other portions of the research (like the dilute nitrides, intermediate band solar cells and organic on Si tandems) seems unlikely to impact the SETO mission.

*Reviewer 2:*

A major caveat: The project report and poster material were very poorly written with little view to activities and specific accomplishments. The budget listing was in error and from NIST reporting structure. Hence it is very difficult to judge this project. Trying to obtain specific information on-line was also difficult.

**Project Title:** Electroplated Aluminum - An Alternative to Copper or Silver Electrode in Silicon Solar Cells

**Award Number:** 08150

**Principal Investigator:** Tao, Meng, Arizona State University

**Project Description:**

This project is developing a simple, two-layer aluminum electrode to substitute the silver electrode in silicon solar cells. This includes the examination of electroplating to significantly reduce processing costs, improve module reliability and lifetime, and maintain high cell efficiency.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Cost of silver in silicon solar is a significant portion of the total cell cost. Working on an alternative to screen printed silver by developing a lower cost aluminum process is relevant to SETO's long term cost reduction goals.

*Reviewer 2:*

Low-cost metallization plating can help reach lower cost. However, beyond the fact that Al material cost is much lower than Ag cost, it is not clear that the total CoO of the proposed technology will be lower than existing Ag screen-printing.

*Reviewer 3:*

It is true that silver costs are a substantial part of total cell costs for silicon PV and that alternatives would be welcome. It is also true that silver cost is relatively low right now and an increase is certainly possible, further exacerbating the cost issue. On the flip side, it is also true that some metallization approaches – multi-wire – can reduce the amount of silver used, partially mitigating the high cost of silver. Nonetheless, it remains a very real issue. To this extent, the work in this project can be relevant to SETO LCOE goals.

**Project Title:** Two-Dimensional Material-Based Layer Transfer for Low-Cost, High-Throughput, High-Efficiency Solar Cells

**Award Number:** 08151

**Principal Investigator:** Kim, Jeehwan, Massachusetts Institute of Technology

**Project Description:**

This project is developing an innovative method to reduce or eliminate the cost of expensive substrate materials, which are generally used to grow high-efficiency solar cells. The research team is using a single crystal substrate coated with a single layer of graphene to achieve the required cost reduction that helps to make III-V solar cells a realistic option for commercial use. Once the concept is realized, a substrate containing graphene will provide releasable high-efficiency, single-crystalline, gallium arsenide solar cells and a reusable wafer substrate.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Market for this approach is small. Cost reduction efforts, while significantly reduced in this project, are still rather gating for widespread adoption.

*Reviewer 2:*

The technology being pursued in this project is aligned well with the SETO 2030 goals. If successful, this project could reduce the substrate costs associated with III-V Tandem cells significantly. This is the highest cost element of III-V cells which would be very significant for III-V solar cell adoption.

*Reviewer 3:*

This project is attempting to address a specific pain point in GaAs based solar cells – the cost of the substrate, which can exceed \$100 each. Although the market penetration of GaAs is miniscule in the DG and Utility PV markets, substrate cost is one of the barriers. Success in this effort will move the high efficiency capability of GaAs closer to efficacy for the volume PV markets.



**Project Title:** Improving Solar Panel Durability through Novel Panel Designs and Advanced Manufacturing Equipment

**Award Number:** 08152

**Principal Investigator:** Gabor, Andrew, BrightSpot Automation LLC

**Project Description:**

This project is conducting a fundamental study on the nature of cracked cells in crystalline silicon solar panels with the goal of improving module materials and designs to make them more resilient against crack initiation, propagation, and degradation over time due to the electrical isolation of cell segments. Key areas of investigation include determining the effects of accelerated lifetime testing on modules in inducing power loss due to cell cracking, and how these effects can be mitigated.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Improving industry's understanding of crack formation within solar modules and establishing is very relevant to achieving SETO's stated goals of improving the reliability of solar power plants.

Intent is to develop cheaper and more relevant accelerated tests that highlight durability problems associated with cracked cells.

The results of the two above items are to assist in improving module designs that are more robust, resistant to cell cracking and loss of power output.

Scope also seeks to prevent further or recover power loss which may assist in addressing the recycling challenge the industry faces for no longer serviceable modules.

*Reviewer 2:*

This project highlights the importance (and potential current pitfalls) of module quality, in particular issues with cSi module cell cracking. Developing better test sequences may inform these issues before modules are installed in the field, and there is also the possibility of fixing old panels or developing new panels that avoid these issues. This is an example of something that is often NOT currently considered for new projects, and represents a real risk for plant underperformance in the future.

*Reviewer 3:*

Cell cracking is one of the most prevalent observations and the issue appears to be getting more common as we see a reduction in PV cell thickness, but the effects are not well understood.

**Project Title:** Isovalent Alloying and Heterovalent Substitution for Super-Efficient Halide Perovskite Photovoltaic Solar Cells

**Award Number:** 08153

**Principal Investigator:** Zunger, Alex, University of Colorado

**Project Description:**

The primary goal of this early-stage research is to build upon solid state and semiconductor knowledge to improve understanding, design, optimization, and validation of isovalent perovskite alloys. The research team is applying theoretical and computational methods to examine next-generation double perovskites, which replace element pairs with heterovalent pairs, and to collaborate with experimentalists to study the most promising candidates for photovoltaic absorber materials based on their stability and electronic structure. The theory of alloys, defects, novel materials, and materials-by-design will be used to overcome limitations in absorber stability in the application of isovalent alloys and heterovalent-substituted halide perovskites for photovoltaic applications.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is relevant to SETO goals as it plans to extend the knowledge of fundamental properties of perovskites to assist in the development of improved devices. Increasing efficiency and stability of these devices will accelerate the adoption of perovskites to realize their impact on lowering PV cost and ultimately LCOE.

*Reviewer 2:*

Searching for new PV absorber materials is inherently a high-risk approach to impacting the electricity market by 2030. This does not mean that materials discovery projects are not worthy of some SETO support. However, the design and execution of this project make it seem particularly unlikely that it will impact SETO goals.

*Reviewer 3:*

The project goal and approach are straight forward, designed to support the SETO performance goals by showing the technical path (to experimentalists and others), via theoretical calculations (based on modern quantum theories), to higher efficiency and stable hybrid perovskite thin film solar cells. Higher efficiency, stable and predictable performance, and long life time, are the factors that drive cost down. The latter is the ultimate goal of the SETO program.

The project is in a way overdue in the since that few years back, it would have pointed the way to faster progress and to expanded and innovative research approaches to advance state of the art.

Theoretical projects (like this one) that are focused and have a track record tend to impact the experimental approaches, even though they are high risk and sometimes are not validated by experiments.

The project approach explores expanding the knowledge of the science behind the current state of the art, and most importantly explores the little known area of heterovalent mixing of cation. The latter is a unique approach to larger choice of absorber materials and innovative discoveries that fit the design of the ultimate perovskite solar cells.

**Project Title:** Low-Cost Scaffold-Reinforced Perovskite Solar Modules with Integrated Light Management

**Award Number:** 08154

**Principal Investigator:** Dauskardt, Reinhold, Stanford University

**Project Description:**

Novel hybrid perovskites hold great promise for early-stage, next-generation solar cells. However, the mechanical fragility, chemical instability, and moisture sensitivity of the current organometal trihalide perovskites will need to be addressed to ensure a competitive advantage. This project focuses on researching a revolutionary new compound solar cell module design based on a recent breakthrough in Stanford's lab—using an innovative patterned hexagonal reinforcing scaffold filled with perovskite—that mitigates the chemical, thermal, and mechanical degradation of planar perovskite solar cells.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The low fracture resistance of perovskite materials is a concern for cell durability and a suitable topic for study and remediation. It would have been good for the Team to do extended stress test on the devices by standard ASTM methods or equivalents to see if cracking does occur. There is a question remaining in the perovskite field whether this is even a problem -- that seems like an important first step here.

*Reviewer 2:*

This is an outside-the-box project that seems to be very complicated, but with inherent logic for stability/reliability of the PV and extending performance beyond the normal "flat-plate" approaches. This project is to be ready for the hybrid perovskites which the PI identifies as most in need of this approach--but it does have application to other technologies as well. The PI is for expert in optics than is cell/module technology. Will the cell receive sufficient light coverages? Is it partially illuminated for substantial times? It appears that the acceptance angle might be high enough, but is this true? There are some technical issues with this approach on the illumination of the cell and the "concentration," which is probably no more than 1.2 or 1.3.

*Reviewer 3:*

The goal of the project is to move perovskite solar cells forward to achieve commercial, low-cost solar modules. This is well aligned with the SETO goals for low-cost solar energy.

**Project Title:** Characterization of Contact Degradation in Crystalline Silicon Photovoltaic Modules

**Award Number:** 08155

**Principal Investigator:** Davis, Kristopher, University of Central Florida

**Project Description:**

This project is developing a highly-automated metrology solution that can non-destructively extract the series resistance and recombination of individual cells encapsulated within a photovoltaic module with minimal uncertainty for both parameters using calibrated electroluminescence imaging. This metrology can be used in reliability and durability evaluations to accelerate cycles of learning and to help develop new technologies that reduce cell- and module-level power losses and integrate them into high-volume manufacturing. Each of these applications has the ability to reduce the solar costs by minimizing variance in production, reducing the number of failures due to contact and interconnect failure, reducing degradation rates due to contact and interconnect degradation, and accelerating the adoption of new technologies.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is an excellent proposal that focuses on developing non-destructive imaging techniques for determining module contact resistance and the reverse saturation current. This is a very important need, and everyone who has dealt with fully encapsulated modules knows how difficult it is to extract information about what has degraded the module after field use or accelerated aging. This technique, if successful will address some of the present issues in this field.

*Reviewer 2:*

This project addresses a number of needs in the solar PV industry and therefore addresses key goals of SETO. It provides a tool that can provide quantitative feedback on performance and yield at different stages of the module manufacturing process, which can allow rapid feedback of potential issues in the manufacturing line. It can help introduce new module materials into production more quickly, improving cost and performance more rapidly. It can also help reduce risk associated with modules degrading in the field at an unknown rate. This can result in a lower cost of capital and a lower LCOE.

*Reviewer 3:*

This project seeks to diagnose key electrical issues with modules in the field, specifically, series resistance and recombination losses, especially due to metallization degradation. The thrust of this project is highly relevant to SETO goals as metallization degradation is an important factor in determining module lifetime, and increasing module lifetime is a key goal for SETO.

**Project Title:** Direct Current Arc-Flash Safety for 1,500 Volts: Methodology, Verification, and Codifying

**Award Number:** 08156

**Principal Investigator:** Bolen, Michael, Electric Power Research Institute

**Project Description:**

The rapid release of thermal energy, pressure waves, and electromagnetic interference from an arc-flash all pose risks to people and equipment in a photovoltaic plant. However, there is a lack of understanding regarding how to calculate incident energy from direct current arc-flashes. This project is increasing the fundamental understanding of arc-flash mechanics in photovoltaic systems and providing the quantitative foundation and recommendations for adoption by the industry. This is being done by physically testing arc-flashes in a laboratory; developing a detailed physics-based model to confirm underlying methodology and key input variables; and documenting and disseminating results through guidelines submitted to code bodies, journal and conference publications, and an easy-to-use incident energy calculator.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Project scope seeks to improve industry understanding of ARC flash to improve safety, enhance codes & standards, and improve equipment designs. Primary benefit is to be generated through reduced insurance rates for solar projects. The proposed work also seeks to develop a tool that may be used by the site owners and IEs as a guide for selecting the appropriate PPE for field personnel. The provided materials make reference to "Measure and model DC arc-flash hazards for 1,50 Vdc PV system" as well as "tests actual PV components and/or mock-ups, focusing primarily on string inverters." Field experience indicates arc risks occur through a variety of system components. The full scope of what PV equipment and components to be examined is insufficiently defined.

There is an applied underlying assumption that proper arc-flash guidelines have been established for lower voltage ( $\neq$  /< 1,000) systems. In spite of any established guidelines, based upon field experience, PPE selection for field construction and service, at best, appears to be up to the technician and varies greatly across projects.

Improved understanding of arc-risks and elimination of their potential is very relevant to the health and continuation of solar's contribution to grid resilience and reliability. While insurance costs are not the largest contributor to LCOE, the exceptions, when things go wrong, may be.

Interesting and very relevant work, however, may not directly support SETO goals and better aligned with UL.

*Reviewer 2:*

Field safety is a key goal and needed.

*Reviewer 3:*

This project has a high focus on safety, which relates to the efficiency of operation within a PV power plant. As the utility-scale industry moves to 1500 Vdc systems, incidental arc-flash energy calculations must be done on equipment to ensure O&M personnel are treating the equipment with the proper safety respect, but also can also help reduce some PPE requirements, essentially making O&M more efficient and cost effective.

**Project Title:** Levelized Cost of Energy Reduction through Proactive Operations of Photovoltaic Systems

**Award Number:** 08157

**Principal Investigator:** Walters, Joseph, University of Central Florida

**Project Description:**

This project is developing new methods for characterizing fielded modules in order to provide greater certainty in fielded energy output and degradation rates over their lifetimes. New methods for data analysis and interpretation algorithms are under development in order to maximize fleet performance through a monitoring system that has a higher resolution than state-of-the-art methods currently allow. Additionally, models are being developed to examine the effects that different resolution photovoltaic monitoring systems have on energy yield simulations based on a power plant's design, size, location, environmental considerations, and expected system lifetime.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project supports a technique that has potential to improve the long-term output of solar installations, which is in keeping with SETO goals.

*Reviewer 2:*

This project is still in early stages, but the feasibility of utility scale implementation has yet to be shown. The report doesn't provide good justification for the cost of such a system (outside research applications), or the specific benefits that this could provide over existing monitoring systems (inverter level, etc.).

*Reviewer 3:*

Insuring good performance of fielded systems is an important activity. It is not clear that this project is the most cost effective path to that goal.

**Project Title:** Understanding and Overcoming Water-Induced Interfacial Degradation in Silicon Modules

**Award Number:** 08160

**Principal Investigator:** Fenning, David, University of California, San Diego

**Project Description:**

This project is developing a spatially-resolved characterization methodology to detect the location and amount of water present in photovoltaic modules and to connect the presence of water to acceleration in performance degradation. The quantitative understanding of water ingress and its effect on module performance will enable mitigation strategies extending lifetime of photovoltaic modules and thereby lowering solar costs.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reliability is a significant concern. This is relevant.

*Reviewer 2:*

Increasing the ability to characterize a potential source of environmental stress in modules is positive to designing seals for long term service life.

*Reviewer 3:*

Moisture is known to play a role in module degradation; mechanisms are not fully understood. Developing a viable method for observing moisture ingress is important, and as will be then utilizing that method for understanding related degradation mechanisms.

**Project Title:** Advanced Module Architecture for Reduced Costs, High Durability, and Significantly Improved Manufacturability

**Award Number:** 08161

**Principal Investigator:** Barth, Kurth, Colorado State University

**Project Description:**

This project is investigating a new module architecture for thin film photovoltaic modules to reduce manufacturing costs, cap-ex costs, and degradation rates associated with moisture ingress. The proposed method will provide an improved process cycle time compared to standard lamination procedures. Key areas of investigation include obtaining a complete understanding of layer formation during the encapsulation process as well as the evolution of material properties, interfaces, and module performance over time during accelerating testing.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The successful completion of this project would result in new module architecture with the potential to deliver a significant reduction in PV module manufacturing costs. Moreover, this new module architecture may also lead to improved long-term reliability. Both the reduction in module manufacturing costs and the improved reliability would in turn led to a significant reduction in the LCOE of PV systems using this new module technology. This new type of module should be particularly advantageous for CdTe PV modules and should benefit First Solar, the major thin-film PV producer and a U.S. owned company.

*Reviewer 2:*

The project addresses reducing module assembly costs for thin film modules. This will help lower costs, but is rather narrowly focused on a small portion of the PV module market.

*Reviewer 3:*

Project is developing tooling for implementing a new module construction. The new module design uses glass-glass construction that appears to be more suited for thin-film PV. The new technology has reported cap-ex, material cost, and productivity benefits over the incumbent technology (vacuum lamination). Some thin-film modules have historically used batch autoclave process for the lamination. The project needs to be sure that it is comparing to current production standards in thin-film PV.



**Project Title:** Operando X-ray Nanocharacterization of Polycrystalline Thin Film Modules

**Award Number:** 08163

**Principal Investigator:** Bertoni, Mariana, Arizona State University

**Project Description:**

This project is developing an X-ray based characterization framework that enables module evaluation cadmium telluride and copper indium gallium selenide cells under a variety of operating conditions with nanoscale resolution. Researchers are using several lab-based mapping and synchrotron-based techniques (fluorescence, diffraction, and spectroscopy) coupled with the collection of IV curves in custom-designed stages capable of handling different temperatures, atmospheres, and illumination conditions to enable higher module efficiencies, longer warranties, and lower degradation rates.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

If CdTe is to continue to have market share vs crystal silicon, or to increase its share, the present trend toward more rigorous applied physics understanding of cells will be essential. This is a good example of well-planned applied science: Careful microscopic measurements of impurity fluorescence, diffraction, and spectroscopy, corrected for thickness and other effects and correlated to 2d XBIC maps of Voc and Jsc. It is extremely relevant to increasing efficiencies of CdTe and also CIGS.

*Reviewer 2:*

This proposal is likely to provide 'some' feedback to thin film PV manufacturers in terms of chemistry, metastability of defects and some nanoscale effects in films of CdTe and CIGS. It is not at all clear whether this information can be of use to the one or two PV companies left in this space, especially if they are pretty settled on the fabrication recipes and protocols. Furthermore, the techniques proposed, such as micro-Raman or X-ray measurements are not necessarily new or unique and they certainly are not one-catch-all tool. Still, I think there are good merits in this proposal.

*Reviewer 3:*

The project goals are well aligned with the SETO performance goals: measure with high resolution tools the rate of change at the nanoscale level that occur in the module in real time (compositional, structural, defect migration, etc.) under conditions equivalent to the real world conditions in the field. Based on understanding what stress condition produces what change, a mitigation path will be proposed to reduce the rate of change, i.e. degradation. The outcomes are improved performance, better stability (longer life), elimination of transient behaviors, and predictability of module output. The overall benefits translate in lower cost. The latter is the primary goal of the SETO program.

The tangible benefit to industry is a general model as a guide to produce modules that are higher in efficiency, stable, with predictable lifetime.

**Project Title:** Fault-Tolerant, Shade-Tolerant High-Voltage Photovoltaic Modules

**Award Number:** 08164

**Principal Investigator:** Bowden, Stuart, Arizona State University

**Project Description:**

This project is developing a solar cell architecture called the M-CELL, which enables higher voltage and lower current than conventional modules. The M-CELL architecture results in a single silicon wafer on which multiple cells are monolithically integrated and interconnected in series. This project is researching the series connection configuration, current-voltage characteristics, shadowing reduction, and impact of higher voltage on power losses of this early-stage technology.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project involves a new way of processing Si solar cells so that multiple cells are fabricated in series on a single wafer. This approach has the potential to lower the cost of Si PV modules by reducing the amount of silver paste (no busbars), simplifying the manufacturing of modules by having all interconnections on the rear and using metal foils, and leading to higher voltage modules that will reduce wiring costs and make it easier to use module integrated inverters. The use of higher voltage cells, modules and systems could also lead to higher PV system efficiencies due to reduced series resistance losses as well as more efficient inverters.

*Reviewer 2:*

Even if successful, impact on lowering cost and improving module power will be marginal.

*Reviewer 3:*

Possibly relevant if easing module integration while elimination of  $I^2R$  interconnection losses.

**Project Title:** Non-Contact Simultaneous String-Modules I-V Tracer

**Award Number:** 08165

**Principal Investigator:** Tamizhmani, Govindasamy, Arizona State University

**Project Description:**

This project is developing a non-contact module-level I-V tracer for the rapid and accurate characterization of photovoltaic modules under operating conditions. This tracer will enable accurate degradation science and fielded performance monitoring to be conducted on modules under operation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The proposed work seeks to develop a method for obtaining IV curves at the module and string level on fielded modules. Such a capability will be of great help to those performing final acceptance testing at COD and during O&M in subsequent years. This will help improve system reliability and optimal performance assuming questionable or underperforming modules are repaired or replaced.

Providing the means to obtain IV curves for fielded modules without the need for physical array contact by field personnel will be of great importance to improving safety. In most instances, with current practice, module strings are isolated before connectors are separated. Therefore minimal current is passing through a given string when any contact is made thereby minimizing any potential damage to connectors.

There is a potential reduction in the time it will take for field personnel to gather IV information with the proposed ESV device. However, the provided information does not adequately define the collection actual or intended procedure to assess this.

SETO's goals include achieving significant (~50%) reductions in system costs. Field measurements of IV curves, at the moment, are assumed to be a small part of system commissioning and operating costs. Therefore, reducing the cost of collecting IV information may not contribute to significant lowering of LCOE. Moreover, the provided information does not sufficiently quantify the costs of the proposed ESV approach in a manner that establishes clear cost reduction targets or comparisons with current state-of-the-art.

*Reviewer 2:*

Yes, it may be true that perhaps doing module or string level measurements in the field are tedious or time consuming; yet, it is routinely performed and in fact it is not necessary to be performed too frequently. Therefore, I personally don't see any added benefits to doing this relatively infrequent measurement by less accurate, higher uncertainty non-contact ESV based equipment.

*Reviewer 3:*

The goal of a partially contactless method of acquiring module and string level IV measurements is a good goal. It would be a very useful tool. It is not clear how it would meaningfully impact LCOE however. It would improve safety, which is a very good thing.

**Project Title:** Direct Metallization with Reactive Inks: Assessment of Reliability and Process Sensitivities

**Award Number:** 08166

**Principal Investigator:** Hildreth, Owen, Arizona State University

**Project Description:**

This project is investigating the material and growth properties of reactive metal inks in order to explore their potential use in the metallization of silicon solar cell. The research team seeks to radically change the cost structure of the cell by dramatically reducing silver consumption. This technique is of particular importance to temperature sensitive devices, such as heterojunction architectures, where the low processing temperatures of reactive inks offer a significant advantage and alternative metallization methods are currently expensive.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The cost issues (and some health issues) associated with the contact formation to solar cells is very important. This project addresses these through metallization schemes using ink technologies, but not "traditional ones." This approach is different in that the chemical reaction is the key, not the inking by a nozzle. In this, the program offers some new approaches and potential advances in the cost/technology/energy use/processing. The focus is on c-Si and heterojunction Si cells, with the latter seemingly to have the most pressing need to reduce any costs for greater market penetration. It should be noted that this metallization approach has potential for other technologies (emerging ones) in the DOE EERE Portfolio as well. This project directly addresses the relevant cost, processing, and performance goals of the DOE PV Portfolio.

*Reviewer 2:*

This project directly addresses the high cost of metallization of solar cells, which is well aligned with the SETO goals of reducing solar cell costs. The metrics for reducing silver usage by a factor of 10 would be significant in terms of materials cost reductions.

*Reviewer 3:*

It is true that metallization for HIT cells and other cell architectures that are confined to low processing temperatures is in need of improvement, as silver pasted that fire at low temp do not reach as high conductivity as higher firing temp inks, being a factor of 2 lower in conductivity. Since HIT cells are an important vehicle for high efficiency PV, work on this issue is very relevant.

**Project Title:** Perovskite on Silicon Tandem Solar Cells

**Award Number:** 08167

**Principal Investigator:** McGehee, Michael, Stanford University

**Project Description:**

This project is studying newly developed perovskite on silicon tandem modules to determine the best interconnection design and material properties for each module component. The perovskite material will be characterized and modified to produce a top cell with an ideal band gap and few structural and electronic defects. Modeling will be used to predict outdoor panel performance under realistic spectral variations, which affects how well the electrical current is balanced between the two types of cells.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Silicon is already the most commonly used PV material and its reliability and safety has been investigated for many decades. This project seeks to incorporate low-cost perovskites technology with already existing PV cells and modules, potentially giving Si cells a boost in efficiency of up to 10% points or more. If successful, this will significantly drive down the cost of PV panels.

*Reviewer 2:*

Increasing the efficiency of Si PV technologies would have direct impact on the SETO goals, due to the dominant position of Si technologies in the PV marketplace. The relatively low cost and low temperature deposition techniques used for halide perovskite (HP) devices, combined with the band gap values of HP materials that span the region 1.5 ... 2 eV, has focused the PV community on the opportunity of developing HP-on-Si tandem devices. If successful, such an approach could increase the efficiency of Si PV by several percentages points absolute at relatively low manufacturing cost. Although significant hurdles remain, notably including the stability of HP devices, this is clearly an area of research relevant to SETO goals.

*Reviewer 3:*

The hybrid perovskites and reached laboratory (research) demonstrations for their high efficiency performance. This is the next level--a tandem that leverages the performance of the existing, demonstrated, and manufacturable Si technology to enhance the overall performance. Certainly the efficiency gain is credible--but more, the promise of increasing the reliability and stability is a needed aspect. This is world-leading research and the group should be acknowledged for its rapid progress--and its insight into coming their perovskite expertise into this much different area. Some questions do exist: (1) Are there issues with scale up? What are the manufacturing alternatives? (2) Are there cost benefits? Is the addition of the perovskite any better cost wise over if the original high-efficiency heterojunction. It should be noted that the results on the damp Heat, exposure, and thermal cycling mainly show how well that the tandem has been encapsulated. Finally, it is indicated that that some very credible companies has "requested" meetings about this technology. It does not look like any of these are "heterojunction" manufacturers (e.g., Panasonic) that might be expected to have a real interest. Overall, it is just very nice research.

**Project Title:** Enhanced Convection for Higher Module and System Efficiency

**Award Number:** 08168

**Principal Investigator:** Cal, Raul, Portland State University

**Project Description:**

This project is developing new solar photovoltaic modules and solar system-scale designs that promote an increase of the convective heat transfer coefficient of at least 40 percent. This reduces the operating temperature of the solar photovoltaic panels and leads to a boost on the annual energy yield and a potentially significant increase in the reliability of modules over time. Extensive modeling and early stage experimentation is being conducted to determine the dynamics of air flow needed to produce vortex generation and flow channeling effects that would lead to lower temperature of the array.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reduction of a module's NOCT has been shown to increase its power. Integrated over time, lower module operating temperatures have been shown to improve energy output. This work appears novel in that the normal operating temperature of fielded modules will be reduced through an increase in convective heat transfer by use of air flow deflectors. Lower module operating temperatures may also yield lower degradation rates of module materials.

This work has the potential to lower the levelized cost of energy from solar plants but this is dependent upon the cost of deploying the required wind deflectors and their effectiveness. The provided information is insufficient in regard to O&M cost impact assessment.

*Reviewer 2:*

Improving energy yield through reduction of operating temperature has the potential to reduce LCOE.

*Reviewer 3:*

Improved performance of PV modules by different cooling methods would impact LCOE, although the scale of the impact is not so clear.

**Project Title:** Spread Spectrum Time Domain Reflectivity for String Monitoring in Photovoltaic Power Plants

**Award Number:** 08169

**Principal Investigator:** Scarpulla, Michael, University of Utah

**Project Description:**

This project is investigating the application of spread spectrum time domain reflectivity to detect faults and their locations in a photovoltaic string in real time without disconnecting the string during the test. For example, the technique can decipher which panel or section of wiring has experienced a physical or operational change. By detecting the fault location in the connected string, this project will enable more efficient repair and maintenance of photovoltaic power plants, maximizing future energy output, and reducing the levelized cost of energy.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Tools that help reduce the O&M costs of the systems are important since O&M is a critical line item in the LCOE calculation. Finding faults today without module level power electronics (MLPE), like DC-DC optimizers or micro inverters, can be extremely time consuming. Technicians may spend hours with traditional instruments tracing down an intermittent fault and still not be certain of its exact location.

*Reviewer 2:*

Existing system monitoring tools provide reasonable notice of open and short circuit conditions in module strings. Inverter monitoring circuits already provide indication of ground fault and other performance related shortfalls at the string level.

The project proposed the evaluation of Spread Spectrum Time Domain Reflectivity (SSTDR) technology to detect and characterize changes in the impedance in operating PV strings. Though the intent is to deploy SSTDR engines in a cost-effective manner, the provided materials provide insufficient financial modeling to evaluate the benefit of this technique over existing options for string and plant monitoring.

**Project Title:** Sound Assisted Low Temperature (SALT) Spalling: Upscaling and Throughput

**Award Number:** 08170

**Principal Investigator:** Bertoni, Mariana, Arizona State University

**Project Description:**

Exfoliating a wafer from a silicon block, known as spalling, has been shown to be a promising kerfless, or waste-saving, technique in wafer production. This project is researching an early-stage, novel spalling process called sound-assisted low-temperature spalling to address defects, wafer thickness, and surface planarity through the use of acoustic waves to sharpen and facilitate crack formation during the spalling process.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reducing silicon consumption by a factor of 2 is very relevant to the SETO goals. However, this is a high-risk project and probability of success is low.

*Reviewer 2:*

Achieving a low-cost, high-throughput method for kerfless wafering of silicon ingots would significantly reduce the cost of silicon for solar modules. This is exactly in line with the SETO goals for reducing the cost of solar power.

*Reviewer 3:*

Mono crystalline Si wafers are a key building block for very high efficiency solar cells. Creating wafers from an ingot with no sawing is a difficult, but worthy goal. Success would have a very significant impact on LCOE by providing the highest crystallographic quality of silicon with dramatically less silicon cost and reduced wafering cost. This project is highly relevant.



**Project Title:** Revealing the Mechanism of Light Induced Degradation and Regeneration of P-Type Czochralski Silicon

**Award Number:** 08171

**Principal Investigator:** Agarwal, Sumit, Colorado School of Mines

**Project Description:**

This project employs advanced spectroscopic tools to explore boron-oxygen related defects in p-type Czochralski monocrystalline silicon that informs processing strategies to permanently suppress these defects and improve cell efficiency. Early-stage materials research is improving understanding of the hydrogenation and dehydrogenation of boron-oxygen complexes, and light-stimulated electron spin resonance methods is clarifying their bonding configurations and evolution during intense illumination.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Fundamental understanding and characterization of LID process is very relevant to lowering cost and increase durability of PV plant.

*Reviewer 2:*

LID in PERC cells is a problem for most manufactures not implementing regeneration steps - this is rather commonplace now, so the project aims to clarify the defect formation/annihilation and possibly eliminate this process step for cost reduction.

*Reviewer 3:*

A large portion of solar production is in p-type PERC and more is switching to it. This cell architecture is sensitive to light induced degradation (as well as potential induced degradation). Thus, the focus of this effort is relevant and timely.

While the industry believes that they have a solution to PID in PERC cells – ‘regenerating’ the device under 1 sun at 150C. However, there is only a standing hypothesis about the physical mechanism for this. Of course, no modules treated this way have been in the field for more than a few years and so, there remain significant questions about stability and reliability. Therefore, improving our understanding of the mechanisms behind regeneration would be very helpful in anticipating issue that might arise in the field.

**Project Title:** Reliability and Power Degradation Rates of Passivated Emitter Rear Contact Modules Using Differentiated Packaging Strategies and Characterization Tools

**Award Number:** 08172

**Principal Investigator:** French, Roger, Case Western Reserve University

**Project Description:**

This project is conducting a systematic study of module degradation pathways in passivated emitter rear contact photovoltaic modules, benchmarking them relative to known degradation mechanisms and pathways of older module designs, such as full-area aluminum back surface field, which have been exposed to real-world and accelerated exposure conditions. Statistical models incorporating outdoor performance and accelerated testing data will be used to understand the dominant physical degradation mechanisms that occur in the field for a variety of encapsulant and backsheet combinations. These models will allow for new and previously unmapped material interactions that are present in newly developed module architectures to be modeled, characterized, and ultimately accounted for in future design efforts.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

PERC is growing in market share and relevance in the market. Several independent engineering firms attribute a higher degradation for PERC modules, which is negative to project economics and LCOE. Developing a better understanding of PERC degradation is valuable to the industry.

*Reviewer 2:*

Reliability of modules is a concern, and module manufacturers cannot be relied upon to give representative estimates of degradation unless there is a justifiable warranty (and assurance the company will be around to pay any claims). This work is important to test the lifetime/reliability of relatively new PERC modules to ensure successful PV projects using this technology.

**Project Title:** Adhesive Mounting of Conventional Photovoltaic Modules for Residential Solar

**Award Number:** 08173

**Principal Investigator:** Honeker, Christian, Fraunhofer USA Inc., Center for Sustainable Energy Systems

**Project Description:**

This project aims to reduce the installation cost of photovoltaic systems by researching a non-penetrating adhesive mounting interface for securing conventionally framed and glass-glass modules to asphalt shingles. Key areas of investigation include characterizing and understanding the direction and balance of forces between the proposed adhesive chemistry and the target surface, and the physical changes that take place in the mounting materials over time. Eliminating penetrating adhesives has the potential to mitigate the risk of expensive roof leaks, speed module mounting, and reduce the training requirements of the installer.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The goal of reducing the labor component in residential system installations is a key area. The labor cost varies widely from region to region and is highly dependent on the structure and roof material type. There are many opportunities here where important research could help to reduce the dependency on skilled labor and man-hours spend on rooftops.

*Reviewer 2:*

The project as proposed, may lead to direct and significant reductions in the cost of residential PV systems. The approach, as proposed, may contribute to both reduced time for installation as well as substantial reduction in componentry (support structures) and complexity.

A cost reduction target of 50% in installation labor and a \$0.05/W may yield significant reduction in residential LCOE.

*Reviewer 3:*

The projects goals are relevant because it would obviate the need for roof penetrations, but unfortunately, there's too much uncertainty about the strength of the roofing material to rely on adhesion alone.

**Project Title:** Perovskite Solar Cells: Addressing Low-Cost, High-Efficiency, and Reliability through Novel Hole Transport Materials

**Award Number:** 08174

**Principal Investigator:** Sellinger, Alan, Colorado School of Mines

**Project Description:**

A very important component of a perovskite solar cell is the hole transport layer, which is generally an expensive and a relatively unstable component of this early-stage technology. Currently, the state-of-the-art hole transport layer is based on a lithium salt doped aromatic amine that is very difficult to prepare and has no paths to becoming cost-effective at high volume. This project is researching new hole transport layer materials for perovskite solar cells to address the current bottlenecks, such as cost, tunable conductivity and energy levels, hydrophobicity, lithium-free dopants, and stability.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The hole transporting layer of the perovskite cell seems to be the source of much of the problem with poor cell lifetime, due to the use of the small Li<sup>+</sup> dopant atom. Also, the spiroOMeTAD in the HTL represents about half the projected cell cost. This group has synthesized a less expensive small molecule alternative that can be doped with similar molecules that will not diffuse much. Therefore, they attack an important pair of problems to today's cells and have shown over 16% efficiency already.

*Reviewer 2:*

This project is directed at reducing the cost of the hole transport later (HTL) in Perovskite solar cells. The current favored organic HTL is expensive. Perovskite solar cells are relevant to SETO goals as they offer a path to low cost and high efficiency, albeit one that lies in the future. As such, the overall goal of this work is very relevant.

*Reviewer 3:*

Dr. Sellinger's work on alternative hole transport materials for perovskites is very important because the standard material used for all ultra-high efficiency devices, Spiro-OMeTAD, is an identified Achilles heel for perovskite device stability. While other work successfully focuses on all-inorganic contact layers, the alternative organic route by Dr. Sellinger is a very important contribution to the field with possible game-changing outcomes.

**Project Title:** Tunneling Back-Contacted Silicon Photovoltaics

**Award Number:** 08176

**Principal Investigator:** Strandwitz, Nicholas, Lehigh University

**Project Description:**

This project is investigating the introduction of atomic layer deposited tunnel barriers that simultaneously allow carrier flow and passivate the silicon surface for silicon-based solar cells. The tunnel barrier is combined with metal oxide materials that selectively transport electrons or holes. This work employs an atomic layer for the deposition of these thin film layers, which is a potentially scalable technique capable of uniform sub-nanometer control of film thickness, even on non-planar substrates. This work quantifies the electronic behavior of these contacts, which may establish some of the most efficient electrical contacts to silicon photovoltaics to date.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project goal to develop a new configuration of aluminum oxide passivation/tunnel layers in conjunction with  $\text{MoO}_x$  and  $\text{TiO}_2$  carrier-selective contacts has the potential to lower the cost of Si solar cells. Currently, the highest performance crystalline Si solar cells are all-back contact cells that utilize interdigitated amorphous Si heterojunctions as carrier-selective contacts. However, the deposition of amorphous silicon requires relatively expensive plasma-enhanced chemical vapor deposition equipment. Moreover, the processing options for cells containing amorphous Si are limited to relatively low temperature due to out-diffusion of hydrogen at temperatures  $> 200^\circ\text{C}$ .

*Reviewer 2:*

It is unclear to estimate the project's ability to hit cost targets given the complexity of multiple ALD layer stacks as selective contacts - despite avoiding diffusion or oxidation steps.

*Reviewer 3:*

Passivated contacts are likely the next technology node after PERC for p-type cSi PV.

**Project Title:** High Lifetime and Mobility Cadmium Telluride Alloys by Co-Sublimation

**Award Number:** 08177

**Principal Investigator:** Sampath, Walajabad, Colorado State University

**Project Description:**

Researchers are investigating the composition and grading of cadmium selenium telluride material to understand how it changes the performance and material properties of absorber layers. The effects of novel surface passivation techniques on carrier lifetime and other device properties will also be investigated. Material and device characterization will provide insight to the unique properties of these new materials and architectures. The project aims to produce record carrier lifetimes for cadmium telluride based devices.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project of grading the CdTe band gap to improve efficiency and increase band gap in CdTe devices is directly relevant to the SETO goals to decrease LCOE. The team are aiming to increase their current in-house efficiency record from approx. 19% to 20.6%. This improvement will impact BoS costs (i.e. reduction) as long as the team can show that there will be no significant increase in cell/module costs associated with the innovation.

*Reviewer 2:*

I feel thin film technology affords the best chance to meet ZETO goals sustainably. Silicon technology is reaching cost targets, but manufacturers are going bankrupt in the meantime. This is NOT a sustainable business model if we need terawatts of solar panels. Thin film, on the other hand, meets cost targets profitably. As soon as First Solar brings the Series 6 to full production, thin films will once again be the lowest cost leader by a good margin. CIGS is also capable of this, but CdTe is currently better funded. As such, pushing the efficiency of CdTe while maintaining its process flow and therefore low cost may be the most important SETO goal of all. That is the intent of this project, so it should receive the highest support possible.

*Reviewer 3:*

The project is aimed at improving the efficiency of CdTe by forming a ternary compound that incorporates Se into the semiconductor absorber, lowering the band gap of the cell. This project is consistent with SETO goals to lower the cost of PV and improve the performance of the technology.

**Project Title:** Solar Energy Research Institute for India and the United States

**Award Number:** 25537

**Principal Investigator:** Ginley, David, National Renewable Energy Laboratory

**Project Description:**

This project, which is co-led by the Indian Institute of Science, develops and prepares emerging solar electric technologies by lowering the cost per watt of photovoltaic and concentrating solar power. Scientists focus efforts on high-impact fundamental and applied research and development, overcoming barriers to technology transfer by cutting the time from discovery to technology development and commercialization through effective coordination, communication, and intellectual property management, and creating a sustainable network from which to build large collaborations and foster a collaborative culture and outreach programs.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This was a project mandated by the executive branch to help build our political relationship with India through technical interaction. Projects could have an impact on cost of solar in the US and around the world, but a number of them seemed to be focused on specific Indian issues (e.g. SAM for India, soiling in India) that do little for SETO US focused goals.

*Reviewer 2:*

Generally the projects are relevant to the goals of EERE, but the program started in 2012 and is now finishing. The perovskite work and the CSP work were particularly relevant. The India deployment goal was excellent, but it seems like too little was done in this area.

*Reviewer 3:*

India is a potentially large market for solar, and has necessary infrastructure to support significant solar manufacturing. This program provides a means for early stage technical cooperation.

**Project Title:** Selective Area Growth of III-V Materials on Silicon Patterned with Nanoimprint Lithography

**Award Number:** 28394

**Principal Investigator:** Tamboli, Adele, National Renewable Energy Laboratory

**Project Description:**

This project mitigates the issues surrounding the integration of III-V and silicon into solar modules by incorporating a nano-patterned buffer layer that results in a low-cost method for selective area growth of lattice mismatched triple junction solar cells. This will help to reduce defect density in the top cell and on the silicon interface, preserve silicon interface passivation, and provide a platform to integrate nano-photonics light management for enhanced cell performance. The nano-patterning and growth techniques developed by this project will be compatible with industrial photovoltaic manufacturing.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The PIs proposed a new, interesting and worthwhile approach to solve an old and difficult problem that of growing device-quality III-V films directly on silicon. The PIs overcame some significant hurdles on the path to testing their hypothesis. In the end, the results clearly show that nanoimprint lithography does not solve the problem. This is an example of a successful hypothesis test: the answer is no, and this work should not be further supported by SETO.

*Reviewer 2:*

This project addresses several important aspects of achieving SETO's goals for 2030. Specifically, the project seeks to reduce the substrate cost of III-V solar cells by developing a mechanism to grow III-V cells on Si instead of GaAs or other expensive substrates. It had additional goals of reducing costs related to thick metamorphic buffer layers of III-V material and hoped to use Si as the bottom junction of a multi-junction cell, further reducing III-V material growth costs. These are all important areas to target for cost reduction of III-V tandem cells. The work built from the large body of work for very high efficiency III-V cells. Achieving high efficiency is very important for the SETO goals of reducing both equipment costs as well as soft costs.

The project does not address the costs associated directly with III-V material growth, which is a significant hurdle. However, the scope of the project is appropriate. Addressing the direct growth costs in other projects is the right strategy for this project.

*Reviewer 3:*

The program deals with two aspects of SETO's goals, achieving a 30% cell and lowering cost. The program is limited in scope, only dealing with the elimination of the metamorphic buffer for growth on Si. Other issues, such as additional costs of NIL and actual growth of the III/V materials are not addressed.



**Project Title:** Optimized, Low-Cost, Higher Than 30 Percent Efficient Indium Gallium Arsenide Phosphide and Silicon Tandem Solar Cells

**Award Number:** 28395

**Principal Investigator:** Ptak, Aaron, National Renewable Energy Laboratory

**Project Description:**

This project is developing indium gallium arsenide phosphide and silicon tandem photovoltaic technology that leverages extremely high efficiency devices and low-cost, high-throughput methods to meet and exceed cost targets. Researchers are conducting controlled liftoff of III-V devices grown on germanium substrates with attention toward device quality, substrate reuse, and manufacturability, while also developing a low-cost, high-throughput growth of highly efficient III-V solar cells with the optimal bandgap, which will achieve the maximum efficiency from a two-junction structure. In addition, this project is attempting a proof-of-concept integration to illustrate that the technology is capable of achieving a conversion efficiency of more than 30 percent.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project focuses on reducing costs associated with high efficiency solar cells. Specifically, this project has addressed the costs associated with substrates for high-efficiency tandem solar cells. This is very well aligned with the goals of the SETO program.

*Reviewer 2:*

The three major goals are consistent with the SETO goals of a 30% PCE solar cell at low cost. It would have been good if the cost goals would be revisited. Based on what is known about spalling now, and the required treatment of the Ge substrate to attain good epi growth post spalling, can a significant cost reduction be achieved. The same is true for HVPE, i.e., what kind of system is required to achieve lower cost growth compared to MOCVD.

*Reviewer 3:*

Project is investigating high-efficiency Si tandem cell as means to reduce LCOE.

**Project Title:** Ultra High-Efficiency and Low-Cost Polycrystalline Halide Perovskite Thin-Film Solar Cells

**Award Number:** 28396

**Principal Investigator:** Zhu, Kai, National Renewable Energy Laboratory

**Project Description:**

This project is developing high-efficiency single-junction perovskite solar cells, helping to gain an understanding of basic material and device properties related to halide perovskites, which will lead to the demonstration of ultra-high efficiency tandem thin-film devices. Researchers are using two complementary methods: solution processing and co-evaporation deposition. Theoretical modeling is being conducted to understand doping/defect physics for perovskites, while information learned on doping physics, defect chemistry, and device modeling will be made available to the photovoltaic community and will support solar manufacturers and start-ups looking for their next-generation photovoltaic products.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project has set out to develop high efficiency, low cost tandem solar cells based on a new class of PV materials (halide perovskites). It basically pursues all the research elements that go into developing new materials and testing of them, including various deposition and optimization techniques, various electrical characterization, and achievement of various milestones.

*Reviewer 2:*

This is a very interesting perovskite approach to tandems--in which each of the cells is a perovskite. It builds on the strengths and knowledge of some other past advanced PV technology approaches (e.g., a-Si:H or even GaAs multiple junctions). Bandgap tuning and engineering has been a foundation of the PV research community--and this approach with perovskites seems to have some very strong benefits for these methodologies. From the science viewpoint alone, this is not only relevant, but very important. This involves the engineering of the bandgaps, the interfaces, defects, etc. It is not an easy approach--especially with a technology so young as the perovskite are. However, the achievements show that this has high potential that supports the high relevance. (The science aspects have benefits to other technologies as well.)

*Reviewer 3:*

An all-perovskite tandem module is, according to the reviewer's cost models, the only tandem solar device that would be attractive in a utility installation, where area-dependent balance-of-system costs are low.

**Project Title:** Non-Destructive Evaluation of Water Ingress in Photovoltaic Modules

**Award Number:** 29911

**Principal Investigator:** Bora, Mihail, Lawrence Livermore National Laboratory

**Project Description:**

A better understanding of the water diffusion process substantiated by experimental data analysis from deployed modules has the potential to improve both reliability and performance of photovoltaic modules. This project is developing a non-invasive optical detection technique based on hyperspectral near infrared imaging of modules.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

SETO goals of achieving a 50-year module will likely require minimal moisture ingress into the module package. Developing a non-contact method to measure moisture content inside of the module is valuable to help development of edge seals, encapsulants, backsheets, etc.

*Reviewer 2:*

Moisture is known to play a role in module degradation; details not clearly elucidated for various module types. An in situ analysis method will be useful.

**Project Title:** Performance Models and Standards for Bifacial Photovoltaic Module Technologies

**Award Number:** 30286

**Principal Investigator:** Stein, Joshua, Sandia National Laboratories

**Project Description:**

Bifacial photovoltaic technology is available today, but due to its more complex light collecting dynamics, its performance advantages have not been fully exploited and commonly available tools do not allow it to be considered for major projects beyond current niche applications. Unpublished field data indicates that this technology has the potential to increase system outputs by 10-30 percent. This project provides the data, standard test methods, and validated models to allow developers to fairly evaluate the potential benefits bifacial photovoltaic technologies for specific projects.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is relevant understanding system performance over time thus improving the understanding of LCOE since bifacial performance modeling is not represented to in today's modeling tools. Many customers rely on manufacture data sheet claims of performance gains. However, the performance gains are very dependent on the installed condition in the field. Often manufacturers will publish the best case numbers or lab test numbers. This work will help to improve how installed rooftop and ground mount systems are modeled for performance over the life of the system. Once the performance is accurately modeled, developers can make informed cost vs. performance decisions that will ultimately reduce LCOE.

*Reviewer 2:*

Bifacial modules have the potential to increase energy production without significant increases in cost (therefore, lower LCOE); the ability to accurately model plant output through development and validation of models is critical to adoption.

*Reviewer 3:*

Bifacial PV is a very quickly growing segment. The impact on energy production is not well understood. This project is continuing to improve the accuracy of bifacial energy production estimates, a key requirement for financing bifacial projects.

**Project Title:** Regional Test Center Operations

**Award Number:** 30287

**Principal Investigator:** Stein, Joshua and Deline, Chris, National Renewable Energy Laboratory,  
Sandia National Laboratories

**Project Description:**

The Regional Test Center program aims to support technical innovation in the U.S. solar sector by validating the performance of new photovoltaic products in multiple climates at five sites. All sites represent a range of irradiance, temperature, and precipitation averages. This project supports the operation, maintenance, and management of the sites and provides the opportunity to add new collaborative projects with industry partners across the Regional Test Centers.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The concept of regional test centers to help industry reduce bankability related costs with data was an appropriate investment when large-scale manufacturing of modules was expected to happen in the US. History has shown us a different path so that the value of the effort as designed is greatly diminished.

*Reviewer 2:*

Like the PV Lifetime project, this project is valuable because it offers field validation of accelerated lifetime tests and the ability to identify serial defects in the resiliency and reliability of PV that could in turn inform mitigation strategies. This is particularly valuable as PV becomes a large share of the country's energy infrastructure. The process is generally very slow, however, so discoveries should not be expected quickly.

*Reviewer 3:*

The Regional Test Center program provides multiple climate zone test centers for outdoor field evaluation for new technologies - including bot production and data acquisition platforms. While the RTCP provides coordinated efforts amongst multiple labs in multiple environments, this type of program is also available in the private sector. It is unclear why public fund should continue to be utilized in this effort.

**Project Title:** Degradation Assessment of Fielded Copper Indium Gallium Selenide Photovoltaic Module Technologies

**Award Number:** 30288

**Principal Investigator:** King, Bruce, Sandia National Laboratories

**Project Description:**

Conducted at the Regional Test Centers, this project reduces the uncertainties surrounding long-term reliability and performance of copper indium gallium selenide photovoltaics by measuring real-world performance and degradation rates of fielded systems and by publishing accurate, predictive performance models.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The projects goal to improve uncertainty and models is relevant to better understand the long term degradation impacts of CIGS. Unfortunately the CIGS technology has not much growth. Fortunately the approach of using the parametric study to improve correlation to real world data basically improves the curve fitting for the Sandia performance model. This approach can be applied to almost any PV cell technology and has value in technologies that are more in vogue today.

*Reviewer 2:*

CIGS is not currently showing promise to be a disruptive technology in the market. As it stands, there are only a few manufacturers (Solar Frontier being the largest, but only comprising ~1GW of manufacturing capacity), and there are stability and efficiency issues as well. There are definitely some other possible applications of this work to other technologies, but the overall impact is still limited.

*Reviewer 3:*

Developing performance models and predicting long term performance are valuable to the program. Unfortunately the focus on CIGS lowers the value in today's marketplace.

**Project Title:** Improving Photovoltaic Performance Estimates in the System Advisor Model with Component and System Reliability Metrics

**Award Number:** 30289

**Principal Investigator:** Klise, Geoffrey, Sandia National Laboratories

**Project Description:**

This project improves the forecasting of lifetime photovoltaic system performance, operations, and maintenance costs by incorporating the Photovoltaic Reliability and Performance Model into the widely-used Solar Advisor Model software platform.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This research touches on key factors that are missing in today's modeling tools. Less mature developers are typically left using a single availability factor or simplistic approach to system reliability. Typically, only large system integrators with ~ 10 years of experience have the resources and data sets to develop their own proprietary reliability models.

*Reviewer 2:*

More accurate and granular attribution of availability and energy loss will enable more informed effort for improved O&M.

*Reviewer 3:*

This project aligns with the goal to understand reliability, providing information and prediction capability around real time system performance. The focus is not explicitly on increasing module lifetime as stated in the goal, but the health and resulting impact on energy production of other system equipment is essential to the success of projects (and is often overlooked in predictions).

**Project Title:** High-Efficiency, Low-Cost, One-Sun, III-V Photovoltaics

**Award Number:** 30290

**Principal Investigator:** Ptak, Aaron, National Renewable Energy Laboratory

**Project Description:**

This project continues development of hydride vapor phase epitaxy growth coupled with novel epitaxial liftoff strategies toward low-cost multi-junction III-V photovoltaics.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is addressing several of the important cost drivers that limit the adoption of GaAs as a mainstream PV technology: precursors, wafer reuse and reactor design. Success here could accelerate the overall reduction of the cost of PV generated electricity by making high efficiency, cost effective GaAs solar cells available, and delivering the high energy densities that mitigate the fixed costs of solar installations.

*Reviewer 2:*

The performance/technology goals are great. Achieving SETO's cost targets, however, are hard to fathom when you are using a process to create pores in Ge, have them coalesce on annealing, growing on top of this, spalling off the epi growth plus a layer of Ge, and then re-using the substrate? Great technology, but difficult to see how this will achieve the cost targets.

*Reviewer 3:*

HVPE is a promising route for cost reduction in III-V technology.



**Project Title:** Hybrid Perovskite Solar Cells

**Award Number:** 30291

**Principal Investigator:** Berry, Joseph, National Renewable Energy Laboratory

**Project Description:**

This project is working to demonstrate efficient, stable, and scalable hybrid perovskite solar cells, rapidly transforming these new materials into an industry-relevant technology. The team will advance this technology by improving the stability, efficiency, and scalability of perovskites.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Perovskites are an important new material technology, that may further SETO goals. In fact, it is the only new technology I am aware of that might challenge the existing scale technologies. As such it should be investigated. The stability of the film is the major obstacle so the program is addressing THE critical area. This all point to high relevance. The only weakness I see is that the scalability factor is also very important, and although the project pays lip service to scalability, the truth is that little is being done to ascertain the true scalability. It is only the "promise" that solution-based processing is cheap and scalable. Those of us older folks have heard this before, just 8 years ago, with roll-to-roll processing being the fad. It turned out that almost every single roll-to-roll process failed to scale. The devil is in the detail, and those details have not been a focus of the project. Still, this project is for the most part very much on target.

*Reviewer 2:*

The project emphasizes basic understanding of the integrated material stack in the process and the device and has published many papers in the reviewed journals. Although the project objectives articulate and target the SETO goals, its approach and results to date are similar to previous approaches. The data presented here on efficiency are not officially verified and therefore it is difficult to assess whether it is a stable efficiency and how it compares to other work. The demonstrated stability data in Fig 1 is vague since it does not give the initial efficiency (is it low, moderate, high??) and therefore it is not possible to assess the relevance. In fig 2, it shows the initial efficiency with only 150 seconds time line, which is hardly a stable indication.

Even though the project articulates well the relevance to SETO, the milestones metrics and description are very low and difficult to measure in order to assess the impact they will have on the SETO goals. The project output publications will be valuable for those in the field as part of the SETO program and outside it.

*Reviewer 3:*

The clear focus is on perovskite stability, with avoidance of the popular contact materials TiO<sub>2</sub> and Spiro, which both help in achieving record efficiencies while sacrificing durability. The goal of the team is achieving fundamental understanding, versus making record cells. Third, important experience in upscaling (printing) perovskites has been already gathered in this work.

**Project Title:** National Center for Photovoltaics Community Engagement

**Award Number:** 30292

**Principal Investigator:** Al-Jassim, Mowafak, National Renewable Laboratory

**Project Description:**

This project supports the National Center for Photovoltaics educational and outreach activities, such as the Hands-On Photovoltaics Experience for graduate students.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Technical community building (and the concomitant increased US worker skill level) is an important outcome of government-supported PV research. Taking advantage of the expertise and facilities at NREL is a very effective and low-cost method to accomplish this goal.

*Reviewer 2:*

The NCPV is a high visibility organization with a long record of contributions to the world PV community. Because of its world standing, DOE is the proper organization to head these outreach activities. Those that are cited in this submission are relevant and high quality--with very good feedback and evaluation from the participants. This is a unique setting--having many international technology experts in the NCPV--and support and exposure to other renewable energy technologies at this site.

*Reviewer 3:*

Community outreach is a necessary activity for a National Lab that inhabits such a publicly important topic -- renewable energy. The infrastructure improvements project is also needed -- it is not possible to budget for contingencies on tools that span many projects within individual projects.

**Project Title:** Enabling High-Concentration Photovoltaics with 50 Percent Efficient Solar Cells

**Award Number:** 30293

**Principal Investigator:** Geisz, John, National Renewable Energy Laboratory

**Project Description:**

This project is pushing the limits of high-concentration III-V multi-junction solar cell technology by designing and building five- and six-junction solar cells that can exceed 50 percent efficiency under concentrator standard testing conditions. The project aims to develop new physical understanding and break the worldwide photovoltaic efficiency records.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is aimed at increasing the efficiency of high concentration solar cells by about 10% relative. If successful, the increased performance should translate into lower cost CPV energy. However, this market is a niche, and the increase in cell performance is unlikely be transformative to the industry. The research is also relevant to space cells, but that is not part of SETO's goals.

*Reviewer 2:*

The technical work is excellent, but to drive down costs this cell needs to be used in a CPV system. CPV is simply not cost competitive, even with a cell at 50% with flat plate Si or thin films. So while the work is excellent, I don't see this cell as ever being relevant for terrestrial power generation unless there are area constraints.

*Reviewer 3:*

It is a very ambitious project that pushes the state-of-the-art for PV devices.

**Project Title:** Photovoltaic Risk Reduction through Quantifying In-Field Energy

**Award Number:** 30295

**Principal Investigator:** Deline, Chris, National Renewable Energy Laboratory

**Project Description:**

This project is developing standardized methods for determining degradation factors, which will reduce the perceived and actual financial risk associated with solar photovoltaic deployment. In addition, partially shaded photovoltaic system performance models are being validated and added to simulation software used by installers, increasing the accuracy of performance prediction. The project also expands the geographically diverse photovoltaic performance database using the micro-inverter data.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Providing well-supported characterization techniques that enhance accurate system performance and degradation are critical for large scale acceptance of PV as an energy source. Work in this project helps advance these techniques.

*Reviewer 2:*

This is a very strong bundle of projects relating to accuracy of performance predictions. Improving/verifying prediction accuracy for estimating energy of future projects, financing new projects, and verifying performance of existing projects is vital.

*Reviewer 3:*

This project involves the collection and use of data from a multitude of systems across the United States. The project was borne out of an effort to define best practices for determining system degradation, and led to the development of RdTools - a publicly available Python-based platform. PV Derived Data is a further effort to reverse-engineer the solar resource by using PV system output. The ability to accurately assess system degradation will lead to better bankability assumptions, re-powering strategies, and warranties.

**Project Title:** Manufacturing and Reliability Science for Copper Indium Gallium Selenide Photovoltaics

**Award Number:** 30296

**Principal Investigator:** Mansfield, Lorelle, National Renewable Energy Laboratory

**Project Description:**

This project aims to overcome the largest challenges to investor confidence and long product lifetime in copper indium gallium selenide: meta-stability, potential-induced degradation, and shading-induced hot spots. This project is developing cells with a thin absorber layer that will have cost and reliability advantages due to higher reverse breakdown currents. In addition, the project will improve reliability of copper indium gallium selenide to the level of silicon by quantifying and developing mitigation strategies for meta-stability and potential-induced degradation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is relevant to SETO goals as it has addressed CIGS meta-stability, shading-induced hot spots, and potential-induced degradation. However, since the beginning of the project in 2015, there have been significant challenges to the domestic CIGS manufacturing space. Therefore, it is not clear what the magnitude of the impact/relevance for SETO will be by end of the project this year while manufacturing volumes remain low compared to the silicon and CdTe market.

*Reviewer 2:*

The project states that investor interest in CIGS is limited by the three issues mentioned. I have been meeting investors about CIGS for 6 years, in total over 100 meetings, including venture capitalist, governments, strategic partners, investment bankers, and wealthy individuals. The three issues addressed in this project were almost never mentioned as concerns about CIGS. The key concern has been cost. CIGS manufacturing costs have been high compared to CdTe and c-Si. It is simple economics. This work does not address the fundamental economic issues.

*Reviewer 3:*

This project is aimed primarily at improving the reliability and lifetime performance of CIGS solar cells and modules. Therefore, it supports SETO's goals by improving the bankability of the CIGS technology.

*Reviewer 4:*

A general comment regarding CIGS research: It is a difficult decision to make whether the SETO office should continue supporting CIGS research, given that US CIGS manufacturers have not been successful.

**Project Title:** High-Resolution Investigations of Transport Limiting Defects and Interfaces in Thin-Film Photovoltaic Devices

**Award Number:** 30297

**Principal Investigator:** Moutinho, Helio, National Renewable Energy Laboratory

**Project Description:**

This project is developing a capability of high-resolution transport imaging in photovoltaic devices, which is useful for improving polycrystalline thin-film photovoltaic materials.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project sets out to develop an interesting and informative imaging technique to visualize charge transport and recombination in thin film PV materials. The information obtained by this method can be paired with other imaging techniques to provide more information about such things as grain boundary recombination or defects in these materials and hence can help manufacturers improve their materials or understand the limitations of their devices.

*Reviewer 2:*

Understanding charge transport on the length scale of individual grains in polycrystalline absorber materials is tremendously important, and remains a difficult challenge. Any worthwhile new idea in this space is worth funding, in my opinion. This work is still in the early stages, but I think it is on the right path to prove its worth to the PV community. If the development continues in an effective and time-efficient way, it could soon be of use to CdTe, CIGS, and potentially pX Si industries.

*Reviewer 3:*

The project is focused on a specific objective to study charge transport in semiconductor materials for PV, especially in polycrystalline materials that are prone to minority carrier recombination which is the fundamental loss mechanism of carrier collection, and hence low efficiency of light conversion to electrical current. The project approach is to take the current existing techniques to a higher level of spatial resolution to measure local diffusion length/local carrier lifetime in polycrystalline thin films. The parameters are a direct reflection of the material quality and are primary factors in determining the solar cell efficiency.

Its primary impact on the SETO goals is by indirectly contribution to the efficiency of the device and hence the PV module. a secondary impact is its use as an ex-situ tool to probe the Potential Induced Degradation in modules, which is currently a major source of power loss in the life of the module. It is a valuable tool in the area of polycrystalline thin film PV.

**Project Title:** Mechanically Stacked Hybrid Photovoltaic Tandems

**Award Number:** 30298

**Principal Investigator:** Alberi, Kirstin, National Renewable Energy Laboratory

**Project Description:**

This project is developing a gallium indium phosphide on silicon mechanically stacked voltage-matched tandem, aiming at low cost and high efficiency. The project will result in one of the first published demonstrations of voltage-matched modules, an assessment of the advantages and disadvantages of the new architecture, and its promise for module design.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Tandems provide a pathway to have higher efficiency and thus power output in a given area. This is very relevant--to have high performance for PV (at same or lower costs, of course). This objective is well defined in this project. These are tandems that are based on Si--mating with other fairly developed "thin-film" approaches, again aimed at delivering more power than the Si alone. The PI is well founded in these technologies--especially in the materials and characterization aspects.

*Reviewer 2:*

While technically very interesting, there are serious questions if this approach can achieve the SETO cost targets. This approach has to be combined with some form of low cost III-V growth, otherwise the growth and processing of the III-V cells will overwhelm the system cost.

*Reviewer 3:*

Voltage-matched configurations have been described qualitatively in the literature for quite some time. A detailed theoretical investigation might have been more useful than demonstration of VM mini-modules using such small cells and non-optimal subcell technology.

**Project Title:** Silicon-Based Tandem Solar Cells

**Award Number:** 30299

**Principal Investigator:** Tamboli, Adele, National Renewable Energy Laboratory

**Project Description:**

This project is working to demonstrate bonded gallium indium phosphide on silicon tandem cells, evaluate the advantages and disadvantages of this method of forming higher-efficiency tandem cells, and compare two- and three-terminal device configurations.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is very relevant regarding module performance improvements, but not enough emphasis on path to lowering cost.

*Reviewer 2:*

This is highly adaptable and can be used to validate other tandem structures (perovskites on silicon or CdTe for example).

*Reviewer 3:*

Si-based ultra-high efficiency tandem cells are definitely a next-generation concept that should be addressed through a government R&D program. Nevertheless, high efficiencies have already been demonstrated using mechanically stacked approaches.



**Project Title:** Defining the Defect Chemistry and Structural Properties Required for 24 Percent Efficient Cadmium Telluride Devices

**Award Number:** 30300

**Principal Investigator:** Metzger, Wyatt, National Renewable Energy Laboratory

**Project Description:**

This project is improving the defect chemistry and structural properties of polycrystalline cadmium telluride necessary to overcome photovoltage barriers and enable 24 percent efficiency. This project will advance the use of doping in polycrystalline cadmium telluride and improve the way that the community passivates and characterizes grain boundaries. New dopants, new post-processing methods, and new characterization tools and models will be developed and novel device architectures will be explored.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project has been aimed at understanding and improving the electronic properties of CdTe so that the performance of CdTe solar cells can be improved, which should lead to a lower LCOE. The NREL-led project team has made good progress toward this goal. Currently, CdTe PV technology is the main challenger to crystalline Si PV in the marketplace due mainly to the pioneering efforts of a U.S.-owned company, First Solar. While an efficiency of 22.1% has been demonstrated for a laboratory CdTe solar cell, this is still well below the efficiency of 26.6% attained for a crystalline Si solar cell in the lab. Improving the efficiency of CdTe solar cells can decrease the cost of CdTe PV modules and lower the cost of PV electricity and will benefit a U.S. owned company.

*Reviewer 2:*

This project directly addresses outstanding challenges in CdTe PV. It is well-integrated with partners in industry (First Solar), universities, and national labs. The progress to-date is impressive. Just as important, it seems likely that the results can be adopted on the manufacturing line in the near term. This is a tremendous credit to the team and speaks to their design of experiment. To summarize, this is an exemplary SETO project.

*Reviewer 3:*

In my opinion, thin film technologies have the best chance of meeting SETO's long term goals. As such CdTe and CIGS should be supported. This project focuses on a key area for CdTe, efficiency, which is crucial to achieving \$0.20/watt solar panel costs or prices, vital to SETO goals.

**Project Title:** Overcoming Bottlenecks to Low-Cost, High-Efficiency Silicon Photovoltaic and Industrially-Relevant, Ion-Implanted, Interdigitated Back-Passivated-Contact Cell Development

**Award Number:** 30301

**Principal Investigator:** Stradins, Paul, National Renewable Energy Laboratory

**Project Description:**

This project is working to enable high-throughput, lower-cost, higher-efficiency silicon photovoltaics by advancing interdigitated back-contact n-type Czochralski silicon cells, targeting 23 percent efficient cells. This includes the development of non-proprietary high-efficiency silicon technology, which would reduce the barriers for companies to have high-efficiency silicon cells.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Development of very high efficiency silicon cells can be key to lowering the SETO cost goals. This approach in particular lacks focus on finding a path to lower the cost of manufacturing those devices.

*Reviewer 2:*

High efficiency is key to SETO goals to lower levelized cost of elect. This project focuses on passivated contacts - which are a key technology nugget in a wide range of high efficiency devices including: PERC, HIT, back contact, TOPCON, and Triex cell structures. However, these cell structures are expensive to fabricate. Thus, attention on reducing the manufacturing costs of these structures is important.

*Reviewer 3:*

Project is examining passivated contact cell structures on n-type Cz silicon. Passivated contacts are likely the next major inflection after adoption of p-PERC is completed.

**Project Title:** Rapid Development of Disruptive Photovoltaic Technologies

**Award Number:** 30302

**Principal Investigator:** Zakutayev, Andriy, National Renewable Energy Laboratory

**Project Description:**

This project aims to demonstrate potentially-disruptive, novel photovoltaic absorbers by developing proof-of-concept device prototypes composed of defect-tolerant inorganic thin film oxide/nitride absorbers. Defect tolerance is the tendency of a semiconductor to maintain good transport and doping properties despite the presence of crystallographic defects and is a key property of promising photovoltaic materials. The project uses the rapid development approach, which combines high-throughput theory with accelerated experiments to rapidly optimize materials and architectures.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The materials science and technical capabilities in the field of nitride semiconductors that has been developed at NREL for this and related projects is top-notch. This is use-inspired basic research that should be supported. However, the relevance to SETO targets for the price of solar electric power by 2030 is unclear. Any new absorber, even one with exceptional performance, has a long road to commercial relevance, and an even longer road to affecting the electric grid.

*Reviewer 2:*

This is an advanced concept approach addressing a new class of PV absorbers (oxides and nitrides). The investigation, design, and development of new and potentially less expensive PV materials (especially for thin film devices) are a foundation to the program. This project supports this to evaluate the feasibility and functionality of these new oxides and nitrides for PV applications. It combines theory and experiment.

*Reviewer 3:*

The project supports some aspects of the SETO goals by exploring inorganic abundant low cost materials as substitutes to the incumbents. However, the team has chosen to approach this by examining defect tolerant oxides and nitrides, as well as alkali-earth based nitride-pnictides, which are n-type materials that require a search for the matching p-type junction partner (limited choice). This makes the project lacks focus, even with the Rapid Development approach. The above set of materials considered in the project has been explored as PV absorbers using the Rapid Development Method since 2009. So far solar cells made from these materials have not exceeded few percent's in efficiency, nor have it demonstrated that it is easier to scale than the incumbents. No technical pathway and/or roadmap to lower cost have been demonstrated in spite of numerous publications covering the material science and theoretical calculations of their potential.

**Project Title:** From Modules to Atoms: Increasing Reliability and Stability of Commercially Relevant Photovoltaic Technologies

**Award Number:** 30304

**Principal Investigator:** Johnston, Steve, National Renewable Energy Laboratory

**Project Description:**

The project is studying reliability-related defects in major photovoltaic technologies that include silicon, cadmium telluride, and copper indium gallium selenide using imaging and microscopy characterization tools along with multi-physics modeling to derive the causes of power-limiting defects that are responsible for potential-induced degradation in silicon, meta-stability and transient degradations in cadmium telluride, and increased-degradation due to reverse-bias breakdown in copper indium gallium selenide. This project will draw on module samples to develop predictive degradation models and improved testing protocols.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The team looks to specifically reduce susceptibility of PV devices to PID, partial-shading shunt formation, and initial power losses. They state module performance and reliability will increase and lead to cost reductions of PV-generated energy if these 3 failure modes are addresses. They quote NREL's Strategic Energy Analysis Center, who forecast a 0.2¢/kWh reduction in LCOE will occur per 0.1% reduction in Pmax degradation rate. As a result, this work is relevant to SETO's targets.

*Reviewer 2:*

This is a very excellent project that looks at all aspects of module degradation not just by a suite of typical optical or electrical measurements but also by coring materials from the modules and studying them under microscale techniques and tries to correlate the macro and micro findings. A lot of the problems addressed in this work are extremely important to improving reliability and longevity of commercial modules.

*Reviewer 3:*

This project is critical to the SETO performance goals. It impacts most aspects of manufacturing of the modules and their performance output along the value chain, the reliability of the module and repeatability of the relevant processes, and the bottom line economics of PV, i.e. increasing system performance and driving down cost.

The project is a good example of high value and high impact effort with broad reach. The investment of the SETO program in this project is risk free and should be expanded to remove bottle necks and operations challenges in order to accelerate its utility and impact for a wide range of stake holders.

*Reviewer 4:*

Dr. Johnston's work is very relevant because it targets defects and durability in the three leading commercial PV materials. The approach is unique and scientifically very interesting as it spans different length scales - from module-level to nanometer scales.

**Project Title:** Cell and Module Performance Characterization

**Award Number:** 30305

**Principal Investigator:** Levi, Dean, National Renewable Energy Laboratory

**Project Description:**

This project supports the cell and module measurement lab, which provides the only recognized, accredited efficiency measurements in the United States for the photovoltaics industry, and provides direct support to all SETO programs through independent efficiency measurements and reference cell calibrations.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This research is necessary to maintain measurement controls.

*Reviewer 2:*

The services provided by the Cell and Module Performance group are critical to the U.S. PV industry. The entire PV community depends on objective, independent and accurate characterization of solar cells and modules. This is required to establish bankability for PV systems, to quantify progress in the development of new cells and modules and to lower the cost of photovoltaic electricity through better power binning of modules. Reducing the uncertainty in the power ratings of commercial PV modules leads to increased revenues or a decreased module selling price, which helps move toward a lower LCOE.

*Reviewer 3:*

The CMP group at NREL does an incredible job of measuring the performance of cells and modules and during this 3 year cycle, they have significantly improved their measurement system, protocols and uncertainty budgets. All of this makes a big impact on the service they do for their customers and the PV community.

*Reviewer 4:*

It is true that the industry needs a trusted third party to evaluate module performance. This is very important to financing PV projects and companies. A vital function is being performed here.

**Project Title:** Correlative Electronic Spectroscopies for Increasing Photovoltaic Efficiency

**Award Number:** 30306

**Principal Investigator:** Kuciauskas, Darius, National Renewable Energy Laboratory

**Project Description:**

The project is developing fast, no-contact optical metrology methods to detect optically active defects in thin-film materials and map recombination velocities at shallow interfaces. These techniques will speed up the diagnostics and optimization of thin-film absorber materials and interfaces.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This work is focused on developing and/or improving novel PV characterization methods to better understand the underlying physics behind certain efficiency-limiting material properties. The PI has a working relationship with important US manufacturers such as First Solar and his work is presumably of 'some' importance to the researchers in this industry. With SETO's interest in supporting domestic US industries particularly in 2nd and 3rd generation PV technologies; I'd conclude that the PI's work is of importance to that end.

*Reviewer 2:*

Each phase of technology development in PV calls for a fresh look at the techniques used to measure minority carrier lifetime and defect properties. Often, new techniques are required in order to sustain rational engineering of improved device performance. The researchers on this project are at the core of these activities for two thin film material platforms that are important to SETO goals, CdTe and CIGS. The studies reported here are inspired by challenges faced by industry in developing state-of-the-art thin PV technologies, and the results may be directly relevant to industry.

*Reviewer 3:*

The project has value to the SETO performance goals, it probes recombination losses in thin film solar cells and examines origin of metastability/recovery of performance under stresses. Both would suggest mitigation measures to eliminate or reduce the losses up front or in real time in the field. Indirectly, successful mitigation contributes to cost reduction and enhanced reliability and durability of modules.

This project compliments the project "From Modules to Atoms..... FOA/Award# SuNLaMP 30304".

To enhance the relevance of the above two projects, researchers from the measurement side and device/ module fabricators need to debate/discuss practical mitigation steps that can be applied on the factory floor (or in the lab) to validate the value and impact of the output of the projects.

**Project Title:** Interface Science and Engineering for Reliable, High-Efficiency Cadmium Telluride

**Award Number:** 30307

**Principal Investigator:** Metzger, Wyatt, National Renewable Energy Laboratory

**Project Description:**

Surface and interface recombination become more detrimental to cadmium telluride device performance as lifetime increases. This project is developing effective surface passivation and carrier selective contacts for higher efficiency, improved reproducibility, and increased stability.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Interface science is an important factor of CdTe chemistry that impacts contact performance and reliability. Optimizing CdTe interfaces will impact efficiency and, traditionally for this PV type, reliability and meta-stability. It is of high relevance for CdTe technologies.

*Reviewer 2:*

CdTe PV is of clear relevance to SETO goals and to the US PV manufacturing industry. The researchers are at the forefront of CdTe PV research. Interfaces in CdTe are always a particular challenge, due to the complex activation treatment and the low carrier concentration in CdTe. Therefore, this project is relevant to SETO goals.

*Reviewer 3:*

This project aims to extend the understanding of crystal interfaces in the CdTe cell structure and uncover ways to further engineer these interfaces to improve performance, thus lowering the cost of energy produced by these types of cells.

**Project Title:** Support of International Photovoltaic Module Quality Assurance Task Force

**Award Number:** 30308

**Principal Investigator:** Repins, Ingrid, National Renewable Energy Laboratory

**Project Description:**

This project supports the Photovoltaic Module Quality Assurance Task Force to develop the international test standards necessary to validate the quality of photovoltaic modules and determine service lifetimes. The project will improve the quality of modules, implement a conformity assessment system for photovoltaic power plants to meet the requirements of international standards, and develop and implement a rating system to ensure durable design of modules.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

PVQAT is an excellent consortium that is developing meaningful value for the industry.

*Reviewer 2:*

Developing and fast-tracking PV tests and standards is key to supporting the resilience and reliability of PV modules and other PV project components, particularly as the nation's PV infrastructure grows quickly. This project provides a direct connection between research and standards and results in a much faster rate of adoption of new tests and standards, and thus is critical to safeguarding our PV infrastructure.

*Reviewer 3:*

The PV Quality Task Force is an international collaboration led by NREL to develop test methods and standards to drive up the overall quality and reliability of PV modules and module level power electronics. The benefits of this work are felt by the entire PV community, globally. Because of the international collaboration, NREL leverages not only its own expertise, but gains knowledge from interfacing with participants from all regions. NREL is also working with the PVQAT to develop a Quality System encompassing manufacturing, installation and operation of PV modules.



**Project Title:** Scientific Approach to Reducing Photovoltaic Module Material Costs While Increasing Durability

**Award Number:** 30309

**Principal Investigator:** Bosco, Nick, National Renewable Energy Laboratory

**Project Description:**

This project is developing metrics to quantify the performance, safety, and reliability of encapsulants and backsheets at both the material and module level. This includes identifying the material properties that govern their performance degradation, developing the metrics to quantify these properties, surveying historically deployed modules to obtain a threshold value for these properties, and conducting outdoor and indoor accelerated exposure tests to analyze the kinetics of degradation and develop physics-based models that describe the degradation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Need to understand how adhesion degrades over time and begin to predict minimum levels. With a profusion of BOMS for one module "model," it's necessary to understand the impact of different packaging materials and to compare the long term performance of different combinations. A good adhesion test is critical.

*Reviewer 2:*

A large enough portion of encapsulants and backsheets have proved subject to early degradation to justify continued research into durability.

**Project Title:** Reducing Photovoltaic Performance Uncertainty by Accurately Quantifying the Photovoltaic Resource

**Award Number:** 30310

**Principal Investigator:** Sengupta, Manajit, National Renewable Energy Laboratory

**Project Description:**

This project uses an innovative approach to compile data for the lab's Photovoltaic resource that will open new opportunities for significantly higher accuracy in photovoltaic performance prediction and assessment. The work will provide more accurate irradiance data by testing different types of sensors to determine the most consistent and reliable measurement technologies, while also improving satellite-derived irradiance data.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reducing the uncertainty of the solar resource is valuable but will likely not have a big impact on financing costs or transaction time.

*Reviewer 2:*

This enhancement to the NSRDB allows for more accurate quantification of the spectral irradiance that can be expected of any project built in the US. This increase in accuracy can lower the risk of a project and therefore creates impactful value.

*Reviewer 3:*

This project is valuable to the industry because it has demonstrated a reduction in uncertainty in weather forecasts for all PV with a particular benefit to multi-junction PV because of quantification of irradiance over the activating portion of the spectrum. The benefit flows through energy production estimates and project performance, thus allowing more projects to qualify for financing.

**Project Title:** Addressing Soiling: From Interface Chemistry to Practicality

**Award Number:** 30311

**Principal Investigator:** Simpson, Lin, National Renewable Energy Laboratory

**Project Description:**

Natural soiling has reduced the energy output of photovoltaic systems since the inception of the technology. Soiling is a complex problem that increases uncertainty and drives up the levelized cost of energy through lost energy production, increased operation and maintenance costs, and financing rates. This project is developing a predictive soiling model and a soiling rate map of the nation based on the available and, if necessary, additionally collected data and use it to provide operations and maintenance guidance to the industry.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is an expansive project aiming to reduce LCOE on a project by developing predictive methods for determining soiling losses, accelerating tests to approve mitigation strategies, and understanding mechanisms that drive soiling. This is of high value to PV and coating manufacturers as well as integrators/developers/operators, informing their choices related to coatings in the development cycle, setting expectations before/during project construction, and project maintenance (cleaning).

*Reviewer 2:*

Soiling is a significant factor in reduced power output, and presents a complex set of factors to consider in order to optimize a mitigation strategy. This project seeks to understand the relevant factors at a fundamental level. It is very important work.

*Reviewer 3:*

This project looks to characterize soiling based on soiling type and quantity so that regions within the U.S. can be characterized, potentially development of coatings and other methods for soil reduction can be realized, and predictive models can be developed – all of which reduce the LCOE of PV power plants.

**Project Title:** Advanced Thermal Management for Higher Module Power Output

**Award Number:** 30312

**Principal Investigator:** Silverman, Tim, National Renewable Energy Laboratory

**Project Description:**

This project enables lower operating temperatures for modules resulting in higher module power output and lower levelized cost of electricity. This will be accomplished by developing a thermal model for photovoltaic modules and modified passive cooling packaging to lower the module temperature when overheated.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This investigation of advanced thermal management techniques contributes greatly to lower LCOE due to demonstrated reductions in module NOCT. The approach does not require changes to current cell architectures. Lowering LCOE is a core SETO program target.

The techniques for lowering module NOCT may also yield extended module longevity. By operating at lower temperatures, the module and its materials will operate in less harsh conditions and thereby safely operate for extended periods compared to current module technology. Extended module longevity is a core SETO program target.

Techniques that lower module NOCT may not necessarily alter a module's power output at STC. Manufacturers, financiers and other critical user groups may be reluctant to adopt such technology if current assessment tools only consider power instead of energy. The stated program objectives have included the development of modeling tools backed with correlations between field and modeled conditions. Such modeling tools will be released to industry and offer an opportunity to accelerate adoption of these thermal management techniques.

*Reviewer 2:*

Reducing the operating temperature of PV modules and systems is valuable to optimizing the energy yield. 1% yield benefit is roughly worth 1-3 cents of NPV (depending on market), understanding if this economic budget is easily achievable is important to understanding the LCOE benefits of this project.

*Reviewer 3:*

Reduction in operating cell temperature of a PV module has a direct relation to increase in power output. This will lead to increase power density within a given area – as in the example of C&I solar. The research focuses on reducing the waste heat generating during operation through innovations that do not come at a high economical price. Decrease in operating temperature also yields an increase in service life of electronics.

**Project Title:** 2D Materials for Low Cost Epitaxial Growth of Single Sun Gallium Arsenide Photovoltaics

**Award Number:** 30313

**Principal Investigator:** Norman, Andrew, National Renewable Energy Laboratory

**Project Description:**

The project is developing low-cost two-dimensional material substrates to template the growth of gallium arsenide.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is directly related to SETO goals of reducing the cost of solar power by reducing substrate costs for III-V tandem solar cells. This project is a high-risk / high-reward project that is exploring a new and unique method for substrate reuse.

*Reviewer 2:*

The project aims to reduce the cost of GaAs solar cells by eliminating the need for a traditional GaAs single crystal substrate and using inexpensive BiSe that is subsequently converted to InSe, which should be suitable for growing a GaAs solar cell. If successful, the project has the potential to significantly reduce the cost of these types of solar cells.

*Reviewer 3:*

The work is relevant as it is focused on developing a new growth template for GaAs based solar cells. The work also has much wider relevance. However, to achieve SETO's cost goals there are a number of other cost reduction parts that need to be demonstrated.

**Project Title:** Photovoltaic Stakeholder Engagement Initiatives

**Award Number:** 30507

**Principal Investigator:** Stein, Joshua, Sandia National Laboratories

**Project Description:**

The project will support the International Energy Agency Photovoltaic Power Systems Programme, the Photovoltaic Performance Modeling Collaborative, as well as the Underwriters Laboratories, the International Electrotechnical Commission, and the National Electric Code committee work.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Consensus knowledge of PV performance, reliability, and quality are critical for US and worldwide PV adoption. US participation in these activities is vital for the US PV industry to insure appropriate practices and wide information dissemination.

*Reviewer 2:*

Better adoption/deployment of research and technologies is probably the biggest area in need of improvement for SETO. This project is filling that need and, importantly, on an international level. To safeguard the resiliency and reliability of the growing share of PV that makes up our nation's energy infrastructure, it's important to collaborate with international partners to maintain high quality standards that affect imported PV products, which are the majority of components. SETO should leverage the platform created by this project to promote US R&D abroad.

*Reviewer 3:*

The information driven from the collaborative efforts of the global group is disseminated for use throughout the industry for use by the various stakeholders.

The website PVPMC.sandia.gov is used to share information regarding the accuracy and methods of PV systems modelling. Accurate modelling helps EPC's and owners work with financial institutions to properly value their assets and predict long term energy production. This information is critical in working toward reduction of PV system costs.

The reliability resilience of the electric grid is heavily affected by the standards that are developed and adopted across the country. Standards are used to drive minimum criteria of components, as well as interoperability of components within the systems, and from the system to the grid.

**Project Title:** Photovoltaic Lifetime Project

**Award Number:** 31427

**Principal Investigator:** Stein, Joshua, Sandia National Laboratories

**Project Description:**

This project is conducting and analyzing long-term monitoring of performance of photovoltaic modules, investigating equipment widely deployed across the country, and addressing multiple deployment climates. A major focus of the project is on early-life degradation of photovoltaic modules, which may indicate stepwise degradation functions that are too subtle to be detected through typical outdoor monitoring.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This three-year project is in its last year. The intent is to install and evaluate multiple module types and evaluate their degradation and component performance over this time. The three year time-frame should allow reasonable characterization of LID effects for the various technologies. However, multiple factors affect module degradation rates including string voltage and cleaning methods. The proposed sampling plan for module procurement may not sufficiently capture manufacturing and materials excursions.

The reports provided do not provide sufficient information to evaluate the quality and quantity of data recorded for any of the installed modules.

*Reviewer 2:*

Like the Renewable Energy Test Center project, this project is valuable because it offers field validation of accelerated lifetime tests and the ability to identify serial defects in the resiliency and reliability of PV that could in turn inform mitigation strategies. This is particularly valuable as PV becomes a large share of the country's energy infrastructure. The process is generally very slow, so discoveries should not be expected quickly.

**Project Title:** Durable Module Materials Consortium (DuraMat)

**Award Number:** 32509

**Principal Investigator:** Barnes, Teresa, National Renewable Energy Laboratory

**Project Description:**

The Durable Module Materials (DuraMat) National Laboratory Consortium is designed to accelerate the development and deployment of durable, high-performance materials for photovoltaic modules to lower the cost of electricity generated by solar power, while increasing field lifetime. DuraMat is one of several consortia under the Energy Materials Network, which aims to solve industry's toughest clean energy materials challenges. DuraMat supports projects that improve module materials in partnership with industry and academia to further optimize reliability and energy harvest of low-cost PV modules. Sandia National Laboratories, Lawrence Berkeley National Laboratory, and SLAC National Accelerator Laboratory are also collaborating in the consortium.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The DuraMat consortium seeks to leverage the expertise and capabilities of the National Labs in support of new module materials, design and testing protocols. This initiative may extend the reach and capability of applicants to and participants in the consortium.

It is difficult to evaluate the DuraMat project since few details of the funded work are presented. Without details for the funded work, it is also difficult to assess the applicability of this work to current and future US business.

*Reviewer 2:*

Improving the cost of PV module components, while improving their reliability and durability, is an appropriate area of concentration for this stage of the PV industry. It attacks difficult dimensions in the LCOE cost formula (degradation rate and lifetime) that require fundamental technical investigation.

*Reviewer 3:*

Duramat is an excellent consortium to drive up reliability and develop the ability to characterize lifetime.

*Reviewer 4:*

A wide variety of BOMs are used for PV modules, even within on model. How different packaging materials interact is critical to understand for module design. Reliability can be significantly impacted. Low cost drivers without sufficient understanding of the impact to reliability have resulted in preventable field failures, some of them massive. The science exists to bring some wisdom to this area; this project brings the various pieces together so that appropriate, targeted research can be performed to answer some of the large questions with regard to long term reliability. It is crucial to the industry.



**Project Title:** Streamlined Module Manufacturing using Back Contact Solar Cells and Conducting Adhesives

**Award Number:** 33663

**Principal Investigator:** Klein, Talysa, National Renewable Energy Laboratory

**Project Description:**

This project is fabricating modules of back contact silicon solar cells by patterning metal onto the module backsheet or back glass and attaching unmetallized cells to it using a conducting adhesive. The conducting adhesive consists of conductive microspheres embedded in an adhesive and will conduct only in the out-of-plane direction, allowing patterned doped areas on the rear side of an unmetallized back contact solar cell to be conductively bonded to a patterned metal on a backsheet or back glass without patterning the adhesive. This eliminates the complex cell metallization and stringing steps, replacing them with a single metal patterning step on a backsheet/back glass. The cell metallization step would concurrently be the first module assembly step, resulting in lower module cost.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The use of an anisotropically conductive adhesive is an innovative way to simplify the solar cell metallization and stringing steps for IBC cells. The approach has the potential to reduce the manufacturing cost of PV modules fabricated with IBC solar cells. This approach utilizes a patterned metal backsheet or glass to contact the patterned doped areas on the cell and allows one to eliminate the busbars. The one alignment step has a relatively wide tolerance of 0.1 mm. The conductive adhesive may use a relatively inexpensive transparent polymer such as EVA, and this layer at the rear of the cell between the Si and the metalized backsheet should increase the module performance by improving the infrared response of the cells.

*Reviewer 2:*

IBC structures have a proven high efficiency, but commercialization is limited by the high manufacturing costs, including costs related to the metallization. This project has the potential of addressing the cost of metallization.

*Reviewer 3:*

This project is aligned with the 2030 goals of SETO. If successful it would result in reduced stringing and metallization costs in module assembly for back-contact solar cells.

**Project Title:** Metal Nano-Grids for Next-Generation Transparent Conduction in Solar Cells and Modules

**Award Number:** 33665

**Principal Investigator:** Muzzillo, Chris, National Renewable Energy Laboratory

**Project Description:**

This project is developing cracked film lithography for depositing transparent contacts on photovoltaic cells. In this method, a suspension of nanoparticles is deposited onto a substrate, where solvent evaporation cracks the drying film, naturally producing a template for metal deposition and subsequent lift-off. The research will focus on developing a cheap drying cracked film template, followed by metal deposition and lift-off. The resulting metal nano-grids will be delivered with excellent transmittance, sheet resistance, and characterized wire width, ensuring their efficient operation in solar cells.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is a very early stage project looking to generate a new method of next-generation transparent conduction contacts on solar cells. This could be a pathway to lower shading and substituting copper in place of silver. If fully developed and value engineered, meeting all techno-economic requirements this technology would have significant relevance to SETO goals.

*Reviewer 2:*

Even though the proposed technique seems interesting and may have future potential, almost nothing in terms of cost estimates or savings that could result from this method, as compared to traditional TCOs is provided.

*Reviewer 3:*

I like this project. TCOs are important for solar as well as flat panel displays. This is a very novel attempt to deliver a higher performance TCO that might also be very low cost.



# Concentrating Solar Thermal Power

**Project Title:** High Performance Reduction/Oxidation Metal Oxides for Thermochemical Energy Storage (PROMOTES) /CSP

**Award Number:** 00805

**Principal Investigator:** Ambrosini, Andrea, Sandia National Laboratories

**Project Description:**

This project seeks to design a system that concentrates sunlight onto a falling curtain of sand-like particles called perovskites. The perovskites heat up and undergo a chemical reaction. The chemical reaction captures the sun's energy and the perovskites are stored until the sun goes down. The perovskites are then re-exposed to air, reversing the chemical reaction and releasing the sun's heat for use in a very efficient Air-Brayton electric power generation system. The project evaluates how effective the chemical reaction is through a test of a 100 kilowatt hour-thermal thermochemical energy storage system.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

A metal oxide based thermochemical storage system is proposed as part of a particle receiver system. Mixed ionic electronic conducting metal oxide (MIECs) particles are chosen as the redox agents, and are also used as the particles that absorb the heat in the receiver. Both the direct particle heating and the reduction process raise the particle temperatures that are then fed to a storage system. During the heat recovery period the working fluid, air, is directly passed through the hot particles capturing the heat and also oxidizing the particles exothermically. The overall concept appears quite elegant, and enables an air-based- Brayton cycle to be the power block. This approach advances the current SANDIA effort on particle receiver technology.

*Reviewer 2:*

High performance reduction/oxidation metal oxides for thermochemical energy storage are very relevant for approaching the SETO CSP goals. The report indicates that a proper approach was taken and that there is, despite some delays, reasonable progress to reasonably successful completion.

*Reviewer 3:*

The team is developing mixed ionic electronic conducting metal oxides (MIECs) aiming at very high temperature thermal energy storage to enable open air Brayton cycle turbines to be used for electricity generation from the stored heat. They have identified a high-performing oxide for temperatures > 1000 °C (CaAl<sub>0.2</sub>Mn<sub>0.8</sub>O<sub>3-δ</sub>, "CAM28"). Since the challenges on the high-temperature pipes in the towers and other equipment will be very high, the likelihood of such a technology to be implemented is low.

**Project Title:** Particle Mass Flow Control (formerly Fractal Particle Receiver)

**Award Number:** 01506

**Principal Investigator:** Ho, Cliff, Sandia National Laboratories

**Project Description:**

This project designs, develops, and tests novel particle receivers with configurations that use light-trapping geometries. Particle receivers drop sand-like ceramic particles through a beam of concentrated sunlight atop a power tower. The particles absorb heat at temperatures near 800°C, then store the heat in an insulated container below the receiver. This thermal energy can be converted into electricity using a traditional power cycle at a later time. By capturing more sunlight, researchers increase the effective solar absorbance and efficiency of high-temperature particle receivers. Zig-zag release patterns and multi-drop curtain configurations will be compared to baseline planar curtain configurations.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is part of a broader overall effort aimed at exploring particle technology for a solar receiver. In this effort, the PI is exploring ways of maximizing the particle absorption and controlling the mass flow rate of the particles to the storage system so as to have a fixed particle exit temperature despite varying solar irradiances. The project supports the overall goal of developing a solar particle receiver.

*Reviewer 2:*

Increased temperature - increased Carnot efficiency. Is part of a plan to supply sCO<sub>2</sub> with a high of a temperature as it can take?

*Reviewer 3:*

The Sandia team is developing various geometries of “curtains” of falling particle layers in optimizing the heat receiving effectiveness of the CSP system. The flow/falling particle system has the potential for high-effectiveness in receiving and transferring the heat. The particles are also a cost-effective way for high-temperature heat storage.

**Project Title:** Development of a High Efficiency Hot Gas Turbo-Expander and Low Cost Heat Exchangers for Optimized Concentrating Solar Power Applications

**Award Number:** 05804

**Principal Investigator:** Moore, Jeff, Southwest Research Institute

**Project Description:**

This project is developing a supercritical carbon dioxide power cycle that combines high efficiencies and low costs for modular concentrating solar power applications. The technology will be evaluated in a test loop to verify its performance over a wide range of partial-load conditions and during transient operations representative of a typical power cycle.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aims to build a 1MW sCO<sub>2</sub> turboexpander test loop coupled with a 5MWth shell and micro-tube heat exchanger and a simulated 2.5MW heat source for the sCO<sub>2</sub>. Relevant temperatures at 725 deg C and operating pressures are used for a 50% thermal-electric efficiency.

The project was initiated in 2012, and the current phase 3 intended for testing ends in March 2018. The project appears to be behind schedule since the successful recuperator fabrication and testing remains to be done, and only preliminary testing with an alternative printed circuit recuperator has been done.

*Reviewer 2:*

To achieve the SETO goal of power conversion of efficiency of 50% an optimized sCO<sub>2</sub> cycle is critical. The turbo expander and heat exchangers are critical components of the sCO<sub>2</sub> cycle. The current research aims to develop and test MW-scale components towards these objectives.

*Reviewer 3:*

This is a critical project to demonstrate a sCO<sub>2</sub> turbine loop system at a large enough scale. The team has made an excellent effort to make all the sCO<sub>2</sub> turbine system components to work (almost work). Most of the effort is on turboexpander and the heat exchanger.

**Project Title:** High-Operating Temperature Liquid Metal Heat Transfer Fluids

**Award Number:** 05941

**Principal Investigator:** Ju, Sungtaek, University of California Los Angeles

**Project Description:**

This project is investigating the use of metal alloys as a heat transfer fluid in CSP systems operating at temperatures up to 800° Celsius. By allowing higher temperature operation, CSP systems can achieve greater efficiencies and thereby reduce the overall cost of electricity production.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Discovering a liquid metal that can operate well and safely at such high temperatures would contribute to the program objectives. At the same time, the LeB studied was thoroughly investigated in the past for various applications, so the prospective contribution of this project and its accomplishments are low.

*Reviewer 2:*

The objective of the project is to find a suitable heat transfer fluid which can operate above 700 C to drive the efficiency higher and at a cost that supports the SETO's LCOE targets. However, the liquid-metal heat transfer fluid selected, and the results presented here prove that the selected heat transfer fluid (Lead-Bismuth eutectic) falls short of the temperature objective (700 C) and may be too expensive to be viable.

*Reviewer 3:*

The liquid/molten metals seem a good idea at first to store and transfer solar thermal heat, but they may lead to more challenges than the benefits. Molten metals will inevitably lead to leach-away (removal) of the container metallic materials. Unless the containers are made up of some ceramic materials, the system level challenges will be very high.



**Project Title:** Halide and Oxy-Halide Eutectic Systems for High-Performance, High-Temperature Heat Transfer Fluids

**Award Number:** 05942

**Principal Investigator:** Li, Perry, University of Arizona

**Project Description:**

This project is investigating the use of halide salts with oxy-halide additives as a heat transfer fluid in concentrating solar power systems operating at temperatures greater than 800° Celsius. By allowing higher temperature operation, CSP systems can achieve greater efficiencies and thereby reduce the overall system cost.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It is very relevant to the program to develop stable, inexpensive and relatively environmentally-benign heat transfer fluids that have acceptable heat transfer characteristics, and find their properties for use at temperatures around 800C. A question exists whether the fluids developed/proposed are an innovation, since they are rather common and have been widely used in the past.

*Reviewer 2:*

The research effort aims to find high-temperature heat transfer fluids (HTF) by making mixtures of Chloride salts. Two candidates NaCl-KCl-ZnCl<sub>2</sub> and KCl-MgCl<sub>2</sub> have been characterized. The aim of this research is to have a HTF with low melting point and a boiling point higher than 700 C making it suitable for operation in CSP receiver/thermal storage. This is a valid approach as molten chloride salts (NaCl, KCl) are the current heat transfer fluids of choice for CSP plants albeit operating at a lower boiling point (approx. 550 C). By combining ZnCl<sub>2</sub> and MgCl<sub>2</sub> the researchers tried to bring the temperature range of operation closer to the CSP target temperatures.

*Reviewer 3:*

High temperature molten salt heat storage seems an attractive solution at first since high temperature (> 800 C) will lead to higher overall system efficiency. However, the freezing points are too high and corrosion prevention requires completely removal of oxygen and moisture from the entire system. Maintenance of a large system with such tightness will be difficult.

**Project Title:** Design and Field Testing of Manufacturable Advanced Low-Cost Receiver for Parabolic Trough Solar Power

**Award Number:** 06813

**Principal Investigator:** Stettenheim, Joel, Norwich Technologies

**Project Description:**

Norwich Technologies is taking its novel receiver for trough-based concentrating solar spower, the SunTrap™, from proven laboratory prototype to fully manufacturable system integrated with the solar field. The analysis, design, and testing will address 30-yr service life, low cost manufacturability, and low operations and maintenance.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Present evacuated receiver tubes are capable of handling 500-550 C temperatures, even though Norwich claims they can't. Is Norwich designing for molten salt?

*Reviewer 2:*

Improving a relatively higher TRL than many programs this effort focuses on improving the efficiency and reducing the costs of trough receivers. This directly focuses on the prime SETO objective.

*Reviewer 3:*

This project aims to increase the operating temperature of parabolic trough hardware. It is unclear if the system will be used with salt in the field or some other heat transfer fluid. The properties of the heat transfer fluid can have a significant impact on the ultimate feasibility of this technology.

**Project Title:** High Flux Microchannel Receiver Development

**Award Number:** 07108

**Principal Investigator:** Drost, Kevin, Oregon State University

**Project Description:**

Oregon State University is developing a microchannel solar receiver using supercritical carbon dioxide as the heat transfer fluid. The research will resolve key issues associated with the commercial viability of the technology, which allows for a radical reduction in the size of a central receiver. The project will culminate in an on-sun test of a commercial scale receiver module with a surface area of approximately one square meter.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The proposed research aims to develop a micro-pin based modular solar receiver that heats up the working fluid (sCo<sub>2</sub>) to the high temperature and pressures (720 deg C and 250 bar) to drive a power block that is most feasible in a ground-mounted application. There is potential for using sCo<sub>2</sub>, helium and other gaseous working fluids at lower temperatures and pressures, and also a molten salt as a heat storage medium. These goals are relevant to the solar program.

*Reviewer 2:*

It is relevant for the CSP program to be able to manufacture high efficiency long-life reliable solar receivers cum heat exchangers at these high temperatures and pressures at reasonable cost. Using “micro pins”, and “micro” is a popular word, but I doubt that it is the best option. I must also add that the flow patterns in the receiver/heat exchanger and how it fits into a solar system are so poorly described in the report and the poster sent to us that it is nearly impossible to understand.

*Reviewer 3:*

More effective receiver may enable smaller CSP systems to be more economically viable.

**Project Title:** Compression System Design and Testing for sCO<sub>2</sub> CSP Operation

**Award Number:** 07109

**Principal Investigator:** Mortzheim, Jason, GE Global Research

**Project Description:**

This project is developing an optimal compression system for a modular supercritical carbon dioxide power block operation in highly transient CSP tower applications. The compressor train under development will provide high-pressure carbon dioxide compression at state-of-the-art efficiency, required for the operation of a tower-mounted, modular, recompression-type supercritical carbon dioxide power cycle with a wide operating range to be coupled with the turbo-expander being developed for CSP power tower applications.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project focuses on the sCO<sub>2</sub> compressor efficiency which is a crucial part of increasing the overall efficiency of the power conversion cycle to 50% (SETO goal). But per the “stair-step” plot shown in the project poster the goal of the project, if achieved, will contribute less than 1% to increasing the sCO<sub>2</sub> cycle efficiency. The single-shaft design configuration also does not lend itself well in optimizing the compressor efficiency for varying flow/cycle conditions.

*Reviewer 2:*

This project from GE and SwRI addresses two of the most critical issues of sCO<sub>2</sub> closed loop turbines: compressor efficiency and seals. The outcomes of this project will be very valuable to the CSP community.

*Reviewer 3:*

This project is very relevant to the higher temperature power conversion cycles sought for a Gen 3 CSP system. It addresses the need to move supercritical CO<sub>2</sub> cycles from the theoretical to the practical realm.

**Project Title:** Sodium Ion Expansion Power Block for Distributed CSP

**Award Number:** 07110

**Principal Investigator:** Balagopal, Shekar, Georgia Institute of Technology

**Project Description:**

This project is developing and demonstrating a modular sodium ion expansion power block for CSP with an estimated efficiency in excess of 50 percent. These generators will be most similar to thermoelectric generators, though the ion expansion engines are considerably more efficient. The key to innovation is the use of Ceramatec's patented NaSelect™ and  $\beta$ -Alumina solid electrolytes, which have high sodium ion conductivities for operation in a dual stage heat engine.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The advancement of high-efficiency direct heat-to-electricity energy conversion devices, without moving parts, such as this Sodium Ion Expansion power block, which would convert high temperature CS heat to electricity, is a reasonable direction to pursue. The idea of this project is a continuation/advancement of the AMTEC concept which was intensively studied about 50 years ago for space applications, with interest in it significantly waning after that. Perhaps it can be revived if some of the major problems are solved by this project.

*Reviewer 2:*

The project aims to devise a solid-state power block using Sodium Ion expansion for distributed CSP. This Sodium Ion expansion device still relies on a heat transfer fluid to convert solar energy to heat by means of heat transfer fluid/storage medium and then that heat is exchanged into the Sodium Ion expansion power block. In the case of molten salt (heat transfer fluid) and sCO<sub>2</sub> (power block working fluid) system, heat exchanger designs have achieved a high level of maturity. It is not clear how the proposed solid-state power block can be integrated into the heat transfer fluid/thermal storage system so it is at a lower TRL.

*Reviewer 3:*

The team is working on Na-TEC for CSP. Na-TEC has been explored on and off since 1960s, but it never reaches the power density and longevity to be commercially viable. The team is exploring this again with new architecture design of the modules, but it is very likely another step far from commercially viable.

**Project Title:** Thermodynamically Stable, High Temperature, Long-Term Antioxidation Cermet Solar Selective Absorbers

**Award Number:** 07112

**Principal Investigator:** Liu, Jifeng, Dartmouth College

**Project Description:**

This project is developing thermodynamically stable, long-term anti-oxidation cermet solar selective coatings through the use of nanoparticles. The goal is to achieve over 1,000 hours of operation at 700° Celsius in air with a solar absorbance greater than 95 percent and thermal emittance less than 10 percent. The coating will be applied to Norwich Technology's vacuum-free SunTrap CSP receiver systems for prototype analysis, achieving a thermal efficiency greater than 90 percent at 700° Celsius.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

In this project, the investigator has focused on the development of a cermet coating that has high figure of merit (high absorptivity, low emissivity) at the elevated temperatures (750 °C) of interest, and which remains oxidation resistant at these high temperatures. They appear to have explored Ni/NiSi and oxide based (MnO<sub>2</sub> and MnFe<sub>2</sub>O<sub>4</sub>) nanoparticles in a silicon base to evaluate their properties. They have also explored texturing the surface as a means of enhancing the FOM.

They have demonstrated higher FOM and oxidation resistance at the elevated temperatures relative to Pyromark. The results appear promising.

They have teamed with Norwich Inc. for scalability and commercialization.

All these activities appear to be in line with SETO goals.

*Reviewer 2:*

The project is highly relevant: stable long-term oxidation-resistant solar selective absorber coatings for operation at 750 °C in air, with an optical-to-thermal conversion efficiency higher than the existing art, and of low cost are highly important for the objectives of the CSP program.

*Reviewer 3:*

Good selective surfaces are essential to lowering the LCOE from a Gen 3 CSP system.

**Project Title:** Development of 800° Celsius Integrated Flow Channel Ceramic Receiver

**Award Number:** 07113

**Principal Investigator:** Wait, David, SolarReserve

**Project Description:**

This project is developing a concept for creating affordable, compact, and lightweight receiver panels capable of heating air, carbon dioxide, molten salts, or other corrosive and oxidizing fluids to 750° Celsius, which is 185° Celsius hotter than current receiver design through the use of commercially available silicon carbide ceramics. SolarReserve is also partnering with University of California San Diego to utilize its solar selective coating, which provides greater solar absorptivity, lower infrared emissivity, and can withstand higher temperatures than current state-of-the-art coatings.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aims to build a ceramic microchannel receiver with a black oxide coating containing nanoparticles and using molten salts as the working fluid. It aims to meet the sunshot goals for a receiver of 6c/kwh, greater than 720 deg F fluid outlet, 90% thermal efficiency and installed cost of \$150/kwt or less. In this regard, the project is relevant to the sunshot goals.

The project appears to have missed the cost metric in view of the decision to use high temperature alloys. Also it appears that the overall efficiency achieved appears to be less than 90%. There are also potential concerns with corrosion from the salts, and the need for oxygen and moisture to be removed in the system.

*Reviewer 2:*

The project aims to develop CSP tower receiver system to be able to sustain temperatures  $\geq 720$  °C with less than 10% loss from both reflection and thermal conduction. It is based on flow channels with KCl-MgCl<sub>2</sub> eutectic salt. The materials and manufacturing cost of very large components to be installed with for the CSP tower may be prohibitive, especially the pipes running up and down the tower.

*Reviewer 3:*

Higher temperature receivers and storage will be the key to developing a competitive Gen3 CSP system so this project is very relevant to SETO's goals.

**Project Title:** Development of an Ultra High Efficiency Wide-Range Integrally-Geared Supercritical Carbon Dioxide Comander

**Award Number:** 07114

**Principal Investigator:** Wilkes, Jason, Southwest Research Institute

**Project Description:**

This project is developing an integrally-geared compressor-expander (comander) and a novel centrifugal compressor impeller design for use in 10-megawatt-scale CSP applications utilizing a supercritical carbon dioxide cycle. This integrally-geared comander has the potential to improve efficiency, modularity, and process control over other proposed CSP turbomachinery configurations utilizing a supercritical carbon dioxide power cycle.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aims to develop an integrally-geared comander (compressor and expander) for better efficiency. Though it is a novel idea, it is not clear the efficiency increase claimed can be achieved while addressing the increased complexity/risks. However, the proposed design and test will prove or disprove the viability of the concept.

*Reviewer 2:*

The geared sCO<sub>2</sub> comander is quite innovative and cost-effective solution for small-scale sCO<sub>2</sub> system. The target is a 10MW system.

*Reviewer 3:*

Project has relevance due to its focus on sCO<sub>2</sub> power conversion equipment.



**Project Title:** Demonstration of High-Temperature Calcium-Based Thermochemical Energy Storage System

**Award Number:** 07116

**Principal Investigator:** Gangwal, Santosh, Southern Research Institute

**Project Description:**

This project is working to demonstrate its novel high-temperature, calcium-based, thermochemical storage system for use with CSP facilities. This system uses a highly refined and tailored reinforced calcium-oxide sorbent undergoing a reversible carbonation reaction in a parallel-plate heat exchanger reactor to produce a highly energy dense storage system with sorbent material derived from a low-cost feedstock.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The overall goal of coming up with a high temperature thermal storage system is supportive of SETO's goals. However, the project report leaves out many intrinsic details that would provide the reviewer with enough supporting data to have any confidence in the approach proposed. The balance of plant needed to store CO<sub>2</sub> and associated sensible heat is complex and it is not clear how this will influence the overall cost. Certain cost metrics are provided in the milestones table, but it is not clear if the total system meets the SETO goals of 15\$/kwh.

*Reviewer 2:*

High temperature thermal storage systems using CaO-based carbonation reaction use inexpensive and relative environmentally benign storage materials, and have received much attention in the past. Their use in a fixed bed heat exchanger reactor makes them somewhat more complex than molten salt systems, but they deserve further attention at CSP related 700-900 C temperature level, but further R&D must carefully consider an implement experience from the amply available studies over the past 50 years or more.

*Reviewer 3:*

It supports both the goal of increasing CSP operating temperature and of decreasing the cost of TES.

**Project Title:** Robust, Cost-Effective Heat Exchangers for 800° Celsius Operation with Supercritical Carbon Dioxide

**Award Number:** 07117

**Principal Investigator:** Sandhage, Kenneth, Purdue University

**Project Description:**

This project is creating millichanneled heat exchangers comprised of mechanically-, thermally-, and chemically-robust, high-temperature composite materials and will demonstrate the capability of such heat exchangers for operation in high-temperature heat transfer fluids and supercritical carbon dioxide at a temperature of up to 800° Celsius. The proposed composites are comprised of materials with similar thermal expansion coefficients and have been demonstrated to be highly-resistant to thermal shock and to exhibit the necessary strength to operate in a supercritical carbon dioxide environment at 800° Celsius.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project aims to develop high temperature cer-met (W-ZrC) heat exchanger that can withstand the high temperature and high pressures required for the sCO<sub>2</sub> power cycle application; the W-ZrC material has high thermal conductivity, high fracture strength at the elevated temperatures (750 °C) and pressures (20MPa) and exhibits good thermal shock properties. An effective scalable manufacturing process has been developed. These developments are likely to accelerate the SETO goals of 6c/kwH and low cost.

*Reviewer 2:*

Heat exchangers are critical components for SCO<sub>2</sub> cycle and CSP so this research project aiming to find suitable materials and methods of manufacturing are very relevant to reach SETO goals.

*Reviewer 3:*

Among various extra-high temperature materials for CSP, the composites that are being developed in this project make a lot of sense in terms of cost and materials performance. The concerns are that that the composites may not be fully dense and the oxidation resistance on the external surface may be problematic.

**Project Title:** Solar Receiver with Integrated Thermal Storage for a Supercritical Carbon Dioxide Power Cycle

**Award Number:** 07118

**Principal Investigator:** Sullivan, Shaun, Brayton Energy

**Project Description:**

This project is integrating a novel solar absorber architecture and metal hydride thermal energy storage in a single close-coupled system. The high energy density of the thermal energy storage allows it to be mounted up-tower alongside the receiver, which further enables up-tower mounting of the entire supercritical carbon dioxide Brayton power block. Mounting the thermal energy storage and power block up-tower eliminates the need for costly piping and fluidic connections between the receiver and a large centralized element, making the system ideal for modular implementation and growth.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aims to exploit the benefits of a metal hydride thermal storage in an integrated storage-power block system mounted on top of a wind turbine tower. The system requires integration of both a high temperature metal hydride storage system and a low temperature hydride storage located at the base of the tower. The presumed benefits are the high energy density of the storage system and the compactness of the integrated system which minimizes the cost of the piping and auxiliary systems. The 6c/kwH goal is targeted.

*Reviewer 2:*

The project objectives, namely optimization, design, fabrication, and tests of a subscale unit of an integrated receiver mounted on a conventional wind turbine pole, an sCO<sub>2</sub> power block, and low-temperature metal hydride thermochemical energy storage system, to demonstrate integrated operation of the receiver and TES system, all to meet DoE cost and performance targets, is clearly relevant. At the same time, while everything is sort of qualitatively understandable the report we received does not provide sufficient information on any aspect in a way that I can make a quantitative assessment of the specific objectives and of the progress and results.

*Reviewer 3:*

An “up tower” modular configuration like wind turbine installations is proposed. However, it is not clear why many of the components need to be situated up tower except the receiver (as in “Power Tower” concept). The proposed concept is quite complex with the sCO<sub>2</sub> power block having a separate glycol loop from the Low Temperature Metal Hydride thermal storage which increase additional complexity.

**Project Title:** Enhancement of Optical Efficiency of CSP Mirrors for Reducing Operation and Maintenance Costs via Near-Continuous Operation

**Award Number:** 07119

**Principal Investigator:** Mazumder, Malay, Boston University

**Project Description:**

This project is using laboratory-scale, electrodynamic-screen, self-cleaning solar technology with heliostat mirrors and parabolic troughs in large-scale solar plants. The objective is to reduce both the need to clean mirrors with water and the degradation of CSP collector performance due to deposited dust. Building upon a feasibility demonstration of self-cleaning CSP optics, the team will develop new manufacturing processes that are scalable to full-size production and conduct extensive field tests in collaboration with several industrial partners and national labs.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

IF the collectors are in places where it's so dry that there is NO condensation in the morning that basically glues the dust to the reflector, then EDS is relevant. Atacama is super dry, so perhaps this is relevant there. But how many CSP locations are this dry? When the mirror is brush-cleaned will this EDS system be possibly damaged?

This system will not replace brush washing. It will not result in a commercially viable product by 2030 in line with SETO goals.

*Reviewer 2:*

This is only a partial solution to heliostat cleanliness. It does not solve issues related to organics such as bird droppings nor airborne organic chemicals. As such washing is not eliminated. No commercial operator would welcome the added complexity and cost of maintain such a widespread system of wires and electrical supporting equipment. This is not cost effective.

*Reviewer 3:*

This project responds to the SETO goals related to reducing O&M costs and limiting water usage at solar plants. It is not clear to me that the savings will be large, but this work may have significant value in areas where water regulations are very restrictive.

**Project Title:** Advanced Supercritical Carbon Dioxide Cycles

**Award Number:** 07120

**Principal Investigator:** Anderson, Mark, University of Wisconsin

**Project Description:**

This project addresses the fundamental challenges associated with the supercritical carbon dioxide cycle, including the need for a high degree of internal heat transfer that requires substantial heat transfer area. The use of fixed, switched-bed regenerators provides a simple, low-cost alternative for the recuperator. Researchers will design, fabricate, and test a fixed bed regenerator system that is compatible with the operating conditions expected in a supercritical carbon dioxide cycle. The device will be installed in the test loop located at Sandia National Laboratory in order to demonstrate the operation of the regenerator at prototypical conditions.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Heat exchangers are an important part of the CSP cycle and hence any research effort to improve the efficiency of heat exchangers is a major step towards achieving SETO goals.

*Reviewer 2:*

This project addresses one of the key challenges facing sCO<sub>2</sub> cycles - effective heat exchange between the hot sCO<sub>2</sub> and cold/warm sCO<sub>2</sub> flows. The technology, if commercially successful, can help reduce the cost of the sCO<sub>2</sub> turbine systems.

*Reviewer 3:*

This project is very relevant as it addresses the need to develop real sCO<sub>2</sub> power conversion cycle hardware. Furthermore, it is looking at a novel way to substitute valves and controls for larger heat exchangers.

**Project Title:** Advanced Trough with Lower-Cost System-Architecture (ATLAS)

**Award Number:** 07121

**Principal Investigator:** Marcotte, Patrick, Solar Dynamics

**Project Description:**

Solar Dynamics will re-optimize the collector as an entire system to enable the use of molten salt in the collector field, detailing and validating innovative improvements in the concentrator design, drive and controls, manufacturing, installation, plant operation, and optical performance. This will result in a next-generation collector that moves away from the conventional architecture, delivering lower costs and better high-temperature heat transfer fluid compatibility.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This significant evolution in the design of troughs offers the possibility to significantly reduce both the capital cost and the operational cost of troughs. The elimination of the rotary interconnecting joints in short panels alone, substantially reduces the costs and risks of trough plants. Elimination of such joints makes the possible introduction of salt as a heat transfer fluid more plausible thus elevating the operating and energy storage temperatures of such plants.

*Reviewer 2:*

Parabolic troughs are the most widely deployed CSP platform. This project aims to reduce the cost of the trough collector, which will help to further reduce LCOE.

*Reviewer 3:*

While the project looks well thought out and executed to date, the focus on parabolic trough has me questioning its relevance for a Gen 3 CSP system that I can't see being trough based.

**Project Title:** Unique Single-Axis Tracking Planar Waveguide Optical Collector for CSP Modules

**Award Number:** 07338

**Principal Investigator:** Dhar, Bal Mukund, Agira, Inc.

**Project Description:**

This project is developing a very low-cost, flat optical collector based on refraction and total-internal reflection at optical interfaces between silicone polymers of different refractive indices. Incoming sunlight is progressively bent and eventually trapped within a glass substrate. Additional benefits include ease of installation and low operations and maintenance costs. The result will be a novel CSP collector which, when manufactured at large scale, will help to bring the cost of electricity below the target of \$0.06 per kilowatt-hour.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This will not result in a commercial large aperture, durable, efficient collector by 2030. It is not in line with SETO goals.

*Reviewer 2:*

It's not clear that the PI's goals of refracting the light sufficiently and then transferring that light to a device which can capture the energy as heat can be achieved. Gaps exist in showing the application of the collecting wave guide can apply at off normal angles. There is inadequate cost analysis showing that this would have any advantage over the status quo.

*Reviewer 3:*

This project aims to reduce collector costs to the SETO target of 50 \$/m<sup>2</sup>, but the team doesn't explain how they'll get there at a level of performance consistent with state of the art solutions.

**Project Title:** Development of a Planar Focusing Collector for CSP

**Award Number:** 07339

**Principal Investigator:** Toussaint, Kimani, University of Illinois at Urbana Champaign

**Project Description:**

This project is developing a flat solar collector that acts like a conventional curved trough collector. The planar focusing collector is a potentially lower-cost alternative to the conventional parabolic trough concentrator. The collector will be manufactured using specially designed metasurfaces. These metasurfaces are made from nano- and micro-structured thin, metallic surfaces that change the behavior of light in ways that are counterintuitive to an observer. Novel roll-to-roll manufacturing will also be developed to meet design specifications and cost requirements at large scale. The final deliverable will be a flat focusing element that focuses sunlight with 97 percent efficiency or higher.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is basic research, far from commercialization. A 2% intercept factor from a 25 um x 25 um area at a cost of 1.7 million dollars. And what is the plan for ensuring durability of these nanofins in the solar field?

This project will not result in a commercial collector by 2030 that meets SETO goals.

*Reviewer 2:*

This is such basic research that relevance to SETO goals cannot be evaluated. We don't presently know that a product exists at other than very small scales. This is more of a research project to contribute knowledge whose useful application has not been determined. One thing is certain. This can have no beneficial impact goals on SETO objectives and lowering the cost of CSP plants for at least 10-15 years.

*Reviewer 3:*

In theory, the team aims to reduce collector cost. However, they never state how much reduction they might achieve. This project is more of a low TRL study of the fundamental physics of concentrators built from metasurfaces. It's tough to connect the work specifically to SETO goals at this stage of development.



**Project Title:** Dielectric Metasurface Concentrators

**Award Number:** 07341

**Principal Investigator:** Kante, Boubacar, University of California, San Diego

**Project Description:**

This project is increasing the acceptance angle of solar concentrators using planar dielectric metasurfaces. Metasurfaces are extremely thin surfaces with unique properties that change the behavior of light in ways that are counterintuitive to an observer. Currently, existing solar concentrators only work for direct light, which requires a multi-axis tracking system to follow the sun's path. By achieving a wider acceptance angle, tracking systems will not have to move as much, potentially lowering the cost of the solar collector for a comparable efficiency performance.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It seems that this work set out to address one major issue - tracking - but its proposed solution still has to track. Though Dr. Yellowhair is an advisor, where is the holistic view? How will this ever be relevant to CSP? This is basic research.

*Reviewer 2:*

This is very early, basic research. It has little chance of impacting SETO goals within 12 years (220) at all. If the concept works the technology would have to be demonstrated in lab scale, prototype scale, utility scale and have at least a couple of years of operational data before a plant developer could stand before a group of bankers' independent engineers to obtain the financing for the first commercial project. At each step along the way, funding would need to be raised slowing down the time to market. This can have no chance of commercialization by 220.

*Reviewer 3:*

The primary value proposition is reduced tracking demands due to the wide acceptance angle. This reduces the demand for tracking, but doesn't necessarily eliminate the need for tracking. So, this project does support cost reduction, but it is difficult to understand the magnitude of the impact.

**Project Title:** Low-Cost Concentrated Solar Power Collector

**Award Number:** 07342

**Principal Investigator:** Mungas, Greg, Hyperlight Energy

**Project Description:**

This project is demonstrating at large scale the performance of its linear Fresnel reflector CSP collector, which captures the sun's energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube. The project uses lightweight, low-cost materials to hold the mirror surfaces in position. The primary bearing surface is a waterbed enclosed on four sides by low-profile walls. The bottom of the waterbed is a commodity pond liner, which is ubiquitous in the agricultural space because of its low cost, rugged durability, and life span of more than 30 years.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is relevant for process heat, probably not electricity.

*Reviewer 2:*

Reducing the cost of CSP plants is the prime factor in the proliferation of CSP plants in industry.

*Reviewer 3:*

This team proposes to drop cost of the collector to less than \$99/m<sup>2</sup> with a path to \$50/m<sup>2</sup>. These goals align well with SETO cost reduction goals for CSP.

**Project Title:** Green Parabolic Trough Collector Inspired by an Architectural Paradigm

**Award Number:** 07343

**Principal Investigator:** Gleckman, Philip, Sunvapor, Inc.

**Project Description:**

This project seeks to drive down the material and assembly costs of the traditional parabolic trough collector by using an outdoor-proven structural material that is 15 percent of the price of congenitally-used steel, and a different structure using trusses on the concave side of the parabola. This structure minimizes the amount of material needed to achieve the stiffness that it requires, and reduces the number of assembly fixtures and process steps in construction. The project aims to develop the concept by designing, building, and testing an outdoor full-scale prototype.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

An interesting approach - wood has been overlooked as a material. My primary concerns are about longevity and stiffness. The investigators seem to have addressed the stiffness concern. But how long are these collectors project to last? And how is the wood treated?

IPH is interesting but this seems unlikely to address the 5cent/kWh goal by 2030.

*Reviewer 2:*

PI is not focused on driving down the cost and improving reliability of the electrical grid, at all. He is focused on an entirely different market, lower temperature process heat market. This will not SETO's objective at all.

*Reviewer 3:*

The team proposes to reduce collector costs, which are a large portion of the total cost of solar electricity. They are targeting \$50/m<sup>2</sup>, which is in line with SETO goals.

**Project Title:** DROP C: The Drop-in, Ring-Of-Power heliostat

**Award Number:** 08024

**Principal Investigator:** Kattke, Kyle, Solar Dynamics

**Project Description:**

This project will develop and demonstrate a novel heliostat and supporting technologies enabling rapid installation and operation. To promote commercial adoption, the team will complete engineering specifications, prototype validation testing, supplier quotation packages, and commercial outreach. As these are developed, parallel activities will integrate and prove new systems for wireless solar field control and rapid heliostat targeting calibration to further reduce the operations and maintenance costs associated with this type of lower cost, smaller-than-typical heliostat.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The best opportunity for significant cost reductions in the tower based CSP market lies in the optimization of the heliostat field.

*Reviewer 2:*

This project seeks to reduce heliostat costs, which are one of the largest costs in a central receiver system. The work is unique and addresses many of the main technical challenges related to heliostat technology.

*Reviewer 3:*

Project explores ways to reduce solar field cost by addressing the heliostat foundation. This is a good area to explore and is relevant to continuing to reduce CSP solar field costs.

**Project Title:** Hydrogen Mitigation

**Award Number:** 29642

**Principal Investigator:** Glatzmaier, Greg, National Renewable Energy Laboratory

**Project Description:**

This project is a cooperative effort between the lab and Acciona Energy North America. The project's objective is to solve a long-standing performance problem that significantly impacts the electricity output and profitability of parabolic trough power plants. The technical objective is to design, implement, and evaluate a full-scale hydrogen mitigation process at the Nevada Solar One commercial power plant.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It is very relevant to maintain highest efficiency and longer time plant operation.

*Reviewer 2:*

As conceived this project addresses a well-known issue that affects LCOE for parabolic troughs. The potential cost savings are relatively small, but significant.

*Reviewer 3:*

This project has resulted in a system that is of value to every parabolic trough plant currently operating in the USA. It is very close to a commercial product that can lower operating costs, enhance reliability and extend the life of existing trough plants.

**Project Title:** Lifetime Model Development for Supercritical Carbon Dioxide CSP Systems

**Award Number:** 30284

**Principal Investigator:** Pint, Bruce, Oak Ridge National Laboratory

**Project Description:**

This project seeks to develop a predictive lifetime model for materials in supercritical carbon dioxide conditions similar to CSP applications. Experimental work will generate relevant corrosion, creep, and fatigue data to populate the model and then verify model predictions. The test campaign will mirror the thermal cycling expected in CSP applications. The combination of experiments aims to remove the many unknowns of how supercritical carbon dioxide and its containment material will function over the expected lifetime of a power plant.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aims to develop a lifecycle model for material behavior exposed to sCO<sub>2</sub> under temperatures and pressures relevant temperature (700 °C, 300 bar) for 500 hr thermal cycles and 1 bar conditions with the more appropriate 10 hr thermal cycles. One Fe alloy and three candidate Ni-alloy materials appear to have been chosen. Data is collected over a limited time span (10000-15000 hr), and based on this data extrapolation models are to be developed for the 30 year CSP target. This could be challenging since the timespan of collected data is small, and as the PI indicates, the changes in the oxidation layer thickness or other metrics of interest are noticeably quite small.

*Reviewer 2:*

The project aims to measure the degradation of candidate metals that could be potentially used in sCO<sub>2</sub> cycles. Though this is a valid goal it is not clear what criteria, methodology and process were followed to choose the candidate metals have been chosen.

*Reviewer 3:*

Bruce Pint's group is almost the only group who is performing such critical sCO<sub>2</sub>-materials interaction experiments. The data and model are essential designing various sCO<sub>2</sub> systems.

**Project Title:** Refractory Solar Selective Coatings

**Award Number:** 30335

**Principal Investigator:** Elam, Jeff, Argonne National Laboratory

**Project Description:**

This project is developing high-performance, solar selective coatings for power tower receivers in CSP plants. In CSP tower systems, the receiver is where the reflected light is concentrated and converted to thermal energy. The efficiency of the light-to-heat conversion is an essential factor in determining the overall efficiency of a CSP plant. A reliable and durable solar selective coating can significantly improve efficiency by reducing the amount of light that is re-emitted away from the plant.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project goals, as stated, to develop a durable solar receiver coating with high absorptivity and low reflectivity clearly support the SETO goals. A target of 800 degrees Celsius and 91% efficiency with 9000 hours and 10,000 thermal cycles was established. To achieve this, low thermal emissivity at the high temperatures is needed. While these goals are clearly supportive of SETO's stated goals, as discussed later and in the report, this goal was not achieved and the project terminated. The technical barrier appears to be driven by the increase in thermal emissivity of the underlying Haynes material with increasing temperature. No clear solutions to this technical challenge were observed.

*Reviewer 2:*

Although not suitable at 800C, this project could create a dramatic improvement of receiver efficiency at today's generation of CSP plants that operate at lower temperatures.

*Reviewer 3:*

Affordable coatings of high absorbance and low emittance, which could operate well at these high temperatures, are indeed very desirable.

**Project Title:** High-Temperature Heat Pipe Receiver for Parabolic Trough Collectors

**Award Number:** 30336

**Principal Investigator:** Obrey, Stephen, Los Alamos National Laboratory

**Project Description:**

This project focuses on the development of heat pipe receiver technology for use with parabolic trough collectors. Heat pipe receivers use the boiling and condensing of a fluid to efficiently absorb the incident concentrated solar energy and transfer the heat to the thermal energy storage system. The lab is combining its expertise in high temperature heat pipes and optically selective glass coatings with Norwich Technologies' expertise in design, construction, and characterization of high-temperature cavity receivers. The resulting technology will reduce the levelized cost of energy through a reduction in system costs, parasitic loads and a net energy conversion efficiency increase.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The idea of replacing heated working fluid transport by using heat pipes has some appeal, but also introduces many questions about the ways the heat will ultimately get from the sun to the turbine fluid, which they did not solve sufficiently nor demonstrate. Furthermore, the use of sodium as heat pipe transport fluid incurs significant risks, which were neither acknowledged nor assessed.

*Reviewer 2:*

Though heat pipes combined with trough type solar collectors are suitable for some of the CSP plants, they both are mature technologies and the current research does not articulate well what innovations are brought to bear to achieve breakthrough results (long heat pipes, transferring heat from one heat pipe to the next and ultimately to the power block etc.). At best the current proposal tries to incrementally improve the state of the art for heat pipe.

*Reviewer 3:*

The heat pipe receiver is being built to enable higher temperature trough operation. This could result in cost reductions, but only if the s-CO<sub>2</sub> hardware works out. I feel like there may be some possibility of using a heat pipe receiver as a replacement for existing hardware at 400 C, but the value proposition for this case was not articulated.



**Project Title:** Binary Metal Chalcogenides for High-Temperature Thermal Storage

**Award Number:** 30337

**Principal Investigator:** Obrey, Stephen, Los Alamos National Laboratory

**Project Description:**

This project is developing a thermochemical energy storage system that uses binary metal chalcogenides in a modular reactor operating at temperatures of at least 750° Celsius. The proposed chemical cycle stores energy through the heat-driven decomposition of a metal chalcogenide and releases energy by recombining the chemical elements. Because of the cycle's high energy density, this material holds promise for low-cost, high-temperature thermal energy storage.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The overall goal of the project is to use metal chalcogenides as the thermal storage material due, in part, to their lower cost and higher energy density. The project is in its second year and appears to have focused on obtaining data on the decomposition of the metal chalcogenide and recombination of the metal and elementary chalcogenide. It is claimed that the kinetic, property and heat rate data for these reactions are not well understood at the relevant conditions. The development of low cost thermal storage supports the SETO goals. It is not clear that the proposed approach with the metal chalcogenides is the way to go given the complexity of dealing with sulphur, the potential for contamination with air or moisture, potential corrosivity issues. These factors could increase cost significantly and the \$15/kw plus/minus 50% value quoted by the investigators after over a year of analysis is not encouraging.

*Reviewer 2:*

This is basic research to "build a technical library of information concerning the technical knowledge gaps." This may eventually contribute to GEN3 goals but seems to have little or no impact on SETO goals in the current decade.

*Reviewer 3:*

It is very relevant to develop effective and affordable high temperature thermal storage, and the metal chalcogenides are worth exploring. The reporting of the progress, however, does not show sufficient evidence that enough was achieved.

**Project Title:** Concurrent Optimization of Component Capital Cost and Expected Operations and Management

**Award Number:** 30338

**Principal Investigator:** Wagner, Michael, National Renewable Energy Laboratory

**Project Description:**

This project is developing and validating an open-source modeling and simulation tool that optimizes the design and operation for CSP plants by characterizing and forecasting operations and maintenance costs, component failure behavior, and the impact of design and maintenance policies. In addition, researchers will develop detailed performance and cost models leveraging the System Advisor Model, which is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry. These models will maximize profit through thermal storage dispatch optimization and will account for forecast uncertainty, heliostat and receiver stochastic degradation and failure, and operations and maintenance costs including steam turbine service.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Power projects require financing. Investors need tools from 3rd parties to help them rapidly evaluate the technology. This work makes and improves these tools. Speaking as someone who worked in the industry, these tools also serve as a way to check internal company models.

*Reviewer 2:*

The optimization model between initial costs, O&M costs and demand uncertainties aims to provide a tool that can advise CSP operators. This tool has already been used by several entities as part of their techno-economic analysis to make installation decisions. With several of CSP technologies maturing, the tool is continuously getting updated with validation data. Hence this model is very relevant in the adoption of CSP as the viable power generation technology.

*Reviewer 3:*

The project's focus is on providing tools to maximize the value of CSP systems. This is very relevant to helping increase the share of renewable energy in our energy mix at lowest cost, making it relevant to SETO's goals.

**Project Title:** CSP Systems Analysis

**Award Number:** 30339

**Principal Investigator:** Turchi, Craig, National Renewable Energy Laboratory

**Project Description:**

This project supports the lab's core capabilities in CSP systems analysis, including upgrades to the System Advisor Model, market analysis of CSP technologies, and cost benchmarking of CSP components. The System Advisor Model is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry. It will be upgraded to facilitate the techno-economic analysis of state-of-the-art CSP technologies currently under development.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Industry and labs use the software tools proposed.

They have found commercial acceptance.

*Reviewer 2:*

This effort aims to improve and expand CSP system level modeling tools. These tools are an essential element in assessing the feasibility of a range of CSP approaches. The fact that they are provided to the industry at no cost is a huge benefit.

*Reviewer 3:*

SAM is a widely accepted analysis program used throughout the CSP industry by technology suppliers, project developers and plant owners/operators.

**Project Title:** Advanced Anti-Soiling Coatings for CSP Collector Mirrors and Heliostats

**Award Number:** 30340

**Principal Investigator:** Smith, Barton, Oak Ridge National Laboratory

**Project Description:**

This project addresses the need to further develop self-cleaning reflector coatings for solar collectors. When solar collectors get dirty, their ability to collect sunlight is diminished. Through field demonstrations at CSP test sites, researchers are investigating the efficacy and durability of super-hydrophobic coatings that can provide anti-soiling capabilities for trough and heliostat mirrors. In order for the coating to be cost effective, the team is developing a low-cost, industry-standard spray coat technique to apply the anti-soiling coating.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Glass mirrors are already pretty good - cheap, high reflectance, and durable. This search for a perfect mirror gives marginal returns and five years is not near long enough.

In my opinion this will not result in a commercially viable product by 2030 and therefore does not support SETO goals.

*Reviewer 2:*

The PI states that "durability is too costly to implement/difficult to scale up to large glass." Also the PI did not investigate the increase in specularity due to surface treatments and coatings. This may be acceptable for short focal length troughs but is crucial for longer focal length towers. There is weak cost/benefit analysis.

*Reviewer 3:*

The project is somewhat relevant but O&M cost reduction focus and lack of focus on cost of the coating makes it less likely to have a big enough impact.

**Project Title:** National Solar Thermal Test Facility Operations and Maintenance

**Award Number:** 30341

**Principal Investigator:** Christian, Joshua, Sandia National Laboratories

**Project Description:**

This project maintains the National Solar Thermal Test Facility, which provides the CSP industry with established test platforms and highly experienced researchers and technologists. This facility allows for development, testing, and application of new CSP technologies that are instrumental in advancing state-of-the-art technology. With expert staff ensuring safe and reliable operation, the facility allows technologies to form the foundation of the global CSP industry and continue to advance the technology to new levels of efficiency, higher temperatures, lower cost, lower risk, and higher reliability.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The National Solar Thermal Test Facility (NSTTF) at Sandia is an essential infrastructure that serves as a test bed for testing of concepts and ideas under realistic test conditions. Such facilities are not feasible at most universities or companies, and hence, represent an essential need for the nation. Hence such needs should not be part of the competition with other technical projects and should be considered and funded separately.

*Reviewer 2:*

DOE needs a place to test and showcase CSP technologies. The NSTTF is it and needs to be maintained. However, it's so expensive and getting work done there (as we tried to do when working at Abengoa) was often difficult and expensive.

*Reviewer 3:*

NSTTF is a valuable resource for testing new CSP technologies that could lead to lower cost CSP.

**Project Title:** High-Temperature Particle Heat Exchanger for Supercritical Carbon Dioxide Power Cycles

**Award Number:** 30342

**Principal Investigator:** Ho, Cliff, Sandia National Laboratories

**Project Description:**

This project is designing, developing, and testing a supercritical carbon dioxide heat exchanger that operates at temperatures higher than 720° Celsius and record-high pressures. In supercritical carbon dioxide heat exchangers, heat is transferred from hot particles to carbon dioxide, which expands in a turbine to generate electricity. Industry experience with similar heat exchangers is limited to lower pressures, lower temperatures, or alternative fluids like steam or water. The lab is partnering with three experienced heat exchanger manufacturers to develop several designs that achieve both high performance and low cost. A prototype unit will be manufactured and tested to confirm key metrics for performance and cost.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aims to develop a high temperature particle heat exchanger to transfer the heat flowing down from the heated particles coming off the receiver to the sCO<sub>2</sub> working fluid coming from the compressor via intermediate recuperators. Several particle to gas heat exchanger technology and designs have been explored on paper (fluidized bed, tube and shell and shell and plate and shell), and the plate and shell HX has been advanced for fabrication and testing.

The particle receiver technology appears to be a viable path for the high temperature sCO<sub>2</sub> loop in addition to the molten salt path. Sandia has focused on this technology and several awards related to this have been made. This award is one of a series of awards that focusses on the Heat Exchanger (particle to sCO<sub>2</sub>) which is a critical element. In this sense, the project does advance the SETO goals directly and is relevant to the SETO program.

*Reviewer 2:*

Design and testing of an optimal high temperature particle heat exchanger for sCO<sub>2</sub> power systems is a very important component of the DOE CSP program, and the proposers are highly qualified for that. At the same time, a general question remains whether the sCO<sub>2</sub> power system is an optimal way to generate power, and whether collecting heat by a particle receiver is the optimal way for using highly concentrated solar radiation.

*Reviewer 3:*

The goals are aligned with broader SETO goals on capturing the solar flux in receiver. By increasing the heat transfer capacity and efficiency of solar receiver the project aims to increase the cycle temperature match or exceed SETO targets.

**Project Title:** High Efficiency Latent Heat Based Thermal Energy Storage System Compatible with Supercritical Carbon Dioxide Power Cycle

**Award Number:** 30382

**Principal Investigator:** Singh, Dileep, Argonne National Laboratory

**Project Description:**

This project continues the development of a high-efficiency latent heat thermal energy storage system based on a graphite foam filtered through a phase changer material, which has high thermal conductivity. The project will extend the system to make it compatible with supercritical carbon dioxide power cycles, which use heat transfer fluids at temperatures higher than 720° Celsius.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aims to develop an encapsulated Phase Change Material (PCM) based thermal energy storage system that is capable of discharging the sCO<sub>2</sub> working fluid for the power block at temperatures above 700 degrees C. Therefore MgCl<sub>2</sub> with a melting temperature of 715 deg C has been chosen. It is agnostic to the charging fluid from the receiver except that a larger number of tubes may be needed for a gaseous charging fluid in view of the lower internal heat transfer coefficients. The PCM is embedded in a graphite foam to enhance the thermal conductivity on the PCM side.

High temperature energy storage is a critical need, and as such this project is relevant to SETO goals. The challenge is in maintaining the cost below the desired goal of less than \$15/kWH and in maintaining high effectiveness of efficiency in the heat exchange system. Since the system has not been built, the performance of the system cannot be fully evaluated. The project is behind schedule and has been extended by a year.

*Reviewer 2:*

The idea of impregnating carbon foam with a high temperature phase change pcm for good heat transfer and energy density is in principle very good for relevance to the objectives. I suspect that there are, however, several critical problems, described in further answers, that may make this solution unacceptable, and they should have been addressed.

*Reviewer 3:*

The high conductivity solution proposed by ANL is innovative with porous carbon as a thermal conductivity enhancer. There may be problem of residual oxygen or moisture which can lead to corrosion problem down the road. The technology cannot be used together with flowable particle type of systems.

# Systems Integration



**Project Title:** Integrating System to Edge-of-Network Architecture and Management

**Award Number:** 07162

**Principal Investigator:** Nakafuji, Dora, Hawaiian Electric Company

**Project Description:**

This project is working to validate the system-level benefits of enhanced utility visibility and control of distribution system and edge-of-network electricity resources. This project will enable proliferation of a reliable base of solar-plus-storage distributed technologies that offer more plug-and-play customer options for grid participation, and provide cost-effective grid response capabilities to system operators.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project is relevant to SETO's system integration goals of facilitating the integration of solar energy w/ the electric grid infrastructure.

*Reviewer 2:*

The proposed project entitled, "Integrating System to Edge-of-Network Architecture and Management (SEAMS) for SHINES Technologies on High Penetration Grids," will demonstrate successful SHINES (Sustainable and Holistic Integration of Energy Storage and Solar PV) deployments and will show the system-level benefits of enhanced utility visibility and control of distribution system/edge-of-network electricity resource. The success of this project is built upon two pillars: interoperability and holistic approach. The future power grid will definitely see a need to integrate a large number of heterogeneous DERs into the grid. However, it is a very difficult task today because either there lacks a universe protocol or heterogeneous communication/network mechanics may co-exist. If successful, this project will advance the-state-of-the-art to gain a better understanding of how interoperability can be achieved more efficiently. As Hawaiian Electric Company already experiences a high penetration of PV, the grid in Hawaiian is an ideal testbed to evaluate the applicability and performance of the proposed technology.

**Project Title:** Beneficial Integration of Energy Storage and Load Management with Photovoltaics

**Award Number:** 07163

**Principal Investigator:** Huque, Aminul, Electric Power Research Institute

**Project Description:**

This project is working with five utilities to design, develop, and validate technology for end-to-end grid integration of energy storage and load management with photovoltaic generation. The technology is a simple, two-level, and optimized control architecture. Its effectiveness will be verified at three field locations.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is a demonstration project relying on the well-known fact that storage helps dampening the variability of weather-dependent DERs.

In what respect to implementation details, it is a relevant work.

*Reviewer 2:*

The project concerns the development of a DER integration and 2-level control mechanism. The flexibility of using storage and demand-side resources to help alleviate variability and ramping issues with PV is relevant to the program. This project seems to emphasize DER integration and control in general with PV integration taking a secondary role. Nevertheless, the spirit of the work intends to help alleviate challenges that high penetration of PV faces.

*Reviewer 3:*

Demonstrating integration of solar, storage, and customer loads has the potential to increase the value of solar energy while also reducing costs of integration. This will be increasingly important as we see higher penetrations of solar energy.

**Project Title:** Sundial - An Integrated System to Enable High-Penetration Feeder-Level Photovoltaics

**Award Number:** 07164

**Principal Investigator:** Roth, Kurt, Fraunhofer USA, Center for Sustainable Energy Systems

**Project Description:**

This project is developing a highly scalable, integrated photovoltaics, storage, and facility load management solution. Through the SunDial Global Scheduler, the system tightly integrates photovoltaics, energy storage, and aggregated facility load management to actively manage net system power flows to and from the feeder, regardless of whether these individual components are co-located at the same site, or distributed at different sites.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Good example of applied research with specific goals, including a cost target goal, set at onset of project.

*Reviewer 2:*

This project seeks an integrated approach to enable high penetration of PVs to improve economics and reliability. This is consistent with the DOE solar office's mission to promote and support such a technology.

*Reviewer 3:*

Demonstrating integration of solar, storage, and customer loads has the potential to increase the value of solar energy while also reducing costs of integration. This project has elements of each of these and is geared towards enabling a scalable solution that can be leveraged by others.

**Project Title:** Agent-Based Coordination Scheme for Photovoltaic Integration

**Award Number:** 07165

**Principal Investigator:** Kar, Soumya, Carnegie Mellon University

**Project Description:**

This project is developing a distributed, agent-based control system to integrate smart inverters, energy storage, and commercial off-the-shelf home automation controllers and smart thermostats. The system will optimize photovoltaic generation, storage, and load consumption behaviors using high-performance, distributed algorithms.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project relies on the well-known fact that storage a DSM helps dampen the variability of weather-dependent DERs.

This is a relevant, but well researched, topic.

*Reviewer 2:*

Project goals clearly identifies \$0.14/kWh LCOE target. However, project materials do not provide basis through hardware components and control system to achieve the target. Although an agent based vs. group based control scheme is conceptually sound, the project material and project results to date does not appear to provide clear evidence of the developed algorithm or agent system being able to provide cost reductions, although milestone M1 states that this has been proven. More documentation and explanation is needed in this regard. In addition, reliability and resiliency benefits are not explained or quantified.

**Project Title:** Microgrid-Integrated Solar-Plus-Storage Technology

**Award Number:** 07166

**Principal Investigator:** Bahramirad, Shay, Commonwealth Edison Company

**Project Description:**

This project addresses availability and variability issues inherent in solar photovoltaic technologies by utilizing smart inverters for solar-plus-storage with batteries and working synergistically with other components within a microgrid community. This project leverages the microgrid cluster controller, which was funded by the Energy Department, and is connected to the existing 12 megawatt microgrid at the Illinois Institute of Technology.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Quite relevant, as it actually attempts to integrate a system that contains all of the building blocks being researched by various other projects in the program. Tying PV, BESS, and other means of generation together is something that many folks have simulated, theorized about, and of course also implemented on some scales, but this project seems to be attempting to do this with a system exposed to some of the more harsh realities of life.

*Reviewer 2:*

The project is about a microgrid balancing solar w/ BESS. The SETO objective of increasing PV integration seems to have a relatively small microgrid market impact compared with non-microgrid conditions that dominate the sites with PV.

*Reviewer 3:*

Project proposes to solve the inverter integration issue, so it is very important to the SETO objectives.

**Project Title:** Austin SHINES

**Award Number:** 07177

**Principal Investigator:** Popham, Karl, Austin Energy

**Project Description:**

This project is developing a solution adaptable to any region and market structure that offers a credible pathway to a levelized cost of energy of \$0.14 per kilowatt-hour for solar energy when augmented by storage and other distributed energy resource management options. The solution aims to establish a template for other regions to follow to maximize the penetration of distributed solar photovoltaics. In addition, the proposed solution will enable distribution utilities to mitigate potential negative impacts of high penetration levels of photovoltaics caused by the intermittency and variability of solar production.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Project is generally relevant to observing DER interactions on the grid but it's unclear if this project will provide actionable lessons to enable greater penetrations of renewable DG and DERs. Specifically, it's unclear if the dispatch planning for the batteries will be sufficiently driven by market signals or if the lessons learned on this pilot will be relevant to real-world grid integration issues.

*Reviewer 2:*

This project is a pilot to explore the value of energy storage for integration of PV across different levels. Energy storage can have great potential to assist in the integration of PV.

*Reviewer 3:*

Technology demonstration projects, like this one, are important to the SETO objectives as they provide evidence that the research can be successfully applied.

**Project Title:** Scalable and Secure Cooperative Algorithms and Framework for Extremely High Penetration Solar Integration

**Award Number:** 07998

**Principal Investigator:** Qu, Zhihua, University of Central Florida

**Project Description:**

This project designs and develops a scalable architecture and a set of algorithms for distributed control and optimization. The platform encompasses automatic fault location isolation and service restoration and Volt/VAR optimization; distribution system state estimation algorithms for both the conventional non-convex task and the convex state estimation task; a three-phase unbalanced power flow model that captures the non-linear behavior of system components and enables rapid computation of sub-transmission network and unbalanced distribution network; a two-stage stochastic security-constrained algorithm for real-time operational planning; and a distribution energy market framework that utilizes both model-based and data-based techniques to provide market-based signals for real and reactive power control of photovoltaic systems.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project integrates a number of operational tools (OPF, state estimation, restoration) within an optimal control framework to manage, in a decentralized manner, distribution systems with high integration of weather-dependent DERs.

This is relevant.

*Reviewer 2:*

Advancing approaches for coordination of DER are relevant for SETO. The architecture and functions are DER technology agnostic; however, the variability and high penetration scenarios of solar PV on distribution circuits provide driving reasons for considering such coordination approaches.

*Reviewer 3:*

The project can provide optimization of feeder dispatch for reliability, optimization of feeder assets, and resilience of feeder operations.

**Project Title:** Integrated Distributed Energy Resource Management System

**Award Number:** 08001

**Principal Investigator:** Mohsenian-Rad, Hamed, City of Riverside Public Utilities

**Project Description:**

This project designs, deploys, and validates at scale a novel distributed energy resource management system. Its main component is a sophisticated numerical analysis platform that will enable an optimal and active network management solution for real-time control. The solution provides secure and optimal dispatch of distributed energy resources for power system networks (both transmission and distribution) on feeders with over 50 percent solar penetration. This technology deployment will be transformational to utilities that may not have financial resources to deploy full advanced distribution management systems.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Quite relevant as it addresses one of the major issues Utilities seem to have with high penetration of DERs - namely the wide scale control of them. This project proposes a control framework that will help automate some of those controls.

*Reviewer 2:*

I find particularly relevant the integration/implementation dimension of this project, and comparatively less relevant/novel the algorithm development dimension.

*Reviewer 3:*

The integration of DERMS solutions by utility operators is likely a necessary step in achieving high penetration levels for renewable DG.



**Project Title:** Keystone Solar Energy Future Project

**Award Number:** 08002

**Principal Investigator:** Toomey, Megan, PPL Electric Utilities

**Project Description:**

This project leverages several different grid technologies to deploy a distributed system platform that bridges the gap between existing and future technologies by monitoring, controlling, and optimizing a high penetration of solar generation. The team is also developing a multi-layer device and communications architecture and a 500-customer pilot on at least 10 distribution circuits. An extensive one-year real-world testing will be performed, proving all of the target parameters before deploying it system-wide.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

An implementation of a distributed energy resource management system, which if functioning as intended could give the utility in this project the level of centralized control that many have asked for. With this, they could potentially limit the number of voltage excursions and system losses.

*Reviewer 2:*

DERMS pilot in PPL Electricity Corporation is well aligned with SETO's objectives to use improved grid operation to enable greater solar penetration.

*Reviewer 3:*

The project has multiple aspects all of which have a relationship to improved integration of solar PV and other DERs into the utility systems. Improving visibility and providing capability for control are critical components. Improving interconnection processes can help avoid delays and errors that create unnecessary costs for PV customers and the utility.

**Project Title:** Data Driven Modeling and Analytics for Enhanced Systems Layer Implementation

**Award Number:** 08003

**Principal Investigator:** Prasanna, Viktor, University of Southern California

**Project Description:**

This project uses data to develop novel representations of distributed energy resource owners' interactions via data-driven models along with stochastic reserve optimizations that enable net-load balancing in near real-time. The project develops a transformational distributed grid control architecture as a part of an enhanced system layer at the distribution network level that optimizes the coordinated usage of large numbers of variable and distributed resources, decentralized energy storage, and load to ensure real-time, system-wide, net-load management and automated adaptation to real-time variability in a cost-effective, secure, and reliable manner.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project proposes to use data analytics to enable a large integration of weather-dependent DERs in distribution systems.

I find particularly relevant the task pertaining to the prediction of behind-the-meter generation.

*Reviewer 2:*

The project is relevant for research into data analytic-driven approaches to coordinate the operation of DER with the electric system at high penetrations; however, it would be good to give closer ties to the solar technology integration. For example, the use of PV smart inverters could be pointed out more closely. The ambition of the program is very great, making the risk of achieving successful outcomes large.

**Project Title:** Electric Access System Enhancement (EASE)

**Award Number:** 08004

**Principal Investigator:** Xu, Le, Southern California Edison

**Project Description:**

This project leverages existing information systems and processes to increase efficient communication exchange between the utility and the customer or resource provider interconnection process by optimizing control of the resource. This complete lifecycle approach defines the necessary data to be exchanged, the grid and device characteristics, and the operating constraints and protocols to enable effective controls and operations. This structured and automated exchange of characteristics and parameters accelerates the interconnection process, establishes common information requirements, and enables effective operational connection of distributed energy resources to the grid.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Quite relevant, attempting to solve both soft cost and high penetration DER issues. A fairly unique and compelling argument for both.

*Reviewer 2:*

Section 6 lays out a nice description of how this project aims to demonstrate the support for high levels of solar PV and other DER and reduce interconnection time and cost.

*Reviewer 3:*

The project represents an ambitious effort to enable standardization and automation of a number of key processes that threaten to become unsustainable at the scale and penetration being seen in markets like SCE. Resolving each of these challenges in a single platform represents a step forward to the next level of DER integration.

**Project Title:** Robust Distributed State Estimator for Interconnected Transmission and Distribution Networks

**Award Number:** 08005

**Principal Investigator:** Abur, Ali, Northeastern University

**Project Description:**

This project develops, implements, tests, and validates a comprehensive state estimation algorithm for combined monitoring of transmission and distribution systems. This approach allows the computational complexity and solution time to be bounded regardless of the system size and number of measurements. The approach utilizes a mixed set of measurements under different network configurations and is able to handle any number of available solar photovoltaic units connected to the distribution system.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project targets the improvement of visibility for both transmission and distribution network. This is becoming more important as the penetration of PVs increases.

*Reviewer 2:*

This project aims directly at assuring the reliability by giving system operators a clear picture of the system state and behavior.

**Project Title:** Robust and Resilient Coordination of Feeders with Uncertain Distributed Energy Resources: From Real-Time Control to Long-Term Planning

**Award Number:** 08006

**Principal Investigator:** Almassalkhi, Mads, University of Vermont

**Project Description:**

This project develops a layered predictive optimization and coordination framework to coordinate the flexible resources available in the distribution grid, as well as the legacy control devices, to ease the fluctuations and variability in solar generation. Solar forecast data is leveraged to schedule the dispatchable flexible resources in a look-ahead fashion, while any mismatch due to solar forecast errors will be solved through real-time coordination of the controllable resources. New estimation methods are leveraging data from smart meters and sensors to estimate the available flexibility in the distribution system, as well as identify the real-time operating conditions, to aid in the informed decision making process. Aggregated models of the flexible resources will be leveraged in a hierarchical fashion to implement autonomous response to contingencies.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Understand objective of optimized operation of DERs on a distribution feeder. Optimization (or further optimization) of DER resources can assist with achieving LCOE goals and possibly reliability and resiliency goals.

*Reviewer 2:*

This forward-looking project is well-timed to contemplate new distributed device control approaches that can address significant barriers to leveraging these devices to improve integration of distributed PV. Developing a viable scalable architecture can help shape standards development at a critical time. Proceeding with traditional grid control architecture may reach fundamental limits that threaten continued cost-effective deployment of distributed PV devices. This work could help articulate a workable alternative in time to adjust standards to overcome this device coordination hurdle.

**Project Title:** Phasor-Based Control Scalable Solar Photovoltaic Integration

**Award Number:** 08008

**Principal Investigator:** Blumstein, Carl, University of California Berkeley

**Project Description:**

This project designs, implements, and validates an innovative framework to enable a distribution grid with solar photovoltaic generation greater than 100 percent. By explicitly controlling voltage phasors at specific network nodes, this framework simultaneously addresses multiple operational challenges, including high resource variability, reverse power flow, grid visibility, and coordination between transmission and distribution systems. The framework solves the problem of complex interdependencies in large networks by creating options for partitioning the grid both physically and computationally.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project proposes a new optimization and control approach that incorporates PV and storage. It claims to be transformational from today's approach to operating the grid. In this regard, its relevance may be more important for grid operations in general, rather than specifically targeted to improving the penetration of solar resources, though the objective is to do that as well. During the poster session, the phasor framework was also explained to be agnostic to the optimization algorithms used as long as phasor bus targets could be provided.

*Reviewer 2:*

Proper control of the solar assets is critical to the accomplishment of the SETO objectives.

**Project Title:** Power to Gas: Enabling Higher Penetrations of Solar Power Generation Using the Natural Gas Pipeline System for Energy Storage

**Award Number:** 27917

**Principal Investigator:** Palmintier, Bryan, National Renewable Energy Laboratory

**Project Description:**

This project will aim to provide a PV-to-Gas solution. Because of its variability, to use solar power as a baseload generation asset requires a flexible storage system that can store and recover power on both a daily and seasonal basis. The conversion of solar power to natural gas (i.e., first to hydrogen and then to methane) and utility-scale storage in the natural gas pipeline has the potential to make solar power generation a baseload asset.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project investigates a usage for excess solar generation that can help the system mitigate impacts from the variable energy production from solar. Unlike other projects in the SETO systems integration project, this couples the electric infrastructure with the gas infrastructure in a novel way. In the poster discussion, it was also pointed out that this is the last of 6 projects. The other 5 projects are not presented.

*Reviewer 2:*

I consider this a seasonal load shifting application which I don't think is a critical path effort to allowing increasing renewables penetration in the coming decade. In this sense, it won't have a meaningful impact on SETO's 2030 objectives.

*Reviewer 3:*

This project offers a unique way to optimize value of solar resources by taking advantage of a unique storage method for renewable energy that would otherwise be curtailed.

**Project Title:** Additively Manufactured Photovoltaic Inverter

**Award Number:** 30356

**Principal Investigator:** Chinthavali, Madhu, National Renewable Energy Laboratory

**Project Description:**

Integrating hundreds of gigawatts of photovoltaic solar power onto our country's electric grid requires transformative power conversion system designs that find a balance between performance, reliability, functionality, and cost. This project is developing a unique inverter design that combines the latest wide bandgap, high-voltage, silicon carbide semiconductor devices with new technologies, such as additive manufacturing and multi-objective magnetic design optimization. By developing an additively manufactured inverter, researchers aim to significantly reduce the cost of photovoltaic power electronics.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

In general, this seems to be an interesting mix of new technologies tied into a single project. Mentions of industry collaboration seem to indicate that this has the potential for relevant impact on marketable products. The creation of a prototype using these methods is useful, but still a big step away from productization, where costs, long term reliability, and market acceptance become a huge factor. Given what was reported in the documents provided for review, it seems that the project is delivering the things they have promised.

*Reviewer 2:*

The target is to show a way to design/manufacture cheaper and more efficient inverters for PV integration, using new manufacturing and packaging ideas. This is most relevant.



**Project Title:** Sunlamp Solar Resource Calibration, Measurement, And Dissemination

**Award Number:** 30359

**Principal Investigator:** Clifton, Andrew, National Renewable Energy Laboratory

**Project Description:**

The primary objective of this project is to conduct and disseminate foundational research to improve the accuracy and availability of solar resource information through improvements new developments in (a) calibration and characterization of broadband and spectral instruments (b) uncertainty estimation through building standard methods (c) satellite based estimation of US wide solar resource information and (d) development and dissemination of new standards and best practices.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Having good data available is certainly relevant, otherwise “garbage in, garbage out.”

Yes, I think this project is relevant and it serves the need of making available good quality data.

*Reviewer 2:*

The project goal of conducting and disseminating foundational research to improve the accuracy and availability of solar resource information is too broad. The project objectives in Section 8 are more targeted. However, several of the items, such as develop annual updates to the NSRDB, are on-going concerns that do not match with a three year project.

*Reviewer 3:*

Advancing foundational work which is essential for PV project development and other solar companies.

**Project Title:** System Advisor Model

**Award Number:** 30360

**Principal Investigator:** Freeman, Janine, National Renewable Energy Laboratory

**Project Description:**

This project focuses on the System Advisor Model, a performance and finance model designed to facilitate decision making for people involved in the renewable energy industry. It makes performance predictions and cost of energy estimates for grid-connected power projects based on installation, operating costs, and system design parameters that users enter into the tool. This project will improve and maintain many features of the tool that has been instrumental in advancing the solar industry. Basic maintenance for the PVWatts calculator tool will also be completed.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The SAM and PVWatts models are foundational tools used throughout the industry to aid utilities, developers, and others understand the performance and economics of PV systems. They provide the latest decision making information needed by industry, which in turn helps industry achieve DOE's target LCOE goals.

*Reviewer 2:*

This project is critical to SETO and fully supports SETO's goals in terms of driving down the integration cost of PV.

*Reviewer 3:*

Making battery sizing software to the industry and the public is an admirable goal. If applied at the retail customer level, it could be a powerful tool to allow customers to avoid costly engineering consultations for their personal need.

**Project Title:** Concentrating Solar Power in a SunShot Future

**Award Number:** 30361

**Principal Investigator:** Denholm, Paul, National Renewable Energy Laboratory

**Project Description:**

This project investigates concentrating solar power and its ability to increase the overall penetration of solar energy while lessening the variability impacts of solar photovoltaics. Concentrating solar power is unique among solar technologies in that it can provide dispatchable energy through high-efficiency thermal energy storage. Researchers will analyze these next-generation power plants and their ability to provide valuable grid services.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

I consider this a second-order driver of CSP competitiveness (cost is being the primary driver). This analysis won't meaningfully benefit CSP until storage is much more valuable on the grid which may not occur for 10+ years (or perhaps not at all if TaaS EVs can provide sufficient storage). At that time, the assumptions and tools used to perform this analysis may need to be updated.

*Reviewer 2:*

Assessment of CSP is needed to enable better understanding of the potential impacts and costs of deployment. However, this has to balance with the reality that CSP does not look to be a major player in the solar space.

*Reviewer 3:*

The project aims to better characterize how CSP can contribute to a range of grid services that will be required as we reduce reliance on fossil plants. By understanding these capabilities and understanding potential values as well as benchmarking against PV and storage, the project will enable sound decision-making around the appropriate design considerations and performance and cost targets for CSP plants. This information is critical for making sure the technology sees the appropriate investment relative to its expected contribution to our future energy system.

**Project Title:** Opportunistic Hybrid Communications Systems for Distributed Photovoltaic Coordination

**Award Number:** 30362

**Principal Investigator:** Hodge, Bri Mathias, National Renewable Energy Laboratory

**Project Description:**

As more distributed solar power is added to the electric power grid and becomes an increasing proportion of total energy generation, the grid must support more stringent requirements to ensure continued reliable and cost-effective grid operations. New communications systems are needed to allow for bidirectional information exchange between distributed photovoltaic generators and various information and controls systems of the electric power grid. This project is developing a hybrid communications system to meet the needs of monitoring and controlling millions of distributed photovoltaic generators, while taking advantage of existing communications infrastructure, which will greatly reduce the costs necessary to provide these services.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project attempts to address some of the major questions about high penetration distributed energy resources - namely that of providing a channel for coordination with the transmission operator. The methods used to simulate such a system to estimate the operation of such a network seemed to be sound as well.

*Reviewer 2:*

With the seemingly landslide desire to communicate or at least measure PV behavior on distribution systems, the adaptive hybrid communication proposal has merit.

**Project Title:** Accelerating Systems Integration Codes and Standards (ASICS)

**Award Number:** 30363

**Principal Investigator:** Narang, David, National Renewable Energy Laboratory

**Project Description:**

This project focuses on accelerating the revision process of the IEEE 1547 series and UL 1741 standards and testing procedures. Collectively, these standards are the foundational documents that are mandated for integrating solar energy systems with the electric distribution grid. Establishing accelerated development of new interconnection and interoperability requirements and conformance procedures will allow for more photovoltaic solar energy to be added to the grid.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Guiding and supporting standards activities may seem a bit out of scope for DOE funding at first, but having seen the glacial pace at which interested parties normally move things forward in the space I actually found this to be a surprisingly good idea. IEEE1547 has been relied on by just about every utility in the US, and many countries around the world, to define behaviors on the grid for DER. The process for releasing a new standard, or an update to the existing one, often takes 5+ years. NREL has been accelerating this by providing focused leadership.

*Reviewer 2:*

IEEE 1547 and UL 1741 are key enabling standards for distributed connected inverter systems, particularly PV. These standards enable industry standard performance requirements for distribution connected generators which allows for greater levels of DER hosting while maintaining reliability and resiliency performance of the connected system.

*Reviewer 3:*

This project was successful in accelerating development and passage of IEEE 1547.

**Project Title:** Stabilizing the Power System in 2035 and Beyond: Evolving from Grid-Following to Grid-Forming Distributed Inverter Controllers

**Award Number:** 30364

**Principal Investigator:** Johnson, Brian, National Renewable Energy Laboratory

**Project Description:**

Adding large amounts of photovoltaic solar energy onto the grid creates significant challenges for future grid operations, since the electric power grid currently operates with rotational inertia from fossil fuel-driven machines. However, inverters are power-electronic devices with no inherent inertia. This project is developing a suite of inverter controllers to ensure the long-term viability of electric power grid infrastructure and address the large reductions in system-wide inertia with high penetrations of solar. These grid-forming inverter controllers will allow each inverter to act as a controllable voltage source that dynamically adjusts its output to ensure system-level stability, synchronization, and voltage regulation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Very much theoretical in nature. However, if the existing utility transmission & distribution grid would not already be in existence, this would be a really intriguing way to develop a new one. The only downside of the project and theory behind this is that there are a lot of unanswered questions about how to get from one to the other. From the way standards are developed now, and requirements are set by the utility, there would be great difficulty in transitioning to such an independent grid forming method for distributed generation.

*Reviewer 2:*

This project fills the gap in the control design of PV at a high penetration level.

*Reviewer 3:*

Properly conceived and operated inverters are critical to the accomplishment of the SETO objectives.

**Project Title:** Secure, Scalable, Stable Control and Communications for Distributed Photovoltaics

**Award Number:** 30690

**Principal Investigator:** Byrne, Ray, Sandia National Laboratories

**Project Description:**

This project enables high penetrations of solar generation on the grid by updating the current technical metrics for grid communications with a new distributed control and communications architecture that clearly explains the impact of each metric on the grid. A clearer understanding of the variability of each metric will result in optimal levels of performance, reliability, cost, and security.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Cyberattacks are unfortunately relevant in many sectors.

However, given the extraordinary redundancy in data that characterizes the operation of power systems (not the case of the financial sector), I am not sure to which extent cybersecurity is a key problem for power systems operation.

*Reviewer 2:*

The reliability of communication network is becoming more critical as it serves as the backbone for the integration of PVs into the future grid. This project definitely addresses this need.

*Reviewer 3:*

Project explores a topic that will be critical to solve in order to reach the SETO objectives. Cybersecurity is a problem that could have substantial risks to the overall solar implementation if it cannot be solved.

**Project Title:** Rapid Quasi Static Time Series Simulations for High-Resolution Comprehensive Assessment of Distributed Photovoltaic Impacts

**Award Number:** 30691

**Principal Investigator:** Broderick, Robert, Sandia National Laboratories

**Project Description:**

This project accelerates quasi static time series simulation capabilities through the use of new and innovative methods for advanced time-series analysis. Currently, this type of analysis is not commonly performed in photovoltaic interconnection studies because of the data requirements and computational burden. This project will address both of these issues by developing advanced methods that greatly reduce the required computational time and by developing high-proxy data sets.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Dramatic improvement in static analysis of feeder circuit with clear industry uptake is well aligned with high penetration requirements.

*Reviewer 2:*

It is very important to understand the time-dependent aspects of power flow in the distribution system as the power flow can change very dramatically. However, it requires more computation power or innovations to speed up the computation. This project targets at this problem and has potential to increase reliability and resilience of distribution grid.

*Reviewer 3:*

This effort to develop new approaches to distribution planning models that can accelerate the speed of analysis will resolve a key challenge to reaching higher levels of PV penetration. Often the amount of time required to run analyses create a barrier to interconnection and a necessary conservatism amongst the utility planners who must err on the side of caution. This barrier adds to costs of integrating PV and slows adoption. The project has the potential to significantly address this barrier.



**Project Title:** Frequency Response Assessment and Improvement of Three Major North American Interconnections due to High Penetrations of Photovoltaic Generation

**Award Number:** 30844

**Principal Investigator:** Liu, Yilu, Oak Ridge National Laboratory

**Project Description:**

As the number of solar photovoltaic installations continues to grow exponentially, one of the major challenges to grid stability will be mitigating decreasing system inertia and deteriorating frequency response. Preliminary independent studies on two North American interconnections have already demonstrated that the overall frequency response will deteriorate significantly with increasing renewable generation. This project will investigate the frequency response and system inertia impacts with high solar penetration levels for all three major interconnections: the Eastern Interconnection, Western Interconnection, and the Electric Reliability Council of Texas.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project provides a broad, macro-level review of stability of reliability of major interconnections on a going-forward basis.

*Reviewer 2:*

This project provides insights into an important potential revenue stream to drive down the cost while supporting the reliability and resiliency of the grid.

*Reviewer 3:*

This project tackles a key question relating to the overall power system stability with high levels of inverter based devices on the system. Given the high penetration levels already being seen in some parts of the US like Texas, the work is timely for addressing potential barriers that PV deployment could face within the next 10 years as more areas reach very high levels of penetration.

**Project Title:** Visualization and Analytics of Distribution Systems with Deep Penetration of Distributed Energy Resources

**Award Number:** 31003

**Principal Investigator:** Kiliccote, Sila, SLAC National Accelerator Laboratory

**Project Description:**

For high penetration of distributed energy resources like solar, electric power grid operators and planners must be able to incorporate large datasets from photovoltaic sources, local and line mounted precision instruments, customer load data from smart meters, and electric vehicle charging data into their analyses. This project will design and implement a platform for the visualization and analytics of distribution systems with high penetrations of distributed energy resources. This unified data analytics platform will enable the integration of massive and varied data streams for real-time monitoring with analytics, visualization, and control of distributed energy resources in distribution networks.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Unique approach to enabling higher DG PV penetration. Current successes are meaningful and future potential is much greater.

*Reviewer 2:*

This project proposed advanced analytics for the operation of a grid with deep penetration of DERs. This is directly supportive of the missions of DOE Solar Office.

*Reviewer 3:*

The objective is supportive of the SETO --it is attempting to provide meaningful visualization for solar participants.

**Project Title:** Combined Photovoltaics and Battery Grid Integration with High-Frequency Magnetics Enabled Power Electronics

**Award Number:** 31004

**Principal Investigator:** Ohodnicki, Paul, National Renewable Energy Laboratory

**Project Description:**

This project is developing new power electronics devices, systems, and materials to address power electronic and dispatchability challenges that result from connecting hundreds of gigawatts of solar energy onto the electricity grid. These devices will incorporate advanced high-frequency magnetics along with the latest wide bandgap silicon carbide switches. This design enables cost-effective grid integration of photovoltaics while increasing its dispatchability.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Combined PV and energy storage solutions are definitely poised to have a big impact on the proliferation of PV on the grid. Research on this topic is relevant, and some of the steps taken in this project to implement a solution for such a system were also relevant. The only concern is the specific implementation here, which may be useful only for a small subset of applications in PV + Storage - namely where we do nothing but peak shift / maximize capacity factor.

*Reviewer 2:*

The project is using power electronics and transformer designs in a novel way to more easily accommodate the integration of solar energy coupled with battery storage. This promises to mitigate the variability in the solar resource and to reduce losses.

**Project Title:** Dynamic Building Load Control to Facilitate High Penetration of Solar Photovoltaic Generation

**Award Number:** 31081

**Principal Investigator:** Kuruganti, Teja, Oak Ridge National Laboratory

**Project Description:**

This project aims to develop, demonstrate, and validate a sensing and control mechanism for using power loads to address variable photovoltaic generation, which will reduce two-way power flow and mitigate voltage instability on distribution level circuits. The availability of this technology will enable increased penetration of renewables while weakening the challenges that arise due to their intermittency in generation by using flexibility on load side.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project addresses a rather classical problem: What happens if the flow in a distribution feeder reverses? How to mitigate voltage issues in such a circumstance? How to keep the protection system working?

This problem is well understood from a research viewpoint, but there are still relevant engineering issues to be sorted out. Thus, the project has engineering relevance.

*Reviewer 2:*

The project is using the flexibility in buildings to address PV variability so that the distribution system can accommodate more PV. This is in line with the SETO objectives for PV integration; however, it is more about buildings control that could be used for many grid services.

**Project Title:** An Integrated Tool for Improving Grid Performance and Reliability of Combined Transmission-Distribution with High Solar Penetration

**Award Number:** 31221

**Principal Investigator:** Abhyankar, Shirang, Argonne National Laboratory

**Project Description:**

High penetration of solar photovoltaics in electric power grids has created a need for changes to power system planning and operations analysis. Important technical issues such as two-way power flow, coordination of protection devices, transmission-distribution interaction, and reduction in inertia need to be resolved to enable a greater deployment of solar generation. To overcome these technical barriers, this project will develop a suite of software tools that creates a holistic understanding of the steady-state and transient behavior of transmission-distribution networks' interaction under high solar penetration levels, along with the capability of real-time monitoring of the distribution systems and integration of system protection.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

A joint, reliable operation of the transmission and distribution system is a key objective of the SETO program.

*Reviewer 2:*

Better integration of transmission and distribution models is important as we reach penetration levels on the distribution system that matter from a transmission perspective. Understanding how these systems will interact and having an ability to address penetration scenarios from both perspectives is a key need for the industry.

**Project Title:** Enabling High Penetration of Distributed Photovoltaics Through the Optimization of Sub-Transmission Voltage Regulation

Award Number: 31251

**Principal Investigator:** Nader, Samaan, Pacific Northwest National Laboratory

**Project Description:**

This project is developing a coordinated real-time sub-transmission Volt/VAR control tool to optimize the use of reactive power control devices for stabilizing voltage fluctuations caused by intermittent photovoltaic outputs. In order to capture the full value of the Volt/VAR optimization, the project team will couple this tool with an optimal future sub-transmission Volt/VAR planning tool for short- and long-term planning analyses. Together, these real-time control and planning tools will remove a major roadblock in the increased penetrations of utility-scale and residential solar.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Project explores voltage regulation capabilities for the subtransmission system. Effective voltage regulation capabilities could increase the hosting capacity of subtransmission lines and enable greater PV additions at the distribution and subtransmission level.

*Reviewer 2:*

This project clearly addresses a gap in today's operational practice, i.e., how the transmission and distribution operation should be coordinated at high penetration of DERs.

*Reviewer 3:*

The project answers key questions around PV smart inverter and utility equipment interactions and implications in high penetration scenarios as are currently being experienced in the Duke distribution system. The approach will enable expansion of the integration capabilities, thereby reducing cost of interconnection and the overall cost of solar energy.

**Project Title:** CyDER: A Cyber Physical Co-Simulation Platform for Distributed Energy Resources in Smart Grids

**Award Number:** 31266

**Principal Investigator:** Joo, Jhi-Young, Lawrence Berkeley National Laboratory

**Project Description:**

This project focuses on developing a modular, scalable, and interoperable tool for power system planning and operation that will seamlessly integrate with utilities' existing tools to enable analysis of high penetration of distributed energy resources. The tool will enhance current utility tools by providing a computationally efficient platform that will be capable of quasi-static time series simulation and smart inverter controls with in-feed data from real-time distribution sensor measurements.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project seeks to develop a software platform to make visible behind-the-meter generation sources.

This is a relevant engineering endeavor.

*Reviewer 2:*

The project aims to enable improved analysis of simulations, visualizations, and controls but also seeks to achieve this utilizing a functional mockup interface which may enable integration of previously segmented aspects of grid analysis.

**Project Title:** Demonstration of Ancillary Services by Large PV Plant in California

**Award Number:** 31797

**Principal Investigator:** Gevorgian, Vahan, National Renewable Energy Laboratory

**Project Description:**

The main objectives of this project, in collaboration with CAISO and First Solar, are to develop a detailed test plan for a field project to demonstrate the ancillary service capabilities of the 300 MW Stateline PV power plant, conduct demonstration tests, and to analyze and disseminate project results among industry, policy and regulator stakeholder groups.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Relevant work that includes solutions to improve the performance, reliability, resilience, and security of electric grids, via the use of combined PV & BESS systems.

*Reviewer 2:*

This project can define the how-to road map of integration large PV with storage.

*Reviewer 3:*

The project has clearly thought through the evolution to a renewable and storage only grid and is seeking to not just evaluate technology performance for providing current ancillary service products but actually informing market products that will be needed in the future. The open dissemination of performance and controls approach for a wide range of grid services applications will help accelerate industry knowledge in this space and will better lend itself to electricity market evolution.



**Project Title:** North American Renewable Integration Study (Naris)

**Award Number:** 32402

**Principal Investigator:** Brinkman, Gregory, National Renewable Energy Laboratory

**Project Description:**

In this project, the U.S. Department of Energy Wind and Solar Energy Technologies Offices, Natural Resources Canada, and the Mexican Ministry of Energy are working together with researchers on a North American study of the issues and opportunities associated with the integration of large amounts of renewable energy into their respective electric power systems. The goal of the study is to help inform and assist power system planning entities, electricity system operators, government energy agencies, legislators, and regulators to better understand the implications of integrating large amounts of renewable resources into the Canadian, U.S., and Mexican electrical systems.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Tighter integration between the power systems in North America could have a big impact on increasing DER resources throughout. At the very least, this research will give operators and planners a better understanding of what impacts changes in the grid can and/or should have on their activities. Having only an international viewpoint from a power systems perspective is healthy and relevant in this changing environment.

*Reviewer 2:*

This large-scale analysis of North American power systems pertaining to both planning and operation is, in my view, most relevant and most needed.

*Reviewer 3:*

Not clear what benefits would be of a multinational review of the issues. Each country has a substantially different generation asset base which will likely lead to different implementations.

**Project Title:** Estimating the Impact of Solar Eclipse on Grid Operations

**Award Number:** 32918

**Principal Investigator:** Veda, Santosh, National Renewable Energy Laboratory

**Project Description:**

The National Renewable Energy Laboratory (NREL) partners with Peak Reliability to evaluate the impact of the August 21, 2017 total solar eclipse on the reliability and grid operations in the Western Electricity Coordinating Council (WECC) territory. Peak Reliability used inputs from the study to augment its own analysis for preparing transmission operating plans for the day of the eclipse. Peak Reliability also provided NREL with data from across its footprint to uncover important insights into the impact of the eclipse from the penetration of photovoltaics (PV) along its path.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

A brusque withdrawal of solar generation throughout an extended geographical area might have a serious impact on both the stability and the economic operation of an electric energy system. This project is thus relevant.

*Reviewer 2:*

This project defines a process by which future eclipses can be evaluated for their potential to disrupt grid operations. It is squarely in the reliability assurance aspects of SETO's goals.

*Reviewer 3:*

The project is only indirectly relevant to the SETO mission.

**Project Title:** Voltage Regulation and Protection Assurance Using Distributed Energy Resource Advanced Grid Functions

**Award Number:** 32931

**Principal Investigator:** Johnson, Jay, Sandia National Laboratories

**Project Description:**

This project creates an open-source advanced distribution management system that encompasses distribution circuits and distributed energy resource management, including state estimation, voltage regulation, protection coordination, economic optimization, interoperability, and cybersecurity. This system software provides real-time visibility into distribution circuits and optimizes the active and reactive settings to meet voltage regulation, protection, and economic objectives in the presence of forecast uncertainty. The open-source software is being incorporated into a commercial vendor's platform to validate the technology with extensive testing at 20 feeders located within two utilities.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Project is very ambitious with a very broad project scope, encompassing state estimation, forecasting, protection, DER dispatch, and cyber security. Concern is that with this breadth, the project, within budgets and schedules, may not be able to develop each element far enough to meet SETO goals.

*Reviewer 2:*

This project supports SETO's goals by offering a solid method for exploring protection and voltage support.

**Project Title:** Grid Optimization with Solar

**Award Number:** 32960

**Principal Investigator:** Zhang, Yingchen, National Renewable Energy Laboratory

**Project Description:**

This project develops a novel control scheme that provides system-wide monitoring and control using a small fraction of the active devices on the grid. The key innovation of this project's approach is to proactively manage very large distributed energy resource populations using only a few measurement points for input through predictive state estimation and a few carefully selected control nodes identified and dispatched through online multi-objective optimization. The platform gives utilities the capability to seamlessly dispatch legacy devices and distributed energy resources to achieve system-wide performance and reliability targets.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is highly relevant to the need for optimization of reactive dispatch on distribution systems. It, perhaps, should be coupled with another project on optimization of a combination of distribution and the sub-transmission network.

*Reviewer 2:*

Reliable operation of the legacy voltage control devices with large scale solar penetration is a key objective of the SETO program.

**Project Title:** Enhanced Control, Optimization, and Integration of Distributed Energy Applications

**Award Number:** 32962

**Principal Investigator:** Baggu, Murali, National Renewable Energy Laboratory

**Project Description:**

This project develops, validates, and deploys a unique and innovative data enhanced hierarchical control architecture that enables the efficient, reliable, resilient, and secure operation of future distribution systems with a high penetration of distributed energy resources like solar energy. This architecture enables a hybrid control approach where a centralized control layer will be complemented by distributed control algorithms for solar inverters and autonomous control of grid edge devices. The architecture aims to be fully interoperable and include all the cybersecurity aspects that are necessary for reliable and secure system operation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Project address issues related to penetration limits for DER. Further it aims to achieve this using a Data-Enhanced Hierarchical Control (DEHC) architecture compatible with realistic grid assets. If the results from this project are adopted, it could cost effectively enable significantly greater PV penetration.

*Reviewer 2:*

This project clearly solves the relevant problems for DERs integration and drives down the integration cost as well as enhancing the reliability of the grid.

*Reviewer 3:*

Proper coordinated DER control on feeder is the seminal task facing very high levels of PV penetration.

# Soft Costs

**Project Title:** Glare and Avian Hazard Analysis

**Award Number:** 01535

**Principal Investigator:** Ho, Cliff, Sandia National Laboratory

**Project Description:**

This project reduces soft costs associated with siting, permitting, environmental compliance, and operations and maintenance to address glare and flux-related avian hazards for concentrating solar power (CSP) plants. Enhancements, training, and technical assistance will be provided for the Solar Glare Hazard Analysis Tool (SGHAT), which determines when and where solar glare can occur throughout the year from a user-specified solar array as viewed from user-prescribed observation points. By addressing glare and avian issues, this project will allow for solar projects to be installed on or near airport property in compliance of federal regulations.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Size of problem and size of applicability more broadly very questionable.

*Reviewer 2:*

For CSP, where avian concerns have become significant and public, this project is fairly critical. If CSP plants pose a serious risk to birds in reality or public perception, then that represents another significant challenge for future CSP development.

For PV, the issue of glare is less critical but still quite important, particularly for projects sited around airports or other public facilities.

*Reviewer 3:*

Solar glare and avian-flux hazards are technical and political concerns, the cost of which is borne in permitting, siting, and compliance. The project is relevant in tackling these costs and expediting the development of large-scale solar.

**Project Title:** Solar in Your Community Challenge

**Award Number:** 06015

**Principal Investigator:** Fancher, Michael, State University of New York Polytechnic Institute

**Project Description:**

This prize challenge aims to expand solar electricity access to all Americans, especially underserved segments such as low- and moderate-income households; state, local, and tribal governments; and nonprofit organizations. In order to make solar more accessible and inclusive for every American, the challenge works to spur the development of new and innovative financial and business models that serve non-rooftop solar users, such as community solar. Offering \$5 million in cash prizes and technical assistance over 18 months, the challenge supports teams across the country to develop projects and programs that expand solar access to underserved groups, while proving that these business models can be widely replicated and adopted by similar groups. In addition to teams, the challenge supports technical assistance providers that assist teams by providing resources to develop their business models.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Driving down the cost involves making solar more affordable to all those who would want access and can participate.

*Reviewer 2:*

Hard to tell as it is early in the project with very many and diverse sub-projects.

*Reviewer 3:*

The stated objective of the project is to “expand solar electricity access to all Americans, especially underserved segments such as low- and moderate-income (LMI) households, state, local, and tribal governments, and nonprofit organizations” by creating new business models and approaches. Although more solar will possibly eventually drive down installation costs, it’s not a direct outcome of the project.



**Project Title:** Leveraging Industry Research to Educate a Future Electric Grid Workforce

**Award Number:** 06338

**Principal Investigator:** Reddoch, Thomas, Electric Power Research Institute

**Project Description:**

In 2013, the Electric Power Research Institute collaborated with four universities and 17 utilities and system operators to establish the GridEd Distributed Technology Training Consortium in the eastern United States. This consortium aims to effectively combine utility and industry research with educational expertise in power engineering. The project team is empowering new and continuing education students to become not only competent and well informed engineers, but also influence major technological, social, and policy decisions that address critical global energy challenges. This project received additional funding under the Solar Training and Education for Professionals program in 2016, which allowed it to establish a new consortia in the western United States. The Center for Grid Engineering Education in the West leverages the existing structure, knowledge, and successes from the GridEd-East team, and adds new three new utility partners in California, Arizona, and Oregon.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The more that utilities understand about distributed generation will improve relations with the solar industry and indirectly bring down soft costs. It is unclear how much training goes towards the permitting process for solar, but confidence in maintaining grid systems with PV will most likely positively affect policy improvements over time.

*Reviewer 2:*

This project is exactly the right kind of work for SETO and the DOE to support. This project has identified strong barriers to adoption (lack of local bandwidth and technical expertise) and is coordinating an effort to mitigate them.

**Project Title:** Foundations for Engineering Education for Distributed Energy Resources

**Award Number:** 06340

**Principal Investigator:** Qu, Zhihua, Univeristy University of Central Florida

**Project Description:**

This project consists of seven universities in the Southeast United States, eight utility companies, five supporting industry partners, two national labs, and a research center. This consortium is upgrading the existing power systems engineering workforce by improving programs at participating universities and developing a pipeline of new power systems engineers and engineering faculty. Through the efforts of this consortium, a new group of engineers will enter the workforce capable of re-engineering the existing electrical grid infrastructure to include a highly sophisticated communications platform. This project received additional funding to expand research, curriculum development, and education and training activities to five additional university partners in California, Hawaii, Pennsylvania, and Texas.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Preparing Utility grid engineers for our changing infrastructure is critical to the success of the solar industry. Bringing greater awareness of Solar and storage to these audiences will help with future adoption.

*Reviewer 2:*

This project acknowledges the need for professionally competent engineers within the established utilities so that PV can be deployed at an effective scale and cost. Good that there has been sustained support of this initiative. The course sharing across universities took multiple years to get approved through each university administration (which is to be expected in public institutions). Only a publicly funded initiative would work for this.

*Reviewer 3:*

STRENGTHS - The Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) initiative identified the aging utility workforce as an area of national need. This is also a target population of interest for the accelerated adoption of Solar PV and CSP. Educating a future workforce that is amenable to solar resources is important to the future of the industry.

AREAS FOR IMPROVEMENT - The FEEDER project's impact on driving down costs of PV are indirect at best. All of the GEARED projects involve training of engineers at four year universities, most of whom are in some type of electrical engineering program. The assumption is that a subsample of those students will pursue an emphasis in power engineering, and a subsample of those will go to work in the utility industry. Of those, a smaller subsample may find themselves in future positions working with distributed energy. And of that group, the hope is that based on their educational experience in the FEEDER project they will be able to execute reductions in the cost of solar energy. This project is thus a long-term investment in training the future workforce. By exposing them to solar and other distributed energy technology in their formative educational years, the idea is that they will be more inclined to entertain the incorporation of these technologies in their later careers, and that they might be better educated to implement them on the electrical grid.

**Project Title:** The Mid-America Regional Microgrid Education and Training Consortium

**Award Number:** 06341

**Principal Investigator:** Long, Suzanna, Missouri University of Science and Technology

**Project Description:**

This consortia is integrating cutting-edge research and advanced instructional methods to create a flexible, evolving approach to microgrid training for all levels of students. This effort aims to impact more than 500 technical employees by offering certificates, professional development hours, continuing education credits, and engineering degrees through a variety of workshops, short courses, and semester courses.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The focus on education for microgrids is absolutely relevant to future reliability and resilience of the US grid.

*Reviewer 2:*

Course development and industry engagement ranging from current engineers to graduating seniors has this focusing on the very core of what will help engage and direct future activities.

*Reviewer 3:*

This project was a part of the GEARED solicitation. It has a broader focus than solar and includes microgrid efforts. Training has been acknowledged as a key soft cost focus area for SETO.

**Project Title:** National Network Administrator of GEARED

**Award Number:** 06342

**Principal Investigator:** Sarubbi, Joseph, Interstate Renewable Energy Council

**Project Description:**

The Interstate Renewable Energy Council and the Smart Electric Power Alliance, operating as the national network administrator of Grid Engineering for Accelerated Renewable Energy Deployment (GEARED), facilitate efforts to build a national framework for power systems training and curriculum that will accelerate the growth of power systems programs and human capacity.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Training current and incoming utility sector personnel is critical in successfully expanding the potential for grid structure, security and resilience, all of which could add to the improvement in soft costs based on actionable changes.

*Reviewer 2:*

STRENGTHS - The Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) project served to create a National Network Administrator for the network of GEARED grantees. The GEARED initiative identified the aging utility workforce as an area of national need. This is also a target population of interest for the accelerated adoption of Solar PV and CSP. Educating a future workforce that are amenable to solar resources is important to the future of the industry.

AREAS FOR IMPROVEMENT - This project's impact on driving down costs of PV are indirect at best. The GEARED projects all involve training of engineers at four year universities, most of whom are in some type of electrical engineering program. The assumption is that a subsample of those students will pursue an emphasis in power engineering, and a subsample of those will go to work in the utility industry. Of those, a smaller subsample may find themselves in future positions working with distributed energy. And of that group, the hope is that based on their educational experience in the GEARED project they will be able to execute reductions in the cost of solar energy. This project is thus a long-term investment in training the future workforce. By exposing them to solar and other distributed energy technology in their formative educational years, the idea is that they will be more inclined to entertain the incorporation of these technologies in their later careers, and that they might be better educated to implement them on the electrical grid.

*Reviewer 3:*

Workforce training is a key part of reducing costs of distributed solar and they appear to have had a strong influence.

**Project Title:** A Solar Market Pathway for Independent Colleges in Virginia

**Award Number:** 06904

**Principal Investigator:** Lambeth, Robert, Council of Independent Colleges of Virginia

**Project Description:**

The Council of Independent Colleges is leading a program to boost Virginia's solar market by partnering with 15 of its member colleges and their hometown communities. This collaborative and replicable approach will guide campuses through the process of preparing for installation and purchasing solar panels, reducing operating costs and demonstrating associated economic benefits.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Seems to be very narrow in scope, and not novel in approach given co-operative purchasing model seems to be exactly this.

*Reviewer 2:*

The target audience of independent colleges in Virginia is fairly distinct, so lessons learned may not have wide applicability.

*Reviewer 3:*

OUTSTANDING - This project sought to create a solar market pathway for Virginia Private Colleges. Colleges and Universities are logical targets for solar development for several reasons: They typically have large electrical loads – some of which may be critical (e.g. hospitals), they have extensive built infrastructure that lasts for many decades, they have access to capital resources, and they have a campus constituency that is generally supportive of renewable energy. However, colleges and universities also have several challenges to solar adoption, most of which are related to soft costs: They are not able to take advantage of tax-based incentive policies, they have complex legal restrictions on use of funds, they have strict contracting and procurement rules, administrative staff generally lack expertise in solar energy technology, and the decision making and project execution processes are generally long and tedious. These latter factors make colleges and universities unattractive potential customers for many solar contractors – the customer acquisition costs are simply too large. This has held back what might otherwise be a promising market for solar technology. Thus, targeting colleges and universities for solar PV development is an area with good potential to make an impact on soft costs.

**Project Title:** Solar Plus Storage for Resiliency

**Award Number:** 06906

**Principal Investigator:** Denver, Jessica, City and County of San Francisco Department of the Environment

**Project Description:**

This project is expanding the solar market by serving as a national model for integrating solar and energy storage into existing disaster preparedness plans. The project team is working closely with stakeholders to overcome regulatory, financial, and technical barriers and create a roadmap for deploying solar with storage for resilience both locally and nationally.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

“Resiliency” is the number one reason why homeowners want storage. Homeowners are not only interested in power during emergencies, but also power when the local utility grid goes down. This 2-48 hour outages are increasingly common, and are more than annoying since homes are now completely dependent on electricity for heating, eating, bathing and communications.

*Reviewer 2:*

Hardening urban infrastructure with solar + battery storage solutions is a great step towards grid resilience.

**Project Title:** Solar Market Pathways National Coordinator

**Award Number:** 06907

**Principal Investigator:** Perry, Debra, Institute for Sustainable Communities

**Project Description:**

This project creates a learning network that enables communications, coordination, and shared learning across the 14 organizations in Solar Market Pathways. This includes providing targeted technical assistance to help awardees develop high-caliber, technically sound, broadly supported plans, models, and strategies. The team also identifies and disseminates best practices and lessons learned from program partners' experiences to advance solar deployment throughout the country.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is critical to SETO and very much supports SETO's goals to drive down soft costs. Many other projects I reviewed in the BOS portfolio were light on dissemination and knowledge-sharing, whereas that is the strength of this project. Good dissemination pathways and infrastructure can directly reduce soft costs, and this project has documented success in synthesizing and sharing best practices with other technical projects that can directly benefit from receiving such information.

*Reviewer 2:*

This project supports the Solar Market Pathways objective to reduce soft costs and accelerate solar deployment by creating a learning network to encourage communication, coordination and institutional capacity building across 14 different projects. It provided targeted assistance to help develop models and strategies to serve as guides for a broad range of parties and projects. It will document and disseminate best practices and lessons learned to help other projects across the U.S. in various communities. It will also include a strategy to make the project accomplishments self-sustaining.

*Reviewer 3:*

SMP projects have created strategies that will expand markets in areas previously lagging in solar market development.

**Project Title:** Community Solar Design Models for Consumer, Industry, and Utility Success

**Award Number:** 06909

**Principal Investigator:** Sterling, John, Smart Electric Power Alliance

**Project Description:**

This project is conducting comprehensive and collaborative research on the intersection of community solar business models and consumer demographics to develop more standardized program design options. By producing a range of more standardized, streamlined, and cost-effective business models that can be easily localized for different regions across the country, this project will spark the growth of community solar programs more closely aligned with the needs and interests of consumers and stakeholders.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project supports SETO's goals to drive down soft costs, especially in the focus on community solar and the ideal positioning of SEPA to reach a high number of utilities for dissemination of findings and best practices. The project has direct impacts on lowering soft costs because the outputs were created for the stakeholder audience that SEPA can easily access.

*Reviewer 2:*

This project has direct relevance to the Solar Market Pathways program goals to bring down solar soft costs and accelerate broad solar adoption because it is identifying models and best practices for design and marketing community solar programs, disseminating the data to a broad audience, and applying research findings to real world community solar development efforts that seven utilities and 2 nonprofits engaged in developing community solar projects. Community solar will play an increasingly large role in providing opportunities for residential customer investment in solar for individuals and households who are not able (or are not willing) to install solar on their own properties. Because community solar is a new effort, as the report states, communities face technical and informational hurdles in designing community based solar projects and are in the position of reinventing the wheel of community solar, creating significant soft costs that this project will help overcome. This project will help demystify the process of planning, developing and financing community solar projects, and bring the best models and practices to the public.

*Reviewer 3:*

The goals of this project are very relevant to the expansion of solar and the reduction of soft costs. The focus on community solar is timely and strategic, as states begin to expand community solar programs and regulations. A major problem within the community solar industry is the vast array of program design and regulations surrounding the programs, so a goal of standardizing and creating replicable models is very important.

*Reviewer 4:*

Community solar has the potential to be even more of a game changer than rooftop solar, because (1) it has better economies of scale than smaller residential rooftop PV; (2) has the potential when coupled with improved hosting and locational analyses to deliver better grid benefits than random placement of rooftop PV, which can improve resiliency and reliability; and (3) can be made accessible to a larger segment of the population (e.g., including renters and people with unsuitable roofs) and thereby support SETO goals for diversity. Yet, based on nationwide



research I've done and as shown in this project, the number of community solar gardens is puzzlingly low; and based on observation of my local market, there are less-than-obvious obstacles that are limiting expansion.

This project is therefore highly relevant to the program goal of increasing the reach of solar to more diverse groups. Further, work that facilitates more projects and can be used to create a "library" of successful models, should help reduce soft costs. So, in this context, any steps forward to accelerate the deployment of community solar helps achieve SETO goals, as explained above, and the project appears aligned with these goals.

However, this project's "value proposition" suggests it will help organizations understand the steps to developing a program. In actuality, it focuses primarily on marketing and the customer experience, which is only a part of the program. Thus, while it's a bit unclear as to what the project really promised to deliver, certainly it falls short of providing comprehensive program development. Since many of the soft costs lie in the other parts of program development -- the legal and financial structure, site developments, etc., which this project does not address -- it falls short of being "critical" to meeting SETO's goals although in alignment with them.

**Project Title:** NYSolar Smart Distributed Generation Hub

**Award Number:** 06913

**Principal Investigator:** Case, Tria, City University of New York

**Project Description:**

This project is creating a roadmap for the integration and tracking of resilient solar systems, which can supply emergency power and provide energy storage, as well as conducting analysis for deploying resilient solar energy systems on designated critical infrastructure facilities. Additionally, the project is developing a calculator that will help capture the full spectrum of value streams for solar systems with battery storage, such as supplying emergency power, peak shaving, and load shifting capabilities, consequently providing decision makers with the necessary tools to make educated investments.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It is absolutely critical to understand the degree to which solar + storage can be integrated, deployed and effectively used in an urban environment like NYC.

*Reviewer 2:*

While advancing the solar + storage market should certainly be a key SETO objective, helping NYC officials “get out of their own way” has a fairly narrow application outside of the city. NYC is an important market, without a doubt, but some of its issues are so idiosyncratic that it is hard to see the wider benefit to the industry.

*Reviewer 3:*

Good relevance for replicability across lots of other jurisdictions. Storage permitting guide important for resiliency.

**Project Title:** Solar Powering America by Recognizing Communities SolSmart Designation Program

**Award Number:** 07154

**Principal Investigator:** Fox, Andrea, International City/County Management Association

**Project Description:**

This project creates a national program to recognize local governments across the country for their efforts to build stronger local solar markets. With guidance from a panel of industry experts, the project team has crafted a fresh and accessible designation program signaling that participating communities are prepared to build local workforces and economies through solar market growth. To spur innovation and friendly competition among communities, the team provides annual awards for achievements in various categories. The awards and other competitions will celebrate communities and other stakeholders that break new ground and make remarkable progress.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project is relevant in targeting soft costs associated with permitting, inspection, and interconnection (PII). Assistance to AHJ is important and the designation can provide incentive for AHJs to tackle PII soft costs and raise awareness of the issues within their jurisdiction and in adjacent ones. The question is whether more can be done once an AHJ is engaged. For example, can AHJs assist in educating their constituents on solar and how to find the right solar installer, thereby reducing customer acquisition costs? How well do the designation actually translates to actual results?

*Reviewer 2:*

“Local governments (such as counties and municipalities) are uniquely positioned to both reduce red tape surrounding the use of solar energy and exert significant influence in overcoming informational and other market barriers” that contribute to soft costs. By providing embedded technical assistance, SolSmart can directly reduce soft costs arising from knowledge gaps.

*Reviewer 3:*

This project is directly relevant to SETO goals to lower costs by rewarding cities that do the most to take steps to reduce those costs. More information on evaluating impacts as well as outcomes would help to better determine and make the case for relevance.

**Project Title:** SPARC SolSmart Technical Assistance

**Award Number:** 07155

**Principal Investigator:** Haddix, Philip, The Solar Foundation

**Project Description:**

This project provides technical assistance support to communities pursuing SolSmart designation. The team will enable at least 300 communities across the U.S. to qualify for the SolSmart designation via a three-pronged approach to delivering technical assistance: one-on-one technical assistance delivery to communities from a team of experienced national experts; the use of SolSmart Corps Fellows to help select communities identify and reduce soft cost barriers; and peer mentorship and learning.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

SPARC objectives are directly aligned with bringing down soft costs in the US. Permit offices are actually rewarded for bringing their permit costs down.

*Reviewer 2:*

This project is directly related to education, policy, and outreach efforts that can result in lower soft costs due to improved processes. The project is large enough to have a meaningful impact on reducing soft-costs, and also covers a large geographical area. This is quite relevant to DOE's objectives.

*Reviewer 3:*

The SolSmart Technical Assistance is an excellent way to connect the high-performers and leaders in this space with the resources and assistance they will need to make a big impact. A similar approach is taken to solar and energy efficiency work at HUD, where technical assistance is given to entities that sign up to be energy efficiency leaders or commit to renewable energy projects. In this way, funds can be used most efficiently by ensuring they go to those who will be having the biggest impact and are most motivated to perform.

**Project Title:** Orange Button Phase 3: Standardizing Datasets

**Award Number:** 07314

**Principal Investigator:** Kaminsky, Jason, kWh Analytics

**Project Description:**

This project supports the adoption of industry-led data standards, including the development of a data format translation software tool that which will instantly translate original data formats into data standards, significantly reducing the effort and time required to adopt the data standards, leading to 60 percent adoption of data standards by the U.S. solar market within two years.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Development of software to standardize bidding et al activity for developers/other demand side participants is interesting and difficult. As with everything, software development advances. Today's standard is rapidly outdated.

*Reviewer 2:*

Data translation tool seems to be focused on helping a select set of existing companies with data get their data translated without getting them to adopt the standard. Why not get companies who would benefit from the standard to commit to developing Orange Button applications? Since they've scaled back scope of this translation tool to only one input format, the overall value is limited. The tool's base assumption is that key parties, the banks, will adopt Orange Button into their IT systems and require developers to submit in that format. If this holds true, then this is relevant.

*Reviewer 3:*

This is connected to the Orange Button project by SunSpec Alliance being separately funded through another grant. The work being performed here by KWH Analytics is important and relevant to the industry as without an industry partner to put the work into practice (Orange Button) the investment in creating a standard may never gain traction within the market. Market adoption is a key element of a program like this being impactful in driving down soft-costs.

**Project Title:** Orange Button Phase 1: Convening Stakeholders

**Award Number:** 07315

**Principal Investigator:** Smallwood, Aaron, Smart Electric Power Alliance  
(formerly Smart Grid Interoperability Panel)

**Project Description:**

This project convenes stakeholders and managing working groups to define the requirements of the project. It focuses on driving out inefficiencies in data exchanges that lead to reduced soft costs associated with solar projects. The work completed helps integrate data standards across the life cycle of a solar project.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project has done an excellent job of raising initial awareness on the orange button program. It is addressing an important goal to continue to lower the solar costs and improve data quality.

*Reviewer 2:*

The project is highly relevant to SETO goals to lower the soft costs of deploying solar and accelerating solar penetration in U.S. markets. The project will create and support adoption of an industry led standard for solar data that will improve real estate market and financial investor efficiencies by establishing common solar data standards, open market information and tools for accessing the data. The project convened a broad based working group to help develop the Orange Button data taxonomy and requirements by attributes demanded by the following markets: real estate, deployment, finance, grid integration, and solar operation and maintenance. The standardization of data around solar projects will have a profound effect on the finance and investment sector as solar projects can be more efficiency financed and bought and sold as renewable energy assets. Solar RECs can traded and sold, and whole projects purchased by third party investors more quickly and efficiently when the real value of solar assets can be translated accurately into long term power purchase agreements that are fair to both parties. The Orange Button initiative reduces the soft costs for the third party aggregators and investors (like CleanCapital) who in turn will be able to purchase solar assets at more favorable terms for original investors selling them and sell them to investors for more favorable terms for third party investors.

**Project Title:** Orange Button Phase 2: Establishing Data Standards

**Award Number:** 07316

**Principal Investigator:** Tansy, Thomas, Sunspec Alliance

**Project Description:**

This project is establishing an open, easy-to-adopt solar data architecture and standards —comprised of uniform data taxonomy, information models, data schemas, data exchange protocols, functional specifications for interoperability, compliance test suite and reference software—that will enable the free flow of data between existing software products that address critical aspects of the solar asset life cycle. This system will leverage the inherent capabilities of existing international data standards, extend them using uniform data taxonomy built with industry consensus, and combine them with common data exchange technologies, thus establishing a basic dictionary for interchange of interoperable datasets created throughout the solar project lifecycle.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project fully supports SETO's goals to lower soft costs. The materials and presentation were very clear in explaining how standardizing finance will reduce soft costs.

*Reviewer 2:*

High financing costs are based on slow processes and elevated risk. Clear, complete Information that can be machine processed is a key enabler. While the target market already has the resources and technical ability to effectively take on an effort to standardize data for the PV market, its likely that Orange Button can expedite cost reductions and increase speed of PV deployment, although its scope is potentially limited when focused on financing use cases, particularly ones for third party ownership.

*Reviewer 3:*

This project is a good example of the type of research that SETO should support as it creates forward progress for the entire solar industry however it is beyond the ability of one company within the industry to put into place. Further, without SETO support, the industry group may not be able to raise the funds needed to develop such a standard. Solar financing costs have been and continue to be a soft cost that can be reduced through better efficiency. This project creates efficiencies for solar to better access financial capital. These efficiencies coupled with a common or matching dataset to finance industry should create additional liquidity for solar assets and therefore lower perceived risk in turn lowering solar finance costs. Lower finance costs will lead to further expansion/ deployment of solar.

**Project Title:** Personnel Certifications for the Design, Installation, and Maintenance of Photovoltaic Systems

**Award Number:** 07318

**Principal Investigator:** O'Brien, Shawn, North America Board of Certified Energy Practitioners

**Project Description:**

This project is developing three new industry-validated personnel certifications for individuals working in photovoltaic operations and maintenance and in mid-scale system design and installation. These new certifications fill the need for third-party validation of the skills and competence required for the solar labor force, as represented in professional credentials in these sectors. North American Board of Certified Energy Practitioners (NABCEP) is also improving and updating its current Photovoltaic Installation Professional Certification program and examination. In addition, NABCEP aims to have certified at least 100 new solar professionals in these programs by completion of the award.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

NABCEP has been a leader in setting quality standards for PV installation. Now that there is a system design cert the industry should see larger standardization in the permitting process which will reduce soft costs.

*Reviewer 2:*

Training is critical - enough said.



**Project Title:** Solar Training Network

**Award Number:** 07319

**Principal Investigator:** Gilliland, Ed, The Solar Foundation

**Project Description:**

This project connects solar workforce trainers, solar employers, and individuals interested in working in the solar industry. By developing and expanding training and workforce capacity building nationwide, it builds on the success of the earlier Solar Instructor Training Network.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Building a better workforce will help improve the overall quality of installations in the US.

*Reviewer 2:*

Relevance of subject matter is there, but the execution is concerning.

*Reviewer 3:*

The Solar Foundation (TSF) project gets to the heart of solar soft costs – labor and productivity. This is one of the few projects in the DOE solar portfolio that is targeted directly at the point of installation of solar PV in the field. It goes without saying that if workers are more productive, and if they make fewer mistakes, soft costs can be dramatically reduced. A few individual large national employers have figured this out, and gained significant market advantages by scooping up well qualified employees. This has left many others – especially smaller employers -struggling to find workers. This project both documents the shortages in the solar workforce, and seeks to address them by creating online tools and in-person events to connect prospective employees, training organizations, and prospective employers.

**Project Title:** Training for State Officials to Make Solar More Inclusive, Affordable, and Consumer Friendly

**Award Number:** 07321

**Principal Investigator:** Leon, Warren, Clean Energy States Alliance

**Project Description:**

This project develops resources and training for public officials, mostly at the state level, on how to deal with two issues that have important implications for the future cost and continued public acceptance of solar energy. The first issue is ensuring inclusive participation in the solar economy, especially for those with low and moderate incomes and those without solar-friendly roofs. The second issue is helping consumers find and use reputable, competent vendors and contractors.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project provides a high level of relevance to SETO's goals. The project is providing training to state officials to open new solar markets (low-income). Solar access is of key interest for SETO. Access to untapped markets is important to drive down residential solar costs. The project directly engages important decision makers to educate and inform them in opening new markets.

*Reviewer 2:*

Training and educating state officials is a very important goal that can help increase uptake of solar and impacting soft costs such as permits and inspections. The state officials will benefit significantly from this support and learning about best practices and experiences from their peers.

*Reviewer 3:*

Solar equitability is a major concern in states pursuing solar policies, and barriers to low-income deployment can be a hurdle or stumbling block to instituting large scale solar in a city or state. For that reason, it's relevant to DOE and SETO's mission to focus on this area. Likewise, solar for low and moderate income families and communities is an area which may face market barriers, so to the extent that DOE wants to ensure broad access; this is an area where government should play a role.

**Project Title:** Training Real Estate Professionals to Find the Value of Solar

**Award Number:** 07322

**Principal Investigator:** Brookstein, Pamela, Elevate Energy

**Project Description:**

Elevate Energy educates residential real estate agents, appraisers, and appraiser regulatory officials about solar energy systems through web-based, continuing education classes. The lack of current solar information for these professionals is slowing demand for residential solar by decreasing its contribution to resale value and often presenting challenges to home sellers with solar installations. The project also works to add an expanded solar component to the Multiple Listing Service, or MLS, a suite of services used by real estate professionals to establish contractual offers on properties, facilitate cooperation with other brokers, and distribute listing information.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Although it is necessary to have Realtors trained to understand and “sell” solar, there is no direct correlation as to the reduction of soft costs since their commission will not be affected by this learning. It needs to be required by the National Association of Realtors and not seen as an elective. Starting in the states with the most solar penetration would make sense, as there would be a legitimate reason for them to want to understand.

*Reviewer 2:*

Over the long term, appropriately valuing residential solar will shift market dynamics and encourage adoption by normalizing solar as part of the real estate ecosystem, rather than treating it as an “exotic add-on” that isn't part of the mainstream. Having said that, over a shorter time horizon, this type of project does not advance SETO's goals of reducing soft costs to a significant degree.

**Project Title:** Integration of Solar Training into Allied Industry Professional Development Platforms

**Award Number:** 07323

**Principal Investigator:** Davignon, Laure-Jeanne, Interstate Renewable Energy Council

**Project Description:**

This project creates an engagement strategy to facilitate the integration of state-of-the art solar training into existing professional development platforms for firefighters and fire code officials. This includes using integrated technology solutions, such as online 3D interactive simulations and mobile tools and resources. Through this training and professional development platform, this project hopes to train more than 10,000 firefighters and fire code officials who will be able to communicate the information to another 90,000 people.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Working with Firefighters and code officials reduces many of the obstacles that inflate soft costs. More firefighters and code officials being confident around PV systems will improve the future reliability of our grid.

*Reviewer 2:*

Having first responders and code officials up to speed on the relevant aspects of solar systems is critical for the health and safety of personnel as well as the proper functioning of the systems.

*Reviewer 3:*

AIPDP is highly relevant in reducing soft costs and meeting SETO goals. Training for key professionals is important to reducing non-solar related barriers, such as permitting etc. The project has trained over 8000 individuals to educate them and improve on-the-job performance. The project has engaged clients across the country and across key professions.

**Project Title:** Solar Training for Design Professionals

**Award Number:** 07324

**Principal Investigator:** Guttman, Maureen, Trust for Conservation Innovation

**Project Description:**

This project supports the development and dissemination of solar reference materials and training for building design professionals. The project targets multiple interrelated audiences in the building design field, leveraging the similarity of educational materials needed, while establishing consistency in and amplifying understanding.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Full adoption for the new homes sector will help to expand the industry which will bring down costs for retrofit as well.

*Reviewer 2:*

The idea of training the trainers to spread the adoption of solar is an interesting one. Solar does face barriers to adoption which ultimately increase the costs. It's difficult to understand the KPIs that are being tested pre and post training to understand how this program is increasing solar knowledge.

*Reviewer 3:*

STRENGTHS - Customer acquisition is a large soft cost for solar PV. By educating architects and other design professionals to include PV in their buildings from the point of inception, this project has the potential to dramatically reduce the cost of customer acquisition. The project targets these key gatekeepers in the sequence of PV deployment. Early results from the project appear to indicate that as a result of the training, design professionals are more likely to incorporate solar PV in their buildings. If this result can be translated to a larger group of designers nationwide, it could have very significant impact.

**Project Title:** Multimedia Solar Knowledge Library

**Award Number:** 07325

**Principal Investigator:** Ronen, Amit, George Washington University

**Project Description:**

The GW Solar Institute at the George Washington University is developing multimedia solar energy training materials that can be used to train a spectrum of diverse audiences. The resulting solar knowledge library serves as an invaluable resource for other program awardees who are directly engaging and training communities as diverse as real estate agents, financiers, and state regulators and policymakers.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This seems like a good unifying platform for other STEP programs.

*Reviewer 2:*

Educational content is all well and good, but this project seems completely disconnected from market needs and lacks an approach to dissemination that could actually help drive down soft costs through adoption of these materials by real market participants.

*Reviewer 3:*

**STRENGTHS** - The project created a collection of short videos intended to educate various groups of stakeholders that contribute to soft costs in solar PV. The intended target audiences: Code Officials, Architects, Realtors, Solar Installers, and Homeowners all have well documented and understood contributions to the high soft costs for solar in the U.S.

**WEAKNESSES** - This project's impact on driving down costs of PV are indirect at best. The project created 11 videos totaling under an hour of footage. These will only impact soft costs if they are accessed by the intended target audiences.

There does not seem to be any sort of dissemination plan in the project. A website has been created at GWU to support the "solar library" with the hope that others will access it. The term "library" is a bit generous for what is really just a collection of the 11 videos combined with other URL links to other resources (most of which are to other STEP awardee projects, National Lab Publications, or other DOE funded initiatives).

**Project Title:** Using Behavioral Science to Target Low- and Moderate-Income and High-Value Solar Installations

**Award Number:** 07657

**Principal Investigator:** Gillingham, Kenneth, Yale University

**Project Description:**

This project is testing new messaging, financing, and shared solar approaches for enhancing the diffusion of solar energy in low-and moderate-income populations. The project also quantifies the benefits to the electricity grid from programs that expedite and increase deployment of solar energy in areas where solar provides additional value to the grid. In addition, pilot projects within three states test the models developed under this work in the field with the intent to use lessons learned from messaging studies to encourage more populations to go solar, particularly in areas of high grid congestion.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project somewhat supports SETO's goals to drive down costs, but the design of the field experiments makes it difficult to pinpoint the exact contributors to reducing soft costs. The Solarize CT campaign has yielded a reduction of costs, but as the PI pointed out in his presentation, not all the results are attributable to the field experiment programs. In that case, then, the project has been able to document reduced soft costs but it hasn't been able to experimentally isolate how different aspects they are testing lead to a reduction in soft costs.

*Reviewer 2:*

The subject of this project is very relevant to the growth of solar energy in the LMI segments of society. Understanding behavioral factors that can affect decision-making process, especially in a difficult financial situation, will help find solutions, and ultimately help grow solar in that segment. Typically solar companies try to sell technology or long-term savings, but for LMI segment the motivators are quite different. Therefore, this study is quite relevant.

*Reviewer 3:*

Understanding how to best motivate and connect with Low and Moderate-Income potential customers is an important goal, and one that is not well understood nor researched by market-based solar installations, so this is an appropriate role for government to play. However, it's not entirely clear how this research contributes directly to SETO goals of lowering costs and increasing resilience and reliability.

**Project Title:** Knowledge Spillovers and Cost Reductions in Solar Soft Costs

**Award Number:** 07658

**Principal Investigator:** Rai, Varun, University of Austin Texas

**Project Description:**

This project studies the size and mechanism of knowledge spillovers in the solar industry, specifically how best practices related to solar soft cost issues are transferred. These best practices include installation processes, permitting processes, customer acquisition, and overhead costs. The project examines the importance of knowledge spillovers, the types of knowledge most likely to spill over, and how policies can be designed to address them.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reducing soft costs is the best way to reduce solar + storage deployment costs. Extremely relevant.

*Reviewer 2:*

There is a gap in knowledge dissemination across the industry and the ability to accelerate the sharing of information on best practices can help to lower soft costs. This research seeks to identify which areas are most likely to have knowledge spillovers. With this information programs can be developed to encourage effective knowledge sharing although it is not clear if this project will attempt to provide programmatic deliverables vs. just fundamental research.

*Reviewer 3:*

This study focuses on knowledge acquisition, production, and mechanisms of transfer in the solar industry, and how those relate directly to soft costs. This has gone largely unexplored in the case of solar soft costs.



**Project Title:** Data-Driven Understanding of Low- to Moderate-Income Customers' Adoption and Financial Qualification in Community Solar

**Award Number:** 07659

**Principal Investigator:** Speirs, Stephanie, Solstice Initiative

**Project Description:**

This project gathers customer data to assess the assumption that metrics other than a traditional FICO score can and should be used to qualify customers for community solar. Using customer data on income and FICO score, as well as utility, rent, and cell phone repayment history, the project tests whether new qualifying metrics open up the community solar market to additional households. This new model is then tested by enrolling customers in community solar and comparing actual payment. This project identifies and tests better ways to finance and perform due diligence on solar purchases for nontraditional adopters.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

If this project could expand the pool of candidates eligible for these solar financing products, the project would be highly relevant. However, it's not clear to me that this formula creation will expand the pool to any great degree, just that they hope it will be slightly more accurate in terms of predicting default rates. It's also not clear why private industry wouldn't be interested in and capable of developing such a score themselves, if it would increase confidence and reduce non-payment.

*Reviewer 2:*

Yes, creating new financial tools for community solar will drive down project costs – costs of capital, and cost of time.

**Project Title:** Coupled Social and Infrastructure Approaches for Enhancing Solar Energy Adoption

**Award Number:** 07660

**Principal Investigator:** Marathe, Achla, Virginia Polytechnic Institute and State University

**Project Description:**

This project identifies social and behavioral factors that influence the adoption of solar in rural areas and incorporates that information into diffusion models using agent-based modeling technology and synthetic information systems. These diffusion models will integrate social, behavioral, financial, and demographic data. The project's primary data collection area is in the state of Virginia, but the results are anticipated to inform rural communities throughout the country.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Moderate alignment of driving down costs. Very specific attempt to drive down cost of customer acquisition, so questions around broader applicability.

*Reviewer 2:*

This project is critical to SETO and fully supports the goal to drive down soft costs. The idea of creating a method for calculating solar adoption propensity scores, and especially for rural communities, is innovative and valuable. The propensity score as a main project output has the ability to lead to tangible impacts. This is not just academic research stuck in unusable white paper format.

*Reviewer 3:*

This study of dispersion and adoption for large constituencies is extremely promising.

**Project Title:** Machine Learning for Solar Technology Portfolio Management

**Award Number:** 07661

**Principal Investigator:** Freyman, Christina, SRI International

**Project Description:**

This project creates a data-driven tool that describes the development of different solar technologies through the use of machine learning and text analytics. The tool identifies the types of variables, and the influencers that impact them, that enable a solar energy technology to transition across readiness levels using unique solar energy data sources. In doing so, the model helps explain prior technology transitions, as well as predict the likelihood of a technology's advancement to future readiness levels.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

No direct impact could be shown for SETO's goals. Development of machine learning algorithm for technology readiness level labeling and forecasting does not clearly translate into SETO goals or lowering the cost of solar.

*Reviewer 2:*

This project aims to create a tool to better predict the TRL level of a project which might be part of a portfolio (such as DOE's SETO portfolio) through machine learning, in order to better manage the portfolio and more strategically select future investments.

The project does not seem to have any immediate impact on SETO's goals of lowering the LCOE for solar PV and CSP, or grid resilience or reliability.

*Reviewer 3:*

I see no obvious reason SETO should fund this project.

**Project Title:** Modeling Photovoltaics Innovation and Deployment Dynamics

**Award Number:** 07662

**Principal Investigator:** Trancik, Jessika, Massachusetts Institute of Technology

**Project Description:**

This project evaluates the mechanisms driving photovoltaic system cost reductions, delving deeply into specific past technological innovations and policies, and prospectively assessing solar's potential for future cost reduction. New datasets and advanced modeling frameworks are being developed, which will provide a complete picture of how specific technology and policy developments led to the dramatic cost reduction in photovoltaics in recent decades. In addition, this project provides insights for policymakers, engineers, and other stakeholders to inform their research and development investments and policy designs in the future.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Useful to understand more specifically how hardware technology continues to help reduce soft costs.

*Reviewer 2:*

This research falls under SETO's subprogram on foundational research under soft costs. While this research is relevant to soft costs it may be more relevant to general Photovoltaic and Technology to Market categories of research supported by SETO. It can be a useful tool in providing foundation and insight into technology funding under SETO's Photovoltaic funding grants.

*Reviewer 3:*

This project deploys newer mathematical methods to quantify how much of a technology's cost reduction arises from different improvement mechanisms. This methodology is a fundamental improvement over previous methods. Because of the foundational nature of the research, government support is important. Because of the focus on solar PV, and identifying cost contributions, it is relevant to SETO goals.

**Project Title:** Understanding Adoption of a Key Soft Cost Reduction Strategy: Modeling Administrative Choices Regarding Streamlined Solar Permitting

**Award Number:** 07663

**Principal Investigator:** Taylor, Margaret, Center for Sustainable Energy

**Project Description:**

This project analyzes streamlined solar permitting and the associated bundle of standardized ordinances, documents, and practices. The team studies different authorities having jurisdiction throughout California that have adopted streamlined solar permitting at different times in the recent past, as well as those that have not. By analyzing this diversity of jurisdictions, the team is able to scientifically design streamlined solar permitting packages that are ideally suited for other jurisdictions around the country, and will design such packages in at least two other states.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Very nuanced and specific project on soft costs. Questionable on the magnitude of impact. Indirect impacts at best.

*Reviewer 2:*

Attacking high permitting costs is an extremely effective way of reducing installation soft costs.

*Reviewer 3:*

This is a very relevant, yet complex issue that needs further analysis and solution. Permitting process of solar projects varies and can be uncertain and costly. Coming up with a scalable solution to this vexing issue will go a long way into reducing soft costs associated with solar projects.

**Project Title:** Advancing Solar Innovation for Low and Moderate Income Households: Analysis of the Arizona Experience

**Award Number:** 07664

**Principal Investigator:** Hettel, Jacqueline, Arizona State University

**Project Description:**

This project identifies key socioeconomic factors and social values that enable and constrain solar adoption in low- and moderate-income communities in Arizona. The team is developing an accessible and easy-to-understand database of social drivers for solar adoption and non-adoption. By closely studying the areas that represent a large portion of the state's population, this project provides insights regarding adoption patterns that will not be observed in larger-scale national studies. In addition to assessing Arizona, the project will begin to compile driving factors for adoption in select communities within Arkansas, Georgia, and Mississippi.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project is addressing important goals of SETO to both lower costs and bring the benefits of solar to LMI populations.

*Reviewer 2:*

A lot of attention is directed on the LMI segment. It would be very helpful if this study could illuminate the reasons why this market segment is not meeting its presumed potential.

*Reviewer 3:*

This project falls under SETO's objective to support solar deployment in Low and Moderate income communities. The information gathered in this study can help inform future programs and projects to increase solar adoption rates in low and moderate income communities. It further works to dispel myths held by decision-makers about the interest in solar in these communities. It also serves as an educational opportunity as participants learn about solar.

**Project Title:** Solar Plus Strategies for Oregon and Washington

**Award Number:** 07665

**Principal Investigator:** Valdez, Jaimes, Washington Department of Commerce

**Project Description:**

This project manages a regional effort to plan and implement state strategies in Oregon and Washington to achieve the full technical, social, and economic benefits of solar. With state-level plans that leverage the added social and economic benefits of solar, the project is working to accelerate market growth in the Pacific Northwest and triple solar capacity over three years, reduce installed costs for rooftop solar by almost half, and add 5,000 solar jobs, which would double the solar-related employment in the region. This will be done, in large part, through community solar projects.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project is working with the important goal of establishing stakeholder buy in to develop the right policy frameworks to support solar deployment in Oregon and Washington.

*Reviewer 2:*

The project is highly relevant in that it creates regional alignment around principles for solar adoption. The program expands state scale focused approaches to create economies of scale. Creating methodologies for solar value and associated goals creates market certainty for deployment and is likely to reduce soft-costs. The project identifies a quantifiable per watt goals and other associated benefits. Reduction in costs is a key SETO goals. The project is directly aligned.

*Reviewer 3:*

The project goals range beyond far beyond driving down costs or increasing reliability, resiliency etc. (that is, they relate to equitable distribution, fair compensation, and job creation) but the goals are all related to expansion of the market which will help drive down costs. However, some of the goals will also place upward pressure on costs, although for excellent reasons (e.g., serving lower income neighborhoods, providing compensation that reflects environmental value).

**Project Title:** Finding Pennsylvania's Solar Future

**Award Number:** 07666

**Principal Investigator:** Althoff, David, Pennsylvania Department of Environmental Protection

**Project Description:**

This project uses detailed scenario modeling to analyze current solar development and legislation and determine how they will be applied in 2030 under a scenario where up to 10 percent of electricity sales are from solar generation. The project will inform strategies that help meet state energy goals, develop environmental compliance plans, and increase grid resiliency. This work will result in a well-informed solar deployment plan that will be available to policymakers, regulators, industry, investors, and consumers. This project is expected to help lower the costs, increase the speed, and lower the barriers to solar market expansion in Pennsylvania.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Given that Pennsylvania is a state with low solar penetration and with constituents that may be strongly against solar (given the prevalence of coal), developing pathways for both utility-scale and distributed solar can significantly drive down cost for solar and expand access. Learnings from stakeholder may potentially be transferrable to other similar states or use-cases, though the mechanism for such transfer hasn't been well-articulated.

*Reviewer 2:*

Basically the proposal hopes to set in motion a set of State of PA actions to meet 10% of PA energy needs by solar – which could lower costs to consumers if markets are aggregated.



**Project Title:** State Strategies to Bring Solar to Low- and Moderate-Income Communities

**Award Number:** 07667

**Principal Investigator:** Chase, Diana, Clean Energy States Alliance

**Project Description:**

This project works with the state governments of Connecticut, Minnesota, New Mexico, Oregon, Rhode Island, and the District of Columbia to provide technical assistance necessary to develop and implement strategies for expanding the amount of solar available to low- and moderate-income residents and communities. Each participating state is developing goals and a plan of action that matches its programmatic needs, demographic profile, solar potential, and financial resources.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project works with states to build plans to deliver solar to low-income customers. The project is relevant to SETO goals in that it works to open new solar markets and creates pathways for delivery. The project provides resources for states to create their own plans for delivery. States create their own goals and strategies. The project tie to these state efforts is unclear beyond facilitating group discussion.

*Reviewer 2:*

The project is relevant to SETO objectives and is just finishing its first year. The report states that the strategies will emerge in the coming year. The reviewer believes that it will be a better stage to review this project once those strategies become available.

*Reviewer 3:*

This project could significantly assist states with their efforts to reach low and moderate income consumers and communities, something that falls squarely within the realm of government, and could expand the solar market and lower costs.

**Project Title:** Florida Alliance for Accelerating Solar and Storage Technology Readiness

**Award Number:** 07668

**Principal Investigator:** Meeker, Rick, Nhu Energy

**Project Description:**

This project conducts analysis and planning activities in Florida to increase solar deployment and maximize the benefits of solar, including combining solar with other distributed energy resources like energy storage and demand response. This project will lay the foundation to enable Florida municipal and cooperative utilities to reach 10 percent of solar in their electricity capacity in less than 10 years.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project aligns with SETO goals in that upon implementation, the project will significantly drive down costs. It also may possibly result in added valuation of solar resources in FL and increase installed solar capacity in the state. The project has added potential to add to grid resilience and reliability in that it explores grid value for solar.

*Reviewer 2:*

The project focuses on scaling solar and solar+storage for Florida municipal and cooperative utilities which will cause replicability, lower times and costs for solar deployment to 10% in these sectors.

**Project Title:** Minnesota Solar Pathways: Illuminating Pathways to 10 Percent Solar

**Award Number:** 07669

**Principal Investigator:** Miller, Stacy, Minnesota Department of Commerce

**Project Description:**

This project uses a scenario-based tool to examine the potential for key technologies and management approaches—such as demand management strategies, storage, and synergy with wind—to overcome grid integration challenges with increased solar penetration. This project identifies barriers to deployment while laying a technical foundation to understand how much solar capacity potential exists across Minnesota. In addition, it tackles grid management approaches to overcoming solar integration challenges.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is focused on a staged strategy that incorporates real-world technical, economic, and political considerations to reduce barriers to solar adoption and guide market actors towards successful deployment.

*Reviewer 2:*

The project aims to identify pathways to reach 10% solar penetration, overcoming local barriers in the process. Every state is different and so taking this local approach is appropriate.

*Reviewer 3:*

By engaging a wider set of stakeholders than has been traditionally engaged with solar deployment, and providing data-driven pathways for a variety of sectors, this project should serve to drive down soft costs.

**Project Title:** Community Solar for the Southeast

**Award Number:** 07670

**Principal Investigator:** Shrestha, Achyut, North Carolina Clean Energy Technology Center

**Project Description:**

This project makes solar more affordable and accessible through shared solar projects developed by cooperative and municipal utilities across the Southeast. The North Carolina Clean Energy Technology Center leads a stakeholder process with rural cooperative and municipal electric utilities, which can influence many states within the Southeast region. The project is expected to result in a dramatic increase of shared and community solar projects in the region.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Community solar is oftentimes not understood or is blocked by utilities. This can be not only a boost for areas that are new to solar but an effective way to deal with LMI households who want access to solar but cannot afford the up-front costs or their structure cannot support roof panels.

*Reviewer 2:*

Community Solar is a key way to bring down costs and increase adoption of solar. It is also hard to convince conventional utilities to accept and to compete against low prices and non-solar friendly constituencies.

**Project Title:** Montana Community-Scale Solar Strategy Project

**Award Number:** 07672

**Principal Investigator:** Martin, Garrett, Montana State Energy Office

**Project Description:**

This project is developing a cost-effective, community solar energy strategy for Montana that will expand access to solar energy. The project aims to develop model community solar projects that will be promoted across the state to meet the needs of interested consumers and communities, as well as electric utilities or cooperatives.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Questions about broader applicability, and actual cost reductions other than those that might be achieved by increased supply under normal market conditions.

*Reviewer 2:*

The project works to lay the groundwork for solar development in a nascent market. The project is on the right path for initially catalyzing the market. The project is aligned with SETO goals in that it is working to develop installed capacity in a new market. The project is in too early of a stage to be focused on cost. Instead the project appears to be focused on baseline.

*Reviewer 3:*

This is a good project with a clearly defined scope and geographical focus area. It also leverages the unique set of conditions for the State of Montana. Quite relevant to the SETO objectives, and may help reduce soft costs in the process as residents and state administrators better understand solar, as well as the solar market attains scale through community solar.

**Project Title:** Enhanced Distributed Solar Photovoltaic Deployment via Barrier Mitigation or Removal in the Western Interconnection

**Award Number:** 07673

**Principal Investigator:** Galbraith, Maury, Western Interstate Energy Board

**Project Description:**

This project with the Western Interstate Energy Board, an organization of 11 western states that provides the instruments and framework for cooperative state efforts on energy, focuses on analysis to mitigate or remove the impact of interconnection, reliability and rate design barriers to distributed solar photovoltaic deployment in the Western Interconnection. If successful, the project will result in greater deployment of distributed solar in the Western Interconnection than is currently predicted.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Without knowing about whether other prior art in this space exists, I agree that understanding and documenting the causes and frequency of interconnection issues is quite relevant to SETO's goals.

*Reviewer 2:*

The project is highly relevant to SETO established goals and objectives. The project targets directly, through quantitative and qualitative metrics, the growth of distributed PV in the Western Interconnect. The project focuses on reducing barriers to interconnection at a regional level. The work is novel and timely.

**Project Title:** Towards a Low-Cost Solar Future: Tracking and Analyzing Solar Cost, Price, and Market Trends

**Award Number:** 30123

**Principal Investigator:** Wisner, Ryan, Lawrence Berkeley National Laboratory

**Project Description:**

This project consolidates efforts to measure solar cost reduction, identify pathways for further cost reductions, and speed solar deployment. The team is building large and varied datasets to track and analyze trends in the cost, performance, and pricing of solar systems through the Tracking the Sun and Utility-Scale Solar reports. This will provide foundational analysis to help address the remaining non-hardware cost and deployment barriers.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This is a foundational project for the Solar Program as a whole and Soft Cost work in particular as it tracks the status of installed solar costs nationwide. Good data on this topic is critical.

*Reviewer 2:*

The compilation of unbiased data is non-trivial and requires vigilance. The project has well-explained its focus on the demand side of the market that is on the installation side of the equation including PPAs for utility scale and large commercial. However, assuming that a low priced PPA or trend to lower PPAs and low installation costs are reflective of a healthy value chain, and that does not consider margins for manufacturers and installers/ Developer/EPC in the equation insinuates bias in the work. That is, a low installation price is a market function not necessarily reflective of margins through the value chain and thus not necessarily progress. As a PPA is required for financing and other contracts Developers have no negotiating power and a low PPA and downward PPA price trends, again, a market function, are also not reflective of progress.

Isolating data that would seem to prove that prices/costs on the installation side are decreasing and are therefore reflective of progress may tend to blind the researchers to the realities behind the data that is, a hiccup in the value chain (tariffs on modules) might serve to reveal the bias.

*Reviewer 3:*

The project provides highly relevant information to track progress towards SETO's goal. The analysis informs public and private sector activities in addressing deficiencies in cost reductions and solar access. The inclusion of demographic data into the analysis is a welcomed addition.

*Reviewer 4:*

Accurate and unbiased data is critical to measuring progress, not just of the SETO program, but of what is becoming a significant and rapidly growing part of the economy. The data collection aspect of this project, in particular, is a core governmental function. The topical reports are useful and provide an opportunity for the people closest to the data to flag emerging trends.

Of concern is the 2018 end date for this project. Continuation of the Tracking the Sun and Utility Scale Solar portions of this project are essential, as continuity and consistency must be maintained. Further, with the growth of the solar sector, more nuanced issues are emerging, such as the accessibility of solar to low/middle income people, job growth, the importance of specific incentives, etc. Having detailed data is essential to being able to

accurately identify issues, pinpoint changes that might suggest successful mitigation strategies, etc. In the absence of governmental funding, it is unlikely that such a comprehensive dataset would be maintained and made publicly available.

The topical reports, and particularly the integration of student capstone projects are very valuable, but upon expiration of the project, conceivably others in academia and industry will continue to report out on areas of interest. However, as noted above, the people closest to the data are uniquely qualified to identify emerging trends that others might not think to explore. Thus, the topical reporting is also highly valued, but perhaps just not as mission-critical as building the basic data sets and making them publicly available.



**Project Title:** Aligning Utility and Solar Interests: Utility Regulation and Planning for a SunShot Future

**Award Number:** 30348

**Principal Investigator:** Barbose, Galen, Lawrence Berkeley National Laboratory

**Project Description:**

This project assesses emerging and innovative options for aligning high solar deployment with utility shareholder and ratepayer interests. The team is evaluating the potential for bankable demand charge savings and identifying best practices for incorporating solar into resource planning studies. Through this combination of targeted analyses and stakeholder engagement, the project empowers key decision-makers to alleviate market barriers in order to increase deployment and lower business risks and market inefficiencies that inflate soft costs.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The objective of this project is to reduce or remedy “misalignments between solar energy and current utility business models and regulatory structures.” This is a complex topic and providing 10 different scenario analyses that can be used to inform the solar industry, policy makers, and utilities by a neutral third party is a start to helping drive down soft costs. Several examples of soft cost reduction exist from a more efficient relationship between utilities and solar industry businesses. One example is interconnection, where within the solar industry, one can find several examples of some utilities delaying or fighting interconnection of solar where the utility has a business incentive to slow solar coming onto the grid (revenue depletion). By shedding light on where solar can support the grid and the utility, the utility and solar businesses can work with public utility commissions to promote mutually beneficial policies, rules, and rate design. In addition to driving down soft costs, this research has the ability to help drive down long-term electricity rates for ratepayers through better alignment and use of a generation asset (solar).

*Reviewer 2:*

This project includes a number of discrete parts, making it difficult to generalize. Some of the projects clearly and directly support the SETO goals. For example, collecting and publishing information on improved planning tools that incorporate solar are clearly supportive. Integrating solar into utility planning is essential for expanding the market (which helps drive down costs) as well as reliability and resilience. The studies of the impact of solar on the utility business model are also helpful in guiding policy discussions.

The studies analyzing the impact of solar on demand charges seem less directed toward the SETO goals because it's not apparent how these studies can be applied in practice. From a policy-making perspective the key issues revolve around structuring rates to either encourage load to better match resources or assure utilities recover their costs. From a user perspective, the issue is how much savings can be expected. But in both cases, these issues are specific to a geographic area and the associated rate structure. A general analysis does not inform either a utility, a PUC or a customer about what is appropriate for a specific system or location. There is some “headline” value in being able to show, for example, that across a wide data set, a small PV set can be as effective as a larger one in reducing demand charges for a grocery store (when it moves the peak to a later period), but this type of finding is highly academic. It has no direct impact on driving down cost, at most a tangential impact on increasing adoption (because while it might encourage exploration, it does not answer any specific need), and doesn't support reliability or resilience.

**Project Title:** Solar Photovoltaics and Real Estate: Harnessing Big Data to Drive Demand, Increase Transparency, and Lower Balance of System Costs

**Award Number:** 30349

**Principal Investigator:** Hoen, Ben, Lawrence Berkeley National Laborator

**Project Description:**

This project analyzes the extent to which photovoltaics can add value to real estate properties. Past analyses have shown that solar adds value to host-owned residential properties, but there is a lack of information for residential properties with third-party owned systems and commercial properties. This project will analyze the impact of these systems on home values and other factors, which will allow for increased growth of the solar market by providing real estate professionals and potential adopters with accurate valuations.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It is imperative that the appraisal community construct and adopt a supportable formula for establishing the add-on value of solar in any marketplace. The tool has to adjust for local and regional differences (potential generation in light of insolation rates, etc.) and has to be vetted and required by the national appraisal organizations to be utilized in the field. Once this is achieved, then lending underwriters will be less prone to question derivation of value and more likely to approve the value established in the appraisal.

*Reviewer 2:*

Real estate appraisal practices and the appropriate valuation of solar are clearly core to the “mainstreaming” of solar PV from a customer standpoint, and an improved understanding of the appraised value of solar should both ease initial adoption of solar and support secondary market transactions, so this is an important area of pursuit. However, the real estate side of the solar equation is at best a secondary consideration in terms of lowering soft costs and driving down the upfront cost of going solar.

*Reviewer 3:*

Adding transparency to the added value of solar to residential properties increases the efficiency of home values and home energy labeling, and have PV auto populate in real estate listings will help remove barriers to PV solar rooftop installs related to lack of information about the value of rooftop PV to both home buyers and sellers. The project shows significant market premiums for host-owned PV systems.

**Project Title:** Promotion of Photovoltaic Soft Cost Reductions in the Southeastern United States

**Award Number:** 30426

**Principal Investigator:** Fox, Elise, Savannah River National Laboratory

**Project Description:**

This project creates a replicable model for solar soft cost reduction in South Carolina through human capacity-building at the local level and direct efforts to harmonize policy at the regional level. This effort will close the gap between South Carolina installed costs of residential rooftop solar and national averages and develop a portable and replicable model that can be applied to other jurisdictions in the future.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project is directly focused on soft cost reduction in a multi-state region. Although the scope of this project is not nationwide, it is a part of a portfolio of projects covering multiple regions. Soft costs are often inherently local, so this focus on a specific geographic area makes sense and helps SETO better reach national targets.

*Reviewer 2:*

Overall, the project aligns with SETO's goals to drive down soft costs. The execution of the project and the question of how much of the insights are generalizable prevent me from giving an "outstanding" rating in relevance. The costs were certainly reduced in the main use case, but it's not clear how everything would generalize because there were so many moving parts- policy, training, messaging/marketing.

*Reviewer 3:*

Developing the Solar Installer Apprenticeship Program and training First Responders will help sustain the goals and achievements of the effort to jumpstart solar PV in the Southeast Region of the U.S. where costs are assumed to be 25% greater than national averages. It developed a replicable model for other jurisdictions to use and has a particular focus on low income. It increased solar PV penetration from 0.1% to over 2%, developed educational materials for municipalities and regional training materials, and developed datasets to support expanding solar markets. It also took a comprehensive approach and considered how policies affect penetration and how state legislation and grassroots approaches can increase and accelerate solar. The project is on target to achieve a 25% reduction in soft costs and a 25% increase in participation in rural, low to middle income areas. These accomplishments are significant! I also thought it was rather ingenious that the PI developed an informational website that framed the information in consumer protection terms and to provide educated estimates about the costs and benefits of solar and what to expect from installers.

**Project Title:** Orange Button Phase 3: Standardizing Datasets

**Award Number:** 30820

**Principal Investigator:** Brodst-Giles, Debbie, National Renewable Energy Laboratory

**Project Description:**

This project is developing tools to convert paper-based solar records to machine-readable formats and establish a marketplace for standardized solar datasets. This platform will provide an open source data repository, easy access to data that is housed on the internet, a central catalog for solar energy data, a means to combine data, a gateway to common data standards, and a searchable interface.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Project is necessary to assist in the compilation of large disparate data sets.

*Reviewer 2:*

While having an Orange Button website that markets the data standard and provides access to resources for using OB in application development is really important, it's a bit odd to see it done separately from the data model project. Furthermore, there does not seem to be any clear market use case for the "data market" functionality (upload meta-data, sell data, etc.). I find that confusing.

*Reviewer 3:*

The standardization of the data will be extremely pivotal in reducing confusion, errors, and costs. Tools to automate the transition of legacy systems/documents to new standards are highly relevant. While the need is clear, progress towards goals is not completely clear. This is perhaps too due to the project's recent start and its dependency on prior Orange Button phases. Nevertheless, metrics on market uptake are insufficient.

**Project Title:** Unlocking Widespread Solar Adoption: Understanding Preferences of Low- to Moderate-Income Households to Create Scalable, Sustainable Models

**Award Number:** 32307

**Principal Investigator:** Sigrin, Benjamin, National Renewable Energy Laboratory

**Project Description:**

This project focuses on identifying novel, data-driven, and evidence-based strategies that could dramatically scale up solar adoption rates in low- and moderate-income communities. The goal is to develop pathways for reaching parity in solar penetration rates across socioeconomic groups. This project serves a core need for developing objective tools and datasets for policymakers and identifying the barriers that have previously limited deployment. The primary focus of this project is to rate the technical solar potential of buildings in low- and moderate-income communities across the country, develop predictive models to understand previous deployment, and then work with a national nonprofit solar installation group to determine how communication about solar energy usage occurs within these communities.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project has the potential to support SETO's goals to drive down soft costs. In its current state, it is quite theoretical, and the real test of the project's relevance will be whether the outputs and dissemination of the outputs are impactful. The project is still young and there is still time, but if it continues in a very theoretical direction, the relevance will be limited.

*Reviewer 2:*

This is quite a relevant study for the US as solar has traditionally not directly benefitted LMI residents.

*Reviewer 3:*

Very sound proposition. Looking at social context for LMI decision making. The Deep Dive they conducted on multiple factors will make for better interpretation of the role of different variables in terms of decision making.

**Project Title:** Strategic Analysis: Core Analytical Support to SunShot

**Award Number:** 32310

**Principal Investigator:** Margolis, Robert, National Renewable Energy Laboratory

**Project Description:**

This project provides core analytical support that will enable the Solar Energy Technologies Office to carry out its activities more effectively and efficiently. Laboratory analysts will draw on multiple internal and external data sources, as well as management and staff, to develop timely information and analysis. This project will continue the longstanding collaboration with the labs and leverage ongoing work to better serve the Energy Department's needs.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

By providing overarching analytical support to SETO, this project streamlines SETO's knowledge acquisition and directly saves time and costs by putting analytical support in the hands of national labs, which are better equipped to support analyses than SETO itself.

*Reviewer 2:*

A reasonable budget to provide necessary analysis.

*Reviewer 3:*

The project provides valuable analytical support for an array of research and analyses that enables SETO understand and benchmark various areas of soft costs. There is some uncertainty, though, to what extent all the analysis is being used by stakeholders to drive down soft costs or whether some of the analysis could be primarily academic in nature and not very applicable for practitioners.

**Project Title:** Meeting SunShot Cost and Deployment Targets through Innovative Site Preparation and Impact Reductions on the Environment (InSPIRE)

**Award Number:** 32311

**Principal Investigator:** Macknick, Jordan, National Renewable Energy Laboratory

**Project Description:**

This project achieves cost reductions through the first comprehensive assessment of baseline costs, cost reduction strategies, and environmental impact reduction strategies. The assessment covers site preparation practices for utility-scale solar projects, opportunities for addressing environmental impacts, and innovative siting practices to minimize impacts, such as utilizing contaminated lands and co-locating solar projects on agricultural lands. Extensive industry stakeholder engagement will guide translation of the results into industry-focused products that reduce costs and increase development.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Site preparation is shown to be an increasing percentage of the overall costs for utility scale solar with costs projected to be as high as 20% of overall costs in 2020. Smart and scalable GIS enabled tools that allow developers to identify sites that analyze a variety of characteristics from local permitting laws, requirements for environmental impact studies, wetlands and flooding overlays in addition to the impact on O&M costs with various vegetation choices will be important to continue to lower these costs. Also, there are increasing requirements at a state level to limit the building on agriculture lands. The research on how to co-locate solar and agriculture or site solar on contaminated lands is also important to both lower costs and continue to develop policies that encourage smart development.

*Reviewer 2:*

Relevant in multiple respects and addresses both environmental, cost, and NIMBY issues that all tie back to lower LCOE targets when viewing project costs holistically. Contaminated land portion of project seems to be a unique project in its own right given the number and multi-faceted nature of that particular problem.

*Reviewer 3:*

This projects meets the goals of SETO by addressing the soft costs associated with land. As the price of solar equipment has declined land costs have become a bigger percentage of the total cost of a solar project. Further, in some regions many of what would be considered the easy sites for developing solar have already been developed or secured pointing to a need for additional land areas where solar can be developed. This research has the potential to identify land previously thought to be undevelopable. Increasing the available land to solar applications through the mitigation of important environmental factors expands the opportunity for solar while reducing costs.

*Reviewer 4:*

The project has a direct effect on the cost of site acquisition, which is a significant part of the BOS. Of particular interest, the project appears to be exploring how solar may enhance the value of land (by improving its suitability for certain crops) or produce other benefits (co-locating with pollinators, reduce erosion), which has both value in reducing costs and producing other environmental benefits. In addition to driving down costs, this work would appear to have a direct impact on acceptance of solar, particularly in agricultural communities. Thus, its primary relevance to SETO's goals is cost reduction, but its overall focus on sustainability and acceptance of solar is also important.

**Project Title:** Innovative Framework to Increase Dispersion of Lab Data

**Award Number:** 32312

**Principal Investigator:** Brodst-Giles, Debbie, National Renewable Energy Laboratory

**Project Description:**

This project supports hundreds of new collaborations and partnerships for startups and growing companies through effective dissemination of lab data, models, and tools. Specifically, this project will create new relationships within the industry to shape priorities on tool enhancements and define opportunities for co-development of tools, such as the Utility Rate Database and OpenPV.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

A unique and creative way to engage outside and industry connected software experts to arrive at novel ways to manage large data sets.

*Reviewer 2:*

Enhancing distribution of some of NRELs key work has direct benefits to cost reductions because it makes it easier for stakeholders to use the resources NREL has developed (for both workforce education and potentially some private sector business development). Question the need for a mobile SDK for the SAM tool, but apparently that was not actually developed. The SDK for SAM that is available is highly valuable.

*Reviewer 3:*

This project leverages previous work of the labs in user-friendly ways.



**Project Title:** Solar-Plus-Storage: Removing Barriers through Cost-Optimization and Market Characterization

**Award Number:** 32313

**Principal Investigator:** McLaren, Joyce, National Renewable Energy Laboratory

**Project Description:**

This project examines cost-optimal system configurations for solar-plus-storage through data-driven, model-based analysis and creates an economic-based customer adoption classification for these systems. The analysis will be completed through data collection from existing solar-plus-storage projects, world-class modeling tools, and innovative methodologies to identify optimal configurations at the project level, as well as stakeholder engagement.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Excellent study looking at “solar + storage” potential based on economic motivations.

*Reviewer 2:*

“Solar + storage” is a concept in the very early stages of development and thus there is much analysis to be done. This project provides a great foundation. Additionally, the focus on the commercial segment is of particular value since that market has historically been very challenging to penetrate. It may be that commercial solar will not be fully realized until it is paired with storage capability and this project provides needed data/analysis to accelerate that effort.

**Project Title:** Towards a Low-Cost Solar Future: Baselines, Trajectories, and Impacts

**Award Number:** 32314

**Principal Investigator:** Margolis, Robert, National Renewable Energy Laboratory

**Project Description:**

This project accurately quantifies the soft and hard costs of solar in order to target research and development activities that increase market transparency, disseminate research that guides accelerated solar deployment strategies, and identify opportunities to facilitate solar cost reductions. This foundational analysis will help address the remaining non-hardware cost and deployment barriers to achieving ubiquitous solar.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The cost benchmarking and research that comes out of this report is highly important when benchmarking the success and areas of needed improvement to lower costs. The industry remains highly fragmented still and this research helps businesses to appropriately plan and focus on where to bring increased efficiencies in the market.

*Reviewer 2:*

The goal of this project is to track costs and as such cannot affect costs.

*Reviewer 3:*

Because the project didn't include a report (the Margolis report attached to this project is appropriate for the Margolis/Ardani project but not for this one), I have scored it good because the poster by itself doesn't provide enough information to evaluate for an outstanding score. Nonetheless, I think the work is very relevant for accelerating the penetration of PV because it provides information to better understand the potential impacts to the distribution system and identifies ways to minimize costs of efficiently integrating new PV generation and overcoming technical utility constraints and will identify new policies to encourage low-cost high value integration.

**Project Title:** Best Practices for Operation and Maintenance of Photovoltaic and Storage Systems

**Award Number:** 32315

**Principal Investigator:** Walker, Andy, National Renewable Energy Laboratory

**Project Description:**

This project addresses the needs of the rapidly growing photovoltaic operations and maintenance industry to ensure that solar projects are maintained at a high level of consistency and quality. A working group of financial and legal firms, solar developers, operations and maintenance service providers, and utilities will contribute to a best practices document, sharing field data in a performance database and a failure and reliability database. The group will also create a cost model to estimate costs of delivering a program that considers system characteristics and what conditions determine the optimal cleaning and repair schedules for solar projects. This work will enable financial firms to easily categorize, predict, and support solar projects with lower financing costs, which will increase the effectiveness of operations and the resulting energy delivery and reduce the cost of maintaining photovoltaic systems.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The work product from this project is extremely impressive and relevant to lowering the overall LCOE of solar. While many public and private institutions focus on lowering the up-front costs of solar lowering the O&M costs has an extreme impact on the LCOE. There has been huge variability in the costs of O&M and by transparently sharing best practices the industry has been able to both lower the O&M costs and decrease volatility of O&M costs.

*Reviewer 2:*

O&M is a particularly relevant issue, especially when examined systemically. However, if the metric for DOE is \$/W of capital costs, O&M costs doesn't impact that narrow metric but does on a \$/kWh basis. However, owners/asset operators' ability to price lower O&M costs achieves the objective of lowering overall project costs including cost of capital.

*Reviewer 3:*

From a long-term financing perspective, understanding the linked nature of system performance and asset management costs is critical not just to delivering more MWh per dollar invested, but also to lowering the cost of capital by providing greater certainty to investors and lenders, thus de-risking capital decisions. This project is representative of an important set of initiatives on this front.

**Project Title:** SunShot State Solar Technical Assistance Team Network

**Award Number:** 32316

**Principal Investigator:** Doris, Elizabeth, National Renewable Energy Laboratory

**Project Description:**

With thousands of state-level legislators and a range of state energy office models throughout the country, there are significant challenges to directly informing policymakers about program support mechanisms. This project creates the Solar State Technical Assistance Team Network, which will multiply state policy and program assistance programs by partnering with, training, and deploying information through trusted government membership organizations. Combined, these organizations will provide non-advocacy solar information to every state-level government in the United States.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

While only scored 'fair,' the driver of that score has more to do with the metric being reduction of costs. I think the project is incredibly relevant and value in achieving the ultimate objective of deploying more solar, which lower LCOE is ultimately a contributing factor.

*Reviewer 2:*

STAT is highly relevant in assisting in meeting SETO goals. Assistance for state office staff is important in building capacity to reduce soft costs on a local level. The STAT program provides states with specialized and knowledgeable resources, which could not otherwise be employed for a variety of reasons. The analytical support of STAT aids in innovation and deployment of solar. STAT provides a direct pathway to policy makers to achieve SETO goals.

*Reviewer 3:*

By providing unbiased information and assistance to states and local governments, this project fulfills a role that is highly appropriate for a federal agency and will certainly contribute to the reduction of soft costs. As states and localities understand more about how to navigate the complexities of solar, they will spend less money on and time on each project, so costs will go down as it becomes more mainstream and streamlined. More information would be helpful, however, in understanding the true impact of this project, and whether this project could be combined with other similar projects to reduce costs. Additionally, some examples of the more cutting edge projects, such as floating solar, may not be the right focus for this particular project, since this project should focus directly on helping locations lower costs and not on innovation itself.

**Project Title:** Untapped Markets: Catalyzing Mid-Scale Solar Deployment through Deep-Dive Analysis and Decision Support

**Award Number:** 32317

**Principal Investigator:** Heeter, Jenny, National Renewable Energy Laboratory

**Project Description:**

In collaboration with the Environmental Protection Agency's Green Power Partnership, this project aims to increase the deployment of mid-scale photovoltaic systems by identifying important untapped market segments, then engaging relevant stakeholder groups to identify and solve key market barriers, while providing technical tools and expertise to empower decision makers. This project will also help solar developer and installer communities by providing analyses that quantify the size and suitability of potential markets, while defining barriers and opportunities for mid-scale solar energy systems.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The mid-project redirection to corporate PV procurement was valuable. Direct technical assistance to universities seems to be of diminishing value as the solar market matures but offsite corporate solar procurement is an emerging opportunity.

*Reviewer 2:*

The project assumes that the market for system sizes up to 2-MWp is untapped and offers no support for this. The approach, engaging with universities to help them choose solar is good, but the market for solar on universities and schools is not untapped or new.

*Reviewer 3:*

This project is very relevant to SETO goals to accelerate distributed PV and bring down soft costs and support the reliability and resilience of the U.S. electric grid. It targets midscale solar at universities and screens 15 universities using NREL's REopt model and provides implementation assistance to another 20 universities. Almost a third of universities touched are moving forward with an RFP or another procurement approach, and 5 additional universities are moving forward with plans to install solar.

**Project Title:** Solar Energy Innovation Network

**Award Number:** 32954

**Principal Investigator:** Ardani, Kristen, National Renewable Energy Laboratory

**Project Description:**

This project brings together teams composed of electric utilities, regional planning commissions, state and local governments, and others from across the United States. These teams work to develop innovative solutions that explore new approaches to solar market barriers, reduce integration risks, and increase market opportunities. The network supports selected project teams through in-person, facilitated peer learning and targeted research and analysis over an 18-21 month period.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

While the project goals are important and the program seems to be getting a good number of interested applications it is still fairly early in the project and difficult to tell from the write ups if the goals/milestones are focused enough and leveraging existing research to produce meaningful results.

*Reviewer 2:*

While the Solar Energy Innovation Network (SEIN) concept holds promise for applying national lab capabilities to a variety of projects and sharing results with others to spread information to other potential projects, it's not entirely clear what issues they will be tasked to do and what the results will be. The project does not have very clearly identified stakeholder issues that it intends to solve, but assuming that it will, it is too early in its cycle to know specifically about its relevance.

*Reviewer 3:*

Project objectives definitely support SETOs goals, both implicitly and explicitly, but it's not clear whether the results will show this relevance. It's early in the project period so it's difficult to discern project outcomes.

More than other projects, this project focuses on grid reliability and resilience, which is important to the Department of Energy as a whole, but may be less relevant to the reduction of soft costs.

*Reviewer 4:*

The defined topic areas for round 1 (as set forth in the poster) are fully consistent with the SETO goals. Applicants' projects will necessarily influence how effectively the topics are addressed, but the project appears well focused.

The use of the cohort idea is commendable. As we move deeper into implementation of solar, many of the hurdles are local; and generally speaking, a federal government program is often not the most effective means of addressing these. But, this project appears targeted to bridge that gap by trying to find comparable projects from diverse areas, having them working together, and then disseminating the result -- hopefully resulting in identification of common elements, yet recognizing the need for local variation.

**Project Title:** Studies and Information for Public Utilities Commissions

**Award Number:** 33469

**Principal Investigator:** Doris, Elizabeth, National Renewable Energy Laboratory

**Project Description:**

This project is a collaboration between three labs to provide high-impact research and analysis for state public utility commissions on technical issues related to the integration of solar photovoltaics, both alone and combined with other distributed energy resources within the country's electricity system. In addition to the state-specific analyses, the project will use these analyses to prepare broader studies applicable to the larger stakeholder community. A successful program will result in innovative solutions in the selected topic areas that can be replicated by other public utility commissions.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

PUCs need far better data to make the grid reliable and friendly and to send the intended price signals. This project is just beginning so it is premature to give a critical evaluation.

*Reviewer 2:*

It is highly relevant. While the connection may not be obvious on the surface, regulatory barriers drive up costs. Removing these barriers with improved hosting capacity analyses, rate designs that maximize benefits, improving grid utilization, and by providing DER with fair compensation, etc., it will expand the market for solar and other DER. These measures can reasonably be expected to reduce the time needed to interconnect and drive down transaction costs.

**Project Title:** Valuing PV and EE

**Award Number:** 33761

**Principal Investigator:** Shah, Monisha, National Renewable Energy Laboratory

**Project Description:**

Buildings are evolving to not only consume, but also store and generate energy. The electric grid is also becoming more variable and uncertain. Though buildings with energy efficiency (EE), photovoltaics (PV), and distributed energy resources (DERs) can contribute to this variability, they can also help manage it. If this value proposition is captured when new buildings are designed or when investments in existing buildings are considered, the deployment of PV and EE can benefit building owners and the electric system. Analytic frameworks that underpin building energy policy need to be able to consider the time and locational value of EE, PV, and other DERs with respect to the electric grid and current and future electricity rates or compensation mechanisms for grid services.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project appropriately recognizes that solar on commercial or residential buildings exists in conjunction with other technologies that save or control energy use. Further, as retail markets evolve, when and how a building uses energy can be just as important as how much it uses over the course of a year. This analysis further prepares solar to engage in retail markets.

*Reviewer 2:*

Absolutely relevant to the climate change environment in which we find ourselves, building goals going forward and reducing costs.

*Reviewer 3:*

The research is relevant as technology in both PV and EE along with DERs is changing and there is a need to look at the value they provide on a holistic basis vs. and individual basis. The findings can inform SETO and policymakers in making key decisions with regards to PV, EE, and DER investment. The project leans towards more foundational research however it can inform policies that could help reduce soft costs.



# Technology to Market

**Project Title:** Catalyzing PV Manufacturing in the US with Cogenra Solar's Next-Generation Dense Cell Interconnect PV Module Manufacturing Technology

**Award Number:** 07190

**Principal Investigator:** Okawa, David, SunPower Corporation

**Project Description:**

Though utility-scale solar has grown in past years, innovation in tools available to project developers and managers has lagged behind. We still rely mostly on humans to manage complex data for decisions ranging from project selection to construction management to operational performance. SunPower sees opportunities to change the way that companies collect, filter, and process data by using a combination of software and hardware automation. The impact of automated tools could lower utility-scale PV system LCOE from balance-of-systems cost savings caused by more intelligent decisions during project design, more efficient deployments, and faster construction. These savings will bring the industry closer to achieving the DOE's 2020 cost target of 6 cents per kWh.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is not only aligned with SETO's goals but clearly addresses real customer/market needs and is on a credible commercialization pathway due to PV industry engagement and involvement.

*Reviewer 2:*

Targeting cost, performance, reliability and resilience will clearly support SETO's goals.

*Reviewer 3:*

The technology would increase the module efficiency and lower the system cost, thus the LCOE. It impacts a field accounting for 90% of PV products. If the manufacturing is proven reliable with high yield and cost effective, it will attract more adoption.

**Project Title:** One-Step Super Emitters for High-Efficiency Solar Cells

**Award Number:** 07191

**Principal Investigator:** Hutchings, Douglas, Picasolar

**Project Description:**

Imperfections in a solar emitter, a critical layer that collects the current-producing charge carriers in a solar cell, causes significant efficiency loss in most of the commercial solar cells. Picasolar's Hydrogen Super Emitter perfects emitters after cells are already made, helping to use less silver, avoid multiple processing steps and disruptions, and improve efficiency gains. The technology is a one-step, low-temperature process that electrically deactivates 99.5 percent of the dopants at the surface of the solar cell. This significantly lowers surface recombination, or the charge carrier losses experienced in the surface layer of a solar cell, thus helping to make the solar cells more efficient. In addition, Picasolar will create a tool that uses this new process and will integrate it into a high-volume manufacturing line.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

One step emitter with compatible efficiency with multi step is quite a step to reduce cost of cell fabrication. However, for an n-type Si, the efficiency should be higher than the p-type counterpart to match the power output from the module of similar area. More so, the additional hydrogenation step does not seem to buy the anticipated increased in efficiency.

*Reviewer 2:*

The demonstrated as well as anticipated results will both reduce cell costs (\$/W) but also reduce Balance of Systems (BoS) costs via improved efficiencies. BoS costs can be significant compared to the cell/module costs and could be a bigger contributor towards SETO's goals.

*Reviewer 3:*

The project supports SETO's drive to lower cost PV by enabling efficiency improvement of N-type solar cells. It proved that the efficiency can be improved by 3.5%. That would help reduce the system cost for PV. However, the market impact would be limited since very few companies are making diffusion junction N-type solar cells.

**Project Title:** Interconnect Circuit Manufacturing Technology

**Award Number:** 07200

**Principal Investigator:** Coakley, Kevin, Cellink Corporation

**Project Description:**

This project is developing a flexible conductive backplane that will provide module manufacturers with efficiency gains and a reduction in manufacturing cost per watt. Through proprietary fabrication techniques and advanced materials, CellLink's conductive backplanes are much more conductive, larger, lighter, and less expensive than traditional flexible circuits. These attributes are uniquely suited to the needs of rear-contact solar modules and other power electronics applications.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It appears that the company has pivoted away from the initial solar application to more lucrative ones in the lighting, storage and vehicle segments. Having said that it is a great project and they seem to have made significant progress.

*Reviewer 2:*

While the project has shown significant results in other industries, it is not clear (as stated in the proposal) that the technology can still be relevant to the mass market of PV modules that would significantly drive towards SETO's goals.

*Reviewer 3:*

This project leverages the progress in printed flexible electronics for cost reduction of solar modules. Although its original target of MWT market never realized, there would be potential market if more adoption of IBC in coming years.

**Project Title:** High Performance, Self-Cleaning, Antireflective Coating for PV Glass to Increase Module Output

**Award Number:** 07582

**Principal Investigator:** Thompson, Cory, WattGlass

**Project Description:**

This project is further developing an antireflective coating for the top glass of solar modules. The coating has a refractive index closer to that of glass, leading to higher transmission and higher module power. This project allows WattGlass to test the coating on panels from a number of manufacturers in order to gauge wattage improvements achieved over competing coatings. Modules with the coating will be tested in various regions to evaluate increases in panel performance due to the antireflective coating and reductions in soiling rate due to the superhydrophilic nature of the coating.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Cost reduction in LCOE of up to 3-6% depending on the scale of the system. Lower cost of O&M and increased power output due to weighted transmittance gain of ~3.75%.

*Reviewer 2:*

If successful and able to be delivered to market at the same price point as current solutions, the project would drive down the costs of PV through performance gains and reduced O&M costs.

*Reviewer 3:*

SETO's goals include cost reductions as a starting point. While the project claims self-cleaning ARC films I did not see this demonstrated very clearly at all. Most of the data presented showed an alternate ARC which is interesting only if it is cheaper. Finally the data are always compared to bare glass which was both not relevant and unimpressive.

**Project Title:** Interplay Solar Training Platform: A New System of Learning

**Award Number:** 07585

**Principal Investigator:** Donovan, Doug, Interplay Learning

**Project Description:**

This project develops the first 3D, interactive, training simulation tool for solar installers and employees. Through this training platform, installers will improve quality control, reduce construction costs from mistakes, and provide a better experience for their employees. These gaming-quality simulations immerse the trainee in a life-like learning environment and are supported by an intelligent system of learning that is both scalable and practical in application.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The grantee has identified training for solar installers as a required but missing service in the industry. Residential solar installation is a fast-moving, low overhead industry, and much of the workforce is new to the industry. Quality training can significantly speed the process, decreasing immediate costs, and increase the quality of the installation, decreasing lifetime system costs, and improving reliability.

*Reviewer 2:*

The premise that training is expensive and difficult is true. Each company must independently develop their own materials. A platform to create high quality and easily accessed content is desirable.

**Project Title:** Achieving Ubiquitous Solar Through Market Transformation and Grid Integration

**Award Number:** 07589

**Principal Investigator:** Crespo, Joe, Genbright

**Project Description:**

This project creates a commercial third party aggregation platform to integrate distributed energy resources (DERs), including solar, into wholesale electricity markets as a means to increase their value to the grid and decrease soft costs. The software platform will facilitate this market access through a combination of open source data repositories with information necessary to participate in various markets and enhancements to existing DER asset management software. Finally, through this project, Genbright will demonstrate both the technical capability of the platform on a small scale of diverse DERs and the commercial potential to expand to a much larger portfolio of DERs.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The topic of open-source software and data structure platform is relevant to making it easier to integrate solar energy into the energy market. It should translate into lowering the cost of bringing distributed energy resource to market and for the energy market, managed by ISO's, to accept and deploy them.

*Reviewer 2:*

Genbright's project addresses a very complex issue and is optimistic in its scope (a grand undertaking). If the project (software development) is successful it should support SETO's goals to reduce project implementation cost (through share interconnection), and improve efficiency and grid resilience.

*Reviewer 3:*

This project could create additional revenue streams.

**Project Title:** Scalable Direct-To-Consumer Community Solar

**Award Number:** 07590

**Principal Investigator:** Murray, Daniel, Ethical Electric (doing business as CleanChoice Energy)

**Project Description:**

This project builds a platform and underlying business architecture to enable the sale of community solar at a significantly lower cost per customer acquired than comparable residential solar sales. Leveraging its competitive retail electricity experience, CleanChoice is creating the customer acquisition, finance, and development tools needed to offer solar as a subscription at scale. This project will generate the demand for community solar and a method to deliver it at scale, dramatically increasing the availability and cost-effectiveness of community solar projects.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Clean Choice Energy's platform to enroll those families/entities wishing to participate in solar (buying solar energy) will increase the number of solar participants (buyers) and reduce administrative costs associated with community solar programs.

*Reviewer 2:*

Growing community solar is key to bringing more low cost solar to more people including low income homeowners and renters.

*Reviewer 3:*

Customer acquisition cost is a stubbornly high part of the cost stack. Solar via community solar is a potential pathway to reduce costs but adds complexity. Providing a platform and templates is a good idea.



**Project Title:** Sunfolding Mass-Manufactured Trackers For High Performance Photovoltaic Systems

**Award Number:** 07594

**Principal Investigator:** Madrone, Leila, Sunfolding, Inc.

**Project Description:**

This project is further developing a modular, single-axis tracker system powered by air pressure in polymer bellows that has the flexibility and installation simplicity of a fixed-tilt system. The key is a distributed, mass-manufactured drive system with shared control. This tracking system opens up new opportunities to significantly reduce component costs, improve efficiencies in construction and site design, and improve long-term reliability for all tracking solar projects. This project will build upon the demonstrated technical successes by applying advanced U.S. manufacturing and automated assembly techniques to achieve significant cost reductions.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Cost reduction through generation of higher output power than from a system that does not use the AirDrive™ to track the sun.

A unique technology which avoids the use of the motor with its associated mechanical deficiencies and maintenance cost. Increased system reliability and further cost reduction in O and M.

*Reviewer 2:*

This project is very relevant to the SETO goal of driving down cost of photovoltaics to improve the LCOE for tracking system that increase PV production. By supporting this project, the DOE has accelerated the cost reduction of PV tracking system. This project is what I consider a classic example of what the DOE can do to accelerate a product to market by supporting startup companies and accelerating the cost reduction with USA high volume manufacturing.

*Reviewer 3:*

The Sunfolding AirDrive is a novel and fully developed concept that is ready for final bankability and manufacturing scale up. This project addresses a significant challenge in a tracking system levelized cost of electricity and should substantially reduce the long term cost of solar tracking systems while optimizing land to be used for the trackers.

**Project Title:** Software Development: A Tool for Smart Integration of Solar Power

**Award Number:** 07595

**Principal Investigator:** Monson, Susie, Kevala, Inc.

**Project Description:**

This project is developing a platform for solar energy system developers that uses sophisticated analytics and detailed local distribution systems data to help reveal where demand and grid value for solar and solar-plus-storage are most beneficial. The tool can also help at the regulator and commission level by increasing transparency and facilitating long-term planning activities. This new software lowers financial risk by providing transparency into the current and future value of projects based on their location.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project aligns with a SETO Market Acceptance topic. This project is trying to make data readily accessible to project developers to assist them in evaluating locations of potential solar projects. That should in turn reduce the cost of project evaluation. This project is developing a one-stop software product incorporating mapping and other pertinent data, such as infrastructure, that solar developers can use to accelerate the evaluation of potential solar projects.

*Reviewer 2:*

DER can provide much more than energy and power. Ancillary services, though, are highly site specific. So tools that reduce the cost of finding optimum sites are desirable.

**Project Title:** Advanced Manufacturing Toolset for Low-Cost Copper Metallization of High-efficiency Heterojunction Solar Cells and Glass-Glass Bifacial Modules

**Award Number:** 07632

**Principal Investigator:** Moghadam, Farhed, Sunpreme, Inc.

**Project Description:**

This project is developing an advanced manufacturing toolset and process technology for low-cost copper metallization of high-efficiency heterojunction solar cells and glass-glass bifacial modules. While copper electrodes are well-known to be the best option for high-performance solar cells, very few are made with copper due to the complex and costly process needed to pattern it. This project adapts technologies from the ultra-cost-sensitive printed circuit board industry and modifies them for processing solar cells with higher throughput.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

High volume manufacturing with Cu metallization of >23.5% efficient HIT cells will lead to LCOE of 3.7 cent/kWh.

*Reviewer 2:*

If even 1/2 of the goals and targets outlined in this proposal would be delivered it would have a significant impact towards achieving SETO's goals. It seems very aggressive.

**Project Title:** Reducing Storage Cost with Photovoltaic Forecasting and Load Control

**Award Number:** 07858

**Principal Investigator:** Glasgow, Nathan, Edgepower Inc.

**Project Description:**

This project allows EdgePower to enhance its building energy management technology that integrates solar forecasting and load control tools by adding battery storage control capabilities. The prototype under development will establish standardized communication protocols between the building energy load gateway, the photovoltaic system, the energy storage system, and the solar forecast server. The integration of battery storage control capabilities will allow facilities with commercial solar to reduce their demand charges, making solar energy a more affordable option for businesses.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

EdgePower ability to forecast gross loads to calculate resulting net loads by combining solar forecasts and battery storage is an excellent goal. Low score is due to lack of commercial support by both industry manufacturers and commercial adaption which is critical in building and equipment software integration.

*Reviewer 2:*

The project aims to reduce demand charges that commercial building owners face by integration of solar forecasting, battery storage, and building load control with PV systems. If successful this approach could reduce cost of solar PV electricity to commercial building owners, in line with SETO's goals.

The technology also minimizes the effects of solar intermittency on the grid allowing for better reliability of the US electric grid as pertains to solar PV, also in line with SETO's goals.

*Reviewer 3:*

This project would shorten the payback period for behind-the-meter solar and storage solutions and would thus make these projects more attractive/speed deployment.

**Project Title:** Installation and Soft Cost Reduction for Horizontal Single Axis Trackers

**Award Number:** 07859

**Principal Investigator:** Taha, Yezin, Nevados Engineering

**Project Description:**

This project is working to optimize Nevados' horizontal single-axis tracker design for potential manufacturing. The technology helps solar developers build commercial solar projects on lands that are raised and uneven and would typically not be considered for solar development. This creates more site options and eliminates major construction costs. This project will update the product design in an effort to find cost-cutting opportunities and further testing will be conducted to demonstrate the reliability and robustness of the single axis tracker design.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is 11 months into an 18 month timeline. The project will expand usable land assets by allowing placement of solar trackers on rolling/sloping terrain. This is in alignment for SETO's goals. The All-Terrain Tracker (ATT) has already demonstrated a reduction of manufacturing cost and increased software efficiencies, as well as completion of UL listing. The Nevados technology is being proven bankable and financially feasible with its first test tracker sold and a commercial pipeline being accumulated.

*Reviewer 2:*

The grantee is designing a tracker that will allow more land to be developed with higher output solar PV, which will reduce LCOE. The secondary result of this tracker design is a control system that can be optimized better than the standard tracker control system, and will therefore reduce installation commissioning costs and improve the marginal output of any single axis tracker on even moderately rolling hills. The tertiary result of this tracker could be a modeling tool that allows more precise modeling of PV energy from backtracking single axis trackers on complicated topography, which is not currently possible in any of the major PV energy modeling tools.

*Reviewer 3:*

Solves cost and efficiency in utility scale solar within a real world scenario.

**Project Title:** sCO<sub>2</sub> Power Cycle with Integrated Thermochemical Energy Storage

**Award Number:** 08126

**Principal Investigator:** Held, Timothy, Echogen Power Systems

**Project Description:**

Echogen and Southern Research will design, model and test a novel integrated supercritical carbon dioxide (sCO<sub>2</sub>) power cycle and thermochemical energy storage system for concentrating solar power. The system will use CO<sub>2</sub> both as a power cycle working fluid and as a reactant in the thermochemical energy storage reactor. The team will design, build and test a prototype-scale sCO<sub>2</sub> power cycle and reactor to validate the design and performance of the system.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It is unclear from the proposal if the project seeks to replace or complement other sources of dispatchable power. This could have a bearing on its ultimate relevance and feasibility especially since the ramp rates may have challenges.

*Reviewer 2:*

The overall project objective is integrate supercritical CO<sub>2</sub> thermalchemical energy storage (TCES) with CSP, which has the potential to provide an additional means to help manage power demand requirements on the grid, especially in situations where there is high penetration of intermittent power sources like solar PV (as is the case in California). Supercritical CO<sub>2</sub> is preferred to other thermal energy storage mediums because of potential to meet the SunShot power block thermal efficiency target of 50% and because other technologies being considered have disadvantages such as high costs.

If this project is successful, the benefit could be that CSP is considered more competitive to PV whose costs are declining faster than CSP.

*Reviewer 3:*

This work complements DOE's thrust for operational sCO<sub>2</sub> systems in the future.

**Project Title:** The Democratization of Solar: Expanding the Commercial and Industrial Solar Market to Small and Medium Businesses through Financial Risk Mitigation

**Award Number:** 08127

**Principal Investigator:** McAulay, Jeff, Energetic Insurance

**Project Description:**

Energetic Insurance will research novel, data-driven, actuarial models that will allow for substantial expansion of the commercial solar market by mitigating off taker credit risk through the deployment of a unique new insurance product. Funding will be used to develop the advanced underwriting models and enable collaboration with lenders, project developers, and insurance companies. The project will result in a new insurance policy being issued on commercial and industrial solar projects across the country.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

“For commercial and industrial (C&I) projects, lenders and tax equity providers usually require the offtaker be publicly rated with agencies such as Moody’s or S&P. Most companies in the U.S. don’t have such a rating” and therefore are often excluded from PPA transactions (typically the easiest structure for which a C&I customer can purchase solar energy because it does not require an up-front capital investment). Removing the “credit rating” barrier provides C&I customers access to a PPA contracting structure. The C&I customer may be creditworthy but because they are not a publicly rated company the investor community is not as willing to offer PV project financing. In addition, it is costly and time consuming for the project developer to prove to the potential investor otherwise (having to conduct financial due diligence themselves for which they may not have the expertise or time to do).

*Reviewer 2:*

Solving credit for commercial offtakers is a great concept.

**Project Title:** Low Cap-Ex, High Speed Roll-to-Roll Perovskite Solar Module Development

**Award Number:** 08128

**Principal Investigator:** DeLuca, Stephan, Energy Materials Corporation

**Project Description:**

Energy Materials Corporation is developing a process to manufacture perovskite photovoltaic modules at unprecedentedly low cost and capital expense using high speed roll-to-roll printers. Unlike other thin-film technologies, perovskites combine the advantages of low-cost production with efficiencies on par with the dominant crystalline silicon technology. At this stage, the company is developing pilot production tools that will generate prototype modules demonstrating the module efficiency, stability, and cost structure needed to move into full production. Using existing production printers at Kodak, the company expects to produce modules at \$0.30 per watt while utilizing U.S. manufacturing.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project has just begun with the hope to develop prototype perovskite PV module with interconnected roll-to-roll cell arrays printed on roll-to-roll equipment. This might lead to cost reduction if it is successful. According to their assessment, it can lead to perovskite module production at a cost of <\$0.23/W with Cap-Ex 90% lower than the competition.

*Reviewer 2:*

The stated objectives of the project appear to be broadly consistent with the SETO goals and if successful could provide a pathway for a resurgence of competitive, high volume PV manufacturing in the US.

*Reviewer 3:*

In general people have made very good progress in the field of Perovskite. It is about the time to commercialize the technology. Roll to roll method provides low cost in terms of capital spending.



**Project Title:** An Online Marketplace that Allows Consumers to Comparison Shop for Solar Equipment, Financing, and Labor, Independently

**Award Number:** 08129

**Principal Investigator:** Biggar, Jamie, EnergySage

**Project Description:**

This project will apply best practices from online shopping in other industries to the solar shopping process to lower customer acquisition costs and the installed price of solar photovoltaic systems. The approach focuses on scalable online tools that facilitate consumer decision making, while streamlining the sales process for suppliers. By adopting best practices from other industries, this project aims to better align the consumer experience with consumer expectations, reduce customer acquisition costs, and increase solar deployment.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project will create market efficiencies and added transparencies to the residential solar market adaptation. Consumer Choice in Solar utilizing a home computer for online ease of “self-service” research, product comparisons and cost assessment will further clarify customer expectations for solar to be deployed on their rooftops or in their yards. This project is aligned with SETO’s goals.

*Reviewer 2:*

This project aims to reduce customer acquisition costs of residential PV solar through providing additional transparency in the sales process through an online platform, Customer acquisition costs are a significant portion of the soft costs associated with the residential solar PV market. If the project is successful, this would support SETO’s goal to drive down the cost of PV for residential consumers.

*Reviewer 3:*

Transparency and convenience in the PV array shopping experience should increase general public confidence rather than being approached by a cold call or door-to-door salesperson. Improving the access to shop (and therefore educate themselves), prospective residential customers interested in having a PV system installed at their home/business should ultimately lead to an increase in installations.

**Project Title:** Brittle Fracture Wafering of Silicon Ingots for Low-Cost, High-Efficiency Crystalline Silicon Solar Cells

**Award Number:** 08130

**Principal Investigator:** Iancu, Andrei, Halo Industries

**Project Description:**

Halo Industries will develop and prototype new solar wafer manufacturing technologies with the goal of significantly reducing the materials cost of all existing crystalline silicon solar cell architectures. The objective is to streamline the solar wafer fabrication process through more efficient and automated production line tools that eliminate silicon waste while reducing both process and operational complexity. Using a proprietary technology, this will reduce silicon solar cell material costs by at least 40 percent as well as drastically improve operational efficiencies for the majority of solar wafer fabrication steps through process simplification and automation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Cost reduction by eliminating kerf loss due to wire saw of the competing technology. Advantageous for thin wafers down to 50 um. This can bring immediate reduction in solar module cost. This can certainly lead to the goal of SETO if it can be deployed at scale.

*Reviewer 2:*

The project is aimed directly at supporting SETO's goals to drive down costs of PV electricity toward 2030 cost targets however it does not seem to have much relevance in supporting the reliability and resilience of the U.S. electric grid.

*Reviewer 3:*

Continuous effort to disrupt wire saw technology and reduce kerf loss. If it is successful, it still can work with main stream CZ grown ingots and help the industry.

**Project Title:** Krypton Shine

**Award Number:** 08131

**Principal Investigator:** Albanese, Ed, KryptonCloud

**Project Description:**

Krypton is researching a product to photovoltaic operations and maintenance organizations learn from every data point to increase asset performance and improve productivity. Krypton unifies data from disparate sources, is developing machine learning to detect anomalies in real-time, and provides rich applications to monitor and visualize events.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reducing O&M costs and improving O&M results is a key area in the PV industry for reducing LCOE, both on plants to be built in the future, and currently existing plants. This project has identified a useful way to achieve these goals.

*Reviewer 2:*

O&M costs have one of the largest impacts on solar returns.

*Reviewer 3:*

Existing data librarians for energy performance management, such as Maximo, are very expensive and difficult to use and implement. A lightweight system to do this would be very valuable for DER fleet owners/managers.

**Project Title:** Refinement of the Floating Silicon Method: A Low-Cost Monocrystalline Silicon Wafer Manufacturing Process

**Award Number:** 08132

**Principal Investigator:** Kellerman, Peter, Leading Edge Crystal Technologies

**Project Description:**

Leading Edge Crystal Technologies is developing the first kerfless manufacturing process that continuously produces single crystal silicon wafers. This process leverages breakthrough developments in heat transfer and crystal growth to yield high quality wafers at unprecedentedly high production rates, underpinning a potential 60 percent cost reduction over existing single crystal wafer. As a drop-in substitute in the existing solar supply chain, these wafers have the potential to reduce the all-in solar module manufacturing cost by 25 percent. This project will support the production of sample wafers from an experimental production machine that will be used to both refine the process and demonstrate wafer performance to the industry. These wafers and corresponding cells will generate the market traction needed to initiate further commercialization of the technology.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reducing waste and cost in silicon wafer manufacturing are consistent with driving towards SETO's long term PV goals.

*Reviewer 2:*

The project is squarely aimed at driving down the cost of PV via wafer cost reductions. No impact on grid resilience however. Well aligned to SETO's goals.

*Reviewer 3:*

The project is aligned towards the goal of cost reduction of PV products but with low likelihood for success. However, various ribbon methods proven to be not competitive in either material property or cost. This method is not too much different than others on those aspects.

**Project Title:** Building Windows with Transparent Photovoltaics to Lower Costs

**Award Number:** 08133

**Principal Investigator:** Hoven, Corey, Next Energy Technologies

**Project Description:**

Next Energy Technologies Inc. (NEXT), has developed transparent photovoltaic coatings for integration into commercial windows. NEXT's low-cost, wet-coated materials selectively absorb and convert light in the infrared and UV spectrum while allowing significant visible light transmission with colors that are desirable to the window market. The approach uniquely allows the photovoltaic windows to look like conventional windows, but also allows for reduced module and balance of system costs by leveraging existing window costs. This project will enable NEXT to transition from small-scale 3.5" units produced using laboratory processes to larger format devices utilizing manufacturing-relevant processes.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Although the windows can generate some electricity, the power output may not be high enough to drive a meaningful load. However, aesthetically for net zero building it might meet specifications.

*Reviewer 2:*

The program clearly targets SETO's goals by virtue of being both a groundbreaking, and early-stage technology. BIPV is an area that can significantly impact the introduction of new PV markets at reduced cost.

*Reviewer 3:*

The project report described addressed market for BIPV and potential cost saving especially on BOS which is aligned with SETO goals of cost saving for PV systems.

**Project Title:** A Software Platform to Drive Disruptive Innovation in Solar Performance Assurance Through Software Automation

**Award Number:** 08134

**Principal Investigator:** Kenny, David, Omnidian

**Project Description:**

Soft costs associated with solar installation continue to act as a prohibitive factor in the expansion of solar technology, at times comprising of up to 64 percent of the cost of a new solar system. Omnidian is creating an analytical, predictive performance model able to remotely and automatically diagnose performance issues in solar systems thereby driving down these soft costs across the solar industry. This project will result in a scalable asset management offering to the solar market, lowering the risk associated with solar investment, freeing up capital tied down in large-scale residential portfolios, and providing homeowners with continuous monitoring and a system performance guarantee.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Performance assurance for residential-owned PV systems is a concern but likely limited to a small subset of potential purchasers who are more technically aware of the potential negative impacts to production by improper maintenance or fault detection. It would be helpful to include in a PV contractor's marketing/sales material why proper maintenance and monitoring of a PV system is so important, what factors can impact production and why they should care (and use in their evaluation when interviewing contractors to install the system once they have made the decision to do so). With regard to the statement Omnidian makes with regard to industry impact - "Increased confidence in the Solar Asset. When potential customers and financiers see an industry with high performing assets, it increases their confidence in the asset class. It increases the probability that a homeowner will buy a system or take out a loan for a system. Increased confidence also generates more interest from the financial community in providing capital for leases and loans at lower rates." This statement is likely true; but, it would be helpful to substantiate/quantify the number of prospects that would actually make the decision to buy (and therefore increase the number of solar installations) and to measure the expected impact and contribution to SETO's goals.

*Reviewer 2:*

The residential O&M market typically must balance expensive truck rolls with underperforming systems. Reducing the cost of identifying and classifying issues requiring truck rolls are key to driving the cost out of residential O&M. Particularly due to the number of systems and variations of designs, automation is key.

**Project Title:** Reliable and Secure Bidirectional Communications Link for Distributed Energy Resources

**Award Number:** 08135

**Principal Investigator:** King, Randall, Operant Solar Corporation

**Project Description:**

Operant Solar has developed a network gateway that reliably, securely, and inexpensively connects distributed energy resources such as residential solar sites to the internet. Currently, the industry relies on single path internet connections that are unreliable. Twenty percent of fleets have dropped offline, becoming invisible to their operators and creating significant operations and management issues for companies. Operant's innovative software protocol provides a wireless backup connection between sites. The protocol, developed by a consortium led by the University of California, Los Angeles, can securely parallel an extremely long-range wireless mesh protocol with standard internet connections, such as WiFi or cellular. The concept is similar to smart meter networks used by utilities, but for more widely dispersed applications, like solar systems.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project does align well with the SETO goal of reducing PV cost by creating a communication module that is expected to provide more reliable communication of installed PV systems. This will in turn reduce the cost of O&M of PV and to provide a more reliable communication medium pr PV systems.

*Reviewer 2:*

The project is designed to create a robust communication path for residential systems. Residential systems are known to have issues maintaining connections to the TPO database, and can be expensive to troubleshoot. Keeping those communications stable is important to support various parts of the stakeholder value, particularly in regions with RECs.

*Reviewer 3:*

I believe this project has the potential to lower communication costs and improving reliability.

**Project Title:** Highly Efficient Steel Cable Solar Photovoltaic Mounting System

**Award Number:** 08136

**Principal Investigator:** Fuller, Michael, P4P Energy

**Project Description:**

P4P has developed a unique photovoltaic panel suspension system utilizing tensioned cable design to reduce cost of solar parking structures. P4P's strategy is to minimize weight and materials cost, while increasing assembly and construction efficiency to produce a markedly less expensive solar canopy that produces valuable shade as well as electric power. P4P is researching a high volume, high efficiency product that will be both aggressively competitive and aesthetically pleasing.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Incomplete or nonexistent information regarding cost of structure as it relates to other options in market. Incomplete report with regards to Challenges, Milestones, Scalability/Replicability/Impact, Project Results and Budget tables. Unable to determine relevance to SETO's goals.

*Reviewer 2:*

This project aims to demonstrate the cost-effectiveness of a steel cable mounting system for solar PV parking structures relative to existing technology for such structures.

Success of the project could result in wider scale adoption of solar PV parking structures due to reduced cost of installation.

*Reviewer 3:*

The project does not decrease the cost of installed solar.



**Project Title:** Customer Acquisition Platform for Rooftop Solar Property Assessed Clean Energy Financing

**Award Number:** 08137

**Principal Investigator:** Kremen, Gary, Pace Avenue

**Project Description:**

Pace Avenue is researching an online platform that will target and prequalify eligible homeowners, specifically low and moderate income homeowners, for Residential Property Assessed Clean Energy (R-PACE) financing. R-PACE is a financing mechanism for solar, energy efficiency, and water conservation upgrades for residential property owners. Homeowners will be matched with the most appropriate solar and energy efficiency product bundle, R-PACE administrator, and installer.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

PACE does the customer acquisition and is the broker between the homeowner and the contractor. It is another mechanism available to homeowners to learn how solar may be beneficial and be able to “afford” a solar energy system by essentially and easily financing it over time with no upfront capital investment (it being paid by the homeowner as an added amount to their annual property tax bill).

*Reviewer 2:*

PACE has done a lot to drive energy efficiency and solar adoption in the home but its costs have not lowered the cost of solar.

**Project Title:** Ultra-Compact High Efficiency Multi-Level GaN-Based Photovoltaic Inverter

**Award Number:** 08138

**Principal Investigator:** Pilawa, Robert, Power Integration Laboratory

**Project Description:**

The project objective is to research methods to develop a hardware prototype of a scalable multi-level, interleaved 60-100 kilowatt photovoltaic inverter, comprising several sub-modules that enable various power levels to be implemented using a common framework with advanced grid support features.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

With the industry moving to larger MW solar farms using 1.5 kV DC inverters, this maybe a timely development to create and bring to market a lower cost 1.5 kV inverter product then is available today. The use of GaN has the potential to dramatically reduce the form factor of inverters.

*Reviewer 2:*

The project combines two trends of inverter development, but two trends which may not combine to be used in the same system. 1500Vdc inverters are typically used for larger utility systems, while the smaller inverters, sized around 60-100kW are used for smaller commercial rooftops and small utility plants. Personally, I would not consider 1500Vdc on a rooftop to be prudent, but I am not familiar with current industry attitudes about that potential shift. It is possible the industry will ultimately want modular inverters for faster replacement, increasing uptime in the field, even for large utility project, but at the moment the larger projects still tend to stay with 1-2+ MW inverters, and avoid smaller inverters due to expectations of excessive failures.

*Reviewer 3:*

The project supports SETO's goals to drive down costs of PV by lowering the BOS and soft costs of projects.

**Project Title:** Low-Cost Wireless Voltage and Current Monitoring of the Distribution Grid

**Award Number:** 08139

**Principal Investigator:** Hines, Jacqueline, SenSanna Incorporated

**Project Description:**

SenSanna Incorporated is working to enhance the resilience and reliability of the distribution grid and to enable increased levels of solar and other distributed energy sources through the use of cost-effective distributed wireless monitoring systems. LineSenSTM systems wirelessly measure current, voltage, and temperature on power lines without any batteries in the line units and without harvesting energy from the power lines. Unlike other line sensor systems, LineSenSTM operates even at zero current, providing current and voltage waveforms, relative phase, and temperature data for a cost similar to simple fault indicators.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The development of low cost electric utility grid sensors is very important. This project appears to be able to reduce the cost of sensors by at least 50% compared to what is on the market today. Low cost sensors on the grid are of great value to the electric distribution utility industry. With so much of the distribution circuits without monitoring, sensor projects add immense value to support the reliability of the electric grid.

*Reviewer 2:*

The project directly enables reliability and resilience by providing low cost monitoring of distribution lines on the grid. This is visibility the utilities currently can't afford to install.

**Project Title:** Design and Reliability Improvements for High-temperature Parabolic Trough Solar Fields

**Award Number:** 08140

**Principal Investigator:** Marcotte, Patrick, Solar Dynamics

**Project Description:**

Parabolic trough technology is the most commercially mature CSP technology, but its hydrocarbon-based heat transfer fluid limits the upper operating temperature of power plants. As a result, trough plants must use an indirect molten salt thermal energy storage design that is not as efficient or cheap as storage is in molten salt tower plants. The next major advance for trough technology is the move to using molten salt directly as the heat transfer fluid in the solar field. This project introduces innovative solutions to address the two of the key issues still to be resolved for using molten salt in trough plants: the cost of the molten salt freeze recovery system in the solar field and the development of a reliable collector interconnection that works with molten salt.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

I see this as providing support for SETO goal of bringing down the cost of CSP trough systems by attempting to reduce system design cost. This is an early T2M funding award and a very early T2M project stage.

*Reviewer 2:*

This next generation Molten Salt trough plant appeared riddled with technological barriers. The team should have clear benchmarks to begin the cost analysis of goal deliverables (i.e., 50% reduction of what base cost?). Salt at temperatures to remain molten needs energy to allow the flow through non trough areas - to assess the financial benefit of the project the entire energy needed to run the facility would need to be accounted for in the energy output. Could not assess the value of the project and with the first go/no go milestone at the end of the project the score is very low as no SETO goals are addressed.

*Reviewer 3:*

I am not a fan of Molten Salt Troughs because I think failures and freezes will limit their commercial viability. However, this project is trying to address 3 main hurdles that MSTroughs face right now: 1) there's still not a good flexible joint to connect modules, 2) how does the collector recover in the case of a freeze?, and 3) what 3rd party evaluation tool is available to analyze their performance? These are all relevant if DOE wants to investigate MSTroughs.

**Project Title:** Re-Designing the Concentrating Solar Power Thermal Energy Storage System to Enable Higher Temperature Performance at Reduced Cost

**Award Number:** 08141

**Principal Investigator:** Gould, William, SolarReserve

**Project Description:**

SolarReserve is working with the National Renewable Energy Laboratory and others to develop designs that will eliminate the need for expensive alloys and lower costs in today's hot tanks operating at 565° to 580° Celsius and in tomorrow's systems that will use a much higher operating temperature. The research will reduce costs in two ways. First, the introduction of internal insulation within the tank will reduce the temperature of the steel pressure boundary enabling designers to use less expensive alloys. This internal insulation may take the form of ceramic or metallic materials and structures and may take advantage of the inherently low thermal conductivity of a layer of stagnant salt adjacent to the pressure boundary. The second aspect of the work consists of relocating the salt pumps from their present position, suspended above the roof of the tanks on expensive platforms cantilevered from nearby building steel, to a point at or below grade. In their new location, the pumps and the required supporting structures will be much cheaper and more conventional.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

3-5% total bid cost reduction of the present CSP plant. This may lead to reduced cost of LCOE for CSP, although it is not stated how much reduction it will bring.

*Reviewer 2:*

Lowering the cost and complexity of CSP installations is consistent with the program goals and the practical pathways proposed in this project seem feasible.

*Reviewer 3:*

The TES system in CSP differentiates it from PV. It needs to be cheap and work well. This project seeks to make it cheaper, work better, and disseminates knowledge amongst stakeholders to support the technology in the future.

**Project Title:** Cost-Efficient and Highly Weather-Resistant Solar Panel Backsheet Produced through Continuous Co-Extrusion Processing

**Award Number:** 08143

**Principal Investigator:** Thellen, Christopher, Tomark-Worthen

**Project Description:**

Photovoltaic backsheet is a critical component to most solar modules as it provides insulation and protection to the module from environment forces such as moisture and ultraviolet light. Tomark-Worthen LLC will use novel thermoplastics to develop a backsheet material that is lower in cost than fluoropolymer-based backsheet in the field today, while reducing solar panel replacement costs by providing more than a 30-year expected service-life. This novel backsheet is created through co-extrusion, which allows for recycled content to be used in the production of the backsheet without the use of adhesives and polyethylene terephthalate, which are known to suffer from hydrolytic degradation in solar applications.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

It is unclear how “cost competitive” backsheet will significantly advance the SETO goals apart from minimally. The pathway to broad market acceptance of this product is very clear given the dominant incumbents and IP barriers in place.

*Reviewer 2:*

It is not clear that the issues with current PET back-sheet have been adequately traced to all materials or just some. Also, differentiating between material issues and process/manufacturing issues was not addressed in my opinion. I do not see this reducing manufacturing cost nor do I see it increasing grid resilience.

*Reviewer 3:*

Backsheet failure would require replacement and increase the cost of operation of PV systems. The project supports the goal of SETO.

**Project Title:** Unlocking Utility Data to Address Solar Soft Costs through a UtilityAPI OpenESPI Data Custodian

**Award Number:** 08144

**Principal Investigator:** Roesler, Daniel, UtilityAPI

**Project Description:**

UtilityAPI is building an Underwriters Laboratory-certified Green Button Connect product that enables utilities to implement the Green Button Connect standard specifically for solar consumers and solar providers. Green Button Connect is an interface that utilities can deploy to enable their customers to easily and securely access their utility data and share it with qualified third-party providers of services in a consumer-friendly and computer-friendly format.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The concept of having a more user friendly method for companies to obtain utility customer load data is worth enhancing. It is time to update the Green Button to make it easier for solar and energy efficiency companies to obtain energy usage data for their clients.

*Reviewer 2:*

Although utility account data may be available for use by the account holder, the data is not typically easily accessible by the solar contractor who must design the solar array for a residential or C&I customer. The solar contractor must have accurate energy usage data for a house or building in order to properly size and design the PV system for a specific application. This project will build a ULcertified NAESB OpenESPI Data Custodian implementation (i.e. Green Button Connect) that can be easily used by solar providers. This should help make the solar installer's job easier and therefore more efficient while bringing technical accuracy to the process and therefore ultimately installing a PV system for the client that can optimize solar production and provide the most benefit (making the investment worthwhile).

*Reviewer 3:*

Projects require utility bills in order to be priced or quoted accurately; this attempts to make that process more efficient.

**Project Title:** The Pecan Street Leveraged Assets for Technology Feasibility Review, Optimization and Market validation (PLATFORM) for Product Launch

**Award Number:** 08237

**Principal Investigator:** Russo, Suzanne, Pecan Street Inc.

**Project Description:**

Pecan Street Inc. and the Translational Research Institute created the PLATFORM (Pecan Street Leveraged Assets for Technology Feasibility, Optimization, and Marketing review) for Product Launch to demonstrate and validate a new model for dramatically improving the effectiveness of investments in clean energy technologies and accelerating market entry of disruptive technologies. Over the past five years Pecan Street has developed a platform that integrates data-driven market intelligence, lean product development and validation methods, rapid prototyping, and collaboration between industry and the technical community. The PLATFORM model leverages these assets to co-locate the resources required to carry an innovative idea into a commercializable product while at the same time aligning progressive stages of market validation with funding and providing verified technology impact reports that unlock new impact investing opportunities. Product demonstrations within the testbed will allow utilities and key players in the energy space to evaluate technologies without risk or commitment. The model introduces a critical paradigm shift in clean energy innovation that overcomes the critical barriers to market adoption and enables a step change in how these technologies are developed, funded, marketed, and procured.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is creating a platform for innovative clean tech startups to test and have their product evaluated by industry partners with the goal of linkage to venture capital funding. By providing this testbed and validation, it will make it easier for clean technology startups to have access to funding to bring their product to market.

This project links to an important goal of helping innovative clean technology startup-American companies bring their product to market. The results of this project should be applicable to other industries beyond clean tech.

*Reviewer 2:*

The Pecan Street PLATFORM is unique as it does support SETO's goals in creating a testbed of live systems performing in real time in the field along with the preliminary lab testing.



**Project Title:** Partnerships for Intelligent Energy

**Award Number:** 08238

**Principal Investigator:** Kirsch, Emily, Powerhouse Accelerator

**Project Description:**

Powerhouse LLC will design, develop, and pilot systematic approaches to facilitating partnerships between early-stage clean energy companies and industry or investors. The team will aim to meet ambitious targets for supporting startups to secure mentors, channel partners, and capital. Program findings will be distributed for replication by energy commercialization organizations. At scale, this framework will accelerate the commercialization and deployment of clean energy technologies, including solar.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project aims to address a key challenge faced by many early stage companies in solar (as well as other energy sectors): forming successful partnerships with large corporations such as utilities.

In the energy sector, it is rare that a startup company will go all the way to IPO as an independent entity. More than 9 times out of 10, a partnership with a larger entity, to license, manufacture, or provide a distribution channel, at a minimum, will be needed to successfully scale the technology.

To meet SETO's goals of reducing the cost of PV and CSP, grid reliability and resiliency, new technologies MUST actually make it to market. Thus, programs addressing the valley of death between R&D and commercialization are absolutely essential to meeting SETO's goals.

*Reviewer 2:*

This project has tremendous merit however tying it directly to "efficiency, reliability and cost" at the outset is difficult. Matches or pairings that are made by Powerhouse to introduce promising technologies and product enablers by their creators to potential companies/entities that can help to commercialize the idea/prototypes will in fact mobilize the potential supporting technologies to advance the objectives of SETO, but with perhaps a few steps to get there.

*Reviewer 3:*

This is an Innovative Pathways award and the activities and milestones align with the goals of that program.

**Project Title:** First-Look Fund – an Early-Stage Aligned Intermediary to Enhance the Flow of Private Capital into Energy Companies

**Award Number:** 08239

**Principal Investigator:** Price, Matt, Activation Energy

**Project Description:**

This project aims at creating a business-model-agnostic investment vehicle (First-Look Fund) that provides small investments to concept-stage companies and provides access to information that will reduce uncertainty and risk misalignment for investors.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project aims to address a key challenge faced by many early stage companies in solar (as well as other energy sectors): finding the capital these innovative young startups need to take an early prototype to product and demonstrate that product's effectiveness in a real world environment.

There are few traditional venture investors left who will invest in an early stage solar company. While this area was very active in 2006-2008, many investors lost money and did not achieve the returns that they could typically expect from a similar portfolio of non-energy internet early stage companies. Thus, American investors in Silicon Valley and elsewhere turned away from the field of clean tech as a whole. New models are needed to bring early state investment capital back into supporting solar innovations. This funding is critical to supporting new technology through the valley of death between R&D and commercialization by industry.

To meet SETO's goals of reducing the cost of PV and CSP, grid reliability and resiliency, new technologies MUST actually make it to market. Thus, programs addressing the valley of death between R&D and commercialization are absolutely essential to meeting SETO's goals.

*Reviewer 2:*

This is a DOE Innovative Pathways project and its goals align well with that program.

**Project Title:** 501Vc – A New Model for Investing in Energy Innovation

**Award Number:** 08240

**Principal Investigator:** Gaddy, Ben, Clean Energy Trust

**Project Description:**

Clean Energy Trust will launch a new investment model to attract a new class of investors to early-stage cleantech businesses. The model combines the structure of a venture capital fund with the benefits of a mission-driven, non-profit organization. Leveraging philanthropic donors' support, the new model will address the longer time horizons, capital requirements, and bounded upsides that have driven investors from cleantech.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project aims to address a key challenge faced by many early stage companies in solar (as well as other energy sectors): finding the capital these innovative young startups need to take an early prototype to product and demonstrate that product's effectiveness in a real world environment.

There are few traditional venture investors left who will invest in an early stage solar company. While this area was very active in 2006-2008, many investors lost money and did not achieve the returns that they could typically expect from a similar portfolio of non-energy internet early stage companies. Thus, American investors in Silicon Valley and elsewhere turned away from the field of clean tech as a whole. New models are needed to bring early state investment capital back into supporting solar innovations. This funding is critical to supporting new technology through the valley of death between R&D and commercialization by industry.

To meet SETO's goals of reducing the cost of PV and CSP, grid reliability and resiliency, new technologies MUST actually make it to market. Thus, programs addressing the valley of death between R&D and commercialization are absolutely essential to meeting SETO's goals.

*Reviewer 2:*

This is a project for philanthropy.

**Project Title:** Flexible All-Metal Pipes and Pipe Couplings for High-Temperature Fluid Transport

**Award Number:** 11965

**Principal Investigator:** Caruso, Bill, Brayton Energy

**Project Description:**

Rotational pipe couplers for high-temperature molten salt are required to reduce the cost of renewable electricity generated by solar plants. This project will develop a flexible coupler made entirely out of metal. The coupler has a smooth internal shape, which prevents fluid from being trapped in convolutions such as those present in existing rotational couplers. It is optimized to be highly flexible while still able to withstand the pumping pressures required in typical molten salt plants. It will be able to move through 180° of motion daily for the entire lifetime of a solar plant. Future applications may include additional fluids, such as supercritical carbon dioxide.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

CSP electricity cost reduction effort through a high temperature fatigue-resistant helical coil, optimized for larger angular and axial displacement common to parabolic trough systems. By eliminating seals and highly stressed small radius convolutions of bellows, a robust system that allows for maintenance free operation over an operational design life of 30 years can be achieved.

*Reviewer 2:*

The precise alignment with the SETO goals is not clear. There “may” be cost reductions and performance improvements but no quantitative estimate as to the extent of the improvements or enhancements that might be realized.

*Reviewer 3:*

In general I feel that molten salt troughs are too risky. This supports molten salt troughs with a long length of coil that will lose a lot of heat.

**Project Title:** Solar Load Balancing Simulator

**Award Number:** 15792

**Principal Investigator:** Powers, John, Extensible Energy

**Project Description:**

This project will develop modern software tools to assist electricity customers in commercial buildings to maximize the use of distributed solar within the facility where the solar array is installed. The software will save customers money on their energy bills and will allow the electric grid to support a higher percentage of solar generation.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The solar load balancing simulator does not necessarily drive down the cost of PV directly however it could enhance the reason C&I customers should/would implement a PV system - to help minimize/lessen demand charges which can be costly. The SLBS is an enhancement to a PV installation in that it can help optimize the value of the PV system therefore increasing the PV owners ROI.

*Reviewer 2:*

The project identifies a specific value from solar / storage combinations - reduction of demand charges, which increases the value of solar in commercial buildings. This can help drive adoption of solar on commercial rooftops, a historically challenging segment.

*Reviewer 3:*

This is a reasonable concept to address the problem of solar intermittency and demand charges. However, it is one that is almost certainly being addressed by incumbent EMS providers.

**Project Title:** Middleware Oriented Community Solar Platform

**Award Number:** 15868

**Principal Investigator:** Dahnke, Eric, ProjectEconomics

**Project Description:**

Community solar has the potential to increase access to solar for households and businesses that cannot put solar panels on their roofs. ProjectEconomics is developing its community solar platform to help utilities and third parties deliver community solar programs efficiently at scale.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The grantee is building a software platform to reduce costs and allow seamless adoption of community solar, which is a currently underutilized PV asset class, for a number of reasons, but the overhead of managing the paperwork for all stakeholders is one reason. This project should reduce these costs and allow this PV asset class to grow, allowing more people to adopt PV.

*Reviewer 2:*

Software solutions like these that reduce the friction and soft costs for Community Solar projects will help drive down the costs of PV.

*Reviewer 3:*

The proposed solution looks important to managing microgrids, community solar as well as providing a backend tool to manage existing DER assets.

**Project Title:** Developing Optimal Control Technology for Distributed Energy Resources (DOCTdER)

**Award Number:** 15936

**Principal Investigator:** Meeker, Rick, Nhu Energy

**Project Description:**

The Nhu Energy team is developing breakthrough control technology to drastically improve the value proposition for distributed energy resources such as solar photovoltaic, storage, electric vehicles, and price-responsive load, to enable significant improvements to electric power system resiliency, economics, and environmental impact.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project does support the resiliency and reliability targets of DOE. This projects direction to optimally control DERs is the direction electric utilities are heading. That is, advance distribution management system (ADMS) located at the utility, does optimization of its own resources with the functionality to be able to provide energy management system control of customers systems participating in a utility marketing program.

*Reviewer 2:*

The project focuses on improving the reliability and resilience of the grid, and minimally on lower costs of PV.

*Reviewer 3:*

The project would make solar and DERs more attractive by reducing the payback period because of reduced electricity costs. The project would also increase the reliability and resiliency of the grid if solutions are eventually adopted by electric cooperatives or municipalities.

**Project Title:** Novel Corrosion and Erosion Protective Amorphous Alloys Coatings

**Award Number:** 17682

**Principal Investigator:** Vogli, Evelina, LM Group Holdings

**Project Description:**

The program will develop unique amorphous alloys coatings with high corrosion and erosion properties using high-velocity oxygen fuel technique. This novel approach will increase concentrating solar power throughput and improve the overall properties of manufactured parts.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project has relevance to SETO's goal to drive down costs of CSP-generated electricity toward 2030 cost targets.

Specifically, materials used in conjunction with molten salt heat sinks to enable next generation CSP will require high corrosion resistance. This project aims to identify amorphous alloy materials that are more corrosion resistant than commercially existing materials. This could reduce costs if such materials require less replacement of components in the use of CSP plants or if the materials that are developed are less expensive than those currently commercially available.

*Reviewer 2:*

At higher temperatures, it's hard to find materials for CSP applications that will last. These protective coatings could help.



**Project Title:** An Open Source Proactive Energy management System for Integrated Control of Energy Storage and Solar Powered Buildings

**Award Number:** 17683

**Principal Investigator:** Xu, Jeff, Leaptran

**Project Description:**

Leaptran develops a control and communication software platform that enables the integrated control of battery energy storage and solar-powered buildings so that grid can penetrate renewable and distributed energy sources deeply. The solution will integrate building energy management and battery energy storage to unlock the potential for battery in buildings.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The project, if successful, would appropriately benefit the reliability and resilience of the U.S. electric grid.

*Reviewer 2:*

While energy storage integration is important to gain access to solar markets where users have demand charges embedded in their electric bill, this solution is already being solved by the market.

*Reviewer 3:*

Currently, there are no open source solutions for intelligent solar and battery storage management. However, the attempt here is clearly one being worked on by existing EMS providers. Jeff may have an interesting patent for a related sensor that looks at RBG sky info which can provide better prediction than just global irradiance.

**Project Title:** High Temperature, Raman Spectroscopy Based, Inline, Molten Salt Composition Monitoring System for Concentrating Solar Power Systems

**Award Number:** 17712

**Principal Investigator:** Harsh, Kevin, Sporian Microsystems, Inc.

**Project Description:**

Sporian Microsystems will research and develop a novel, high temperature, in-line, monitoring system to help next generation concentrating solar power (CSP) plants efficiently provide low-cost renewable energy. The monitoring system will leverage Raman Spectroscopy to track chemical composition (e.g. oxygen and moisture) in the high temperature molten salt within the thermal storage loop of the CSP plant. The data obtained will help to ascertain the health of the molten salt, e.g. whether it is decomposing, as well as identify impurities, e.g. leached metals, that might be contained within the mixture. In-line monitoring of the molten salt at high temperature will help to elucidate fundamental chemical mechanisms at play and ultimately result in high temperature (700 C) thermal storage systems that are more reliable and affordable.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The proposal does not make a case for the criticality of the problem they are solving and the need for real-time monitoring. Some industry validation of this problem as a critical path item would have been helpful. Additionally there is no discussion of existing high temperature Raman probes that are available and how the product resulting from this project differs from them.

*Reviewer 2:*

Monitoring the quality of the salt in MSTower plants is important! It helps understand corrosion and what contaminants are in the system.

**Project Title:** Development of Novel Alloys Identified by High-Throughput Computational Methods for Use in Concentrated Solar Power Components

**Award Number:** 17758

**Principal Investigator:** Corn, Isaac, HiFunda LLC

**Project Description:**

HiFunda and Brigham Young University will develop new improved alloy materials based on high-throughput computational analysis for use in high temperature corrosive applications such as concentrating solar power, nuclear reactors, turbines and aircraft components.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is consistent to some degree with the SETO goals though there was a lack of details regarding the possible economic and overall impact. They are addressing just one of many concurrent issues and the ultimate success of this project will depend on a variety of factors outside their control. One major concern is that they are limited to ternary alloys which may prove to be a fatal limitation.

*Reviewer 2:*

This project has some relevance to SETO's goal to drive down costs of CSP-generated electricity toward 2030 cost targets and supports the reliability and resilience of the U.S. electric grid.

Specifically alloys used in conjunction with molten salt heat sinks to enable CSP require high corrosion resistance. This project aims to identify additional alloy materials that are more corrosion resistant than commercially existing alloys through high-throughput computational models. The ultimate goal of corrosion resistant alloys could reduce costs if such materials require less replacement of alloy-based components in the use of CSP plants or if the alloys developed are less expensive than those currently commercially available. Once the technology is commercialized, more cost effective CSP could play a role in providing additional reliability and resilience to the US electric grid.

*Reviewer 3:*

This is longer range basic research. It may find a cheap super alloy to be used by CSP in the future.

**Project Title:** Integration of Battery Modeling with Solar Building Energy Storage

**Award Number:** 17794

**Principal Investigator:** Frogner, Bjorn, Battery Informatics

**Project Description:**

This project is developing software that will improve the economics of using lithium ion batteries for energy storage in the context of energy management of buildings. The solution will allow customers to offer battery installations that will provide 10 to 20 percent more value than current solutions.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This project is related to achieving a reduction in overall LCOE of PV systems with storage. Because of the continued reduction in energy storage cost, storage systems will continue to increase in value to PV systems, especially for microgrids, applications at customer sites and resilience of the grid. For this type of project good coordination between the Vehicle Technology Office, Office of Electricity, Building Integration and SETO is important because each office has a role to play in the energy storage space.

*Reviewer 2:*

Lowering the LCOE for rechargeable lithium ion batteries will help drive solar/storage project deployment through overall cost reductions.

*Reviewer 3:*

The central premise, batteries are not correctly modelled, seems to me dubious. Billions of dollars are spent each year developing batteries. Even if Bjorn has a novel idea here, and I do not see it, his ability to thoroughly test a physical model under many operating conditions seems suspect. I do not think this is an idea that Bjorn can commercialize though his published paper on his physical model findings may be of some interest.

**Project Title:** Mobile In-situ Imaging of Photovoltaic Modules

**Award Number:** 17851

**Principal Investigator:** Horner, Greg, Tau Science Corporation

**Project Description:**

The nation's electric grid depends upon the reliable generation of electricity, and as solar modules are added in greater numbers, they require unique inspection and qualification techniques. This project will develop a non-contact scanner that can operate at night in solar fields to detect various failure and degradation modes.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Reliability is a key aspect of electricity from solar. Mobile in-situ imaging of PV module is therefore a technology to identify degraded cell or cells in a module encompassed in a PV system. This is contactless technology, which is very flexible and universal for any size of PV system.

*Reviewer 2:*

Module reliability in the field will directly impact the grid resilience within the US. Identifying these failure modes can greatly assist manufacturers in identifying flaws which can be used to manufacture more reliable modules. This in turn will reduce the cost of manufacturing (reducing returns, failures etc...) which also addresses SETO's goals of module cost reduction.

*Reviewer 3:*

It is consistent with SETO's goal of reducing LCOE by assisting effective management of cost of capitals. It would be a useful and cost effective tool for evaluation of solar panels installed and provide input to the financial model.

**Project Title:** Predictive Module Degradation and Failure Identification Solution

**Award Number:** 17872

**Principal Investigator:** Elmes, John, Advanced Power Electronics Corporation

**Project Description:**

This research is focused on the development of a highly capable photovoltaic module diagnostics technology that can be integrated into existing solar power system components. The diagnostics system will greatly improve the efficiency and effectiveness of long term solar system operation and maintenance.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This proposed method of monitoring PV panel degradation is promising. By being able to determine PV panel degradation, will allow project owners to manage their O&M which is an increasing portion of their project cost because of hardware cost is decreasing.

*Reviewer 2:*

As stated in the project scope, a significant challenge to the larger scale adoption and investment in distributed photovoltaic (PV) generation is the inherent annual operation and maintenance (O&M) cost due to degradation and eventual failure of PV modules. Diligent O&M of solar energy projects is crucial for success of the project over the long term to ensure maximum energy generation. The PV system owner as well as the customer of the energy production (if not one and the same) should require a robust O&M program - including preventive maintenance. "By allowing for system managers, installers and manufacturers to have advance knowledge of pending module failure and degradation, the planned maintenance/replacement resources can be optimized to reduce the "reactionary" O&M costs," this project appears to support the objectives of any PV system owner. And this project if successful will help to identify problem/faulty modules before they completely fail therefore preventing lost kWh production.

*Reviewer 3:*

The project is consistent with SETO's goal of cost reduction for wider penetration of PV. It allows the PV project owners manage their operation more effectively.

**Project Title:** Automatic Reference for Empirical Soiling

**Award Number:** 17882

**Principal Investigator:** Lewis, Scott, Fracsun

**Project Description:**

The accumulation of dirt on solar panels has drastic, but measurable, effects on the performance of solar arrays. This project will focus on developing and manufacturing a device that addresses this issue by measuring the dirt accumulation and calculating the best day to wash the solar array.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

This product identifies the optimum output level and can mitigate the effects of soiling by identifying when to clean the panels. These all fall within SETO's goals of reducing the cost of solar electricity by maintaining a high level of output throughout the life of the system.

*Reviewer 2:*

This project aims to reduce the loss of energy and revenue from operating solar assets due to soiling. The program involves deployment of 10 prototype devices that compare solar irradiance across two cells, a daily cleaned "reference" cell and a cell in ambient conditions. Algorithms analyzing this data then help to optimize timing and need for cleaning of the array as a whole.

This work reduces LCOE of deployed PV and is well aligned with DOE's SETO goals.

*Reviewer 3:*

This project goes directly towards one of the key SETO goals of reducing cost (LCOE) but may also touch grid resilience by providing more stable power.

**Project Title:** Solar Building Energy Storage Management

**Award Number:** 18167

**Principal Investigator:** Moussa, Albert, Blazetech

**Project Description:**

The adoption of electrical energy storage technologies in the power systems can play a vital role in improving the grid stability and resiliency. Thus, developing a robust energy management software is crucial for a widespread deployment of energy storage systems along with distributed energy resources.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

Blazetech is intended to reduce the potential for grid disruptions thus promoting the use of battery storage and the smooth growth of the renewable and distributed energy industries which are the goals of DOE. So although the project may not directly reduce the cost of PV, it may help support the areas of grid stability which should allow more PV to be accommodated on the grid. However, the payback period of 18 years does not directly align with SETO's intention of achieving goals by 2030.

*Reviewer 2:*

The project appropriately supports enhanced reliability and resilience of the grid through improved microgrid management tools.

*Reviewer 3:*

It seems that a standard for secure and dedicated distributed building and DER management communication would be very important. Are there no standards bodies working on this now?



**Project Title:** Solar Technology Cost Modeling and Competitive Analysis

**Award Number:** 29839

**Principal Investigator:** Margolis, Robert, National Renewable Energy Laboratory

**Project Description:**

This project uses bottom-up techno-economic cost modeling to both benchmark current technology and system costs, and to inform the potential commercial impacts of technology development and system installation improvement pathways. In combination with economic studies of critical materials supply-demand dynamics and possible price trajectories, this project also examines the potential impact to dependent module technology costs and deployment levels.

**Reviewer Evaluation on Projects' Impact on SETO Goals:**

*Reviewer 1:*

The “independent” cost benchmarking analysis provided by NREL are critical resources for a broad range of programs under the SETO/EERE umbrella and provide important objective/impartial data for analysis and validation by a broad range of stakeholders.

*Reviewer 2:*

No correlation.

*Reviewer 3:*

I can understand the need for this function but I cannot see how it fits in with the stated SETO goals nor the T2M goals that are designed to “develop and validate groundbreaking, early-stage technology and business models to strengthen concepts and develop a path to accelerate innovations to the market.” In addition, in reviewing many posters and discussing with the presenters, it did not seem to me that this service was used by any of the presenters I spoke with. The cost seems very high.