$1/W Photovoltaic Systems

Workshop Summary

Workshop Summary and Background

On August 11 and 12, 2010, the United States Department of Energy (DOE) held a workshop in Washington, DC aimed at identifying approaches to reduce the cost of installed solar photovoltaic (PV) systems to $1 per watt ("$1/W") by 2017.

The workshop brought together experts in PV technology, along with experts in parallel and orthogonal fields to brainstorm highly novel technology approaches to break through techno-economic barriers to achieving $1/W PV. The workshop attendees included a combination of representatives from the US government (primarily from the DOE), as well as academia and industry.

The workshop consisted of introductory comments and discussion, a series of breakout discussions (around the topics of modules, power electronics and installation/BOS) and then a plenary session to discuss the breakout sessions, ways of optimizing the integration of PV systems (among the topics of discussion) and management approaches to undertake a dedicated cost reduction effort.

Introductory Remarks

Introductory comments were made by Energy Secretary Dr. Steven Chu and Assistant Secretary for Energy Efficiency and Renewable Energy Cathy Zoi.

Secretary Chu discussed the urgency of developing the solar industry in the light of the dangers of climate change and the need to reduce greenhouse gases. He mentioned that if we can achieve $1/W then the cost of solar electricity can be competitive with conventional sources. He identified the agriculture industry as an area where innovation in the 20th century transformed the way the industry worked versus the 19th century. He encouraged the group to challenge conventions in the PV industry as it seeks to find ways to reduce cost.

Assistant Secretary Zoi discussed the very good work that is going on in solar R&D in the US, but mentioned that incremental improvements are not enough to meet the $1/W goal by 2017. More radical approaches are needed. It might not be one silver bullet, but a wide variety of cost reductions that taken together achieve the goal. She pointed out Toyota's ability to reduce 125 different cost items associated with meeting a management cost target to enter the US market.

Overall Takeaways of the Workshop

For the purposes of discussion during the workshop, the $1/W goal was broken down into targets of $0.50/W for modules, $0.10/W for power electronics and $0.40/W installation and remaining balance of system (BOS) costs. Overall, the general sentiment within the group was that while the target of $1/W installed cost by 2017 was very ambitious, it was possible to achieve given adequate resources, though there was no discussion of precise likelihood. A minority within the group did think that the goal was overly ambitious or was the wrong goal to be focusing on. Below are summary reports from each of the breakout sessions:

Modules

Overall, the group thought that while the target of $0.50/W module cost by 2017 was very ambitious, it was possible to achieve. The three most likely technologies to achieve this goal are thin films, crystalline silicon and concentrating photovoltaics (CPV). To achieve commercial production by 2017, however, the technology has to be at the proof of concept stage now. Other emerging technologies, by contrast, represented technologies that have good prospects, but may not achieve the 2017 target. The group identified seven module cost reduction ideas that had the potential of meeting the $0.50/W target by 2017. The group agreed that in order to reach $0.50/W module cost, the cell cost would likely need to be about $0.25/W for silicon technologies. Generally speaking, this meant achieving 20% cell efficiency in the case of crystalline silicon and thin films in addition to other cost reduction measures. Initial targets of 25% module efficiency outlined by the DOE was thought by many in the audience to be overly prescriptive and unnecessary, especially if the Balance of System costs can be scaled faster than modeled.

Power Electronics

The breakout group concluded that reaching the DOE cost target is feasible for centralized power conversion by leveraging technology advances in motor drives. Assuming today's cost for centralized power electronic is $0.20/W, the breakout group estimated that economies of scale in production could deliver a $.05/W reduction and use of higher frequency switching another $.03-.04/W reduction. The group concluded that to reach the DOE cost target for power electronics by using micro- or mini-converters in a decentralized configuration high-volume production (e.g., millions of units) would be necessary. To achieve scale manufacturing, the group indicated that converter components will require better integration to potentially fit on a single substrate. In addition, the breakout group concluded that adding reactive power capability to power conversion is relatively inexpensive and will likely become a mandatory feature to deal with voltage control and other grid reliability services. The breakout group also discussed alternative power electronic architectures. Cell-level maximum power point tracking with a string-level converter was highlighted due to its potential to improve energy harvest.

BOS/Installation

The majority of the cost reduction opportunities indentified by the BOS/Installation breakout group were design-focused. Advanced design optimization algorithms are needed. Typically, few PV system components, including modules and inverters, have been designed and manufactured to reduce overall system costs. Optimization has occurred at each stage of the value chain, but seldom across the value chain. Solar system designers and installers generally have to take module and inverter form factors as a given and then optimize installation and BOS costs around those constraints. It is likely that significant system cost reduction will occur in dozens, if not hundreds, of areas as opposed to there being one major cost reduction area. A major utility-scale PV system installer indicated that for a 20MW+ plant currently under construction, 45 of 63 cost items cost less than $0.02/W, and total about $0.25/W.

The sections below are a summary of the results of the module, power electronics and installation/BOS breakout sessions.

Module Breakout Summary

Summary

Overall, the group thought that while the target of $0.50/W module cost by 2017 was very ambitious, it was possible to achieve. The three most likely technologies to achieve this goal are thin films, crystalline silicon and CPV. To achieve commercial production by 2017, however, the technology has to be at the proof of concept stage now. Other emerging technologies by contrast, likely represented technologies that have good prospects, but may not achieve the 2017 target.

The group agreed that to reach $0.50/W module cost, the cell cost would likely need to be about $0.25/W for silicon technologies.

The group identified seven module cost reduction opportunities that represented the best opportunities in terms of technical feasibility and impact, with cell design dominating the discussion. The group thought that all seven opportunities had the chance of reaching the $0.50/W target though the precise likelihood of achieving this and the resources required were not discussed.

Framework and Approach

The module breakout group identified cost reduction opportunities in four broad categories as follows: (1) crystalline silicon, (2) thin film, (3) concentrating PV (CPV), and (4) emerging/non-traditional. Initially, in the brainstorming phase of the process, the group spent approximately an equal amount of time on each category. Seven major categories of technologies arose from the group discussion.

Top Seven Cost Reduction Opportunities

The top seven cost reduction opportunities identified by the group were as follows (technology category in parentheses):

Kerfless Wafers (Crystalline Silicon) – This idea involves eliminating kerf loss – the loss of silicon resulting from the wire sawing step, much like the sawdust that falls from cutting wood. The group's idea involved:

- reducing the amount of silicon to 2 grams/Watt (from about 7 gram/Watt today for most c-si processes);
- achieving less than 150 micron wafer thickness; and
- meeting or exceeding current module efficiencies.

A key technical challenge would be to make the wafer compatible with existing manufacturing processes, so that the new technology could be used as an augmentation to proven manufacturing technology and processes. The kerfless wafer, in most respects, should resemble wafers currently used in the majority of the silicon solar panels produced today. The lifetime of the wafer would be 100 microseconds or greater (an indication of the quality of the wafer). As wafer thickness reduces, absorption of light by the indirect semiconductor silicon can be another technical barrier to high efficiency and so light trapping methods need to be developed; thin wafers are also relatively fragile, impacting yield. The group felt that it was possible to achieve $0.25/W wafer cost and $0.50/W module cost with this idea.

Film Silicon (Crystalline Silicon) – This idea is similar to kerfless wafering mentioned above as a way to significantly reduce silicon materials utilization but is considered a category in itself because of the degree of dimensional scaling. Film silicon could be considered approaches where the absorbing silicon layer is on the order of 50 microns or less. The target module efficiency should meet or exceed current silicon modules. High purity silicon would aid in getting a high quality wafer. The ability to handle ultrathin silicon films or wafers without breakage, including the incorporation of a new superstrate material, would be of great importance. Again, process compatibility would be important. A new manufacturing process involving new equipment would need to be developed to manufacture this ultrathin solar cell. As wafer thickness reduces, absorption of light by the indirect semiconductor silicon can be another technical barrier to high efficiency; at 50 micron thickness, silicon is relatively flexible, which may help yield.

1-Sun Tandem (Crystalline Silicon) – This idea involves high efficiency (towards 30%) modules with near 2 eV top cell layered on silicon. This could be achieved with a >20% efficiency of the top cell. The main technical challenges include achieving high lifetime, low defect rate; low recombination at the interfaces, passivation; incorporating cheap, earth abundant materials and density for wide band gap; and tunnel junction optical vs. conductivity tradeoffs.

20% Polycrystalline Thin Film (Thin Film) – This idea involves achieving 20% cell efficiency with earth abundant or very thin materials through a single junction cell, or potentially higher with a tandem cell. The technology could be any of the thin film technologies including cadmium telluride (CdTe), amorphous-silicon (A-Si), copper indium gallium selenide (CIGS), or III-V GaAs-based. There are numerous technical improvements and developments that are required to improve efficiency including better metrology, homogeneity, stoichiometry, automation, and manufacturing process control. In addition, more research and development needs to be done in the area of materials, doping and defects. One key technical challenge is material quality (impurities, structural)/lifetime and manufacturing cost vs. efficiency tradeoffs.

25% Single Crystalline Thin Film (Thin Films) – This idea is similar to the prior except that it involves single crystal rather than multi-crystal structures and a higher cell efficiency target of 25%. Though laboratory demonstrations of thin III-V cells have already demonstrated over 26% efficiency, this technology has never been done before on a large scale and thus, achieving large scale production at the targeted production cost is the greatest technical challenge. Low cost deposition techniques and layer transfer processes would need to be developed and debugged at commercial scale. Special attention to handling ultrathin cells would be required. This idea would require low defect density, high lifetime and passivation. These thin films also provide the potential for flexible PV.

High efficiency low cost CPV (CPV) – This idea involves high efficiency (50% at cell level; 40% at module level) CPV technology. This opportunity requires numerous technological improvements such as low cost wiring at the module level; >500x concentration; and cost efficient and reliable 2-axis trackers. It would also require scale for low cost module assembly. Further challenges include optics cost vs. quality tradeoffs, and cell reliability vs. cost tradeoffs.

Alternative CPV approaches - One of the great challenges of Concentrating Photovoltaics is thermal management. Micro-concentration and low-Sun concentration are two different approaches to solving the problem. With micro-concentration, many more CPV cells are used but each is smaller in size and therefore have lower heat load which may be solved with passive dissipation. With low-Sun concentration conventional silicon solar cells can be used with minimal, if any additional heat sinking.

Other Discussion Topics

<u>Glass vs. Flexible Substrates</u>

The group discussed the difference between flat plate glass and flexible substrates. While flat plate glass may ultimately be more expensive than flexible substrates, they have a much longer track record (leading to a more “bankable” product), the group felt that flexible substrates, particularly those using roll-to-roll manufacturing processes could offer improved costs in the future. On the other hand, flexible substrates are only achieving efficiencies in the 11% range today, meaning that significant technology needs to be solved to get to the higher efficiencies and lower costs. The heavier weight of glass means that it can be used on fewer rooftops compared to the lower weight flexible substrates, not to mention that lighter materials typically lead to lower installation costs. Using thinner glass would improve this situation.

<u>Module Form Factors</u>

The group discussed module form factors, that is, the physical size and shape of the module and how that could impact the cost of the overall PV system. This was later a significant topic of discussion with the BOS/installation group. While form factors didn’t necessarily play into the cost of the module itself, it was seen as a major opportunity to reduce cost for BOS/installation through standardization of size across the industry.

<u>Other Technologies</u>

None of the top 7 cost reduction ideas were in the emerging / non-traditional category. However, several thoughts were mentioned in this section. These ideas included the following:

- Phosphorescent films with 1 photon to 2 photon processes (wavelength shifter) for up to 10% relative improvement in efficiency
- Micro and nanowire silicon to for ultra light trapping and efficient utilization of semiconductor
- Thin glass for more UV transmission and possibly higher efficiency
- Moisture/O_2 impermeable polymeric ultrabarriers

Power Electronics Breakout Summary

Summary

The breakout group looked at reaching the cost goals of $0.10/W for power electronics from a centralized and decentralized perspective. Power conversion that happens primarily at a centralized point could potentially be achieved by leveraging technology in motor drives. Assuming today's cost for centralized power electronic is $0.20/W, the breakout group estimated that economies of scale in production could deliver a $0.05/W reduction and the use of higher frequency switching may achieve another $0.03-0.04/W reduction. In order to achieve the DOE power electronics cost target in a decentralized configuration (using by micro- or mini-converters), the group concluded that high-volume production (e.g., millions of units) would be necessary. To achieve scale manufacturing, the group indicated that converter components will require better integration to potentially fit on a single substrate. In addition, the breakout group concluded that adding reactive power capability to power conversion is relatively inexpensive and will likely become a mandatory feature in order to provide voltage support and other grid reliability services. The breakout group also discussed alternative power electronic architectures. Cell-level maximum power point tracking with a string-level converter was highlighted due to its potential to improve energy harvest.

Framework and Approach

The Power Electronics breakout group approached the identification of cost reduction opportunities through a framework that took into account different power electronics architectures. The main architectures discussed were centralized and decentralized. Centralized power electronic architecture was defined as power conversion that happens primarily at a centralized point. Decentralized power electronic architecture was defined as power conversion that happens in a distributed manner by micro- or mini-converters. For each of these architectures the group discussed how to reduce first cost, improve reliability to 30 years, and integrate smart grid functionality, as well as the implications of changes to power electronics on overall PV system cost (e.g., adjacency impacts). In addition, the group brainstormed alternative architectures for PV system power electronics to deliver cost reduction. The three hour discussion included nearly a dozen participants. The conversation was focused on multi-MW utility-scale PV systems.

Centralized Power Electronics

<u>Reduce first cost</u>: The breakout group concluded that reaching the DOE cost target is feasible for centralized power electronics by aiming for the cost level of and leveraging technology in motor drives. The two main cost component reductions identified were 1) economies of scale in production (e.g., 10,000 units of 500kW size) and 2) use of higher frequency switching (i.e., 80% reduction of passive components which represent over 30% of converter cost). Assuming today's cost for centralized power electronic is $0.20/W, the breakout group estimate that the former could deliver a $0.05/W reduction and the later a $0.03-0.04/W reduction (although switching losses may go up with higher frequency switching requiring use of more expensive silicon carbon switches). Developing self-commissioning systems was discussed as a way of reducing "dead on arrival" failure rates, which were thought to represent a majority of the failures seen over the lifetime of power electronics in PV systems.

<u>Improve reliability</u>: The breakout group discussed the trade-off between cost and reliability and concluded that it might be more cost effective to regularly service power electronics equipment than build for 30 years of reliability. One participant stated that utility transformers last well over 40 years but they are maintained regularly. Several reliability issues were identified and discussed. First, solder

joints fail due to thermal cycling of IGBT which could be addressed by using smaller die with less thermal expansion and improving thermal packaging. Second, the inductance of the packaging leads to over-voltage failure which could be addressed by redesigning packaging to tolerate over-voltage situations.

Integrate smart-grid functionality: The breakout group concluded that adding reactive power capability is relatively inexpensive and will likely become a mandatory feature in order to provide voltage support and other grid reliability services. The trend toward PV systems being required to have reactive power capability was validated in the plenary discussion by another participant. The group indicated that a PV system could provide reactive power even when it is at full output by over-sizing the power electronics 10%. The group estimated functionality to dispatch storage capacity could add $.06-.07/W due to addition of a bi-directional converter with DC-DC capability (excluding storage cost). This would add functionality to the system and was viewed by the group as an optional feature.

Decentralized Power Electronics

Reduce first cost: The group concluded that high-volume production (e.g., millions of units) would be necessary for micro/mini-converters in a decentralized configuration to reach the DOE cost target . To achieve scale manufacturing, the group indicated that converter components will require better integration, including the integration of magnetic components, gate drivers and power switches. Some approaches to improving component integration were discussed including, using wide band gap materials, such as gallium nitride (GaN), to integrate bigger portion of circuit on silicon substrate, having high- and low-voltage electronics on same substrate, and reducing magnetic core losses with new materials (e.g., nano-crystalline). In addition, the group discussed the importance of reducing the packaging cost for mico/mini-converters which represents 25% of first cost by both improving converter efficiency and increasing switching frequency. Finally, the group identified two additional technology improvements that could enable and drive down the cost of micro/mini-converters for utility-scale application: 1) developing 3-phase micro-inverter for utility scale, and 2) developing relatively low-cost and high-voltage switches.

Improve reliability: Given the limited field experience of micro/mini-converters, the group discussed the importance of monitoring systems currently in service and developing tools and analytics to predict failures. The group also considered the need to investigate the reliability of electrolytic capacitors due to potential for limited lifetimes at high temperature and the range of available products.

Integrate smart-grid functionality: The breakout group agreed that similar to centralized converters, reactive power is relatively inexpensive to incorporate. The group concluded that approaches for incorporating storage in the decentralized architecture were not clear. In the plenary session, one participant indicated that advances in storage technologies could enable storage options at the module-level. The group identified the challenge for micro-converters as coordinating thousands of converters, with which the smart grid could assist.

Alternative Architectures

The breakout group discussed three main alternative architectures.

Alternative 1: Cell-level maximum power point tracking with a string-level converter. The main advantage of this architecture identified by the breakout group is to improve energy harvest. Cell-level conversion could help mitigate issues such as shunting caused by variability in cell material, as may occur with less mature photovoltaic technologies (e.g., alternatives to crystalline silicon). The challenge is determining how to inexpensively co-package DC-DC converters with the PV cell. The benefit-cost of this approach would need to be examined.

Alterative 2: High voltage DC system. The main advantage of this architecture identified by the breakout group is that the DOE's cost target could be met today with existing technology. The challenge is the lack of high voltage feeder lines with which to interconnect.

Alternative 3: Local high-voltage DC micro-grid (5kV). The main advantages of this architecture identified by the breakout group relate the higher voltage and subsequent use of less wiring and less expensive electronics. However, the main challenges include lack of demand for DC power (even in a micro-grid setting) and safety concerns.

BOS/Installation Breakout Summary

Summary

The majority of the cost reduction opportunities indentified by the BOS/Installation breakout group were design-focused. Advanced design optimization algorithms are needed. Typically, few PV system components, including modules and inverters, have been designed and manufactured to reduce overall system costs. Optimization has occurred at each stage of the value chain but seldom across the value chain. Solar system designers and installers generally have to take module and inverter form factors as a given and then optimize installation and BOS costs around those constraints. It is likely that significant system cost reduction will occur in dozens if not hundreds of areas, as opposed to there being one major cost reduction area. A major utility-scale PV system installer indicated that for a 20MW+ plant currently under construction, 45 of 63 cost items cost less than \$0.02/W, and total ~\$0.25/W. This reflects an example cited by Assistant Secretary for Energy Efficiency and Renewable Energy Cathy Zoi in which Toyota reduced costs in hundreds of areas to meet a management cost target for the U.S. market.

Framework and Approach

The BOS/Installation breakout group approached the identification of cost reduction opportunities through a framework that took into account PV market segments and value chain stages. Market segments included residential, commercial, and utility-scale. The first two of these were considered markets for roof-mounted systems with capacities of 2-20kW and 20kW-1MW respectively. Utility-scale scale systems, for the purposes of this exercise, were considered ground-mounted systems with a capacity of greater than 10 MW. The three high-level value chain stages used to frame the discussion were materials, system design, and installation. The breakout group utilized a matrix composed of these market segments and value chain stages to stimulate dialogue and to ensure coverage of cost reduction opportunities across a broad range of system sizes and types.

Cross-Segment Opportunities

The breakout group identified some cost reduction opportunities that spanned both roof-mounted and ground-mounted systems. These will be referred to as cross-segment opportunities. The group identified two high-level cross-segment cost reduction opportunities, both of which were design-based. First, the group identified an opportunity to develop and deploy more flexible and sophisticated solar system and process design customization tools. Second, the breakout group agreed that there was an opportunity to design plug-and-play wiring and installation.

In terms of the design tools, these improved solar-specific tools would be leveraged to accomplish a number of objectives. They would be used to develop optimized systems that are not over-engineered to withstand worst case scenarios. There is an opportunity to design a resilient system that suffers some temporary pullback under extreme conditions and then bounces back when conditions improve rather than designing the system for the worst possible scenario that occurs at most once a year. Design tools would be used to design systems that better take into account wind loads (i.e. wind spoiling, “shock absorption”). For instance, façades on a building could act as a spoiler. However, according to current building codes, it is not permitted to use existing structures for this. The solar-specific design tools would also be used to design systems that optimize the split between pre-assembly vs. onsite assembly as well as on-ground assembly vs. on-roof assembly. The tools would leverage six-sigma-like process technology, similar to that used for lean manufacturing. While the breakout group believed these improved design tools would be of great value, it was unclear if the business case would be sufficiently attractive for software developers. In terms of designing plug-and-play wiring and installation, the group felt that such an effort may not drive down total system costs all that much.

Additional production steps and additional components involved in making systems plug-and-play (e.g. embedding wires in rails) could offset any cost savings during installation.

Roof-Mount Opportunities

While the cross-segment cost reduction opportunities focused solely on design improvements, the roof-mount opportunities also included potential improvements in materials usage and installation methods. Nevertheless, the design-focused opportunities were the greatest in number.

First, the group identified an opportunity to aggregate BIPV with windows or façades to "share" PV cost with other building costs. There were, however, a number of challenges involved with this opportunity. There may be a training barrier for roofers if BIPV systems were significantly different than conventional roofing materials. Also, when incorporated into a façade, PV systems could have sub-optimal orientation for energy production. The second design-focused opportunity for roof-mount systems was to standardize module extrusions to easily "snap" to top mounting rails. The breakout group believed there was also an opportunity to reduce design costs through streamlined standards and regulations across geographies. The fragmented nature of standards and regulations increases the number of system designs and subsequently the design cost for system integrators and installers. Another design-focused opportunity was to reduce the costs necessary to communicate PV system performance data from the system to a remote database. The wireless technologies currently used for data transfer can add significantly to system costs. Finally, the breakout group identified an opportunity to reduce wiring costs by utilizing wireless power transfer via magnetic-field coupling. While this technology has been demonstrated on a limited scale, significant technical challenges remain.

In addition to the design-focused cost reduction opportunities for roof-mounted PV systems, the breakout group also identified some material- and installation-focused opportunities. The group believed that mounting and racking costs could be reduced by utilizing adhesives or Velcro-like material rather than ballasts to anchor modules. As adhesives would likely require flat installation, this opportunity would be more appropriate for commercial installations. In terms of reducing installation costs, the breakout group identified two opportunities: Developing and deploying standardized workforce safety techniques (e.g. anchoring) and leveraging specialized ground-to-roof hoisting equipment. Raising materials from the ground level up onto the roof and removing waste materials from the roof can be very labor intensive.

Ground-Mount Opportunities

For ground-mount systems, the breakout group identified material- and installation-based cost reduction opportunities. In terms of materials, the group believed that there was a need to break the dependence on the traditional commodity value chain (e.g. steel, aluminum, concrete) by developing and using new, solar-optimized materials. For example, most of the aluminum used to today was designed with specifications for the aerospace industry. In terms of installation methods, the group discussed the need for automation. By utilizing automated machinery and/or robotics, similar to that used in the agriculture sector, to drive piles and to place modules, installation costs could be significantly reduced. In Germany, a 10 MW system had all of its pillars driven by a GPS-guided robot. However, as with the solar-specific design software identified in the cross-segment opportunities, it is unclear whether a market would be sufficiently attractive for producers to develop and manufacture the needed machinery. In addition, there is a concern that government-led job-creation incentives may not promote higher installation efficiency and automation. Another opportunity for reducing installation time cost as well as for reducing theft was to replace various mechanical fasteners with welds. One disadvantage of this approach, however, is that welds may complicate system maintenance and/or component replacement.

Optimization across the Value Chain

Discussions about the interfaces of the three breakout areas (modules, power electronics, BOS/installation) and ways to optimize these interfaces were held. A summary of the discussion follows.

Modules – BOS/Installation Interface

This discussion revolved mainly around form factor, that is, the physical size and shape of the module and how that could impact the cost of the overall PV system. It also touched on the ability of modules to withstand harsh field conditions (wind and high temperature).

The BOS group wanted to achieve mass customization but is faced with standard parts from module suppliers. Flexible, smaller scale cells would help significantly. Right now, the installers respond to what the module suppliers provide them but if modules were more amenable to form factor customization, it would reduce the installation/BOS costs (though it may increase module costs, so the tradeoffs would have to be evaluated).

Today, installers need to design systems to withstand worst-case weather conditions. If the module or array could somehow have shock-absorbing capabilities, that would reduce cost because the system could be designed to lower standards. Also, higher temperature tolerant substrates would lower BOS costs and extend system life.

If the module were able to handle windy conditions better, then it would make a difference in the BOS materials that you would have to use and thereby, reduce cost.

Though it was acknowledged to be a long shot, wireless power transmission would get rid of wiring cost and roof penetrations.

There was some discussion around the fact that higher efficiency modules result in lower BOS/installation costs. Approximately 60% of BOS/installation costs are impacted by module efficiency.

Finally, a participant mentioned that the lighter the module, the less expensive it is to transport and install.

Module – Power Electronics Interface

A participant highlighted the importance to cost reduction of more broadly enabling 1,000 volt systems for utility-scale applications. This could require coordination with the National Electric Code.

Another participant added that appropriately designed micro-converters have the potential to suppress hot spots and further enhance module performance.

BOS/Installation – Power Electronics Interface

The group discussed two main changes in centralized power electronics that could reduce the cost of other system components. First, operating power electronics at a higher voltage would drive out system wire cost. Second, incorporating higher frequency switching or moving to transformer-less designs will reduce converter size and weight. Later in the plenary discussion it was validated that smaller and lighter converters will drive down multiple BOS costs, by specifically reducing shipping cost, getting rid of the road for a crane, lowering height of the inverter structure, and reducing foundation cost.

The group agreed that decentralized power electronics could increase system yield 4 to 8%, reducing all system components and related costs (including the converter). In addition, moving from a DC system to a 3-phase AC system could lower the cost of wiring, protection features and labor.

Potential $1/W program structures

Principle Deputy Assistant Secretary Dr. Henry Kelly led a discussion of different organizational structures that would be most efficient at channeling resources and research in solving the problems identified as barriers to $1/W systems. Parallels were drawn to other times when scientists and engineers were asked to solve problems of great national importance such as during the Manhattan Project or the Apollo program. Organizations built around those challenges were discussed. Other types of organizations such as Sematech as a parallel to the integrated circuit industry were also debated. The Sematech model of horizontal cooperation between multiple companies occupying similar positions along the value chain was very contentious with some participants. Some were strongly against horizontal consortia as an organizational solution to solving the $1/W challenge. Many believed that the PV industry is too dissimilar to the integrated circuit industry for the Sematech model to work. As opposed to horizontal partnerships, workshop participants were generally supportive of vertical partnerships up and down the PV value chain similar to those supported by DOE’s Technology Pathway Partnership program. Participants generally felt that close partnerships among companies in different vertical positions along the PV value chain would be best at delivering a systems solution to the $1/W challenge.

Attendees

Last Name	First Name	Organization
Alivisatos	Paul	Lawrence Berkeley Labs
Anderson	Tracy	3M Corporation
Armstrong	Joseph	Ascent Solar
Atwater	Harry	Caltech
Baldwin	Sam	U.S. Dept. of Energy
Bennett	Helen	Department of Resources, Energy and Tourism, Australia
Bhattacharya	Subhashish	North Carolina State University
Blair	Peter	National Academy of Sciences
Borak	Brian	Booz Allen Hamilton
Buonassisi	Tonio	MIT
Cagle	Dawson	Booz Allen Hamilton
Campbell	Matthew	Sun Power Corp.
Casey	Leo	Satcon Technology Corporation
Chen	Gang	MIT
Chu	Steven	U.S. Dept. of Energy
Conner	Bob	Semprius
Cummings	Eric	Cool Earth Solar
Danielson	David	U.S. Dept. of Energy - ARPA-E
Deich	Jason	DARPA
Doig	Stephen	Rocky Mountain Institute
Duty	Chad	Oak Ridge National Lab
Eberspacher	Chris	Applied Materials, Inc.
Fornage	Martin	Enphase Energy
Frantzis	Lisa	Navigant Consulting, Inc.
Freilich	Steven	DuPont Central Research & Development
Gamota	Daniel	Printovate Technologies, Inc.
Gay	Charles	Applied Materials, Inc.
Goodrich	Al	NREL
Gopstein	Avi	U.S. Dept. of Energy
Graham	Shannon	Navigant Consulting, Inc.
Grider	David	Cree, Inc.
Griffith	Saul	Otherlab
Gross	William	Idealab
Gur	Ilan	Seeo, Inc.
Hanley	Charlie	Sandia National Laboratories
Hefner	Allen	National Institute of Standards & Technology
Jacoby	Maria	Booz Allen Hamilton

Last Name	First Name	Organization
Johnson	Mark	U.S. Dept. of Energy - ARPA-E
Kelly	Henry	U.S. Dept. of Energy
Key	Tom	EPRI
Kinross	Andrew	Navigant Consulting, Inc.
Kranich	Brian	Schletter
Krein	Philip	University of Illinois
Kuenzel	Sven	Schletter Inc.
Kung	Harriet	U.S. Dept. of Energy
LaSala	John	Corning Incorporated
Le	Minh	U.S. Dept. of Energy
Lushetsky	John	U.S. Dept. of Energy
Lynn	Kevin	U.S. Dept. of Energy
Maracas	George	National Science Foundation
Margolis	Robert	National Renewable Energy Lab
Merfeld	Danielle	GE Global Research
Michael	Christopher	Booz Allen Hamilton
Ngo	Khai	Virginia Tech
Noufi	Rommel	NREL
Palmieri	Jane	Dow Chemical
Parrillo	David	The Dow Chemical Company
Perreault	David	M.I.T.
Peterson	Thomas	National Science Foundation
Petri	Mark	Argonne National Laboratory
Pourdeyhimi	Benham	NCSU
Raffaelle	Ryne	NREL
Ram	Rajeev	ARPA-E
Redmond	Cybil	Booz Allen Hamilton
Rive	Peter	SolarCity
Sachs	Emanuel	1366 Technologies
Sadana	Devendra	IBM
Seidel	Ed	National Science Foundation
Sekaric	Lidija	U.S. Department of Energy
Selvamanickam	Venkat	University of Houston
Shah	Monisha	NREL
Shugar	Dan	Daniel S. Shugar
Sullivan	Charles	Dartmouth College
Swanson	Dick	SunPower Corporation
Utley	Tana	Caterpillar
Wadia	Cyrus	White House OSTP
Wickless	Andy	Navigant Consulting, Inc.

Last Name	First Name	Organization
Yee	Shannon	ARPA-E
Zank	Gregg	Dow Corning Corporation
Zeira	Eitan	Konarka
Zoi	Cathy	U.S. Dept. of Energy
Zweibel	Ken	GW Solar Institute