2009 DOE Solar Energy Technologies Program Peer Review Results
March 11, 2009

Executive Summary

The DOE Solar Energy Technologies Program convened a meeting of solar experts, DOE program staff and key laboratory staff on March 11, 2009 to review the Solar Energy Technologies Program and provide suggestions on current program issues, future challenges to the program and potential actions. Participants in the meeting and the format of the discussion are explained in Appendix A. The meeting immediately followed two days of project-level peer review. The timing was designed to maximize the insights and information the reviewers and staff developed from participating in the project-level review.

DOE program staff also presented information on the program's organization, goals and resources, followed by a presentation by review chairman Joseph Morabito, Director of the Integrated Robust Design and Compliance Engineering Center for Alcatel/Lucent. Morabito explained issues affecting the larger context of solar industry development. This presentation included an illustration that helped focus the discussion: a Senge diagram of the solar industry's value creation. In particular, the graphic highlighted the three leverage points of Systems Dynamic Modeling, Solar Energy Grid Integration Systems (SEGIS) and a Solar Industry Supply Chain Consortium. The illustration is show in Figure 1.

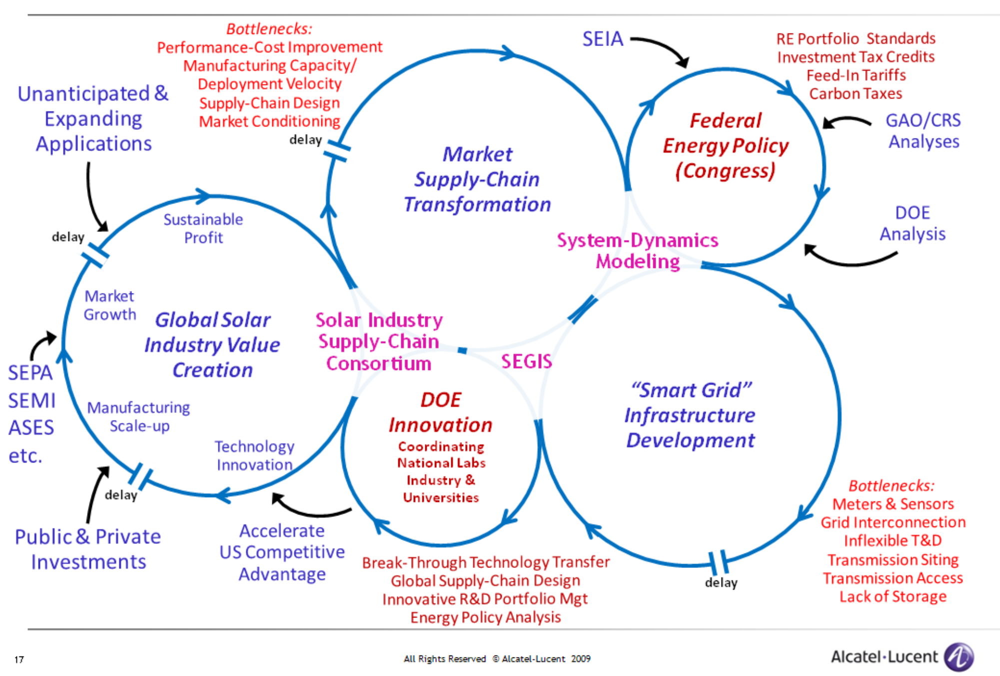

Figure 1: Senge Diagram of System-Focused Solar Industry Development

John Lushetsky, who had just moved from Program Manager for Solar to Acting Deputy Assistant Secretary for Energy Efficiency, led the program side of the discussion. Morabito led the discussion and input from outside reviewers.

Consistent with DOE/EERE's guidance and best practices for peer review, there was no requirement for the group to reach a consensus on recommendations. The following documentation includes all the major topics and discussion at the meeting. However, as the results show, there was actually a high degree of agreement on major observations and suggestions. Key recommendations are summarized in the first three bullets below, while some more specific recommendations are captured in the last.

- An industry consortium is necessary to work on standardization and collaborative research opportunities, starting with PV manufacturing equipment (especially in-line diagnostics and tools for maximizing yield). This is envisioned to be similar to Sematech's role in the semiconductor industry and its influence on that industry's supply chain.
- Enhanced collaboration combining DOE and industry with universities, other agencies, utilities and international researchers and companies is needed to better leverage knowledge and capabilities. The industry needs to "win" interdisciplinary support for the aggressive solar technology development and deployment that will be necessary to have an impact on global energy production and the environment. They should also continue to develop the solar industry's future workforce. This is particularly important in addressing systems integration issues that are likely to become a roadblock to solar development.
- Improved and expanded systems modeling is needed in several areas so that researchers, industry and top decision makers in key markets have detailed information on topics such as:
    - resource forecasting,
    - research investments and performance goals for emerging technologies,
    - benefits and barriers to large-scale solar deployment, and
    - up-to-date and credible metrics that highlight solar's advantages and make technology and environmental comparisons quantifiable.
- Additional comments and recommendations:
    - Much of the focus seems to be on module costs, with not enough work on balance of systems and other costs that are becoming increasingly important.
    - Demonstration and market transformation projects need better measures of success for public outreach, and for tracking progress as systems are installed.
    - Deployment capacity and workforce development will need more attention.
    - Stronger alliances with groups like EIA should be developed to disseminate results and give metrics greater independence and credibility. The quantitative

definition of sustainability presented by Joe Morabito is an approach that improves comparability between industries and technologies. Failure to have that comparison ability is the source of many challenges with metrics.

While the peer review is an essential part of SETP's evaluative process, the results are not considered the sole indicator of any particular project's success or failure, nor does the review alone determine whether a project will receive continued, additional or reduced funding. The review is a critical opportunity to gain insight from external peers and industry professionals and to open discussion about areas of continued and future focus for the program. It is not a solitary measure of progress, however, and this report is intended to be read with that in mind.

Detailed Results

Solar Industry Consortium

The industry consortium concept focused on manufacturing line equipment for crystalline silicon (cSi) technologies and their supply chains. This technology currently leads the market and is more mature and less complicated by intellectual property issues than thin films or III-V. There is common interest in standardizing processing and handling equipment in order to gain economies of scale from equipment and material suppliers. Participants at the review felt that cSi manufacturers can set an example with an effective consortium for other technologies to emulate, particularly thin film and III-V. Reviewers recognize, though, thought it may be more difficult for thin-films or III-V producers to create or successfully manage a consortium as quickly, since manufacturers in those technologies remain concerned with protecting their intellectual property. The leading firms that have products on the market have less interest in helping competitors in any way. Some observers noted that companies may be overestimating the value of protecting their trade secrets compared to what could be gained through collaboration; successful first steps by a consortium could persuade them to become involved.

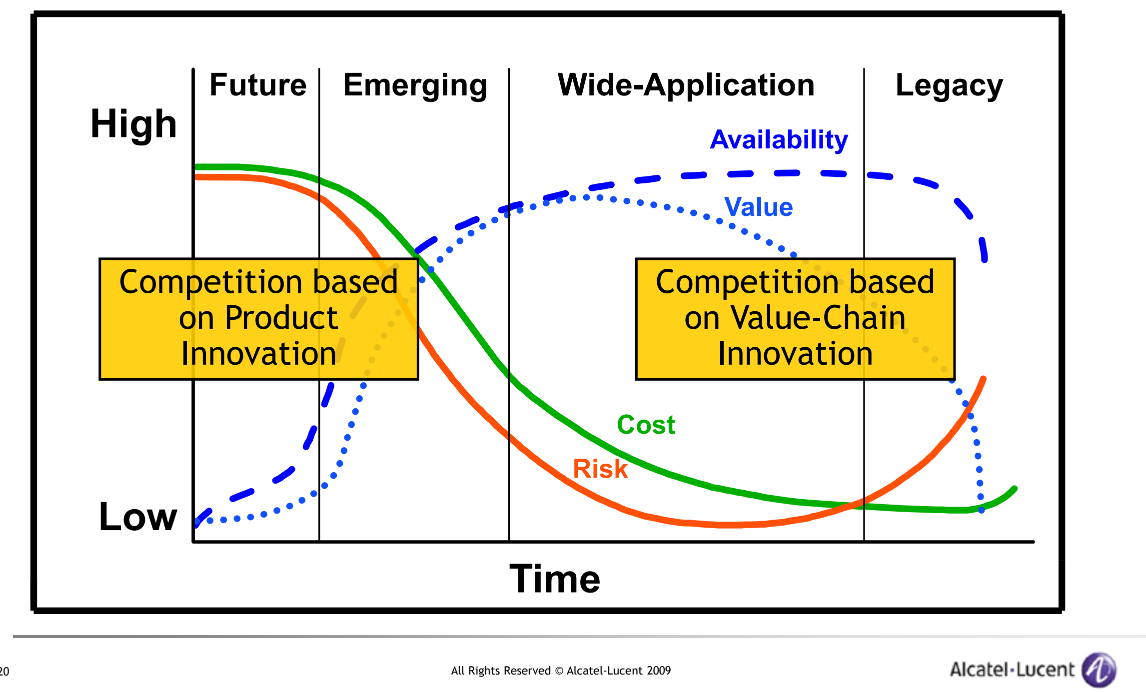

Figure 2: Technology Life Cycle Factors

Figure 2 illustrates technology life cycle factors discussed by Joe Morabito. Over 300 different technologies/product lifecycles were analyzed to produce this chart. The curves are not theoretical; they illustrate that cost and risk decline as technologies move from being classified as “future” to “emerging,” and then from wide application to legacy. The value to the company that introduces the products increases in the early stages, and then peaks as the technology moves from emerging to wide application. A sharp decline in value occurs as the product moves completely into wide application and then into legacy status.

In the future and emerging stages of commercialization, competition is based on product innovation, as competitors vie to perfect the product’s features, performance and cost through advancements in design and manufacturing. As a product’s features and performance become established and manufacturing processes stabilize, competition shifts to value-chain innovation. Dominance in the wide application and legacy stages of a product’s lifecycle goes to the competitors who are most adept at assembling raw materials and components and integrating them with manufacturing processes and delivery to supply the best value at lowest cost.

U.S. companies who were most resourceful in optimizing speed, reliability, and materials usage in semiconductors were once able to dominate sales of products like Random Access Memory (RAM). Now that RAM is a well-established technology, production is dominated by Asian manufacturers who have been able to create flexible, high-volume, low-cost manufacturing and delivery. Crystalline silicon wafer, cell and module production are moving into the wide application phase, as are many CSP components. Thin films like CdTe are still emerging, but moving quickly to wide application. Concentrators, organic PV, dye-cell and other technologies are still in the future/emerging stages of development. It is important to understand where solar technologies are in their life cycle and how to focus research and development on issues that are the most relevant to solar energy’s success and a strong U.S. solar industry. As solar technologies move toward competition based on value-chains in supply and manufacturing, the issues an industry consortium can address become more important.

Based on these discussions, a PV Sematech to develop a roadmap of standards and goals for equipment was recommended, and is ultimately where Sematech succeeded. Sematech started with an emphasis on processes, but that effort soon slowed because of intellectual property issues concerning different manufacturers’ formulations and methods. It is likely that a PV consortium would also break down quickly right now, because of each company’s “secret recipe” for materials and cells; when competition is defined by a company’s ability to innovate, collaboration is more difficult. Sematech found its first success as a collaborative effort in equipment standards and goals, which are also competitively important but less likely to be proprietary. That will probably be the case for PV as well. Aggressive goals for manufacturing line equipment can feed into the PV supply chain, including tools to effectively monitor and optimize manufacturing yields. Another suggested manufacturing focus was in-line diagnostics, which can identify deviations in process parameters that degrade product reliability or performance. Identifying defects during the manufacturing process rather than end-of-the-line can help avoid major production losses.

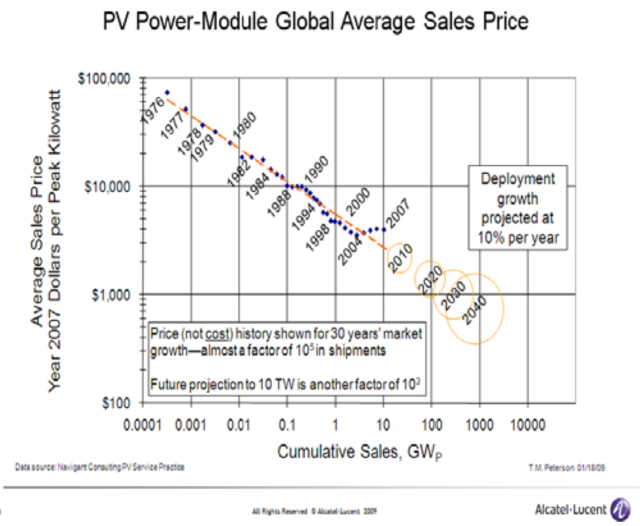

Figure 3: PV Price and Installations, 10% Growth Curve

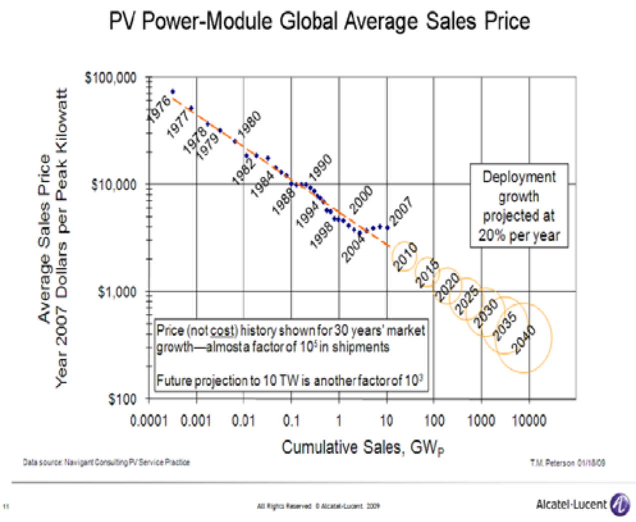

Figure 4: PV Price and Installation, 20% Growth Curve

Participants in the review felt that supply chain issues are going to be increasingly important if PV is to maintain the growth rate necessary to have a significant impact on global energy use. Figure 3 and 4 are from Joe Morabito's presentation. They show the implications of a 10% (Figure 2) versus a 20% (Figure 3) growth curve on PV capacity over time: 10 TW by 2040 vs. 1 TW by 2040.

The group had fewer suggestions on the role DOE can or should play in initiating a consortium. DOE's investment in extensive industry roadmapping may be a starting point to work with industry on an ongoing collaboration that would keep technology goals up to date and enable action. It was suggested that a consortium effort might be centered on the Process Device Integration Laboratory (PDIL) and NREL's measurement and characterization group, which reviewers felt would give the effort the objective technical expertise needed to form a consensus on standardization issues.

Enhanced Collaboration

Although the group's discussion focused on key external audiences or stakeholders, a common theme was enhancing the Solar Program's efforts to work in partnership with these groups and leverage their capabilities. The main groups discussed, roughly in the order of priority and attention focused on each group, were universities, utilities, international researchers and institutions, and other state and federal agencies.

Universities

The discussion about universities evolved during feedback in the tracks that had the most university involvement: Nanostructures and Quantum Dots Research, and Exploratory Research. When DOE initially moved into the SAI and the Technology Pathway Partnerships, there was an emphasis on universities partnering with industry. Reviewers felt that this put industry research high on the priority list, while limiting the access independent universities had to funding. Recently, though, the solar program has expanded opportunities for university research, and reviewers were in support of this effort. Reviewers noted one critical role of university research as that of a training ground for the future workforce in solar - particularly important given the imminent retirement of many top researchers in DOE's labs and in the universities.

University research can also inject fresh perspectives into problems and produce results that are more widely shared and accessible than research by industry. Industry research projects in the peer review were the least forthcoming with results for the panelists to review – a symptom of the closed, proprietary approach industry tends to take. By comparison, universities tend to be committed to publication of results, as well as rigorous peer review. Reviewers felt that there should be more public dissemination of research results, particularly in emerging technologies. This will help broaden the base of research and ensure that researchers aren't duplicating efforts simply because they aren't aware of what other researchers are doing.

Although reviewers overall like the idea of university research playing a role in DOE's solar efforts, there was concern with the quality and management of university and other basic research. First, the peer reviewers who saw those projects felt that some of the work bears little relationship to the cost and performance goals of the Solar Energy Technologies Program. In some cases, reviewers wondered whether the research efforts could ever lead to practical devices. It may be high-quality and interesting work, but it might be more appropriate for funding by the Office of Science or another source designed to support pure scientific research that is less concerned with practical application. The group recommended that DOE apply some of its systems modeling efforts to emerging technologies like dye-sensitized cells, quantum dots and inorganic materials to define broad cost, efficiency and durability parameters that researchers and the program can use to judge the viability of such research. It is acceptable for research in emerging technologies to conclude that a given material or process won't work, as long as there are clear metrics and processes to abandon poor pathways.

A second concern related to university research is identifying research that is not aggressive enough, is redundant, or is reaffirming previously noted barriers and limitations without suggesting any new solutions. Particularly in dye-sensitized research, reviewers felt that some projects seemed to be replicating results that have already been achieved and reported by foreign companies and researchers; U.S. researchers seem to be playing catch-up, but with no clear plan to then *surpass*.

One suggested remedy for these challenges is to increase communication and information-sharing in the university and industry research community. To do so, DOE may need to revive forums like the thin-film partnerships or make activities like the peer review more extensive. More opportunities for universities to work with DOE lab personnel and their facilities was also recommended for workforce development benefits, as a way to improve the quality of university research, and to enhance communication and collaboration among researchers.

There also needs to be more communication with other sources of research funding and research performance to identify duplications and gaps in research. This is where the group recommended that DOE forge closer ties and participate in more technical events with other DOE and Federal agencies (Office of Science, EIA, OE, NASA, DoD); international researchers and companies (IEA and individual country research labs, European and Japanese trade associations); and state agencies (NYSERDA, CEC). Well beyond research in emerging technologies, DOE could also learn (and teach) a lot from their experience in:

- deployment,
- testing and certification,
- workforce development, and
- grid integration at higher penetration rates.

Utilities

Utilities were a key topic in two of the leverage points: systems dynamic modeling and SEGIS (grid integration). As the two luncheon speakers on Day 1 and 2 of the peer review emphasized, solar energy's future with utilities is subject to debate. Robert Hemphill of AES Solar made a strong case that solar will have to compete with central station generation and on the same terms as fossil fuels when it comes to dispatch and reliability. Steve Hauser presented a different view of solar and renewable energy integrated with a smart grid, where solar will play a role in the future as both a distributed resource and a large-scale central application.

One of the utility participants in the peer review noted that the program's cost assumptions for the residential, commercial and utility sectors are subject to change. Utilities are building more of their costs into fixed charges to consumers and allowing less variance based on consumption. As another variation on Joe Morabito's chart on PV learning and growth curves shows in Figure 5, utility acceptance of significant grid penetration is essential and the problem is not very far in the future.

Given the critical importance of utilities and their regulators for both CSP and PV the group strongly supported the program's work in SEGIS and the outreach efforts in Market Transformation. DOE should consider being even more proactive. The group suggested that DOE dedicate more of its system dynamics modeling efforts to grid integration forecasting and issues, and that they engage utilities more actively in the modeling and examining the results. There are only a few hundred top decision makers in the countries among major utilities and their regulators, and this is the audience DOE should try to reach. Closer cooperation with EIA and other outside groups in forecasting and modeling would enhance the Solar Program's results by reducing the perception that the analysis may be skewed to what solar advocates want to find. Elements of effective modeling would include resource forecasting and its implications for reliability across service territories, siting opportunities if utilities have to pay carbon costs, and how integration of storage technologies or combinations of different renewable energy technologies can most effectively shape load and power factors.

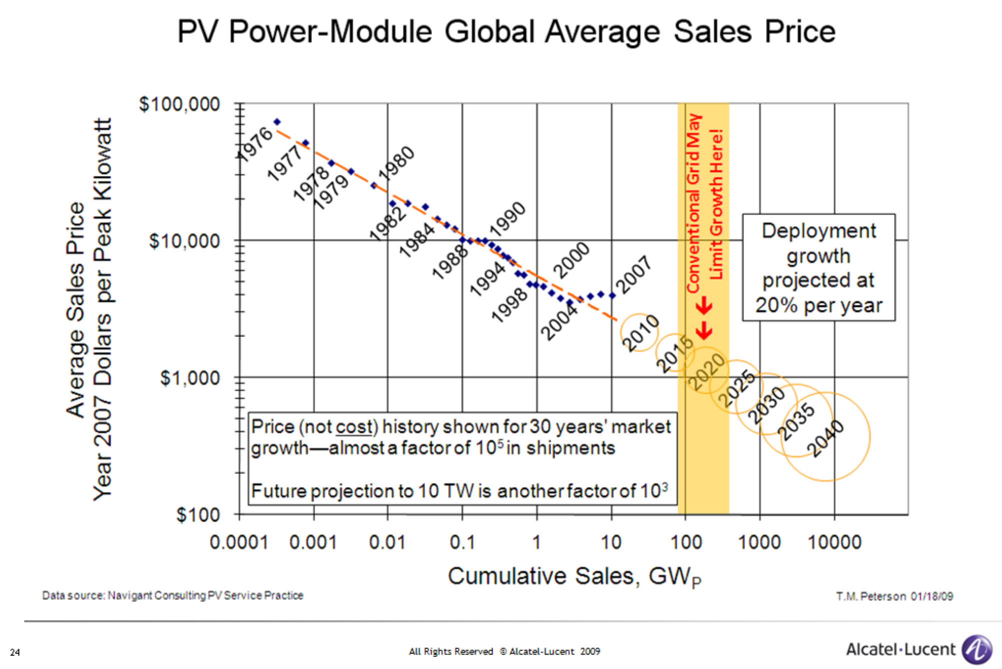

Figure 5: Grid Penetration Limits on PV Growth

Systems Dynamics and Modeling

The recommendations for systems dynamics and modeling recognized the growing investment in this work and the value it has already produced. The comments and recommendations focused more on emerging issues where DOE should consider new or enhanced effort.

As noted in the discussion of enhanced collaboration with utilities, resource forecasting needs to be improved in anticipation of higher grid penetration. Models are needed to understand and ameliorate the local variations in solar resource and solar system output by examining how solar resources, PV systems and the grid interact on a wider geographical scale. Understanding these problems in greater detail and modeling the interactions can help researchers develop grid operating strategies and approaches to combining solar with other technologies like storage or demand management. These steps can help reduce the impact of resource variations on the grid and customers.

Expanded systems dynamics and modeling efforts for emerging technologies are needed to better understand performance requirements, applications and market conditions that could lead to commercialization of these technologies, such as dye-sensitized cells, inorganics, and novel concentrators. The emphasis should be on creating tools that can explore scenarios and pathways to commercial development, including applications or products that are different from the paths taken with currently commercial thin films, crystalline silicon and established CSP technologies. This work would provide researchers with parameters to use in judging emerging technology research plans and accomplishments. This area of DOE research needs clearer objectives and performance measures.

Understanding and communicating benefits and barriers to large-scale solar deployment is also closely related to enhancing utility collaboration, in the context of grid integration issues. However, the group also considered this issue from the larger vantage point of understanding and explaining solar energy to a wide range of decision makers. The focus of the discussion was Joe Morabito's presentation material on defining sustainability and using quantitative methods to compare the sustainability of technologies and industries.[1] Sustainability is often invoked to support solar and other renewable energy technologies, but it tends to be loosely defined, and sustainability is rarely quantified. The most widely used methodology quantifies sustainability and makes it a comparative metric by relating economic value – measured in dollars, just like GNP – to the carrying capacity of the environment for emissions.

Figure 6 shows an example that relates global economic output ($25.4 trillion/year) to global carrying capacity for carbon emissions (8.6 trillion kg Global Warming Potential[GWP]), which is the maximum amount of carbon that can be emitted if climate change is going to be managed effectively according to IPCC analysis. This results in a measure of sustainable productivity of $3/kg GWP. If a business or industry's economic output is less than $3/kg of GWP it emits, its production is not sustainable – that is, its economic impact is not worth the environmental damage it causes, or its actual versus sustainable production is less than 100%. Looked at in these terms, the problem becomes a business challenge, not an academic exercise or theoretical

[1] Work done in collaboration with David Dickinson. Additional technical papers and examples of the methodology will be available on the 2009 Solar Energy Technologies Program Peer Review website.

discussion of sustainability. Figure 6 shows the results of an analysis of the telecommunications and other industries and their carbon emissions in relation to climate carrying capacity. However, the approach has also been applied to other emissions and environmental problems. This method can analyze any emission that has been studied sufficiently enough that there is an identified carrying capacity; i.e., the maximum the environment can absorb of that pollutant and still provide the necessary environmental services.

INDUSTRY DATA | **STM**

LCA

ICT	Avg. No. Units Oper. (mid-2006)	Direct CO2 Emissions (% World)	Total CO2 Equivalents (% World)	Revenue / GDP (% World)	EP (%): Eco-Performance * %GDP / $\%CO_2$	EE (%): Eco-Efficiency * %GDP / %ECC
Mobile Telecom	2.4 Bil. Subs.	0.18	0.12	1.6 (.08)	1100	440
Fixed Telecom	1.3 Bil. Fix. Lns. 220 Mil. BB Lns.	0.3	0.2	2.5 (.08)	1000	400
PCs	950 Mil. PCs	0.8	0.5			
Data Networks	31.5 Mil. Serv.	0.6	0.4	3 (0.3)	600	240
TOTAL:	--	1.9	1.2	7 (0.17)	452	181
Entertainment& Media	1.7 Bil. TV, Disc, Portables, etc.	2.7	2	5 (0.4)	213	92
Transport& Travel	Cars, Trucks, Ships, Aircraft	23	15 - 20	11	54	22
Air Travel / Transport	20K+ Civilian Aircraft	2.8	3 - 8	1.3	31	12
Food & Drink	--	15	20 - 30	11	27	11
Buildings	--	~ 50	~ 33	~ 20	48	19

* Preliminary EP and EE for demonstration, assuming Revenue to be the cumulative economic value resulting solely from the CO_2 emissions tabulated by the source company and that valid basic world GDP and emission data were used.
* Carrying Capacity (ECC), based on IPCC analysis, is world CO_2 emission reduced by a factor of about 2.5.

Alcatel·Lucent

Figure 6: Telecommunications Industry Eco-Efficiency Analysis

For the solar program, using systems dynamics and modeling efforts to quantify the eco-efficiency of solar technologies would help highlight technology options or improvements that research could support to enhance sustainable production. It also provides a quantitative economic basis for responding to environmental and economic comparisons with other energy technologies and industries.

Additional Comments and Suggestions

Additional comments and suggestions addressed changing industry needs and subsequent adaptations the program should consider. The group noted that the program focuses primarily on module costs, with not enough work on balance of systems and other costs that are becoming increasingly important. Demonstration and market transformation projects need better measures of success for public outreach, and for tracking progress as systems are installed. As markets grow and incentives expand, deployment capacity and workforce development will need more attention. Finally, stronger alliances with groups like EIA should be developed to disseminate results and give metrics greater independence and credibility. The quantitative definition of sustainability presented by Joe Morabito is an approach that improves comparability between industries and technologies, which is the source of many problems with current metrics.

Appendix A: Structure of Program Review and Participants

The program review followed two days of project-level peer review that evaluated over 100 research projects funded by the Solar Program, organized into the following ten tracks:

- Exploratory Research
- Nano Materials/Technology and Quantum Dots
- Supporting Research
- Thin Films
- III-V and Concentrator Technology
- Crystalline Silicon
- Evaluation, Validation and Analysis
- Market Transformation
- Demonstrations
- Concentrating Solar Power

Each track had a panel of independent, outside peer reviewers selected by the independent peer review chairperson, Joe Morabito. Each panel was led by a Group Leader, selected on the breadth of their expertise in the field they were reviewing and their broader knowledge of solar energy issues. Each Group Leader attended the program-level peer review, partially to represent the views of their panel and partially to act as an independent observer of the solar program. The group leaders, DOE, Laboratory and support staff who attended the program review are listed on the following page.

First Name	Last Name	Organization
Joe	Morabito	Alcatel/Lucent, Peer Review Chair
John	Lushetsky	Department of Energy (DOE) HQ, Solar Program Manager
Marie	Mapes	DOE HQ, Peer Review Manager
Tien	Duong	DOE HQ
Carolyn	Elam	DOE Golden Field Office (Colorado)
Charles	Hemmeline	DOE HQ
Tom	Kimbis	DOE HQ
Thomas	Rueckert	DOE HQ
Scott	Stephens	DOE HQ
Dan	Ton	DOE HQ
Frank (Tex)	Wilkins	DOE HQ
Charles	Hanley	Sandia National Laboratories (SNL)
Tom	Mancini	SNL
Roland	Hulstrom	National Renewable Energy Laboratory (NREL)
Robert	Margolis	NREL (Washington, DC)
Mark	Mehos	NREL
Sheila	Bailey	National Aviation and Space Administration (NASA)
Manuel	Blanco	CENER (Spain)
Nerine	Cherepy	Lawrence Livermore National Laboratories
Terry	Jester	Hudson Clean Energy Partners
Mark	Kapner	Austin Energy
Jeffrey	Peterson	NYSERDA
Terry	Peterson	Consultant, Solar Power and Green Power Marketing, for EPRI and CEC
Richard	Schwartz	Purdue University
Greg	Smestad	Ed., Solar Energy Materials and Solar Cells
Ed	Witt	Retired NREL
Kevin	DeGroat	Antares Group Support Contractor
Christopher	Lindsey	Antares Group Support Contractor

The review began with presentations on the program and its structure, followed by a presentation by Joe Morabito that more broadly examined solar industry development, challenges and opportunities. In the afternoon, discussion was organized around questions of vision and strategy; management, quality and productivity of the program; and opportunities and challenges, as shown in the agenda:

Solar Program Peer Review Agenda Overview

<u>Wednesday, March 11</u>

8:00 – 8:30 a.m.	Welcome, Announcements
8:00 – 8:30 a.m.	Coffee, General Discussion
8:30 – 8:50 a.m.	**Solar Program Mission, Vision, Organization Overview** John Lushetsky
8:50 – 9:00 a.m.	Questions and Answers (Q&A)
9:00 – 9:20 a.m.	**Solar Energy: Market Trends and Dynamics** Robert Margolis
9:20 – 9:30 a.m.	Q&A

PANEL: Solar Program Managers

9:30 – 9:45 a.m.	Photovoltaics, TBD
9:45 – 10:00 a.m.	CSP, Tex Wilkins
10:00 – 10:15 a.m.	Grid Integration, Dan Ton
10:15 – 10:30 a.m.	Market Transformation, Tom Kimbis
10:30 – 10:45 a.m.	**BREAK**
10:45 – 11:15 a.m.	Q&A for Panel
11:15 – 11:30 a.m.	Morning Wrap-Up and Instructions, Facilitator
11:30 a.m. – 1:00 p.m.	**Luncheon Speaker: Joe Morabito, Peer Review Chair**
1:00 – 5:00 p.m.	**Topical Discussions**
1:00 – 2:30 p.m.	*Vision and Strategy (Relevance)*

- Are we missing anything in our understanding of the market and the context for solar development? Are we missing anything in our strategy for accomplishing our goals? For example, are we or should we be doing more with international applications and collaboration?
- Is the program sufficient? Are the goals we have set enough to make the kind of impact that matters? Is LCOE enough, or is it just a starting point for moving the industry to Global, Sustained Value Creation at a level that makes a significant impact on energy and the environment? What is our position (and impact) on job creation, pro and con? Will solar be on the scale of the automobile industry when all is said and done, or on the scale of the motorcycle industry based on our strategy?
- Where does the DOE program's responsibility end and the responsibility of other players pick up? If DOE can't do everything, what can it do and what is most important? For instance, what can or should DOE do in building industry collaboration beyond our current

work?

- Where do we fit in the broader renewable energy and energy policy issues facing the world? Should we be pushing harder for measures such as eco-efficiency that better define the value of PV in comparison with other technologies and options?

2:30 – 2:45 p.m. **BREAK**

2:45 – 4:00 p.m. *Management, Quality, Productivity and Accomplishments*

- Are our research portfolio, the resources we have allocated, and the priorities we have established covering our leverage points? Are there elements missing that DOE should consider? Will the research and goals move us fast enough to have the impact we want?
- Where should DOE lead, where should DOE encourage, and where should DOE follow? DOE has limited resources and a limited charter, but within those bounds are we engaging the rest of the community effectively? Are there areas for collaboration we are missing?
- Do the elements of the program fit together and complement each other – all pushing together on the key leverage points and spinning the gears faster? Are we missing any key gears/leverage points?

4:00 – 5:00 p.m. *Opportunities/Challenges*

- What opportunities/challenges are coming? Are we facing challenges in manufacturing, in workforce development, international competition and markets, etc.? What could surprise the industry, pleasantly or unpleasantly?
- Where does DOE fit in the broad context of solar industry development, and what can we realistically recommend?
- Given what DOE can realistically achieve and what is being recommended, are there important things outside of DOE's purview that are missing? Are these critical and is there any way to address them?

5:00 – 5:30 p.m. *Summarizing, Next Steps*