Soft Costs in Solar Photovoltaics and Concentrated Solar Power[1]

Background Paper for "Solar Soft Cost Reductions in PV and CSP: Mapping the Opportunities"
Workshop on April 25th, 2015

1. Introduction

In the wake of recent significant declines in solar photovoltaic (PV) module costs, soft costs associated with solar energy are increasingly a focus of research and action by government, academia, and industry. Soft costs, also sometimes referred to as non-hardware balance of system (BOS) costs or business process costs, include marketing and customer acquisition, system design, installation labor, permitting, inspection, profit, and overhead (Barbose et al. 2014; Friedman et al. 2013). According to research conducted by the National Renewable Energy Laboratory (NREL), soft costs for photovoltaics in the US comprised, on average, 64% of the cost of residential PV installations, 57% of small commercial installations, and 52% of large commercial installations in 2012 (Friedman et al. 2013). This percentage has grown substantially in recent years as the cost of solar modules has declined relative to overall soft costs, which have not declined as significantly (Barbose et al. 2014).

Recent research suggests that the path to substantial further reductions in installed solar power system costs will have to come in large part from soft cost reductions. For example, the SunShot Initiative at the US Department of Energy aims to reach by 2020: $1/watt for utility scale PV, $1.25/watt for commercial scale PV, $1.50/watt for residential scale PV, and $0.06/kWh for concentrated solar power (CSP). This goal is based on an analysis of the approximate price points necessary to enable a massive scale-up of solar energy in the United States (EERE 2012). Currently, overall prices for solar energy systems in the United States are approximately $3.29/watt for residential scale PV, $2.54/watt for commercial scale PV, $1.80/watt for utility-scale PV, and $.13/kWh (Feldman et al. 2014; Sunshot Initiative 2014). Achieving this goal will be impossible if soft costs do not decline substantially, a situation made more urgent by the fact that analysts currently expect no significant additional cost reductions for modules in the near future (Feldman et al. 2014). Achieving the SunShot Initiative's goals in 5 years from now will require further reductions in module and other hardware costs from ~$1.00-2.50 today (depending on system size) to $.80-$1.00 in 2020 and reductions in soft costs from ~$.80-2.00 today to $.20-.50 in 2020 (EERE 2012; SunShot Initiative 2014; Feldman et al. 2014).

International comparisons between the US and more mature solar markets like Germany offer one measure of the potential for major domestic soft cost reductions (Seel et al. 2012). Currently, the soft costs of German residential-scale PV systems are significantly lower than those in the United States, at around $.33. This cost disparity is largely driven by differences in permitting, inspection, interconnection, and customer acquisition costs (RMI 2013). The path to significant soft cost reductions in the complex regulatory, technological, and market environment of the United States is highly uncertain in many respects, however (Ardani et al. 2013). Figure 1 shows recent US solar cost trends, highlighting the stagnation of balance of system costs (which include soft and hard components) relative to rapid module and inverter cost reductions.

1 This document was prepared by Miles Brundage and Clark Miller as background material for the "Solar Soft Cost Reductions in PV and CSP: Mapping the Opportunities" workshop on April 25th, 2015, in Tempe, AZ. Please contact Miles Brundage (miles.brundage@asu.edu) with any questions or comments on the document.

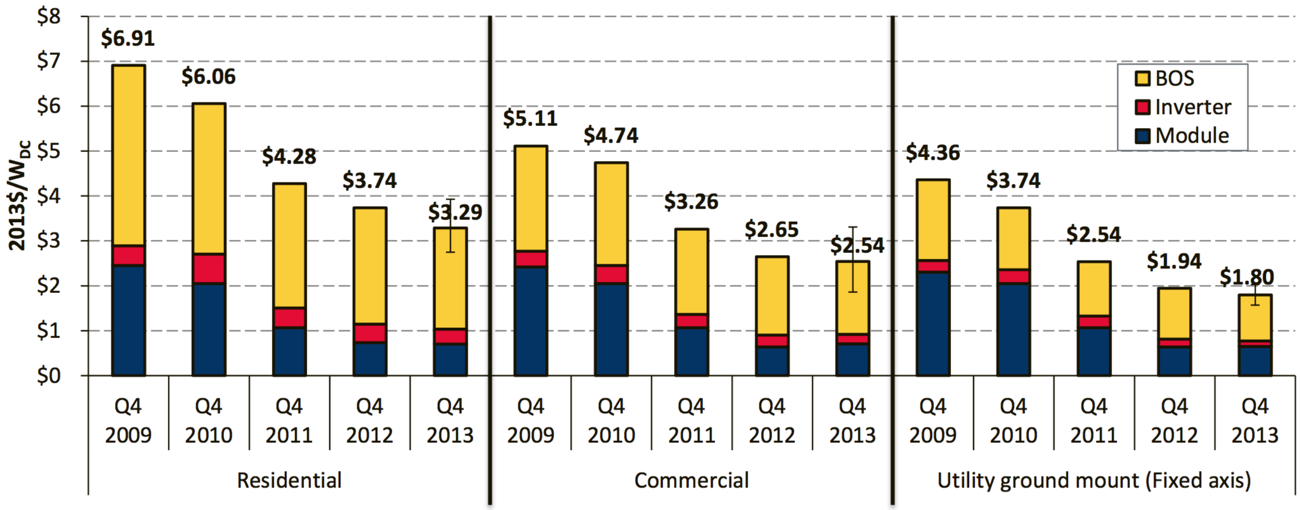

Figure 1: Recent PV Cost Trends (Feldman et al. 2014). Note that BOS (balance of system) includes hard and soft costs.

Independent of the SunShot Initiative's goals, there are three reasons the future of solar soft costs needs to be better understood and more proactively shaped. First, impending policy changes such as the expiration of the federal investment tax credit (ITC) for solar energy in 2016 portend significant challenges for the industry. Soft cost reduction may be critical to enabling continued rapid growth in PV installations as subsidies decline in the near future. Between 1998 and 2013, subsidies for solar energy were reduced concurrently with module cost reductions (Barbose et al. 2014). This long-term pattern, when juxtaposed with the potential for module costs to remain steady in the next few years, means that the industry may see short-term price increases for systems unless soft costs can be significantly reduced. If the ITC expires as currently scheduled, businesses that were highly profitable in part due to the ITC will face reduced margins, and those with lower margins may go out of business, if innovative approaches to cost reduction are not pursued.

Second, the solar soft costs reduction question is intimately related to the future of the utility sector in the United States. The utility sector is facing disruptive competition due to a combination of technological, business, social, and other forms of innovation underway that have accelerated the adoption of distributed solar energy (Graffy and Kihm 2014). This issue has been highly politically controversial, as utilities in states such as Arizona have sought to impose surcharges on adopters of PV systems. As utilities and other stakeholders in the US system of energy production and consumption seek to navigate this landscape, an informed understanding of the nature and scope of future soft cost reductions is urgently needed for planning purposes. For example, if soft costs drop significantly faster than currently expected by industry analysts (as happened with module costs in the past), utilities may see faster than expected rates of solar installations and unanticipated challenges to grid stability. Moreover, plans for the future construction of new fossil fuel and nuclear-based power plants in order to satisfy consumer electricity demand may need to be revisited depending on the scope of possible future soft cost reductions and associated increases in the rate of solar energy adoption.

Third, as elaborated in Section 6 of this document ("Ethical and Political Perspectives on Soft Cost Reductions"), solar soft costs represent a wide range of human activities, and efforts to reduce them will have myriad impacts on individuals and institutions. Innovations aimed at reducing soft costs will affect, for example, the quantity and quality of jobs in the solar industry. It is imperative, therefore, to think ahead about both what is possible and what is desirable with respect to future soft cost reductions, and to account for the diverse needs and values of different localities when developing technological, business, policy, and other innovations aimed at reducing soft costs in the US and worldwide.

The remainder of this document is organized as follows. First, a brief note will clarify the role of CSP relative to PV in this discussion. Second, the recent history of hard and soft costs in solar energy will be summarized, clarifying the necessity of soft cost reductions if overall system costs are to continue declining significantly. Third, examples are given of current efforts to reduce soft costs. Fourth, relevant literature that bears on the nature of the challenges and opportunities ahead will be summarized. Fifth, ethical and political questions raised by significant soft cost reductions will be explored. Finally, the paper concludes by highlighting key open questions to be addressed at the "Solar Soft Cost Reductions in PV and CSP: Mapping the Opportunities" workshop on April 25th, 2015.

2. A Note on PV versus CSP

The precipitous decline in PV module prices has raised serious questions about the future of CSP, which is now significantly more expensive than PV and is not being deployed as widely as PV systems are (Gaspar 2013). CSP retains various advantages over PV such as lending itself more naturally to energy storage (e.g. in the form of molten salt) and its lesser dependence on scarce materials and components. These characteristics of CSP enable it to dispatch energy into the night and to be built largely from domestically obtainable commodity materials in a wide range of countries (Brundage 2014). Whether these advantages will result in CSP gaining market share relative to PV in the future may depend in part on how different types of costs can be reduced for both technologies.

Some of the same soft cost categories (e.g. environmental assessment of large plant development) are applicable to both PV and CSP. However, overall CSP costs remain more dominated by hard costs than are PV installations, for which hard costs have declined more significantly in recent years. Additionally, PV-specific soft cost reduction opportunities have been more extensively studied than CSP-specific ones, reflecting in part the fact that the vast majority of installed solar today is PV rather than CSP. For these reasons, the remainder of the document refers to PV in particular, drawing on the rich literature on such topics, but many of the considerations raised here are also potentially relevant to CSP soft cost reductions.

3. Long Term Solar Cost Trends

As detailed in Barbose et al. (2014), overall PV costs have significantly declined in recent years due to a combination of factors. Key among these factors is the decline in module costs, which accounts for about 67% of overall cost reductions for $\leq$10 kilowatt (kW) systems between 2008 and 2013, a period of rapid cost decline totaling \$2.7/W. Other factors which have contributed to long term cost declines include the economies of scale associated with larger PV systems, which now account for a larger fraction of installed capacity than was the case several years ago. Regarding the history of hard and soft costs and the differences between the two, Barbose and colleagues write:

> "Unlike module prices, which are primarily established through global markets, non-module [soft] costs consist of a variety of cost components that may be more readily affected by local policies – including deployment programs aimed at increasing demand (and thereby increasing competition and efficiency among installers) as well as more-targeted efforts, such as training and education programs. Historical non-module costs reductions from 1998-2005 suggest that PV deployment policies have, in the past, succeeded in spurring cost reductions; however, the fact that non-module costs have remained largely unchanged since 2005 highlights the potential need to identify new and innovative mechanisms to foster greater efficiency and competition within the delivery infrastructure." (Barbose et al. 2014)

A recent report by the Fraunhofer Institute for Solar Energy Systems on the future of utility-scale PV anticipates significant future cost reduction potential on both hard and soft costs between now and 2050, while noting significant expert disagreement and uncertainty about the details and timeline of such reductions (Fraunhofer ISE 2015). Several recent publications on the state of solar costs highlight the urgent need for soft cost reductions if overall system costs are to continue their long-term decline. For example, a report by researchers at NREL and Lawrence Berkeley National Laboratory (LBNL) in September 2014 (Feldman et al. 2014) found that industry analysts expect module costs to remain roughly the same in 2015 and 2016. Module cost changes do not straightforwardly or instantaneously translate into system cost changes due to various time lags in the system and other factors, but over a span of several years, this portends the need for significant soft cost reductions if overall system cost reductions are to continue in the years ahead. As such, the SunShot Initiative and other organizations have initiated a variety of efforts aimed at reducing soft costs.

4. Current Efforts to Reduce Soft Costs

Efforts to reduce solar soft costs are wide ranging and involve a variety of actors, reflecting the diversity of cost components and the difficulty of reducing them.[2] Figure 2 shows the breakdown of overall system costs, including soft cost components, in 2012, the last year in which detailed soft cost benchmarks are available.

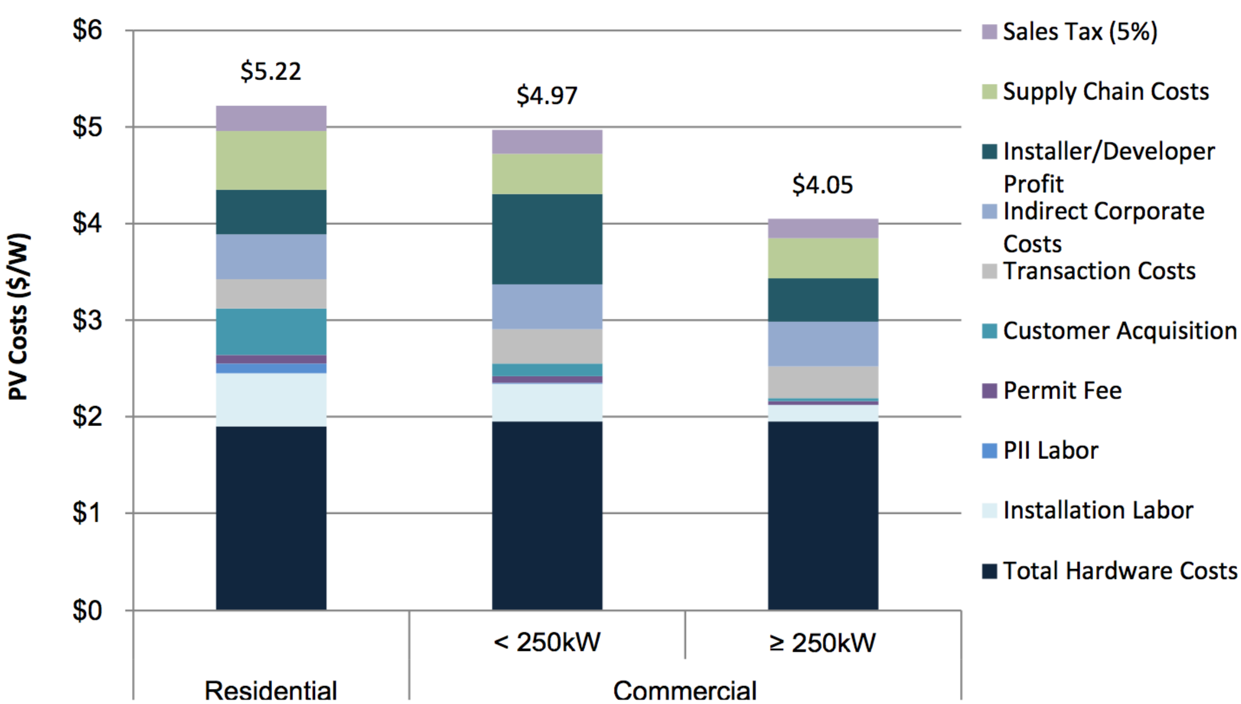

Figure 2: Average cost breakdown of different PV system scales in 2012 (Friedman et al. 2013). Note that since 2012, module costs have declined significantly, increasing the proportional contribution of each of these components to overall system costs.

2 For additional examples, see Friedman et al. 2013, Ardani et al. 2013, and SunShot 2014.

Illustrative examples of current efforts to reduce soft costs include:

- **Streamlining permitting:** One of the key differences between the German solar market and the US solar market is the relative fragmentation of the latter into hundreds of thousands of local jurisdictions and 50 state policy frameworks that has led to complex and time-consuming permitting and inspection processes. This makes it difficult for solar installers to work across jurisdictional boundaries, reducing competition and allowing greater profit margins in many cases, and entails significant direct labor costs involved in filling out paperwork, waiting for inspectors, etc. As such, various efforts are underway in many parts of the US, often supported by the SunShot Initiative, to simplify permitting and inspection requirements and unify them across jurisdictional boundaries.
- **Automation of installation:** Companies such as Brittmore Solar and Alion Energy have developed technologies that automate aspects of solar plant installation. Abengoa, a leading CSP company, automated some aspects of installation for their Ivanpah plant.
- **Software tools for customer acquisition:** Various companies have developed or are developing software tools to assist with customer acquisition, such as using satellite and other data to help identify potential customers, design systems, and produce offers. One example of such a company is SunLayar, which is developing software to assist with various aspects of residential system design as well as augmented reality to assist installers with efficiently completing various tasks. Software tools are also used by major solar companies to assist with plant design.
- **Workforce training:** The SunShot Initiative's Solar Instructor Training Network trains workers for careers in the solar industry in areas such as system design, installation, sales, and inspection. This effort and related ones at smaller scales can help with the maturation of the industry and closing the gap between e.g. German and US soft costs through more productive workers who need less on-the-job training.

Additionally, efforts to increase the efficiency of PV modules have spill-over benefits on soft costs. Greater module efficiency indirectly reduces soft costs by enabling more power to be produced for a given amount of land, labor, and supporting infrastructure (Fraunhofer ISE 2015). Moreover, innovations in other aspects of system hardware design can affect soft costs in various ways – e.g. prefabrication of system units in a manufacturing environment can enable a reduction in installation labor costs by reducing the number of steps involved. Thus, the scope of future soft cost reductions depends in part on the innovations in hardware that can be expected and the interrelationships between various cost elements.

5. Challenges and Opportunities in Further Soft Cost Reductions

As suggested by the examples of current efforts above, soft cost reduction opportunities are very diverse. They differ in the stage of solar development that they target, the actors involved, and the difficulty of implementing them. Some opportunities are better understood than others, and some are more scalable than others. One notable effort to systematically investigate and categorize these opportunities is the 2013 NREL publication, "Non-Hardware ("Soft") Cost-Reduction Roadmap for Residential and Small Commercial Solar Photovoltaics, 2013-2020" (Ardani et al. 2013). This report identified a variety of opportunities for soft cost reductions and compares the currently anticipated trajectory of different soft cost components to different cost reduction opportunities (CROs) that could be implemented, some of which are well understood and others of which are highly speculative. Their comparison of the current trajectory to these CROs, taking into account plausible rates of market penetration, identified several areas in which soft cost reductions are particularly uncertain.

Examples of areas where cost reductions can reasonably be expected are reductions in the cost of capital needed to finance PV installations as a result of market maturation and modest reductions in labor costs driven by standardization of designs and workforce improvements. However, in all categories, uncertainty increases as 2020 approaches. This uncertainty reflects both the currently limited extent of knowledge of how to reduce soft costs in some areas as well as expectations for how quickly innovations will diffuse in the market ("market penetration" in Figure 2), since SunShot's targets are for average rather than best case price decreases. Figure 2 explains the terminology used in Ardani and colleagues' analysis, and Figures 3 and 4 summarize their findings for different soft cost components in residential and commercial scale PV systems, respectively.

Achieving roadmap target is ***realizable*** under current trajectory
(no deviation in roadmap market penetration from current trajectory penetration)

Achieving roadmap target has ***low uncertainty*** (deviation in roadmap market penetration of up to 10% higher than current trajectory penetration)

Achieving roadmap target has ***medium uncertainty*** (deviation in roadmap market penetration of 10 to 25% higher than current trajectory penetration)

Achieving roadmap target has ***high uncertainty*** (deviation in roadmap market penetration of more than 25% higher than current trajectory penetration)

Figure 3: Readiness Factor Legend (Ardani et al. 2013).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Customer Acquisition ($/W)	$0.67	—	—	$0.53	$0.49	$0.45	$0.41	$0.36	$0.28	$0.19	$0.12
PII ($/W)	$0.20	—	—	$0.18	$0.16	$0.15	$0.13	$0.11	$0.10	$0.06	$0.04
Installation Labor ($/W)	$0.59	—	—	$0.51	$0.46	$0.42	$0.36	$0.30	$0.24	$0.19	$0.12
Other Soft Costs ($/W)	$1.86	—	—	$1.30	$1.14	$0.97	$0.82	$0.68	$0.56	$0.48	$0.37
Financing (WACC %-real)	—	—	9.9%	9.4%	8.8%	8.2%	7.7%	7.7%	4.8%	3.4%	3.0%
Total Soft Costs ($/W)	$3.32	—	—	$2.52	$2.25	$1.99	$1.72	$1.45	$1.18	$0.92	$0.65
Total System Costs ($/W)	$6.60	—	—	$4.99	$4.49	$3.99	$3.49	$3.00	$2.50	$2.00	$1.50

Figure 4: Degrees of uncertainty for future soft cost reductions for different cost components (Ardani et al. 2013).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Customer Acquisition ($/W)	$0.19	—	—	$0.15	$0.13	$0.10	$0.08	$0.08	$0.08	$0.05	$0.03
Installation Labor ($/W)	$0.42	—	—	$0.33	$0.30	$0.25	$0.20	$0.16	$0.12	$0.09	$0.07
Other Soft Costs + PII ($/W)	$2.03	—	—	$1.53	$1.36	$1.22	$1.08	$0.90	$0.72	$0.53	$0.34
Financing (WACC %-real)	—	—	8.6%	9.5%	9.2%	8.2%	7.9%	5.1%	4.4%	3.9%	3.4%
Total Soft Costs ($/W)	$2.64	—	—	$1.98	$1.76	$1.54	$1.32	$1.10	$0.88	$0.66	$0.44
Total System Costs ($/W)	$5.96	—	—	$4.03	$3.64	$3.24	$2.84	$2.44	$2.05	$1.65	$1.25

Figure 5: Degrees of uncertainty in future soft cost reductions for different cost components (Ardani et al. 2013).

While limited in important ways noted in the report, Ardani and colleagues' analysis usefully highlights areas where soft cost reductions are particularly urgently needed if SunShot goals are to be met. The areas identified with medium or high uncertainty (and, therefore, the areas where research and innovation may be most urgently needed) are:

Residential PV

- Permitting, inspection, and interconnection (PII): high uncertainty
- Installation labor: high uncertainty
- Financing: medium uncertainty

Commercial PV

- Customer acquisition: medium uncertainty
- Installation labor: high uncertainty
- Financing: medium uncertainty

Notably, these are uncertainties with respect to whether costs will be reduced dramatically in each area, not whether some reductions will occur – they are benchmarked against the current trajectory, which assumes continued innovation and spreading of innovations in various areas. That trajectory itself is uncertain—notably, analysts have been very wrong in the past about solar cost trends, so these identified categories should not be taken as definitive, but represent the most comprehensive analysis of the issue to date.

An additional relevant resource on the future of solar costs is the aforementioned Fraunhofer Institute report, which provided ranges of plausible cost reductions for various aspects of solar (Fraunhofer ISE 2015). While their analysis was not as granular with regards to soft costs as NREL's, they note some areas of particularly high uncertainty, such as the extent to which solar plant construction can be automated, an area of focus of the workshop on the 25th.

As previously noted, hard and soft costs are interdependent in various ways, making their analysis in isolation problematic. Two points she be emphasized here that are relevant for the purposes of the upcoming workshop: first, synergies exist between different areas of cost reduction such as prefabrication, labor cost reduction through automation, and standardization. In general, the design and installation of more standardized and prefabricated components is easier to automate and requires less specially trained workers. Second, tensions exist between some opportunities for cost reduction (such as through standardization and automation) and the need for adapting solar solutions to particular contexts. For example, residential rooftops vary in many ways, making standardization of system design and automation of installation difficult. These variations in context suggest the possible need for adaptive technologies and processes making use of artificial intelligence and robotics that could provide some of the labor-saving benefits of automation while preserving flexibility, through e.g. robots learning new tasks from human demonstration and feedback, another area of focus of the April 25th workshop.

6. Ethical and Political Perspectives on Soft Cost Reductions

Soft costs map to the distribution of financial benefits and a variety of risks associated with the large-scale development of the solar industry. Within markets, this represents the market share that various industries (finance, manufacturing, IT, advertising, construction, installation) will derive from solar development. As a result, reductions in soft costs may have perverse market consequences in some instances. For example, while financing is a big driver of soft costs and thus reducing the cost of capital required for solar installations seems highly appealing, relatively low rates of return on solar financing may also lead banks to neglect the market for solar loans. Such neglect could prevent financial innovation that could further reduce loan costs or stimulate greater investment. At the same time, high soft costs may stimulate business innovation in new sectors, such as IT, aimed at capturing some soft cost revenue while reducing overall soft costs, in turn making other companies in the solar supply chain less profitable and, potentially, reducing overall competition in the sector.

Beyond purely market-related dynamics, but intertwined with them, soft costs also represent opportunities for others to benefit from solar energy development. Overall soft cost reductions will continue to distribute larger gains from solar development to customers who purchase solar systems by increasing their cost savings versus other energy suppliers. Other soft costs currently reflect payments to workers of salaries and benefits, and reductions or redistributions of those costs to other kinds of soft costs (e.g., IT systems) may significantly impact the quantity and quality of jobs created in the solar sector due to improvements in worker productivity, automation, etc. This question is of both direct ethical significance (e.g. considering the impact of different cost interventions on workers in the solar value chain) as well as being politically relevant, since one of the arguments often used to support solar energy is its labor-intensivity and associated job creation. At the same time, reducing the overall costs of solar may allow the industry to grow faster than it otherwise would have, creating more jobs in other parts of the value chain.

Finally, some soft costs reflect regulatory costs associated with a variety of environmental, health, safety, and consumer protection considerations. The rhetoric of “streamlining” permitting and other regulatory costs is meant to convey the idea of reducing costs without reducing regulatory effectiveness, which may well be possible. However, experience in other industries also indicates that regulatory streamlining can lead to shifting burdens of risks, in this case potentially related to reduced effectiveness of environmental assessments associated with large-scale solar development on undeveloped land, or reduction in safety associated with faulty electrical installations (due to system design or installation failures) that aren’t properly inspected. Finally, as previously noted, the future of solar and the future of utilities are closely related, highlighting the need for thinking ahead about the broader social, economic, and political impacts of much larger scale solar deployment resulting in part from significant cost reductions.

7. Questions for Discussion the Workshop

- **How far can automation of solar installation go in the near, medium, and long term?** On the one hand, challenges to significant installation labor cost reductions (other than those achieved by productivity increases) include the diversity of plant designs, the physical/cognitive complexity of some of the involved tasks, and the limitations of artificial intelligence and robotics. On the other hand, there may be potential in the solar sector for novel human-machine dynamics such as robot learning from demonstration which, in conjunction with standardization and prefabrication, could make various forms of automation significantly more tractable.

- **Are there areas of soft cost reduction not currently being considered or implemented that are worthwhile?**
- **What role could hardware innovations play in reducing system costs in the near and long term, both directly (through cheaper modules) and indirectly (by reducing hard and soft balance of system costs through higher module efficiency)?**
- **What differences in soft cost reduction efforts are called for based on differing local needs and values where systems are installed?** For example, developing countries' generally lower labor costs may make automation efforts less urgently needed in order to reach a particular price point, and the local availability of workers with different skill sets may affect which approaches to installation are tractable. Different degrees of cost reduction, moreover, may be more or less urgently needed in different locations depending on the purpose of the system being installed and the relative costs of other energy options.
- **What are the challenges to widespread implementation of cost reduction opportunities such as information technology solutions for customer acquisition?** While some technologies are already available for various possible cost reductions, barriers such as lack of familiarity and expertise may limit their widespread deployment, as could insufficient competition (due to e.g. jurisdictional boundaries) enabling relatively inefficient companies to thrive.
- **What role should government play in accelerating the rate of technical, business, and financial innovation in the solar sector? Is there a need for research and development funding aimed at some of the aforementioned challenges such as the tension between automation and standardization on the one hand and system flexibility on the other?**
- **To what extent could standardization, automation, and other innovations reduce CSP costs in the near future? Could such innovations happen fast enough for CSP to gain market share prior to e.g. innovations in energy storage for PV reducing the relative advantages of CSP?**
- **What opportunities and challenges exist related to automation of PV manufacturing?** Currently, PV manufacturing is typically highly automated, but significant variation exists across facilities and countries, and technical challenges exist in scaling up next generation, high efficiency solar cells. Novel automation methods using artificial intelligence and robotics might help enable the manufacturing of cell designs that would otherwise be difficult.
- **What can/should be done to simultaneously reduce soft costs and address the aforementioned ethical/political concerns?**

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