Addressing Solar-PV Power Generation: Commercialization Assessment for the US Energy Market

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ABSTRACT

Solar-Photovoltaic (PV) utility power is more expensive to produce compared with conventional sources. Current utility power purchase agreement policies discourage private investment because far future cash flow does not add to asset value. This article presents an overview of a study that assesses the commercialization of PV power generation in the US energy market. Data analysis substantiates that for PV power to be competitive with conventional power plants, much lower discount rates are required during the first half of the PV utility lifecycle, after which solar PV will have a much lower cost due to a drastic reduction in the cost of capital. Additionally, the levelized cost of energy analysis for a longer lifecycle indicates that the utility scale solar PV cost gap can be bridged. Therefore, this article aims to influence policy makers to introduce long-term power purchase agreements, taking into account the avoided costs due to the unevaluated quality of long life at anticipated low operating costs. Furthermore, simulations reveal that the proposed solar PV self-financing program may be a viable alternative to the current government subsidy that lacks an inflow of cash to offset the outflow of subsidy payments. Finally, we present selective strategies that can help drive the commercialization of PV power generation in the US energy market.

Key words: levelized cost of energy (LCOE), solar-photovoltaic (PV), investment incentives, technology commercialization, smart grid, commercialization barriers and drivers, technology adoption.

INTRODUCTION

There is recent interest in utility-scale PV electricity generation for various reasons such as the increasing volatility of fossil fuel prices, the desire to reduce carbon emissions, and the availability of new technologies, which make utility-scale solar PV electric power more attractive. However, a primary hurdle to the widespread deployment of PV electric utilities is that PV electricity is more expensive to produce than competing energy sources such as coal and natural gas, which overlooks the vital PV solar system long-life characteristic with anticipated low operating costs. Moreover, the power generation sector is undergoing increasingly stringent environmental regulations, a strong policy push for aggressive emission reduction, volatile fossil fuel prices, new electricity transmission modernization (smart grid), and new entry of less expensive cadmium telluride (CdTe) solar PV technology.

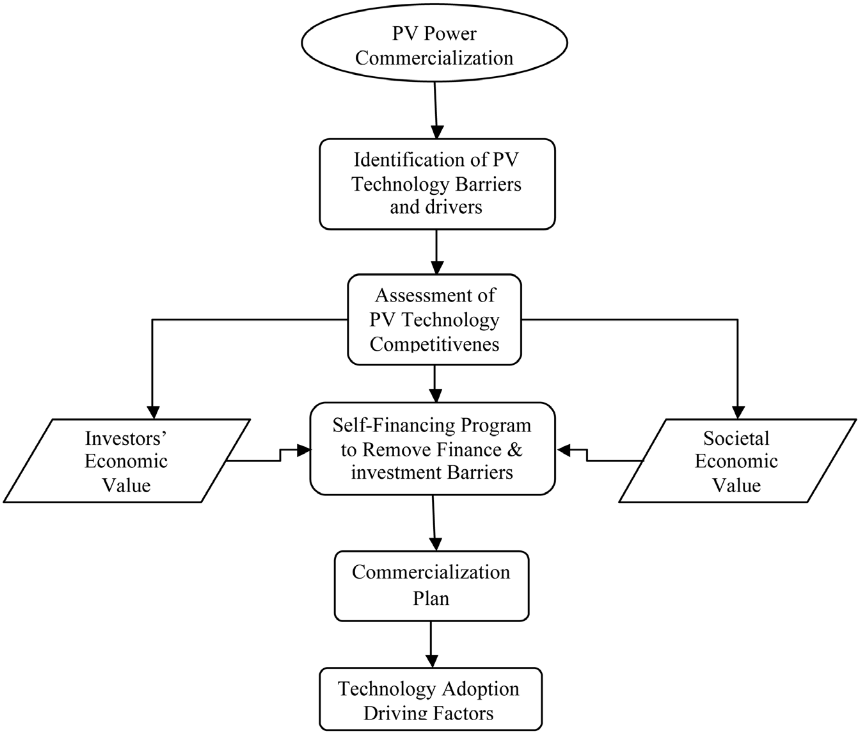

Figure 1. Organizational Flow of this Article's Presentation

These new energy market conditions can make future coal and natural gas power plants less competitive with alternative distributed generation power sources such as solar PV. In response to these new energy market realities, we redefine the levelized cost of energy (LCOE) and present two mathematical formulas. The first represents the investors' viewpoint and allows for transmission and access and upgrade costs and accounts for degradation over the project's lifecycle. The second represents the societal economic value viewpoint and accounts for carbon cost, hedging, peak supply, transmission loss, and reserve costs. Additionally, we propose and simulate a finance and investment program to be considered as a viable alternative to the current government subsidy that lacks an inflow of cash to offset the outflow of subsidy payments. The intent of the proposed model is to begin discussion around the self-financing program and the role of public policy, as well as to use simulations to facilitate strategic planning and decision making. We utilize system dynamics methodology to investigate PV power long-term economic outlooks. Such methods are introduced by system dynamics pioneers, namely J. W. Forrester [7] and John Sterman [8]. Finally, this article suggests a five-parts plan to help commercialize PV technology in the US energy market. Figure 1 represents the organizational flow of this article's presentation.

PV TECHNOLOGY BARRIERS AND DRIVERS

The US energy market still has a high carbon footprint because of electricity generation. For example, US commercial and industrial energy combined account for 50% of U.S. energy consumption. Fossil fuels are still the dominant energy source (approximately 85%); the top three are coal, natural gas, and oil [1]. Other energy sources are nuclear, wind, solar, biomass, and wave/tidal. Figure 2 illustrates US electricity generation by source.

Current US energy market risks are resource depletion, supply production peaks, electric supply's security, environmental impact, and renewable energy cost. Thus, we need an energy policy approach to assess the feasibility of renewable energy technology infusion. This study focuses on the feasibility of solar PV technology infusion in the national electric power system to achieve a low carbon economy. Table 1 summarizes the key barriers and drivers of PV power commercialization.

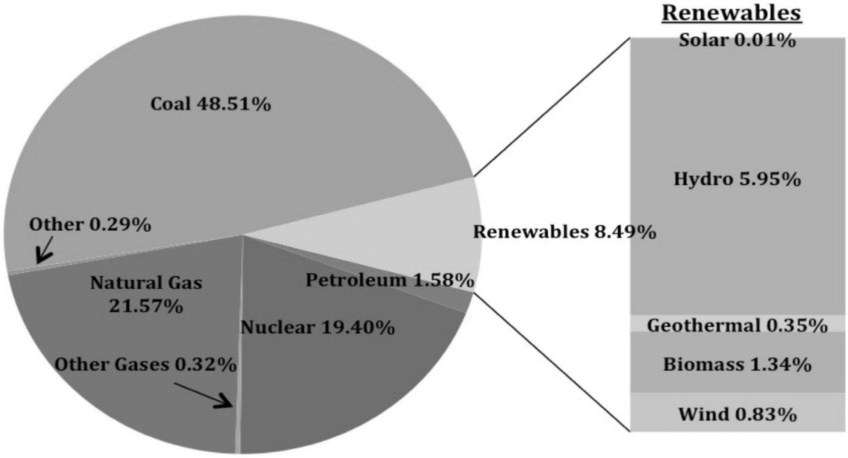

Figure 2. US Electricity Generation by Source

Table 1. Solar PV Power Generation Key Barriers and Drivers

PV Power Commercialization Key Barriers	PV Power Commercialization Key Drivers
Current cost is approximately double that of natural gas and coal. The least expensive systems are now approaching 15 cents/kWh, still twice as much as natural gas.	-Economy of scale. -Largest potential source of renewable electricity. -New technology (CdTe) allows rapid cost reduction.
Output varies depending on the weather/season and time of day.	-Can be generated in most places; however, it is least costly where there is the most sun. -Intermittency and load variations for large systems are much smaller than small to medium systems.
Utility scale solar power requires complex/ costly electric power transmission and distribution.	Smart Grid technology invasiveness is a key enabler for solar PV technology infusion in the national electric power system.
Capital costs are high.	-Construction take months compared with years for traditional power plants. -Electricity prices are stable due to no fuel cost.
Change management and new technology adoption.	-Economic growth and job creation. -Increase U.S. Energy Security. -Carbon dioxide emissions reduction.

PV TECHNOLOGY COST COMPETITIVENESS

Currently, power purchase agreements (PPAs) are 8c-9c/kWh and are difficult to finance even at lower module prices (50% of project cost) without subsidies. To assess if solar-PV (or PV for short) technology is cost competitive in the long run; we evaluate the following cost parametric influence implications. We constructed Table 2 based on data extracted from "Updated Capital Cost Estimates for Electricity Generation Plants" [2] and the National Renewable Energy Laboratory (NREL) System Advisor Model [3]. Table 2 compares the solar PV present value of annual energy cost to the two main energy sources: coal (constitutes 50 percent of total US electricity generation) and natural gas (constitutes 35 percent of total US electricity generation). We calculated the annual costs' present value based on the 30-year project lifecycle without government subsidy. Table 2 demonstrates that solar PV has the highest present value cost of energy compared with coal and natural gas power plants.

Table 2. Utility Sources Annual Cost Comparison ($/MWh)

Plant Type	Capital Cost	Fixed O&M	Variable O&M plus Fuel	Total Annual Cost
Coal	69.2	3.8	23.9	96.9
Natural Gas	41.1	4.7	82.9	128.7
Solar PV	376.8	6.4	0	383.2

Currently, Levelized Cost of Energy (LCOE) calculations lack clarity and completeness, leading to widely varying, inconsistent, and conflicting results. A literature search reveals that most studies do not consider the energy output degradation that leads to the reduction in energy production. Many widespread LCOE calculations do not express such a cost parameter. The following investors' economic value method attempts to capture such an important cost factor.

LCOE Investors' Economic Value Method

The LCOE is a metric utilized to assess the all-in-one unit cost of generating utility electric power from different energy sources. It includes key project expenses such as the cost of capital, operation and maintenance (O&M) costs, and debt. It is expressed in dollars per megawatt-hours ($/MWh) or cents per kilowatt-hours (cents/KWh) [4]. To calculate the levelized cost of a power plant, we converted expenses to annualized payments during the project life. The annualized cost is then divided by the average annual generation (MWh). There are two key components of the levelized cost: fixed costs and variable costs. The costs of capital payments and fixed O&M costs are components of the fixed costs. Variable costs include variable O&M expenses and fuel costs.

For utility projects, we calculate the LCOE such that when the LCOE is multiplied by the utility lifecycle total produced energy and discounted to the assumed analysis year, it can then be represented by the utility project's lifecycle present value of required revenues. In the following equation, we represent the LCOE in a simplified mathematical form. Equation 1 is derived from the Department of Energy's generalized function to generate the annual net present value cost of energy; however, we add a "df" degradation factor variable to represent the reduction in energy output due to system-wide tear and wear over time. Thus, the LCOE function can be expressed as

$$\text{PV LCOE} = \sum_{n=1}^{N} \text{Qn}\,(1 - \text{df}) \times \frac{\text{R required,n}}{(1+\text{d})^{n}} \tag{1}$$

In equation (1), Qn is the energy produced (MWh) by the project in year n. N is the project life in years, and "Required,n" is the required project revenue resulting from electricity generation in year n ($/MWh), df is the degradation factor, and d is the discount-rate. The right hand summation starts at n = 1 (the first year of project revenues). To better understand the competitiveness of the PV LCOE, we evaluate the following PV technology cost influences.

Solar PV Exceptionally High Cost of Capital Implication

Table 3 indicates that the levelized cost of capital of coal power plants is approximately 59% compared with 28% for natural gas and 95% compared with PV power plants [2, 11], as a fraction of their total PV LCOE. Hence, solar PV cost of capital is the key variable metric with 95% share of the total cost, as Figure 3 illustrates. Accordingly, discount rates have a particularly significant impact on solar PV cost competitiveness.

PPA Lifecycle Implication

We evaluate solar PV LCOE over a longer lifecycle of 60 years, shedding light on solar PV's low operating cost and long life advantages. We employ Minitab statistical software to calculate and plot the solar PV LCOE weighted average based on the data extracted from the

Table 3. Estimated Percentage of LCOE for New Power Plant Construction

Plant Type	Fixed O&M	Variable O&M Including Fuel	Trans-mission	CO2 Emission	Levelized Capital Cost	Total PV LCOE
Coal	3%	20%	3%	15%	59%	100%
Natural Gas	3%	56%	6%	7%	28%	100%
Solar PV	2%	0%	3%	0%	95%	100%

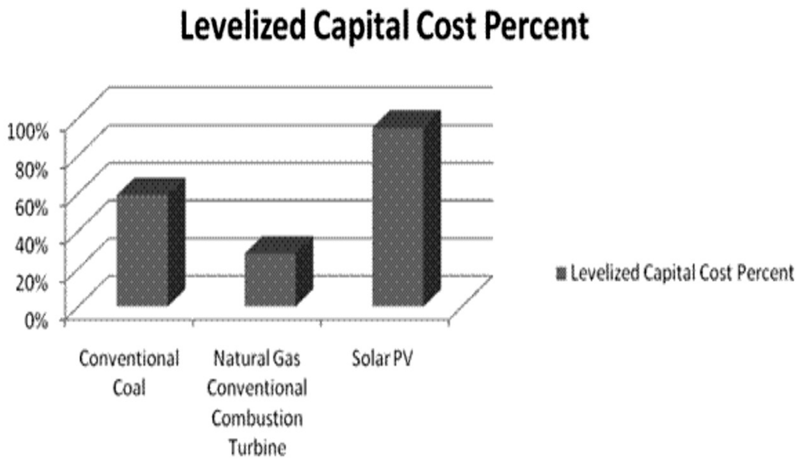

Figure 3. Coal, Natural Gas, and PV Utilities Cost of Capital Comparison

National Renewable Energy Laboratory, Energy Analysis, and System Advisory Model (SAM). Figure 4 plots the weighted average LCOE for the first 18 years and again for the remainder of the 60-year lifecycle. Additionally, this figure illustrates what happens to PV LCOE beyond the first 18-year loan term; the steep decline in year 18 occurs because there are no more loan payments. The only remaining costs are the operating costs, which are anticipated to be low. The LCOE fitted line represents the average of the 60-year combined averages, which were observed to be approximately 8 cents/kWh. This figure must be considered when planning PV strategic planning because it reveals that when extending commercial PPA lifecycle, the absence of capital costs after the first 18 years, as well as the absence of fuel costs, can help PV to be more competitive with traditional coal and natural gas energy. In other words, the cost for PV energy tends to decrease over the life of the project because PV energy does not have the fuel component cost associated with electrical power generation and because the capital cost can be eliminated after repaying the investor loan.

Efficiency and Refurbishing Costs Implications

The efficiency of power plants tends to degrade overtime as a result of material exposure to the environment, tear and wear. At the operational outset, Solar PV arrays degrade at a rate of 0.5% annually compared with 0.2% for natural gas and coal power plants [6]. However, when fossil fired power plants age, their degradation rate increases

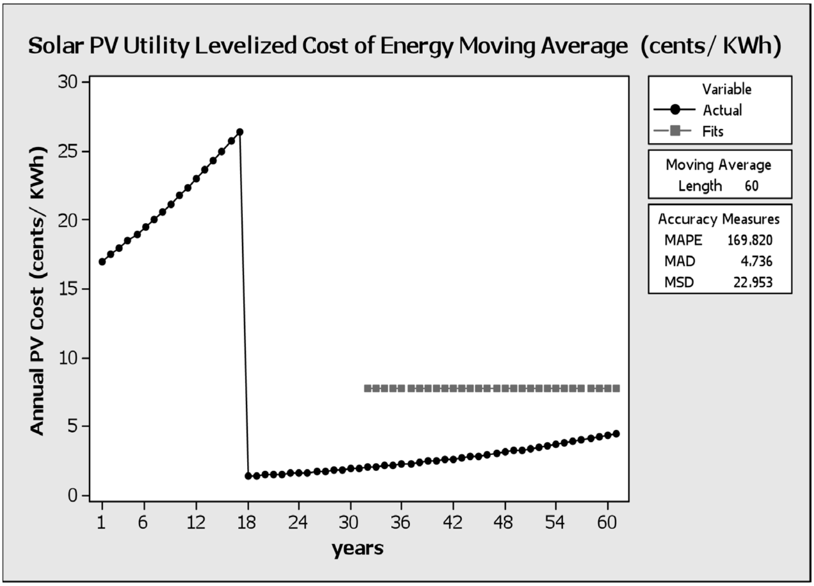

Figure 4. Solar PV LCOE Moving Average for 60-year life

rapidly (above 0.5%). The change to rapid aging of fossil fired plants depends on the original design and construction, as well as the actual operation and maintenance practices. Thus, in general, aging fossil fueled plants can significantly degrade compared with solar PV power plants, which last much longer. By the time loan payments, new capital investments beyond operation and maintenance are required to keep fossil fired power plants fully operational. These refurbishing costs are usually not covered in the operations and maintenance calculations. The cost tradeoff here is that solar PV has higher annual efficiency degradation than fossil fuel power plants. However, fossil fuel plants age much earlier than solar PV and require a high cost of refurbishing that is not part of the operations and maintenance cost.

Thus far, we have presented the economic value viewpoint from the investors' perspective. However, there are societal economic benefits that we must consider, such as CO_2 cost, hedging factor, the cost of transmission loss, and peak pricing economics. The next section offers the foundation of the societal LCOE economic value method.

LCOE Societal Economic Value Method

There are many cost benefit factors that are not included in the LCOE investors' net economic value formula (1), which we discussed in the previous section. Here, we briefly summarize other costs that are not included in formula (1). First, environmental costs are often not included when comparing solar PV to fossil fuel power technologies. For example, fossil fuels can lead to societal costs such as poor human health due to air pollution. Although environmental impacts and the associated costs are sometimes included in economic comparisons in academia and government agencies, investors seldom include such costs in net economic value investment decisions. Conversely, due to the intermittent nature of solar PV power generation, utilities must pay for the operating reserve to deliver power if required. This reserve is an extra cost for which solar PV utilities must plan. Conversely, utilities benefit from a reduction in grid losses due to the distributed nature of solar PV. Another value-adding characteristic of solar PV is the "hedging value." Hedging value can be realized by providing electricity producers with the value of a fixed electricity cost for the lifecycle of the PV plant. The hedging value is based on the volatility of oil, coal, and natural gas prices. The stability of future electricity prices has a tangible economic value that is an additional factor not accounted for in the investors' LCOE formula (1). Additionally, the impact of peak load on electricity cost is not included in the LCOE net economic value formula. Solar PV can influence electricity spot prices during periods of peak demand. The spot price for electricity is, of course, highest during such periods, as electric utility companies run special power plants during electric load peaks to meet demand. Investing in and operating these highly flexible plants is a notably expensive practice. Because most PV electricity is generated during periods of high demand, PV electricity generation can help reduce and stabilize the peak load, thereby reducing electricity prices during the high-peak period. In summary, the following costs and economic value benefits are not covered in Equation 1, which is designed to convey the investors' viewpoint of financing PV PPA projects, namely, CO_2 reduction, hedging, grid loses reduction, and spot pricing, as presented in equation 2.

$$\text{Real PV LCOE} = \frac{\sum_{n=0}^{N}(\text{CEn}+\text{On}+\text{Mn}+\text{GTn})/(1+\text{di})^{n}}{\sum_{n=0}^{N}[(\text{REOn}\ (1-\text{df})^{n}]/(1-\text{df})^{n}}$$

$$+\frac{\sum_{n=0}^{N}(\text{ORn})/(1+\text{di})^{n}}{\sum_{n=0}^{N}[(\text{REOn}\ (1-\text{df})^{n}]/(1+\text{di})^{n}}-\frac{\sum_{n=0}^{N}(\text{CRn}+\text{GLn}+\text{HVn}+\text{PPn})/(1+\text{di})^{n}}{\sum_{n=0}^{N}[(\text{REOn}\ (1-\text{df})^{n}]/(1-\text{di})^{n}} \quad (2)$$

Where:
CE = Capital expenditure
O = Operational cost
M = Maintenance cost
GT = Grid transmission investment and access fees
REO = Rated energy output produced by the project in year n
N = Project lifecycle in years
df = Degradation factor
di = Discount rate.
OR = Operating reserve
CR = CO_2 cost reduction
GL = Grid losses cost reduction
HV = Hedging value cost
PP = Peak power cost reduction

Considering these variables, we can see that the cost of generating solar PV is actually more competitive than what it appears. Accordingly, the next section builds upon the societal economic value foundation and attempts to remove the financing and investment barriers of PV commercial power. The strategic planning of the initial investment is justified by the long-term societal economic value benefits explained in equation 2 in addition to other hidden benefits not included in equation 2, such as energy self-sufficiency and job creation.

SELF-FINANCING PROGRAM

Current PV power projects cannot continue to operate without government funds (approximately 30% in subsidy). The government fund lacks an inflow of cash to offset the outflow of subsidy payments. What we propose here is a self-financing program to promote cleaner power generation in the form of PV utilities; this program uses fees charged on utilities that have high pollution rates to finance low interest rates for PV power generation projects. We simulate a combination of low interest rates and longer PPAs to assess the behavior of such a fund. We propose to use fees on polluting power plants to fund the program instead of deficit spending. Other sources of cash inflow revenues include the program's interest income, the PV projects' finance fees, and bonds' issuance cash inflows. Figure 5 presents the basic structure of simulating cash flow of the self-financing program using Stella software from ISSE [9].

Table 4 provides the inputs for the simulation of longer PPA lifecycle (60 years) and lower interest rates (3% in nominal term) during the first half of the lifecycle.

The simulation presented in Figure 5 explores the financing strategy of a longer PPA life cycle coupled with lower interest rates during the first half of the utility project lifecycle. Such a strategy can help lower the investment risks. Figure 6 plots the results of the self-financing program simulation. This figure indicates that the proposed finance strategy leads

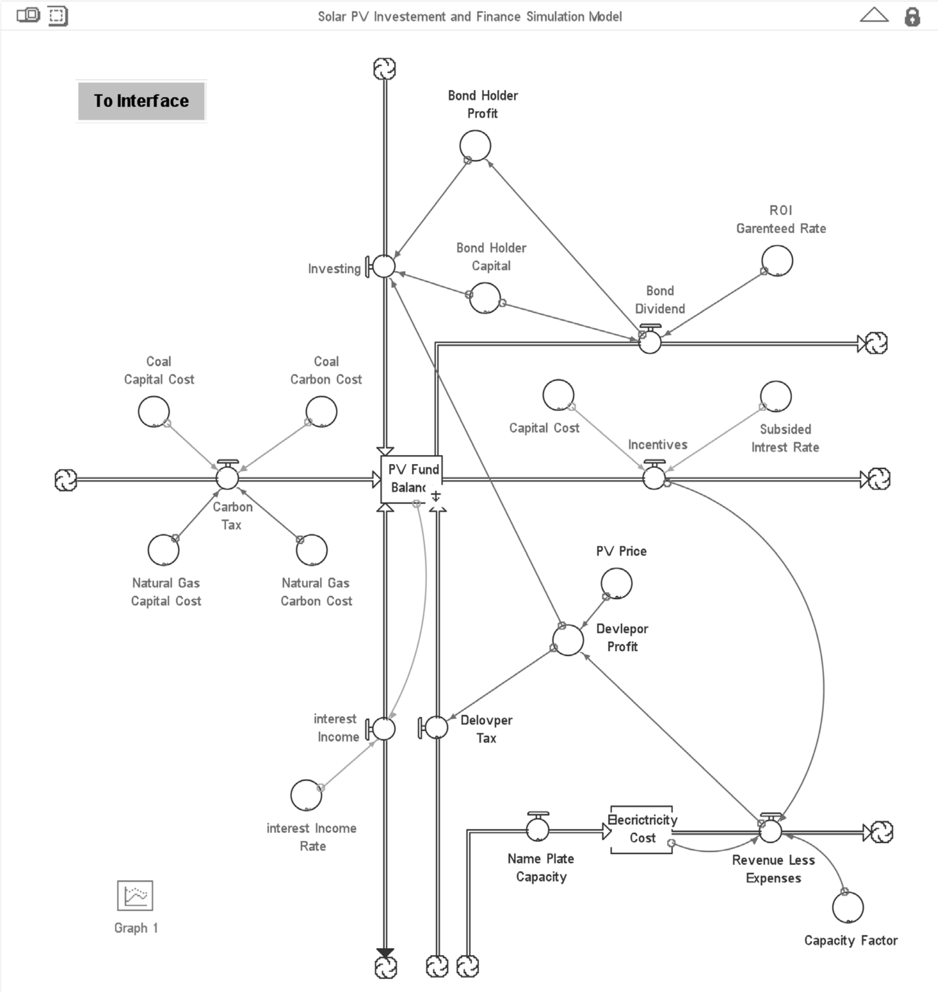

Figure 5. Self-Financing Cash Flow Simulation Structure

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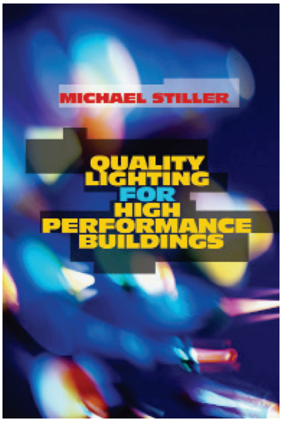

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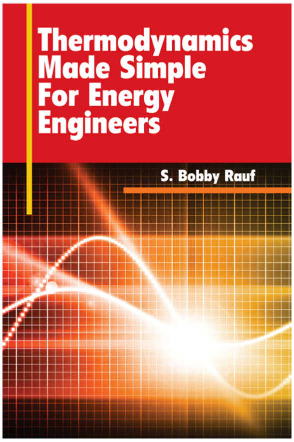

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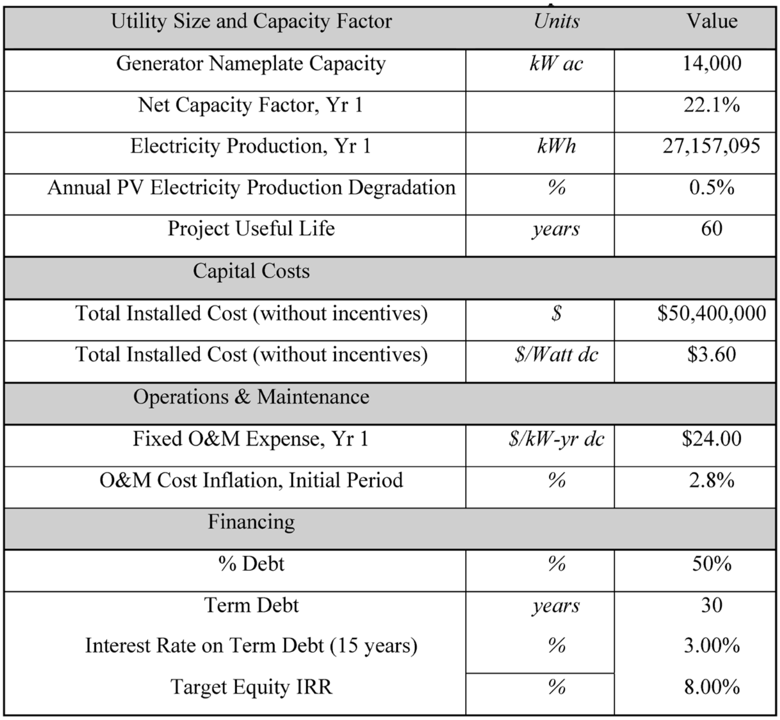
Table 4. PV Generation Simulation Inputs



Utility Size and Capacity Factor	*Units*	Value
Generator Nameplate Capacity	*kW ac*	14,000
Net Capacity Factor, Yr 1		22.1%
Electricity Production, Yr 1	*kWh*	27,157,095
Annual PV Electricity Production Degradation	*%*	0.5%
Project Useful Life	*years*	60
Capital Costs		
Total Installed Cost (without incentives)	*$*	$50,400,000
Total Installed Cost (without incentives)	*$/Watt dc*	$3.60
Operations & Maintenance		
Fixed O&M Expense, Yr 1	*$/kW-yr dc*	$24.00
O&M Cost Inflation, Initial Period	*%*	2.8%
Financing		
% Debt	*%*	50%
Term Debt	*years*	30
Interest Rate on Term Debt (15 years)	*%*	3.00%
Target Equity IRR	*%*	8.00%

to an exponential growth of the PV self-financing fund over time.

Undoubtedly, cost-effective technology investments promise to pay for themselves over the long run in terms of return-on-investment financing. The proposed finance strategy may be modified and expanded to assess financial risks that impact technology commercialization. Now that we have demonstrated that solar PV has the potential to be cost competitive in the long run with low interest financing during the first half of longer PPA lifecycle, we present a five-part plan to help commercialize solar PV power generation.

COMMERCIALIZING PV POWER GENERATION

The following five long-term strategies can favorably affect solar PV long-term commercialization. These five strategies include a self-financing program, a peak load supply segment, transmission infrastruc-

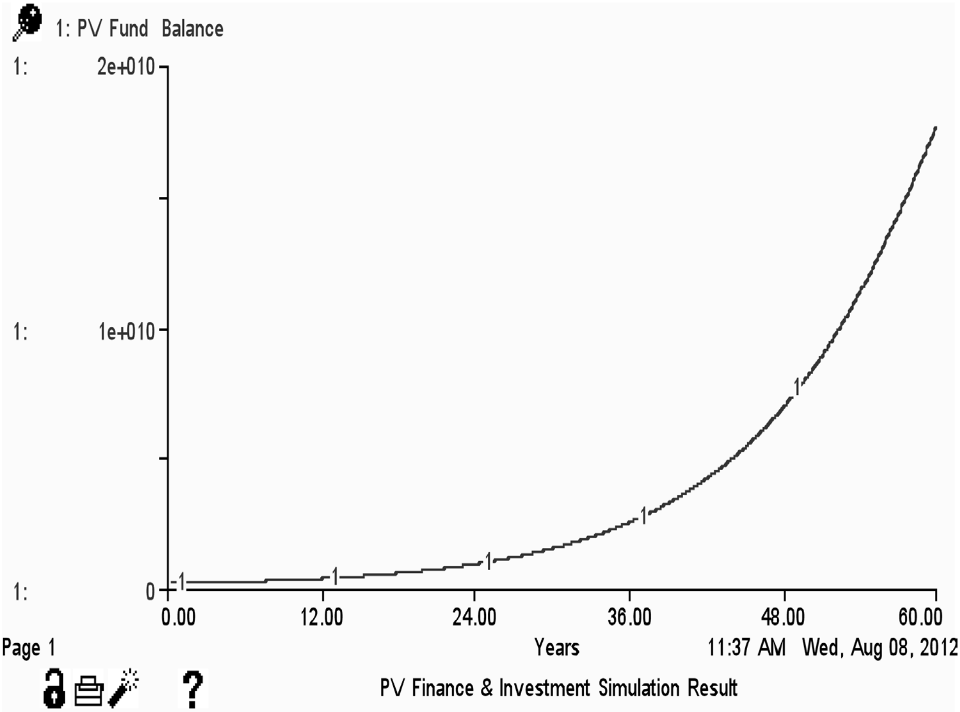


Figure 6. Simulation Results of PV Self-Financing Program Over 60 Years

ture modification, economy of scale scenario, and a government scenario to finance public PV projects with Power Purchase Agreements (PPAs).

A. Self-Financing Program

The proposed investment incentives structure that we introduced earlier can remove the key barriers for financing. Government loans guaranteed on PPAs can promote investment into solar PV projects. One of the most beneficial effects of long-term PPA is a lower cost of finance. Thus reducing interest rates allows for a cost-effective market introduction of solar energy. Once capital and interests have been paid back to investors, the electricity cost drops dramatically because capital cost makes up for approximately 95%. Therefore, a central feature of successful market infusion is lower discount rates that the proposed self-financing program can initially help subsidize. Additionally, longer-time lifecycle costing calculations can account for the expensive refurbishing costs of aging fossil fuel power plants. Currently, PPAs avoid these calculations in shorter lifecycle scenarios. Therefore, doubling the lifecycle planning horizon can offer more realistic and more favorable financing for solar PV long lifecycle projects.

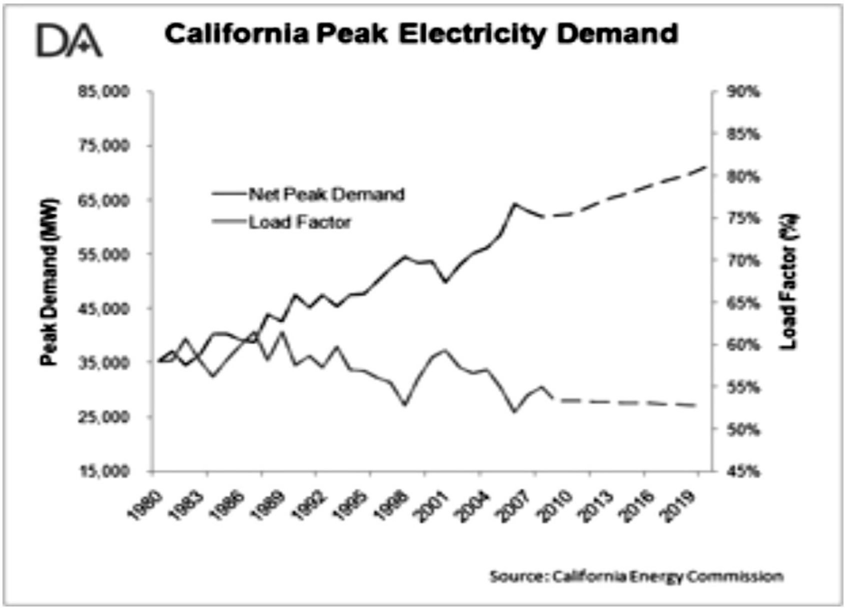


Figure 7. Net Peak Electricity Demand Increases over Time

B. Matching PV Peak Load Supply with Summer Peak Load Demand

The gap between load factors and net peak demand has been increasing in the last 30 years and will continue to grow in the future. Figure 7 reveals that the overall peak demand is expected to increase in the future [12], making coal and natural gas electricity cost even more expensive. For example, during the summer, solar PV power can reduce peak demand by reducing the need for standby fossil fuel power plants. In other words, solar PV can reduce the overall costs of generating electricity during the peak demand supply segment. This cost benefit should be accounted for when financing PPA projects.

We suggest that the solar PV technology commercialization begins in regions where there is a significant peak load segment of the power supply. Accordingly, long-term PPA for these regions should be financed with the consideration of peak-load supply segment costs. In such a scenario, the higher cost of solar PV electricity generation can be justified when compared with the average cost of fossil fuel power production, which usually encounters peak power at a much higher cost. The key to this enigma lies in the fact that solar PV plants can replace peaking base load power. Thus, solar PV can start market infusion in the most expensive market segment, which usually is that of peaking power.

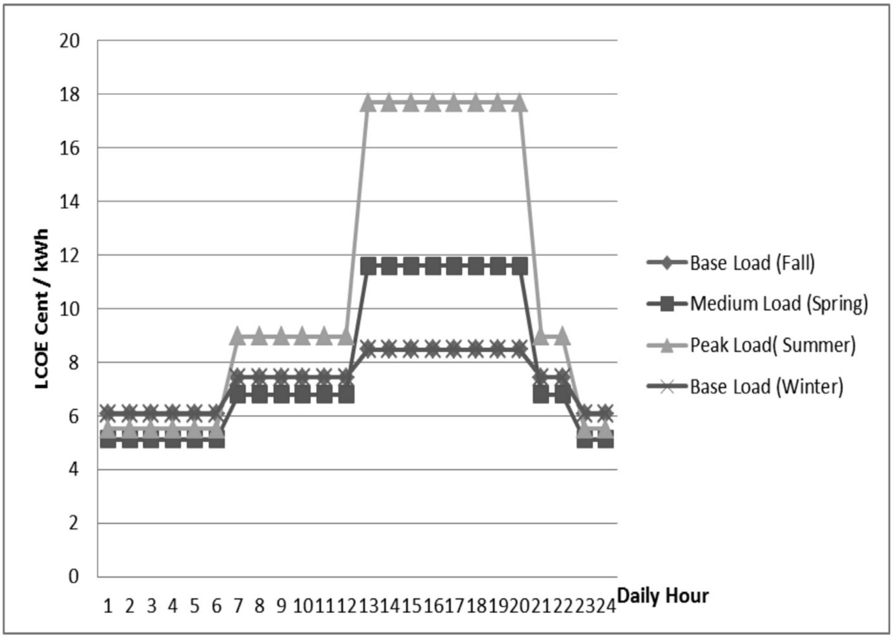


Figure 8. California Spot Pricing Based on California PG&E Payment Allocation Factors

To demonstrate PV peak load cost advantage concept, we constructed Figure 8 to illustrate California peak load spot prices as a numerical example. The prices are based on data we obtained from Pacific Gas & Electric (PG&E) that are available at SAM/Energy Payment Dispatch/PG&E [3, 5, and 19]. The data are available as payment allocation factors, which we converted to PV LCOE. Similarly, the PV can currently replace peaking base load power in other regions (i.e., Arizona, Nevada and Hawaii, etc.).

C. Economy of Scale

For solar PV electric utilities, the largest proportion of costs occurs during deployment, rather than generation, contrary to coal and natural gas power plants. In other words, the opportunities to achieve economies of scale are greater during the solar PV manufacturing stage than at the generating site itself. This economy of scale advantage can help further reduce solar PV power generation costs. Additionally, cost reduction through improved learning curve can make PV power further more competitive with conventional power. Moreover, PV efficiency improvement, which has direct positive impact on capacity factor (CF), can lead to further PV LCOE cost reduction as Figure 9 demonstrates. We have generated this graph based on Table 4 simulation data inputs.

D. Transmission Infrastructure Modernization

The electricity generation intermittency of commercial PV projects is a significant problem for utilities. PV power generation requires special circuits that the current transmission technology may be lacking. Increased deployment of intermittent solar PV power generation into the grid requires the development of "smart-grid" technologies. However, various energy storage and source-load synchronization schemes can mitigate the daily intermittency of PV output. In addition, more investment is required in transmission infrastructure to reduce solar PV

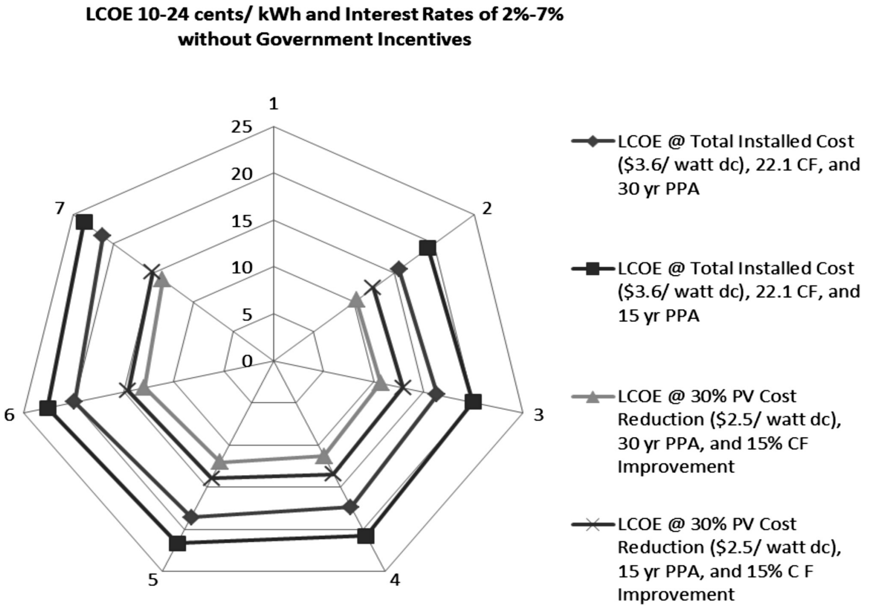


Figure 9. Cost Sensitivity to Economy of Scale Cost Reduction and Different Interest Rates

transmission access issues. The deployment of a smart grid can improve the capacity of receiving intermittent generation [14]. Furthermore, significant advances in digital processing and communications technologies make data flow and information management act as building blocks of modern electric transmission and distribution systems. These technological advances act as enablers for the modern grid system [15]. Today, a possible unified smart grid deployment may force electric utilities to go through three classes of transformations: digital infrastructures, business processes, and information technologies. Currently, the Department of Energy Office of Electricity Delivery and Energy Reliability conducts research and development that can help promote smart grid technologies related to modernizing the electric grid. This effort is coupled with the private industry exploration of new technologies related to distributed systems integration, energy storage, advanced system monitoring and visualization, as well as advanced control systems. Based on these government and private industry research and development efforts, smart grid technology development can be summarized in five key technology areas: advanced control methods, sensors, decision support, advanced components, and integrated communications [16].

To promote solar PV technology infusion, infrastructure integration requires the deployment of information technologies that address the usability and interoperability of software and communications' interfaces as well as significant efforts in standardization frameworks. Table 5 summarizes a framework of smart grid system infrastructure.

Increased deployment of intermittent PV power generation into the grid requires the maturity of smart-grid technologies. More investment is required in transmission infrastructure to reduce PV transmission access issues. Hence, the maturity of smart grid can improve the capacity of receiving intermittent generation. We suggest that the PV technology infusion projects start in regions where there is a significant effort in smart grid deployment. It is necessary to identify renewable energy zones where transmission infrastructure will be built in advance of installed PV generation.

E. Government Finance of Public PV Projects

The government can stimulate demand for solar PV power using a finance model in which the government issues a bond at a low interest rate and transfers that low cost of capital to a developer in exchange for a lower PPA electricity price. Next, the government can use the low

Table 5. Smart Grid Infrastructure Framework

	System View (Why & What)	**Technical View (How)**	**Operation View (Where)**
Planning	-conceptual -mission & vision statement -business strategy -logical requirements	-business transformation -energy transformation	-electric power utilities -national economy -energy resources -integration -smart grid
Development	-governance and regulatory connectivity -energy storage -reliability -security	-energy generation -power flow controls -smart metering -advanced sensors	-electric utility -communications
Deployment	-Internet -demand side economics -standardization -affordability	-specifications -system performance	-system interface -demand side applications -transmission

electricity price to electrify public buildings, such as the Department of Defense, Department of Energy, schools, colleges, and other government facilities. Under such a model, a solar developer builds, operates, and owns a solar project to supply public buildings with electricity. The government sells bonds to finance the development costs of the PV installation. The government subsequently enters into both a lease-purchase agreement with the developer and a PPA to buy the electricity from the PV developer at lower cost. In other words, the government can provide the developer with lower interest rate loans in exchange for lower electricity prices. Such a scenario can trigger the economy of scale cost reduction benefit and stabilize the transient state of the PV power segment. Figure 10 highlights the relationship and money flows between the key players in this scenario: the bondholders, the government, and the PV public sector project developer.

TECHNOLOGY ADAPTION DRIVING FACTORS

Society, the economy, and the environment set the stage for energy technology development. These components have strong influences on the energy markets and can be either barriers or accelerators to new en-

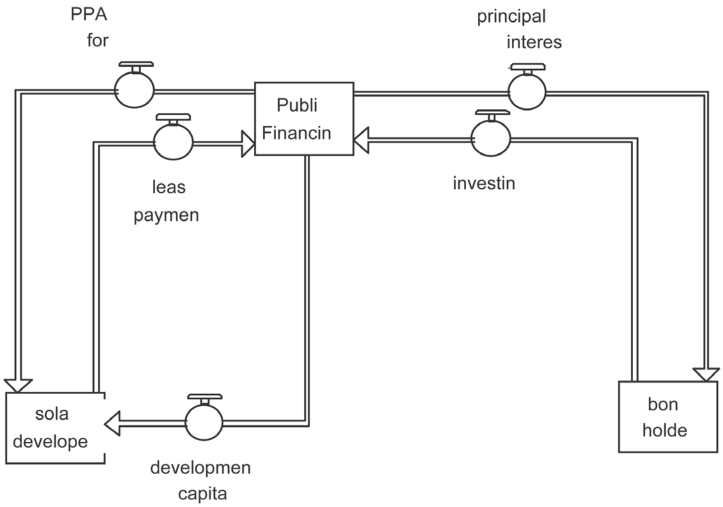


Figure 10. Cash Flow of Public PV PPAs

ergy technology adoption [17, 18].

Policymakers who understand the parametric trade-off factors that affect new energy technology introduction are in a better position to design and implement policies with a beneficial deployment outcome [17]. Sis parametric trade-off factors that impact solar PV energy technology adoption are social acceptance, environmental constraints, technology cost, technology adoption, transmission and distribution, land use and constraints, and finance.

Table 6 summarizes these parametric trade-off factors in a positive, negative, or neutral impact leading to an overall trade-off analysis of key parametric factors.

CONCLUSION

Current PPA policy discourages PV power generation private investment because far future cash flow does not add to asset value. Simulations illustrate that for PV power to be competitive with natural gas and coal power plants, much lower discount rates are required during the first half of the PV utility lifecycle, after which solar PV will have a much lower cost due to a drastic reduction in the cost of capital. The proposed solar PV utility self-financing program may be a viable alter-

Table 6. PV Power Technology Adoption Key Parametric Trade-Off Factors

Trade-Off Factors	Solar PV	Fossil Fuels (Natural Gas/Coal)	Factors Risk Summary
1. Financing & Investment	(-) Requires financing mechanisms to fund long-term investment	(+) Plenty of inexpensive financing available	Require new incentive structures to accelerate PV technology infusion
2. Land Use Constraint	(-) Requires enormous square footage of land	(-) Transportation cost of coal and natural gas (pipes)	Power production locations need to be close to end-use electricity markets
3. Transmission/ Distribution	(+/-) Modernize grid technologies	(+) Applies to current technology.	Smart Grid is key enabler for solar PV technology adoption
4. Technology Cost	(-) Moderately expensive compared with fossil fuels	(+) Currently inexpensive when compared to PV	Simulations reveal that PV cost gap can be bridged in the long run
5. Environmental Constraints	(+) Minimizes impact on natural environment	(-) Negative impact of air pollution	PV has no carbon footprint's associated costs
6. Social Acceptance	(-) Resistance to change	(+/-) Mixed signals from public support	Public support is needed for solar PV deployment
7. Technology Adoption Summary	(+) Long-term can be lower cost for electrify generation	(+/-) Significant environmental and supply chain concerns.	In the long run, PV can be a viable electricity generation source

native to the current government program, which lacks an inflow of cash to offset the outflow of subsidy payments. We have also recognized the current solar PV project returns to be unsound for profitable growth. Accordingly, the risks of upfront cash outlays must be reduced via very low interest rates during the first half of the PV utility lifecycle. It is worth mentioning that the financers of current PV projects have instruments for the right debt/equity structures for small-scale power utilities, but government subsidies are still an important part of the equation. The main competition to solar is now natural gas. It is less expensive than PV, but it is not modular. The modular characteristic of PV leads to a significant economy of scale advantage. Conversely, solar falls behind in capacity factor performance. Its 18% to 24% capacity factor must improve to better attract mid- to large-scale utilities' projects. Another technology improvement issue for commercial projects is the intermittency of PV electricity generation, which can be significantly improved by deploying smart grid emerging technologies.

We propose particular five-part plan to help promote the commercialization of PV power generation. This plan focus on removing the financing solar PV projects as a barrier in both private and public sectors' scenarios, introducing the technology into a peak load supply segment of the energy market as well as in regions where smart grid infrastructure is thriving. The five parts of the plants are:

A. Self-finance projects by better matching financing horizon to PV system life cycle
B. Synchronize PV peak supply to summer peak demand
C. Utilize PV economies of scale in manufacturing and installation (bigger plants)
D. Modernize transmission infrastructure
E. Make government financing available to qualifying PPAs projects

Finally, future studies in cash flow analysis, permit requirements, and simplified transmission connections are required to help accelerate the adoption of PV power in the US energy market.

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