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REDUCING THE COSTS OF GRID-CONNECTED PHOTOVOLTAIC SYSTEMS[1]

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ABSTRACT

This paper presents alternative approaches for reducing the costs of roof-mounted, grid-connected photovoltaic (PV) systems. Six cost reduction approaches are presented, together with examples, data and information from Florida and other states. Finally, the paper identifies these areas on which efforts should be focused to achieve the 2020 cost goals established by the U.S. photovoltaic industry.

INTRODUCTION

In recent years, there has been a resurgence of interest in distributed grid-connected photovoltaic (PV) applications. Key influences have included the onset of electric utility deregulation, national programs such as the Million Solar Roofs Initiative, and numerous federal, state and local incentive programs to encourage the use of PV and other renewable energy systems.

The long-term success of PV markets will largely depend on the ability to reduce costs of installed systems. Since the mid-1970s, the installed costs of PV systems have decreased by nearly an order of magnitude. Over the same period, the area efficiency of commercially available PV modules has doubled, module reliability has improved substantially, and the U.S. annual production capacity has increased from about 5 MW to over 60 MW [1]. In Florida, the present price of PV systems in constant dollars is approximately one-third the price in 1983.

In 1999, the U.S. PV industry developed a 20-year roadmap which set challenging goals for increasing the volume of production and reducing costs to end-users [2]. Goals for the year 2020 include a production volume of 6 GW per year, or a 25 percent per year increase from current levels. Domestic applications are to account for about one-half of U.S. production. Targets for installed system prices are \$3/Wac by 2010 and \$1.50/Wac by 2020. This paper will focus on several different approaches to realizing these price goals. In addition to addressing the selling price of PV system installations, approaches to reducing life-cycle costs are also discussed.

SCOPE

This paper identifies methods of reducing the costs of roof-mounted, grid-connected PV systems, and concentrates on specific infrastructure and technological challenges that must be met for the industry to achieve 2020 goals. Six different approaches for reducing costs are presented, including:

1. Reducing the costs of manufacturing PV system components
2. Reducing the costs to market and distribute PV systems and components
3. Reducing installation, operation and maintenance costs
4. Developing performance-based subsidies and financing programs
5. Improving the performance of power conditioning equipment
6. Streamlining the permitting, interconnection and inspection processes

Examples and experience are used from over fifty grid-connected PV systems recently installed under the Florida PV Buildings

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Program [3] and the long-term potential to reduce costs is discussed. Finally, challenges and opportunities are identified for each approach, with an emphasis on items thought to have major bearing on the industry's ability to reach the 2020 goals. Figure 1 illustrates the planned progression of the technology and costs from the year 2000 to the year 2020.

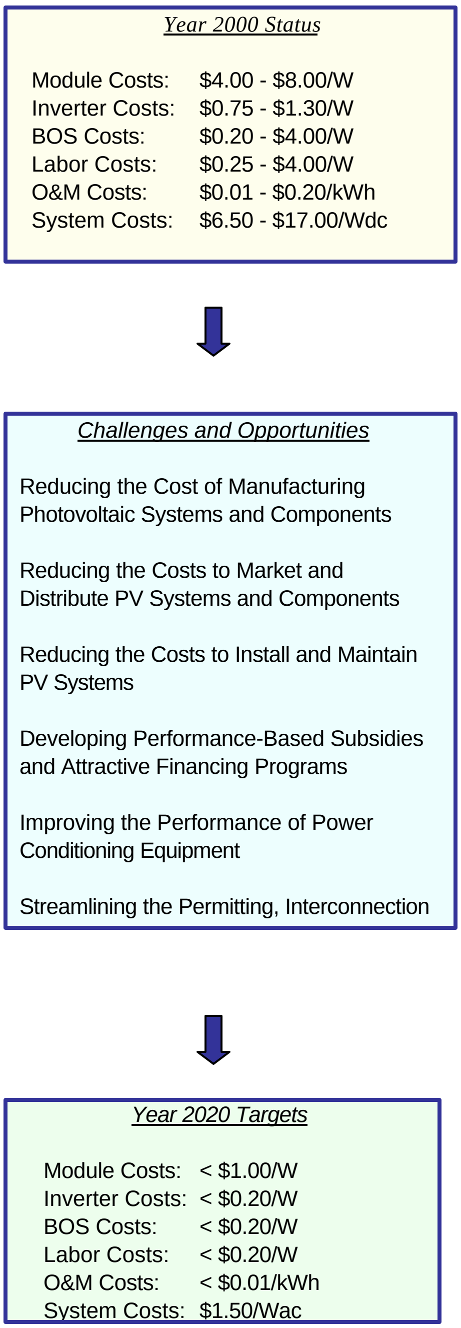

Figure 1. Present prices, future goals, challenges

BASELINE COST DATA

For this paper, the costs of recently installed grid-tied PV systems in Florida will be used as a baseline. Figure 2 illustrates the range of costs for Florida PV installations. Total installed costs are divided into three major categories, 1) costs of major system components, including modules, inverters and module/panel support hardware, 2) additional balance-of-system (BOS) costs required to complete installation, and 3) labor costs for design and installation. The largest costs are for major system components, amounting to between 50 and 80 percent of total installed costs. BOS costs were second highest, ranging from less than 10 to 30 percent of installed system costs. Installation costs were smaller than the costs of modules and inverters, and varied from less than 10 percent to over 40 percent of total installed costs.

In Florida, the lowest installed prices still exceed $9.00 per watt a.c. Reducing these prices by more than a factor of three by 2010, and by more than a factor of six by 2020 will require not only lower hardware costs, but also innovative products, better ways of integrating products into buildings, and new approaches to marketing and distribution.

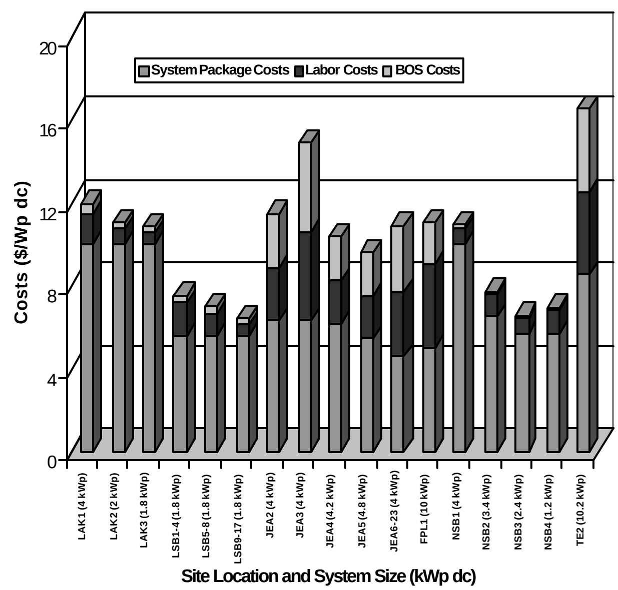

Figure 2. Florida PV system costs.

COST REDUCTION APPROACHES

1. Reducing the Costs of Manufacturing PV System Components

The greatest potential to reduce overall PV system costs is in reducing the costs of manufacturing system components, especially modules and power conditioning equipment (inverters). For most installations, the cost of PV modules and inverters can account for over half the costs. Experience from pilot installations in the Florida PV Buildings Program suggest that module and inverter costs can range from 50 to 80 percent of overall system costs for small rooftop grid-connected systems. Module prices have ranged from less than $3.50/Wp to over $8/Wp dc in the Florida program. Prices for grid-connected inverters have ranged between $0.75 and $1.30/Wac. It is important to note the distinction between the cost of producing a component and the price the end user pays for the component. For example, installed system prices may be considerably higher during periods of high demand than during periods of low demand even though installation costs may be the same.

Cost reductions in manufacturing are closely associated with high production volumes, sustainable markets and technological advances. To achieve industry price goals of $1.50/Wac by 2020, production volume must increase by two or three orders of magnitude from current levels. Average module prices to end-users have decreased significantly over the past couple of decades, from over $10/Wp in the late 1970s to less than $4/Wp in 2000. At the same time, U.S. production volumes have increased from less than 5 MW to over 60 MW. This is a very significant cost reduction in relation to production increases. Other industries typically require one or two orders of magnitude increase in production to reduce costs by one-half [1].

A number of opportunities exist for reducing the cost of manufacturing PV system components. These include standardizing manufacturing equipment, increasing the volume, throughput and efficiency of cell production processes, creating low-cost module packaging and integration methods, and adopting the use of less expensive materials in manufacturing PV products. New, low-cost photovoltaic materials and products, especially those integrated with common building materials, also offer considerable promise for reducing the costs of PV installations. Examples of these building-integrated PV (BIPV) products include roofing materials (shingle, tile, slate and metal roofing), windows and awnings, among other architectural features. In some cases, certain cost advantages may be possible by using PV products in place of conventional building materials. Bonding of flexible, low-cost thin-film PV materials to metal roofing and other building products offers certain advantages over conventional thick-cell modules. Because lightweight, flexible laminates are less expensive to ship than the metal panels, investigations are underway to develop processes for bonding the flexible laminates at or near the site of the installation. Another alternative may involve bonding at regional warehouses, such as commercial roofing warehouses.

Based on years of participation in Southeast Builders Conferences and substantial feedback from builders and home-buyers, there appears to be a public affinity for BIPV products. However, a need exists for improvements in mechanical and electrical integration, reduction in costs and, in many cases, a greater degree of installer specialization. In two of the Florida projects, PV materials bonded to metal roofing were used in place of conventional metal roofing panels. Typical installed costs for conventional metal roofing are approximately $3 per square foot. PV metal roofing panels purchased for the Florida program were approximately $6.50/Wp dc. Considering the power densities of about 4.80 Wp/sq. ft. for these thin-film products, area costs are about $31/sq. ft. including the roofing material. Subtracting the costs of the metal roofing leaves $28/sq. ft. for the PV material alone, or about $5.80/Wp dc. This number is substantially higher (as much as 50 percent) than the lowest costs for conventional flat-plate framed modules purchased under the Florida program. Because many BIPV products use less efficient thin-film PV technologies, larger surface areas (up to 100 percent greater) are required for array installations compared to crystalline arrays of similar output. This drives up area-related costs, requiring competitive thin-film products to be less expensive than conventional crystalline products, per unit of power output.

2. Reducing the Costs to Market and Distribute PV Systems and Components

Reducing the costs to market and distribute photovoltaic equipment offers potential to lower overall system prices. Some companies expend considerable resources in developing marketing and distribution chains, while other companies may take a more direct approach to reduce end-user costs. Therefore, the effects on end-user costs due to the marketing and distribution of PV products can vary widely.

Experience from the Florida program suggests bulk purchases directly from manufacturers are 30 to 50 percent less costly than similar systems and equipment purchased through distribution channels. Examples to support this include recent Florida utility bulk purchases of packaged systems for approximately $4.50/Wp dc. Similar hardware supplied through distributors can be as high as $6-8/Wp dc.

Strategies to reduce these transaction costs include direct sales to end-users, bulk purchasing by utilities or large consortiums, direct sales to building supply centers, and new marketing schemes to reach diverse end-users and geographical areas.

3. Reducing Installation, Operation and Maintenance Costs

Labor costs for pilot projects in the Florida PV Buildings Program have ranged from 10 percent to over 40 percent of overall system costs, with the higher range associated with custom installations. The cost of labor based on system size has ranged from about $0.50 to $2.00/Wp dc for rooftop and building-integrated installations under 10 kWp dc. The skills and experience of installers can have a direct effect on reducing PV installation costs. Labor time (and costs) have been considerably higher for personnel installing PV systems for the first time, or even experienced installers using new products and designs for the first time. Inexperienced installers can take more than twice as long to install a system as individuals having had experience installing a half dozen or more similar systems. Development of a knowledgeable, skilled and experienced workforce is key to reducing labor costs, as well as helping to improve the safety and quality of installations. A need exists for broad-based training curricula on PV technologies throughout electrical trade organizations and training institutions. Goals are to reduce the average number of person-hours required for installations and reduce average labor costs for rooftop installations to less than $0.20/Wac by 2020.

The level of hardware integration and the increasing use of packaged PV systems have had a substantial effect on reducing installation costs compared to custom designs, installations and equipment. Improvements in the documentation, drawings, parts lists, instructions and other materials provided with system packages have greatly facilitated the installation, operation and maintenance of newer systems. In addition, these materials can also aid in the permitting and inspection process for PV installations. Continued development of standard design packages, equipment and installation practices is strongly encouraged.

Cost reductions in installation labor are also achievable with certain design strategies, particularly by using higher voltage modules and equipment. Higher voltage applications translates directly to smaller conductor and conduit sizes, fewer number of source circuits, conductors and overcurrent devices, which all contribute to simplifying the installation, reducing the amount and size of electrical BOS, and reducing costs. Certain product design and manufacturing principles can also reduce the costs of installing PV systems. This includes minimizing the total number of parts and part variations included in systems design, including use of larger modules, fewer panels, and less hardware. Where possible, eliminating the need for special tooling, designing certain parts to be multifunctional, avoiding tight tolerances, and creating components that only assemble in one way also can reduce costs. Designs should allow for ease of assembly and accessibility, not only to reduce the installation time required, but also to reduce maintenance. Mounting designs for PV arrays are needed that allow for easy access for maintenance and repair and are easily removed for re-roofing. Tradeoffs must be identified in system design and installation, including the practice of pre-assembling and pre-wiring panels off-site using less expensive personnel, and in minimizing the number of roof attachment points versus subjecting individual attachment points to larger forces.

For photovoltaic applications on buildings, one interesting approach involves factory-installed systems. Approximately 30 per cent of new housing stock in the U.S. is manufactured housing of one type or another, with higher percentages in Florida. To be effective, the manufacture of buildings in a factory requires careful planning, time-motion studies, and process optimization – areas of interest to industrial engineers. Opportunities exist to include photovoltaic systems in the building manufacturing process. The idea is to accelerate the installation process, reduce costs, and improve quality control. Strategies include both complete and partial installation of systems in the factory, with the latter approach being used to simplify installation in the field. There are several related efforts in Florida and in other states.

Operation and maintenance (O&M) costs can be significant for PV installations. For small rooftop PV systems, one maintenance visit per year can offset the value of energy produced per year by the system. Improving the reliability and fault tolerance of systems and equipment can have a significant effect on reducing O&M costs, and can improve overall system performance. While there have been very few problems associated with PV modules and arrays in the Florida program, a number of reliability issues have been identified with inverters and power conditioning equipment in grid-connected systems. Over fifty percent of these installations have experienced problems with power conditioning subsystem components that required a site visit to correct the problem and return the system to normal operation [4]. Unscheduled maintenance has been required to change out complete inverters, replace fuses, reset circuit breakers, and upgrade software. Based on the amount and value of energy produced from these systems, the estimated costs for maintenance have ranged from $0.05 to $0.20 per kWh ac during the first year of operation. Other studies have identified O&M costs ranging from $0.01 to $0.16 per kWh ac [4, 5]. Challenges to reduce PV system maintenance costs include developing inverter designs that offer improved reliability and fault-tolerant features consistent with those for PV modules.

Identifying problems with PV systems that require maintenance is largely dependent on the level of oversight and monitoring employed. Typically, it requires either site visits by trained personnel or some type of monitoring scheme, such as metered inverter output. What to do about problems identified is another matter, and involves tradeoffs between the effects on performance, cost of maintenance, and the value of system availability. Mean time before failure (MTBF) for PV inverters must be increased significantly. Both MTBF and the mean time to repair (MTTR) information are needed to assess the value of system output and availability [4].

4. Developing Performance-Based Subsidies and Attractive Financing Programs

Since the inception of Florida's $2 per Watt subsidy program in 1998, the number of grid-connected PV systems in Florida has increased from only a handful to more than fifty, with a total installed capacity of more than 200 kW dc. Electric utilities and other program partners have invested more than $1.5 M to leverage funds from the buy-down program.

Over the past 20 years, subsidies, credits, exemptions and other financial assistance have been the principal means to support the cost of PV applications in domestic markets for distributed generation, building-integrated and rooftop systems. A continued reliance on these sources and major commitments by public and private institutions are critical if the 2020 goals established by the U.S. PV industry are to be met. Incentive programs for end-users are necessary, as well as new and innovative ways to finance and buy-down the cost of PV installations.

Energy-related incentive programs have had positive effects on advancing PV technology by opening new markets, increasing resources for R&D, lowering costs to consumers and encouraging investment [6, 8]. While subsidies and buy-down funds for PV applications are increasing the number of applications, building industry infrastructure and developing technology, they do not necessarily reduce the cost to the end user. For example, subsidies in the 1980's for solar thermal systems that were not performance based resulted in unsuspecting buyers paying more with the subsidy than what they would have paid without it. Some concerns about incentive programs include the level of administrative and technical oversight required, and the ability of the industry to reach self-sustaining levels after the subsidy ends. Performance-based subsidies not only help reduce price to the end user, but also challenge the industry to meet or exceed performance claims and expectations for their products. Large users are likely to purchase PV systems and equipment based on performance, and may monitor installations and hold system suppliers accountable for shortfalls in energy production. Performance-based subsidies for PV systems at levels consistent with those afforded to conventional energy technologies are encouraged.

Tax relief can also help reduce the costs of PV systems, and has been implemented as part of state and federal policies. Sales tax exemptions for PV products can be readily implemented at state levels. Property tax exemptions, such as in Florida for solar energy equipment, allow the value of the equipment to be omitted from ad valorem tax assessments. Legislative actions are encouraged to promote these exemptions. Income tax credits, such as those offered by some states, can help stimulate the market for PV systems and send a positive message about the technology. However, federal tax credits in the 1980s were not performance based, and were often abused and actually drove prices higher. Any tax relief or other financial incentive programs to encourage PV installations should not require excessive government oversight or programmatic support. Furthermore, tax relief for installations and/or equipment should directly benefit purchasers and end-users -- not just manufacturers and system suppliers.

Long-term, low-interest financing can help create and sustain PV markets, especially for PV systems included in new home mortgages and home equity loans. This area suggests a real opportunity for reducing PV system initial costs by spreading the costs over the life of the mortgage or loan. Because the average U.S. homeowner is likely to move within 5 to 7 years after purchasing a home, amortizing the costs of PV systems offers distinct advantages. A need exists to educate and build confidence among lending institutions so they will be more likely to finance PV systems in home mortgage and equity loans.

Electric utilities can also help finance the cost of PV systems to their customers through green pricing and other marketing programs. PV systems can help utilities diversify generation sources, and provide additional peak power during critical load periods. With growing concerns about greenhouse gas emissions and global warming, the generation of carbon offsets from non-polluting PV technology may offer additional value for utility PV applications. These offsets may be traded as commodities, or used to mitigate the development of other less environmentally sound generation technologies.

5. Improving the Performance of Power Conditioning Equipment

The power conditioning equipment and inverter used in grid-connected PV systems perform a number of essential functions to permit the safe, reliable and efficient utilization of PV array energy. How well the power conditioning equipment performs these functions directly affects performance, reliability and costs. Unfortunately, progress in inverter efficiency, reliability and costs over the past twenty years has been discouraging compared to developments with photovoltaic modules, and is a serious concern within the photovoltaic systems research community. At present, small market demand and low production volumes result in many utility-interactive PV inverters being largely hand made.

A number of performance issues have surfaced during the evaluation of small PV inverters in the Florida program. These issues include the ability of units to maintain grid-connection, power conversion efficiency, effectiveness of array peak power tracking algorithms, nuisance trips of circuit breakers, and failures of source circuit fuses. Consequently, the performance for monitored systems has been less than expected.

Significant needs exist for increased funding in research and development of utility-interactive PV inverters. These efforts should include highly accelerated lifetime testing, and studies on the effects of load, utility power quality, dynamic conditions, and multiple inverters of the same and different topologies operating on the same ac bus. Development of fault-tolerant inverter designs, including possible use of automatically re-setting overcurrent devices is encouraged. PV inverters must be capable of operating over a wide range of voltage and current output from the PV array, and must rapidly respond to changes in array output during variable irradiance conditions. Furthermore, the equipment must operate the array at maximum power output under these conditions, and must maintain acceptable power quality and interact with the utility grid within specified operating criteria.

6. Streamlining the Permitting, Interconnection and Inspection Processes

Permitting, interconnecting and inspecting PV systems can have significant effects on the costs of PV installations, and in many cases are barriers to technology implementation. However, as with any electrical power system, they are necessary in ensuring safety, reliability and conformity with jurisdictional requirements. Advancements in equipment standards, product listings and the development of packaged systems have helped to reduce the time and costs associated with these processes. A need exists for consensus interconnection requirements, and improved knowledge and familiarity with PV installations among utilities, electrical trades and code enforcement officials.

As part of the Florida program, a complete plan for implementing state and community PV program was developed and delivered at workshops in several states [7]. The plan includes quality assurance measures for systems and equipment, practitioner training and certification requirements, and guidelines for site surveys, system monitoring and inspections. Included are interconnection guidelines and submittal forms that were developed for use by utilities and their customers. These recommendations for small (less than 10 kWac) PV systems were presented to the Florida Public Service Commission in meetings with investor-owned utilities. The Florida Municipal Electric Association and many of its municipal utility members are considering adopting these interconnection guidelines.

Ownership of PV installations is often an issue when interconnecting to the utility grid. Inherently, there are no significant barriers when the utility owns the PV systems that are to be interconnected to their grid. However, privately owned PV systems that are not under direct control of the utility have created serious concerns. Major issues include safety, equipment protection, power quality and reliability of service. Utility requirements for outdoor, accessible and lockable disconnects on privately owned PV systems can add significantly to installation costs [9,10]. One example of this requirement added approximately $0.15/Wp to the cost of a nominal 7 kW PV installation. Over/under frequency and voltage protection are other examples of utility requirements that can add to the cost of PV installations.

Permitting and inspections are an important part of PV installations, mainly due to contracting and liability issues. Installations in most jurisdictions will require licensed contractors, and inspections by code enforcement officials. Lack of local knowledge concerning PV systems has presented problems for PV system installers and owners in many areas. A need exists to develop guidelines for inspecting PV system installations for code officials and installers and to distribute them through national associations and training programs. To help ensure the safety and quality of PV installations, contractor law specifically dealing with PV installations is encouraged.

Codes, covenants and restrictions can increase costs or otherwise hinder the implementation of PV systems. Certain community building standards may prohibit the installation of rooftop PV systems. Legislation, such as that on the books in Florida, is encouraged to prevent barriers to installing rooftop PV systems in deed-restricted communities.

Insurance requirements for PV installations, where applicable, can be a significant factor in the overall cost of PV systems. Several years ago, the annual liability insurance premiums for a grid-connected PV system at FSEC’s main facilities were about four times the value of the yearly energy produced by the system. A need exists to provide underwriters with information and data that will reduce uncertainty, allow more accurate risk assessment, and result in premium rates consistent with risk.

CONCLUSIONS

In summary, this paper identifies a number of opportunities for reducing the cost of PV installations. Considerable variation exists in the present costs of PV installations in the Florida program, ranging from $6 to over $15/Wp dc. PV module costs are between 50 and 80 percent of overall system costs. However, installation labor and BOS (including inverter), which account for between 20 and 50 percent of installed system costs, offer good opportunities for near-term cost reductions. Standardization of components and system packaging are important elements of cost reduction. The reliability of power conditioning equipment is a major driver of operation and maintenance costs. Long-term challenges include reducing the cost of manufacturing PV modules, and in developing new and innovative building-integrated PV products.

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