The Market for Photovoltaics in New Homes Using Micro-Grids

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Abstract

Policy makers have used economic incentives to create a near-term market for grid-connected photovoltaics (PV). How will this market be affected if these incentives disappear? This paper estimates the U.S. market without incentives for PV in new single-family homes in subdivisions. It evaluates grid-connected and grid-independent micro-grids (one-third PV) and grid-connected PV-only systems (all PV, net metered output). Results indicate that the PV market is larger for grid-independent micro-grids than for grid-connected PV-only systems for PV prices above $2,000/kW. The grid-independent micro-grids market ranges from 5 to 120 MW/year at a PV price of $6,000/kW; the variation is due to uncertainty in the utility interconnection cost savings. The paper outlines steps to implement micro-grids.

Introduction

The economic evaluation of PV in residential buildings has been the focus of a number of recent papers [1, 2]. These papers have determined the maximum amount consumers can pay for PV systems and be economically indifferent between buying a PV system and receiving electric service from their utility. The work has taken into account utility bill savings, income tax savings, and the availability of economic incentives on a state-wide basis. As a result, these papers have been particularly valuable in identifying states where the early introduction of PV is economically attractive.

In another research direction, other work has shown that there is great potential for the use of PV in residential applications in combination with cogeneration and efficiency technologies [3, 4]. The work demonstrated that cogeneration and PV are complementary technologies: cogeneration electricity production peaks in the winter while PV electricity production peaks in the summer. The result is that the combined output is a good match to residential demand. Further work evaluated the combined system being applied as micro-grids [5].

Motivation

A grid-independent micro-grid is composed of a set of power generators that supplies all of the demand of a group of customers without any utility backup. Grid-independent micro-grids represent a radical shift from the status quo.

In light of the fact that a grid-connected PV market is already emerging, compelling reasons are needed to justify the added effort of including PV in grid-independent micro-grids. Two such reasons are that economic incentives and net metering may eventually be exhausted or may cease to exist. The loss of them would reduce the size of the grid-connected PV market. It is important to know that their loss would not devastate the market.

Economic incentives drive the break-even PV capital cost. In a recent grid-connected PV analysis, 15 of the 17 states that had economic incentives available were ranked as the states with the highest break-even cost [2]. Incentives could expire (e.g., tax credits) or PV demand could exceed available funds (e.g., the state-wide programs in California, Illinois, and Florida will result in an estimated maximum of 6 MW per year of PV for residential customers[1]).

Net metering allows customers to manage the mismatch between supply and demand by buying and selling power at the same price. The effect of this is that customers can install larger PV systems. Although net metering requirements vary by state, a typical number is 0.1 percent of total sales (or capacity) [6]. PV energy production will exceed 0.1 percent of U.S. electricity sales once 660 MW are installed.[2] In addition, some states do not have net metering requirements and some utilities are contesting their requirements.

Objective

This paper estimates the U.S. market without incentives for PV in new single-family homes in subdivisions. The analysis is performed for three PV system configurations.

1. Grid-connected micro-grids. PV supplies one-third of the electricity and cogeneration supplies two-thirds. Customers incur fixed costs on their utility bills as well as the initial cost of connecting the housing development to the utility grid in return for utility backup. There is no net metering.
2. Grid-independent micro-grids. PV supplies one-third of the electricity and cogeneration supplies two-thirds. Customers do not incur fixed costs or the initial cost of connecting the housing development to the utility grid and they do not have

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[1] There is a total of $54 Million available funds in California. This will result in a minimum of 32 MW of emerging technologies. Sixty percent of the money (or 19.2 MW) is reserved for systems of 10 kW or less (http://www.energy.ca.gov/greengrid/background.html). It is assumed that the program will last for 4 years.

It is estimated that $5 Million per year is available in Illinois. Assume that all of the funds support PV (the program is applicable for PV, solar thermal, and wind). This translates to 1.2 MW per year based on the 60 percent buy down and a PV cost of $7,000/kW. (Phone conversation with Rex Buhrmester at the Illinois Department of Commerce and Community Affairs on January 24, 2000.)

There was a total of $525,000 available for equipment buy downs in Florida. This corresponds to about 0.3 MW based on a $2,000/kW rebate. (Phone conversation with Jennifer Skislak of the Florida Solar Energy Center on January 24, 2000.)

[2] This is based on a 19 percent PV capacity factor and U.S. residential electricity consumption of 1.1 trillion kWh/year (Energy Information Administration, *Annual Energy Outlook 1997*, DOE-EIA-0383(97), p. 102) and the assumption that PV is the only net metered technology.

the benefit of utility backup. Net metering is not an option because there is no utility connection.

3. Grid-connected PV-only systems. The PV supplies all of the electricity. Customers incur fixed costs on their utility bills as well as the initial cost of connecting the housing development to the utility grid. Annual net metering is available.

The analysis focuses on new housing developments and excludes the retrofit market. It uses actual utility rate structures and state and federal income tax information. It is assumed that the new houses are highly efficient (they use 3,000 kWh per year).

The paper is divided into two sections. The first section describes the economic analysis and the resulting market size. The second section describes how the micro-grids might be implemented as well as short-term opportunities available to builders.

Market Estimate

This first section presents the market estimate.

Evaluation Approach

Obtaining a market estimate requires that a decision rule be selected that consumers will use to decide whether or not to invest in PV. This paper assumes that consumers will invest when the PV is cost-effective.

There are a variety of ways to define cost-effectiveness. Net present value (NPV) is one of the most accurate methods when there are no embedded options. The consumer should invest if the NPV is positive. Unfortunately, consumers have a limited understanding of NPV.

Consumers might define cost-effectiveness in practice by comparing the investment's annual savings with its annual costs. The consumer should invest if the savings exceed the costs.

Such a comparison results in the same investment decision as the NPV approach when costs and savings are constant over time. It has the added attraction that it is much more simple to understand. As a result, this is the decision rule used in this paper.[3]

The paper determines the price at which residential customers are economically indifferent between purchasing PV (or a micro-grid with PV) versus connecting to the existing utility grid. This is the maximum PV price consumers can pay and still be economically indifferent between having the PV or staying with utility service.

[3] It is assumed that the first year costs and benefits equal the costs and benefits in future years so that the costs and benefits are constant over time. This is not strictly correct in that the tax savings will go down over time as the balance of the loan is repaid and the utility bill savings may go up over time due to inflation; these factors, however, may have the tendency of canceling each other.

Desired Results

Consumers will invest if the annual savings are greater than the annual costs. The cost savings and cost components depend upon how the system is configured. The three configurations described earlier are evaluated. In addition, low connection cost savings and high connection cost savings are presented for the grid-independent micro-grid.

Table 1 summarizes the cost savings and the costs for the alternatives; Table 2 briefly describes each column.

Consider how the investment rule applies to the PV-only alternative. Table 1 implies that a consumer will invest if the ***Incremental Utility Bill Savings*** plus the ***Income Tax Savings*** is greater than the ***Annual PV Cost***.

Table 1. Cost savings, costs, and PV size for various alternatives.

	COST SAVINGS				***COSTS***		***PV SIZE***
	Inc. Utility Bill Savings	***Fixed Cost Savings***	***Annual Connection Savings***	***Income Tax Savings***	***Annual PV Cost***	***Annual Cogen. Cost***	***Percent of Demand met by PV***
Grid-Connected							
PV-only	Yes	No	No	Yes	Yes	No	100%
Micro-Grid	Yes	No	No	Yes	Yes	Maybe[4]	33%
Grid-Independent Micro-Grid							
connection costs = $0	Yes	Yes	No	Yes	Yes	Yes	33%
connection costs =$2K	Yes	Yes	Yes	Yes	Yes	Yes	33%

[4] PV is not packaged with cogeneration if it reduces the cost effectiveness of the PV in the grid-connected option.

Table 2. Component definitions.

COST SAVINGS	
Incremental Utility Bill Savings	the savings that correspond to reducing electricity consumption from full consumption to no consumption (i.e., the savings do not include fixed costs or minimum bills)
Fixed Cost Savings	the savings that result from disconnecting totally from the utility
Annual Connection Savings	the savings from not connecting the housing development to the utility grid in the first place, amortized over time
Income Tax Savings	the state and federal income tax savings associated with the interest deduction; the savings equal the capital cost times the loan interest rate times the consumer's income tax rate
COSTS	
Annual PV Cost	PV capital cost, amortized over time
Annual Cogeneration Cost	cost associated with the capital and O&M costs to run the cogeneration portion of the micro-grid
PV SIZE	percent of customer demand met by PV system output

Annual Costs and Benefits

Utility Bill Savings

The first step in estimating the utility bill savings is to determine the amount of electricity each home will consume without the PV. While electricity usage varies across the country, this paper assumes that all houses are very efficient and use 3,000 kWh per year. This estimate is based on the expected electricity consumption by a new energy efficient housing development in Southern California. These houses use natural gas for water heating, space heating, cooking, and air conditioning. They have fluorescent lights and use Energy Star appliances [7].

PV will meet as much load as possible without having excess production in order to eliminate the need for electrical storage. An analysis of a load profile and PV system output for San Diego, CA indicates that the PV system can meet about one-third of the total electricity needs without having excess PV output. This suggests that each house will use 1,000 kWh per year from the PV systems for the micro-grid alternatives. This is a non-optimized PV size that is independent of price. This corresponds to a PV system size of between 0.5 kW to 0.75 kW, depending upon location. The remainder of the electricity is supplied by a cogeneration technology, such as fuel cells or micro-turbines.

The PV system will supply all of the load for the PV-only system. The mismatch between supply and demand is dealt with through the use of net metering.

The second step in estimating the utility bill savings is to input this level of consumption into a rate analysis program. The Clean Power Estimator program, a program that contains actual utility rate structures for more than 12,000 cities throughout the U.S. [8], is used to estimate the incremental savings of reducing consumption from 3,000 kWh per year to 0 kWh per year. This assumes that the customer has no consumption but is grid-connected so they pay the monthly fixed cost or minimum bill. The program is also used to estimate the value of disconnecting totally from the grid. This equals the fixed cost or minimum bill.

Reduced Connection Costs

In addition to utility bill savings, grid-independent micro-grids may reduce the costs of connecting customers to the existing utility grid in the first place. Micro-grids will continue to incur the distribution system costs within the housing development. There may, however, be a reduction in the cost of connecting the housing development to the utility grid.

This connection cost is highly variable. On the one hand, connection costs could be low if the development is located near a substation. On the other hand, connection costs could be high if the development is located at a long distance from the grid, there is no substation in the vicinity, the connection is underground, and/or the line must run through solid granite.

The low connection cost estimate is $0 and that the high connection cost estimate is $2,000 per house.

Since these added connection costs are passed on from the developer to the consumer in the form of higher housing prices, eliminating these costs will reduce the price of the house. The two effects of this are a decrease in the size of the mortgage payment and an increase in income taxes because of a reduction in interest write-off expense.

Marginal Tax Rate

The consumer's marginal tax rate is needed to estimate the income tax effects. This rate is based on the homeowner's income and the federal and state income tax structures.

It is assumed that the homeowner's taxable income (Federal Form 1040 line 39) is correlated to their housing expense and that this expense represents 30 percent of the homeowner's income. The U.S. Census Bureau’s housing value by location (same data base as housing starts) is used to estimate annual housing expense and then to infer annual income. Inferred annual income ranges from a low of $12,000 to a high of $113,000 depending upon the location selected and based on an 8 percent, 30-year home loan. The $35,000 average income is close to the U.S. Census Bureau’s national average of $38,000 [9], thus giving confidence in the accuracy of this approach.

These income estimates are then combined with the state-specific income tax rates in the Clean Power Estimator program to determine the combined marginal federal and state tax rate for each city. The effective state and federal tax rate has an average of 20 percent with a low of 15 percent and a high of 35 percent.

Cogeneration Costs

Two assumptions are made about the cogeneration technologies: (1) they have the same thermal efficiency as the end-use appliances they replace (e.g., water heaters and space heaters); (2) meeting two-thirds of the house's electrical needs with cogeneration provides all of the house's thermal energy (see [4, 5] for a justification of these assumptions). The result of applying these assumptions is that there is no added fuel cost associated with the cogeneration's electricity generation (fuel costs are incurred only when more than two-thirds of the house's electricity needs are supplied by the cogeneration); the only costs associated with the cogeneration are the capital, operation, and maintenance costs. These costs are assumed to be $0.10/kWh.

Single-family Houses in Subdivisions

The next step of the analysis is to estimate the projected number of new houses built in housing developments each year. The U.S. Census Bureau compiles information about the number and value of new housing units. It presents this information by 328 cities (called Metropolitan Statistical Areas or MSAs) within the U.S. as well as the number of housing units (1, 2, 3, 4, 5, and more than 5 units) [10]. There were a total of 1.38 Million housing units built in 1998.

This paper focuses on new single-family houses in housing developments. Thus, the total number of housing units needs to be reduced to account for only single-family housing units that are built in subdivisions. According to the U.S. Census Bureau, 1.00 Million of the 1.38 Million housing units built in 1998 were single-family houses.

It is difficult to determine the exact number of single-family houses that were built in housing developments as opposed to the number of single-family houses built on individual plots. Personnel at the US Census Bureau and the National Association of Homebuilders, however, estimate that this number is about 70 percent of the total number of single-family houses [11].

This suggests that the potential market for micro-grids was about 700,000 houses in 1998, or about half of all units constructed.

Results

The cost and cost savings described in the previous section were calculated for 82 percent of the new single-family houses located in subdivisions in the 328 MSAs and PMSAs identified by the U.S. Census Bureau.[5] This was accomplished by collecting the actual utility rate structures and then using the Clean Power Estimator program to determine the utility bill at both 3,000 kWh of annual consumption as well as 0 kWh of consumption (i.e., only fixed costs and/or minimum bills are incurred). The Clean Power Estimator program was also used to determine the location-specific income tax rates as well as the PV output. The customer connection costs were not estimated by city because of: (1) a

[5] The remaining 18 percent of houses were not included in the analysis because of unavailability of rate schedules. In general, however, these houses tended to be located in lower rate regions of the countries and thus, the results of the analysis should give a good indication of the size of the market.

lack of data and (2) the wide variance in connection costs even within a given city due to distance from the utility grid, soil conditions, and other factors.

It is important to re-emphasize at this point that this paper excludes existing economic incentives. Thus, the following results will not identify opportunities that currently exist in the U.S. where PV systems are economical [2].

Figure 1 presents the U.S. market for PV in new single-family homes in subdivisions. The gray area is the range of the market for PV in grid-independent micro-grids (one-third PV). The Low Estimate corresponds to the case where there are no connection cost savings and the High Estimate corresponds to the case where there are connection cost savings of $2,000 per house. The dashed line is the market for PV in grid-connected micro-grids. The solid line is the market for grid-connected PV-only systems (all PV). Table 2 and Table 3 summarize the size of the PV market for the alternatives as a function of PV price. Table 2 presents the number of MW/year and Table 3 divides these results by 350 MW/year.

Results indicate that the PV market is larger for the grid-independent micro-grids (one-third PV) than for the grid-connected PV-only systems (all PV) above prices of about $2,200/kW of PV. The greater number of houses where micro-grids are economically feasible (because of added cost savings) more than makes up for the smaller PV system size installed at each house. Results also suggests the grid-independent micro-grids market ranges from 5 to 120 MW/year at a PV price of $6,000/kW, with the variation due to uncertainty in the utility interconnection cost savings.

Figure 1. U.S. Market for PV in New Single-Family Houses in Housing Developments without Economic Incentives.

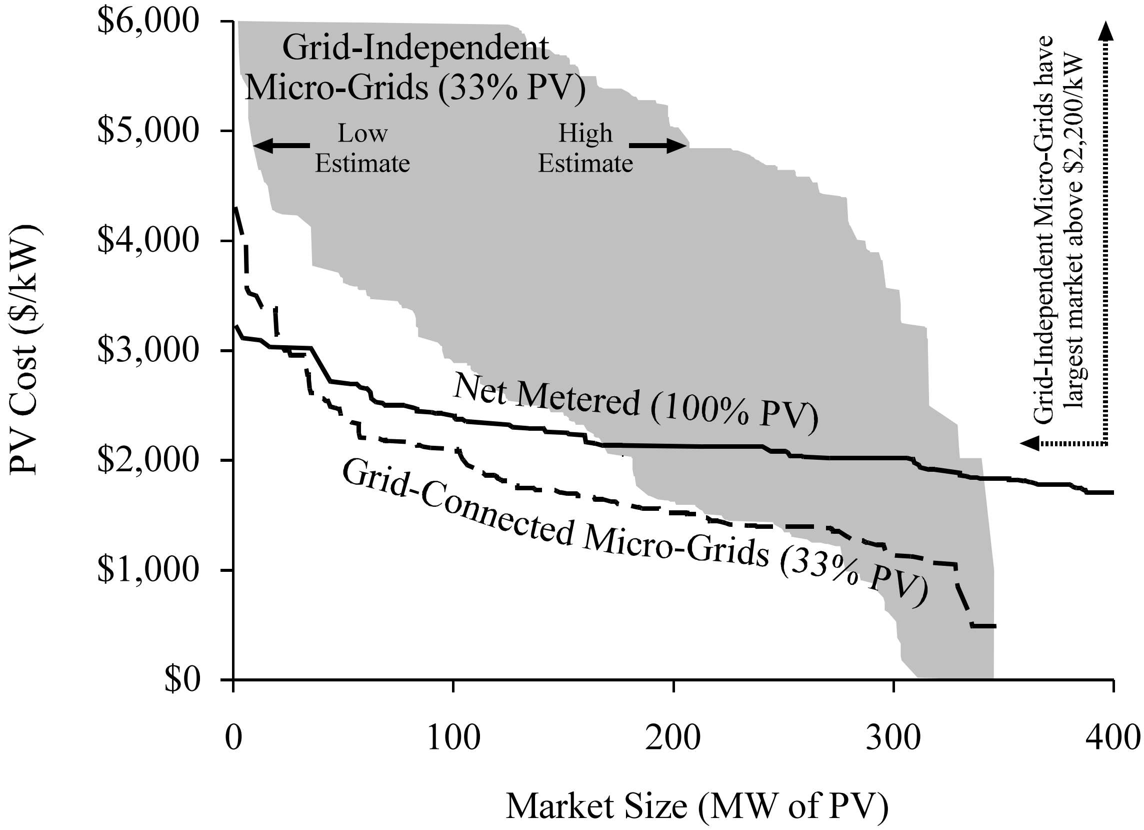

Table 3. PV Market Size

	PV Only	PV as part of Micro-Grid		
PV Price	PV	Grid-connected	Grid-Independent	
			No Cost Savings	$2,000 Cost Savings
$2,000	310 MW/yr	105 MW/yr	172 MW/yr	343 MW/yr
$3,000	35 MW/yr	21 MW/yr	84 MW/yr	319 MW/yr
$4,000	-	6 MW/yr	28 MW/yr	284 MW/yr
$5,000	-	-	7 MW/yr	203 MW/yr
$6,000	-	-	4 MW/yr	119 MW/yr

Table 4. PV Market Size Express as Percent of Total Possible Market

	PV Only	PV as part of Micro-Grid		
PV Price	PV	Grid-connected	Grid-Independent	
			No Cost Savings	$2,000 Cost Savings
$2,000	89%	30%	49%	98%
$3,000	10%	6%	24%	91%
$4,000	-	2%	8%	81%
$5,000	-	-	2%	58%
$6,000	-	-	1%	34%

Implementing Micro-Grids

Grid-independent micro-grids represent a radical change from the status quo. The increased market size identified in the previous section should provide parties interested in increasing PV equipment sales with the motivation to expend the extra effort required to implement micro-grids. There are, however, other parties who will be involved in implementing the micro-grids.

In particular, builders are likely to play a key role in implementing micro-grids. Builders currently give little attention to how the electric utility service is provided. They obtain utility service for the house with a phone call to the local utility company. Utility service issues are the domain of the utility company (not the builder) once the house is sold.

Micro-grids will result in more complications for builders. They add a new level of complexity to the house construction as well as a new set of responsibilities for the builder after the house is built (see Table 5). This will discourage builders from introducing any energy production equipment into homes. Thus, builders need a strong motivation to enter this arena.

Table 5. Issues directly or indirectly affecting builder

Issue	***Affected Parties***
During Construction	
System cost and effect on house price and salability	Builder
PV system placement on roof	Roofer, PV system integrator
Space heating system design that best accommodates cogeneration (radiant heating rather than forced air?)	HVAC contractor; plumber
Electrical circuit changes	Electrician
Cogeneration control system installation	???
Control system integration between homes (grid-independent micro-grid)	???
After Construction	
Service issues associated with equipment failures	Builder
Liability if system fails or does not perform as promised	Builder
System operation (optimal control of cogeneration)	???
System operation for housing developments (grid-independent micro-grid)	???

Motivation for Builders

While builders will have more issues to pay attention to with micro-grids, there are notable reasons why they might be interested in including generation equipment in the houses. In the long-term, these reasons include:

1. All other builders offer the equipment and customers expect it
2. Including the system will increase the house price and thus the builder's profit
3. Builders can create partnerships with utilities in transmission and distribution (T&D) constrained areas where utilities want to promote distributed resources

In the short-term, these reasons include:

4. The equipment may enable the builder to offer the homeowner valuable options that would otherwise be unavailable
5. The system might enable builders to sell the home when it would otherwise have been very difficult (product differentiation in a difficult market)

Steps to Grid-Independent Micro-Grid

Builders are unlikely to risk the leap from the status quo (no energy generation equipment) directly to grid-independent micro-grids. Rather, they will move there in a series of steps. Possible steps are presented below.

- Step 0: build efficient houses
- Step 1: offer PV systems as an option to consumers
- Step 2: equip houses with the capability to accept cogeneration technologies as they are developed; offer cogeneration as an option to consumers
- Step 3: include PV and cogeneration as standard items in the housing development
- Step 4: make the housing development self-sufficient (supply equals demand) but retain the utility connection for reliability
- Step 5: make the housing development grid-independent and eliminate the utility connection

A Near-Term Opportunity

Some builders are currently at Step 0 and a few have activity at Step 1. This subsection describes one way to stimulate activity at Step 1.

Builders will be motivated to offer PV systems to homeowners if the PV systems are a high profit margin item for them. In order for this to be true, builders need to offer customers with a valuable option that they desire.

PV systems are clean energy producers and are good for the environment. This is attractive to consumers. Distributed generation technologies in general can provide customers with added reliability. This is likely to become more attractive to customers, particularly given that a decrease in overall utility reliability may be a by-product of electric utility restructuring. Residential customers are not likely to receive priority over other customers in outage conditions [12].

PV systems alone can neither solve nor are they the best solution to all reliability problems. Housing loads fluctuate throughout the day and night and power outages could occur at any time. The PV system, however, is non-dispatchable and produces power only when the sun is shinning.

There are situations, however, when a PV/battery combination is a good solution to reliability problems. One example is when outages: (a) are long in duration (b) occur during daylight hours and (c) have very negative consequences. Storage-only solutions are inadequate because the system would be too expensive to provide power during the entire outage.

Consumers who want home offices represent one market segment where these conditions exist. Home offices tend to rely heavily on computer equipment with the primary computer use occurring during daylight hours. A long duration outage translates into a loss of income (or the loss of work for the person's employer) and thus has very negative consequences.

A builder could appeal to these customers by offering PV as part of a home office package. The package could include the following components.

1. Equip the house for high-speed Internet access. Wire the house with computer network connections, having outlets at the same locations as the phone jacks (phone connection at the top of the plate and network connection at the bottom of the plate).
2. Add an electrical panel or device that allows customers to select one or more "high reliability" circuits in the house (limit the circuits to potential office locations). Utility service powers these circuits during normal conditions; a small battery system powers the circuits in the event of a power outage.
3. Install a 300 to 500 Watt PV system. The PV provides power to the house during normal conditions and then switches to a battery charging mode during outages in order to maintain power to the "high reliability" circuits. The PV system could even be installed without net metering because only a small amount of electricity is likely to be lost due to overproduction.

Such a system should cost under $5,000 and would appeal to customers who are interested in a high reliability home office powered with clean energy. Including a package with options that customers desire will translate into higher profits for builders.

Motivation for Early Implementation

In addition to markets having high value applications, some locations provide builders with an incentive to integrate PV into their homes now rather than later. This opportunity has been brought about by electric utility deregulation. The establishment of system benefit charge funds has occurred along with deregulation in a number of states. In California, for example, a $54 Million fund was made available to support emerging technologies. Builders can access these funds to buy down the cost of technologies like

PV.[6] While the market estimates in this paper do not rely on incentives, these incentives do offer builders a low-risk opportunity to test a new market.

Conclusions

This paper estimates the U.S. market without incentives for PV in new single-family homes in subdivisions. It evaluates grid-connected and grid-independent micro-grids (one-third PV) and grid-connected PV-only systems (all PV, net metered output). Results indicate that the PV market is larger for grid-independent micro-grids than for grid-connected PV-only systems for PV prices above $2,000/kW. The grid-independent micro-grids market ranges from 5 to 120 MW/year at a PV price of $6,000/kW, with the variation due to uncertainty in the utility interconnection cost savings.

The paper discusses how builders might begin to include micro-grids in their developments and highlights near-term business opportunities that do not require full micro-grid implementation. One opportunity is grid-connected PV that is part of a high-reliability home office package. This and other opportunities could facilitate a transition to grid-independent micro-grids.

Further research should focus on the effect on of including environmental, added reliability, and financial risk mitigation benefits into the analysis. In addition, the effect of optimizing system components (rather than assuming the PV supplies one-third of the electricity) should be considered.

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