INDUSTRY DEVELOPMENT STRATEGY FOR THE PV SECTOR

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I. INTRODUCTION

A. The Problem: Reducing the Price of Photovoltaics

If the price-volume relationship observed to date continues, photovoltaics (PV) will not make a significant impact on carbon emissions in the United States until well into the next century. Given the historical relationship between growth in cumulative volume and decline in price, the installed base will have to increase from its current total of approximately 1 gigawatt (GW) to well over 100 GW in order to achieve a price truly able to compete with fossil-fueled generation technologies. This price might have to as low as $1/watt installed.[1]

And how long might this take? Assuming average annual production increases of 40%—which exceeds last year's record rate—it will be at least 15 more years before this occurs. To put this another way, world sales of PV this year may reach 160 megawatts (MW)—or about a quarter of the generating capacity of a typical power plant. In terms of actual power output—i.e., taking capacity factors into account—annual world PV production is equivalent to just *one* such plant running for less than a month. Meanwhile, in New England alone, developers have proposed over 20,000 MW of new gas-fired power plants.

If PV is going to compete with conventional generating technologies, this price gap must shrink. Barring some radical change in the historical price-volume relationship, the PV sales volumes required are of such magnitude that domestic markets in the United States will not suffice.

In a 1994 report, the Utility Photovoltaic Group (UPVG) estimated that at or near an installed cost of $3/watt, 9,000 MW of domestic demand would exist for PV products.[2] About 7,000 MW of the projected demand, however, consisted of utility deployment of PV for grid support. With utility restructuring, and in particular the vertical disintegration of the electric industry in the United States, much of this potential market may no longer exist. Of the remaining 2,000 MW of UPVG's projected demand, over half depends upon an assumed willingness of customers to pay a premium for green power. Unfortunately, actual experience to date calls into question some of the more optimistic assumptions about customers' willingness to pay a premium for clean power. So the remaining potential domestic PV market based on a price of $3/watt installed—still less than half the current price—may be as little as 1,000 MW, or about 1% of what is needed in terms of cumulative volume.

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[1] Calculated on an after-tax basis assuming an average capacity factor of 18%, 30-year amortization period for equipment, financing at 8%, and allowances for maintenance and inverter replacement charges. Also assumes net metering or load matching, i.e., full offset of bulk power at delivered price.

[2] Utility Photovoltaic Group (UPVG), *UPVG Phase I Final Report* (Washington, D.C., June 1994).

Reliance upon subsidy policies to "buy down" the price of PV to competitive levels in the developed (i.e., wired) world will be very expensive—running at least into the billions of dollars.

We find this ominous scenario plausible—although by no means certain. Fortunately, however, there exists an economically efficient alternative. Even more fortunate, this scenario can accelerate the low-cost expansion of PV markets even if the figures above prove too pessimistic. The path we envision concerns the tapping of markets in which PV can already compete on the basis of price—markets, moreover, of sufficient scale to achieve the volumes necessary to spur cost-reducing investments in PV production and distribution facilities.

B. Implications of the Experience Curve for PV Prices

Most activities to intervene in PV markets depend on the observation that the price of PV declines as production volume increases. This relationship is called the "experience" or "learning" curve. For PV, the experience curve is currently estimated at 82%. This means that the price of PV declines 18% for every cumulative doubling of production. Table 1 projects this relationship into the future from current cumulative module production and price levels.[3]

Table 1: Impact of the Experience Curve on PV Module Prices

Doubling	Installed MW of PV	Price per watt
0	1,043	$3.50
1	2,086	$2.87
2	4,173	$2.35
3	8,346	$1.93
4	16,692	$1.58
5	33,383	$1.30
6	66,767	$1.06
7	133,533	$0.87
8	267,067	$0.72
9	534,133	$0.59
10	1,068,267	$0.48
11	2,136,534	$0.39

The price-volume relationship expressed by the experience curve is based on cumulative output, i.e., the total quantity of PV modules in use. Annual sales this year will be roughly 160 MW, which should bring the world's cumulative stock of PV up to just over 1,000 MW. PV module prices are currently quoted at around $3.50-$3.75/watt wholesale, and installed PV systems at around $6-$7/watt.

An important aspect of the experience curve is that it describes a logarithmic relationship, which implies smaller and smaller price declines for ever larger volume increases. UPVG in its landmark study of PV commercialization concluded that installed system prices would have to fall to $3/watt in

[3]These estimates reflect historical prices for crystalline silicon, the established PV technology. Note also that the relationship describes the price of modules only, not of installed PV systems.

order to create significant sustainable demand, but added that system prices would have to fall to between $1.20 and $2.00/watt to be generally competitive with domestic bulk power.[4] This is actually somewhat optimistic: to be truly competitive with conventional power, installed PV system prices really need to fall to almost $1/watt—and this is assuming that price parity suffices to motivate the commitment that PV requires (let alone offset its lack of dispatchability).

If the PV experience curve is strictly interpreted, however, cumulative output needs to increase to something over 500,000 MW before PV system prices fall that far—i.e., until PV modules cost just over 50¢/watt.[5] At 40% annual sales growth, this won't be achieved until the year 2019, by which time *annual* sales volume would have to be over 200,000 MW.

Of course, all of these estimates are based on the historical price-volume relationship for a relatively established technology—that is, crystalline silicon. Thin films have been touted for some time now as the great hope for radical price reductions, but production problems and poor conversion efficiencies have kept them disappointingly expensive so far.

It is difficult to argue that volumes would really have to increase as dramatically as suggested by the foregoing schedule. Indeed, we emphasize that these gloomy projection may prove too extreme. However, even if the truth proves somewhat rosier, *the trend seems clear: PV firms must sell a great quantity of expensive products before prices falls to more broadly competitive levels.* The question is, of course, sold to whom?

C. Implications of the Experience Curve for PV Subsidies

Regardless of how strictly one interprets the PV experience curve described above, it is clear that reliance upon subsidies to "buy down" the price of PV to $1/watt (installed) would be *very* expensive. Just how expensive is difficult to quantify, in no small part because of the reflexive nature of price subsidies, the point of which is to influence demand in the hope that it will prompt investment and thus influence price. In other words, subsidized prices should prompt much higher demand than would otherwise exist, thus "forcing" the curve.

Nevertheless, if PV subsidy levels were assumed necessary to make up the difference between $1/watt and the price-demand schedule, according to 40% annual sales increases as shown in Table 2 below (with prices declining per the 18% experience curve), the total would exceed $1 trillion, which is five times annual U.S. electricity sales.

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[4] Utility Photovoltaic Group.

[5] It should be noted that price forecasts based upon the experience curve are very sensitive to price and volume inputs. Also, prices do vary somewhat with volume, and Sacramento Municipal Utility District (SMUD) prices under their long-term contract with Energy Photovoltaic (discussed in detail below) are allegedly $2.50/watt for modules and $4.25 for installed systems, and are projected to decline to $2.60/watt under a 5-year, 10-MW contract. It should also be noted, however, that the factory that will supply these modules has not yet been built.

Table 2: Projected PV Sales, Installed Base, and Prices

	Annual Sales		Cumulative Installed		Price Change	Module Price	System Cost
	MW	Growth	MW	Growth			
1997	126	38%	891	16%			
1998	176	40%	1,067	19.8%	-	$ 3.50	$ 6.44
1999	247	40%	1,313	23.1%	-5.8%	$ 3.30	$ 6.07
2000	345	40%	1,659	26.3%	-6.5%	$ 3.08	$ 5.68
2001	483	40%	2,142	29.1%	-7.1%	$ 2.87	$ 5.27
2002	677	40%	2,818	31.6%	-7.6%	$ 2.65	$ 4.88
2003	947	40%	3,766	33.6%	-8.0%	$ 2.44	$ 4.49
2004	1,326	40%	5,092	35.2%	-8.3%	$ 2.24	$ 4.12
2005	1,857	40%	6,948	36.5%	-8.5%	$ 2.05	$ 3.77
2006	2,599	40%	9,547	37.4%	-8.7%	$ 1.87	$ 3.44
2007	3,639	40%	13,186	38.1%	-8.8%	$ 1.70	$ 3.13
2008	5,094	40%	18,281	38.6%	-8.9%	$ 1.55	$ 2.86
2009	7,132	40%	25,413	39.0%	-9.0%	$ 1.41	$ 2.60
2010	9,985	40%	35,398	39.3%	-9.1%	$ 1.28	$ 2.36
2011	13,979	40%	49,377	39.5%	-9.1%	$ 1.17	$ 2.15
2012	19,570	40%	68,947	39.6%	-9.1%	$ 1.06	$ 1.95
2013	27,399	40%	96,346	39.7%	-9.1%	$ 0.96	$ 1.77
2014	38,358	40%	134,704	39.8%	-9.1%	$ 0.88	$ 1.61
2015	53,701	40%	188,405	39.9%	-9.2%	$ 0.80	$ 1.46
2016	75,182	40%	263,587	39.9%	-9.2%	$ 0.72	$ 1.33
2017	105,255	40%	368,842	39.9%	-9.2%	$ 0.66	$ 1.21
2018	147,357	40%	516,198	40.0%	-9.2%	$ 0.60	$ 1.10
2019	206,299	40%	722,497	40.0%	-9.2%	$ 0.54	$ 1.00

Obviously, this amount is unreasonably large, and *we do not suggest that this is the aggregate subsidy that would actually be necessary*. Simply investing, say, $10 billion in a massive PV production facility would almost certainly be more efficient with respect to lowering costs, but this is how the numbers work out. The point is just that if the experience curve is any guide—which lacking any quantitative alternatives it must be—then subsidies may be impracticably expensive to induce the price declines that PV needs in order to compete. And lest the PV experience curve be dismissed too quickly, it should also be noted that the value of 82% it produces falls squarely in the middle of the 70%-90% range observed for other industries.[6]

We emphasize that we do not intend here to condemn direct subsidies, but rather to point out the problematic assumptions that underlie them and consider their alternatives. More specifically, the purpose of this paper is to suggest mechanisms other than subsidies—specifically the application of value-chain analysis and market development strategies—for accelerating the development of PV markets. These alternatives generally do not conflict with subsidies and in several cases are augmented by them. Their main importance and appeal is that they are market-oriented, and more specifically targeted toward developing a sustainable, economically efficient market.

II. POTENTIAL MARKETS FOR PHOTOVOLTAICS

If PV is to become cost competitive through volume-driven price reductions rather than some unpredictable and spectacular reduction in production costs, the industry will require very large markets. Domestic markets in the United States do exist but, as discussed below, they are of insufficient scale to have the desired price impact. Much larger potential markets for PV—on the order of thousands of MW—do exist for off-grid power products in developing countries, where some 2 billion people still lack electricity. In the developing world, where PV doesn't have to compete with an established distribution infrastructure, PV can actually have a price advantage.

A. Potential U.S. Markets for Photovoltaics

PV market potentials are difficult to quantify. In the United States, where PV is at such a price disadvantage relative to conventional grid power but where enough people are also sufficiently affluent so that a green market may be plausibly posited, the situation is even more problematic. On the one hand, a large number of applications can be identified where PV makes economic sense. On the other, given the extensiveness and efficiency of the U.S. power grid, these don't add up to very much in terms of total megawatts.

In what is perhaps the most ambitious quantification of U.S. market potential, the report by the Utility Photovoltaic Group (UPVG) noted above estimates that assuming an installed PV system price of $3/watt (i.e., roughly half the current price), there might exist 9,000 MW of potential U.S. demand for PV. The bulk of this—7,000 MW—was to be deployed by utilities for grid support; with utility

[6] G.D. Cody and T. Tiedje, "The Potential for Utility Scale Photovoltaic Technology in the Developed World: 1990-2010," *Energy and the Environment*, ed. B. Abeles, A. J. Jacobson, and P. Sheng (Singapore: World Scientific Publishing Co., 1992).

restructuring, and in particular the vertical disintegration of the electric industry in the United States, however, much of this potential market may no longer exist.

Of the remaining 2,000 MW of the projected demand, half was for off-grid applications, and half was for what was termed the "PV-friendly" market (i.e., environmentally conscious customers). In fact, it is not at all clear what proportion of the public will pay significant premiums for "green" power. This is further complicated by the fact that PV must compete with other technologies for whatever green market might exist, technologies which are already less expensive. Finally, the nature of PV is such that customers must be willing to have equipment located on site, which can be a hassle, as well as commit to paying a premium for an extended period of time. In sum, it is not reasonable to assume that the domestic U.S. green market is going to result in massive PV demand anytime soon.

Potential domestic markets in the United States are discussed below in terms of economic markets and "green markets":

- ***Economic markets*** are markets where PV is purchased more or less on the basis of some price/performance assessment.
- ***"Green markets"*** are markets where potential PV customers' ideological motives—i.e., grounded in their support of renewables—are strong enough to overcome clear financial disadvantages.

These distinctions should not be taken as too hard and fast, since nonprice issues (e.g., status) influence many purchases. They are made nonetheless in order to sharpen the distinction between where PV is now, in price terms, and where it needs to be.

1. Potential Economic Markets for PV in the United States

The U.S. PV industry's 1996 production and sales figures are shown in Table 3 below. Most striking, perhaps, is that nearly two-thirds of total U.S. production was exported. In fact, there is some indication that PV exports may represent an even higher proportion of U.S. production. The Utility Photovoltaic Group's *PV Vision Newsletter* examined Energy Information Administration (EIA) figures for 1993 more closely and concluded that 40-70% of "domestic" shipments were actually resold outside the United States.[7] Of official 1996 U.S. exports, half went to Germany and Japan, where government subsidy programs "artificially" enhance the demand for PV.

[7] Utility Photovoltaic Group, *PV Vision Newsletter*, Washington, D.C., Fall 1998.

Table 3: Production and Sales by the U.S. Photovoltaic Industry, 1996

	Kilowatts	% of Total
TOTAL U.S. PRODUCTION	35,464	
Exports	22,448	63%
Domestic Consumption	13,016	37%
APPROXIMATE WORLD OUTPUT	90,000	
U.S. Share of World Production		39%
U.S. Share of World Consumption		14%
END-USER BY TYPE	**Kilowatts**	**% U.S. Total**
Electricity Generation		
Grid Interactive	4,844	14%
Remote	10,884	31%
Communications	6,041	17%
Consumer Goods	1,063	3%
Transportation	5,196	15%
Water Pumping	3,261	9%
Cells/Modules to OEM	2,410	7%
Health	977	3%
Other	789	2%

SOURCE: Energy Information Administration and U.S. Department of Energy, *EIA/DOE Renewable Energy Annual 1997 Volume I*, DOE/EIA-0603(97)/1 (Washington, D.C.: February 1997).

In fact, the Japanese market is a good example of a market where PV subsidies may not be resulting in the price reductions they are intended to encourage. Our conversations with manufacturers in Japan indicate that PV equipment there is being priced to include full amortization of new production facilities in very short time frames. This may be intended by producers to minimize the risk of subsidy withdrawal, but in the near term at least has the effect of keeping prices higher than they should be. This situation can only be sustained by a subsidy policy that permits such accounting and pricing practices, and is a dubious use of public funds (which, in effect, wind up buying a disproportionate share of the factory for the manufacturer). With bulk power in Japan costing 28¢/kWh, PV should almost be viable there, at least from an equipment standpoint. Differences in ancillary costs—including installation and maintenance, as well as a notoriously expensive distribution system—may well result in uncompetitive overall costs. A question that remains, however, is whether proper incentives to minimize costs exist in Japan.

A comparison of the foregoing with potential U.S. PV markets identified by the Utility Photovoltaic Group (UPVG) is instructive (see Table 4). Note that the figures in the table are for market potentials assuming an installed cost of $3/watt and that the figures are in megawatts rather than kilowatts.

Table 4: Estimated Potential U.S. PV Markets at $3/Watt

	MW Demand		Percent	Percent
	Low	High	Low	High
Utility-Based				
Grid support	3,800	4,200	44%	42%
Line support	3,100	3,430	35%	35%
"PF-friendly" pricing	1,020	1,130	12%	11%
Residential buildings	215	260	2%	3%
Remote residential service	200	240	2%	2%
Remote military installations	200	400	2%	4%
Commercial buildings	50	60	1%	1%
Railroad crossing signs	45	55	1%	1%
Livestock watering	30	40	0%	0%
Pond and lake aeration	30	35	0%	0%
Utility buildings	20	25	0%	0%
EV charging	15	17	0%	0%
Cathodic protection	5	6	0%	0%
Rural billboard lighting	3	4	0%	0%
National park lighting	2	3	0%	0%
Highway sign lights	Minimal	-	-	-
Bus shelter lights	Minimal	-	-	-
Total	8,735	9,905	100%	100%

SOURCE: Utility Photovoltaic Group (UPVG), *UPVG Phase 1 Report* (Washington, D.C.: June 1994); and *UPVG Phase 2 Report* (Washington, D.C.: August 1995).

Grid support, which constitutes the bulk (roughly 80%) of the UPVG's potential market, didn't account for many actual sales in 1996 (which may be the result of installed PV system costs being around $7/watt that year). On the other hand, the communications market—which doesn't show up at all on the potential list—was the second largest category of actual sales. As noted above, with electricity industry restructuring the grid support market may not materialize anyway, as the incentives for such investments may no longer exist.

Exclusion of estimated green demand, which appears here as "PV-friendly pricing" (and which, moreover, depended upon utility ownership of PV systems as with the Sacramento Municipal Utility District's PV Pioneers I program), leaves economic demand at $3/watt, which is only about 1 GW. To put this in perspective, if this entire gigawatt of demand were to suddenly materialize today at current prices (remember, the assumption here was $3/watt), it would result in a single doubling of cumulative production, hence (if the experience curve holds) an 18% decline in PV prices. Installed system prices would thus fall to around $5.50/watt. The point again is just that there simply isn't enough economically motivated U.S. domestic demand to drive PV prices down to broadly competitive levels. This begs the question of whether there exists enough demand from individuals willing to subordinate their financial interests to their ideological interests?

2. Potential "Green Markets" for PV in the United States

Given PV's higher price relative to conventionally generated power, much faith is placed in PV's ability to command a "green premium" from customers who are committed to renewable energy and therefore willing to overpay, in a sense, for electricity generated by renewables. But green premiums also raise the issue of "willingness-to-pay" (WTP), and it is not at all clear at this early stage of retail deregulation how many people will actually step up and pay the premiums that certain surveys indicate they might. In any case, it is almost certain that green premium markets do not exist at sufficient scale to achieve the volumes (hence price reductions) that the learning curve suggests are necessary in order to make PV competitive on price alone.

Numerous surveys all more or less aimed at quantifying the extent to which consumers are willing to pay a premium for environmentally benign power have been conducted. In their 1996 study, "Willingness to Pay for Electricity from Renewable Energy," B.C. Farhar and A.H. Houston provided a comprehensive examination of the various green pricing surveys that had been conducted in recent years. Their conclusion was the following:

> To summarize results from recent national and state surveys (using various item wordings on WTP), approximately 40% to 70% [of consumers] indicate they would pay a premium for environmental protection or for renewable electricity.[8]

Information on the percentage of customers willing to pay a green premium is only part of the information needed to quantify the market. In addition, it must be determined how *much* people say they will pay, or rather, how many say they'll pay a given premium. There also must be some allowance made for the difference between what people *say* and what they actually *do*; in the case of green premiums, this is known as the "WTP gap."

Farhar and Houston compared what customers indicated they were willing to pay in national and state surveys with what they actually paid:

> The gap between what people say and what they do has been underscored by utility green pricing market research. Perhaps 10% of local area respondents say they will actually participate in a green pricing program, and, at a program's inception, perhaps only 1% will sign up.[9]

Unfortunately, the design and implementation of available surveys tells us very little about customer intentions which, at least if consistent, would permit the application of specific "derating" factors to translate enthusiasm for green power to a quantifiable willingness to actually pay for it.

A major question concerns the extent to which the WTP gap may be a product of inept marketing. E.A. Holt recently examined the WTP gap in his 1997 work *Green Pricing Resource Guide*. His conclusions were as follows:

> Market research indicates there is a segment of the market that will act on its desire to support a cleaner environment through the products and services it buys. What is questioned is

[8]B.C. Farhar and A.H. Houston, "Willingness to Pay for Electricity from Renewable Energy," National Renewable Energy Laboratory, Golden, Colo., 1996.

[9]Ibid..

> whether that market segment is truly as big as the research estimates. Only a well-designed program, properly introduced and marketed, and adequately supported and sustained over a period of several years, will establish how big the market truly is. Unfortunately, such a program does not yet exist.[10]

Holt also points out an issue that further constrains the usefulness of these surveys on willingness-to-pay, which is that distributed PV requires not only the customers' willingness to pay a premium but also their willingness to have the PV equipment mounted on site. Even more demanding, if the price is to be minimized through purchase or long-term lease, is the willingness to commit to pay the PV premium for an extended period of time.

In an attempt to answer at least the first question, that is, the willingness to have PV on site, the Utility Photovoltaic Group conducted a survey of all its member electric utilities and about 1,300 investor-owned utilities, public power systems, and rural electric cooperatives in North America. When asked about what percentages of their residential customers these organizations thought would be "willing to pay $15-$20 more per month on their electric bill to have a PV system installed on their roof," the weighted response was 2.1%.

Given that there are roughly 100 million households in the United States with average monthly power bills of $75, this indicates that more than 2 million would be willing to pay a 20-27% premium, and moreover for PV. Another way to look at this would be as saying that 2 million people would pay something like $200 per year more for PV, which would clearly underwrite a very large market. On the other hand, excitement over this potential market must be tempered with the fact that the percentage of respondents indicating that they'd actually surveyed their customers "regarding their attitudes toward PV" was only 6%.[11]

So what can be concluded from this? Since only a small fraction of actual customers were ever queried as to their attitude toward PV, it is difficult to say what the 2.1% figure really represents. Moreover, the specific arrangement under consideration was something like the Sacramento Municipal Utility District's (SMUD) model, whereby the utility owns and operates the PV system even though it is sited on the customer's premises. The customer thus does not have to make any initial investment or long-term commitment to PV, making the purchase resemble any other green power offering.

In fact, in the most extensive deployment of residentially sited PV to date, SMUD's PV Pioneers 1 program installed some 440 PV systems averaging 4 kW each in the Sacramento area. SMUD reported that according to its 1997 survey *"Distribution 2000,"* 24% of the general public in the Sacramento area were willing to pay more on their utility bill for PV, of which 14% would pay more than $10/month (roughly a 25% premium), and 8% would pay more than $20/month. SMUD also reported strong demand for participation in the PV Pioneers program, with 500 to 1,000 customers volunteering each year for the 100 or so available PV systems.

This enthusiasm for PV in the SMUD program should be put in perspective, however: demand for PV systems may have significantly exceeded supply, but it still represented a very small portion of the total customer base. Also, the cost of participation was a monthly premium of just $4, which according to

[10]Edward A. Holt, *Green Pricing Resource Guide* (1997).
[11]Utility Photovoltaic Group (UPVG), *UPVG Phase 1 Report* (Washington, D.C.: June 1994), p. E-4.

SMUD is roughly equivalent to 10% of a typical SMUD customer's bill. SMUD retained ownership of the systems, so the customer was spared having to make a long-term commitment or take any financial risk. It will be instructive to see how well SMUD's PV Pioneers 2 program, under which users must buy their PV systems, is received. Although buying a PV system is the more economically attractive option (assuming certain tax advantages), there may prove to be a market for leasing PV systems as well, especially if leases are made cancelable.

In short, we lack sufficient data to conclude that a significant—on the scale described in this paper as necessary for meaningful price reductions—green-premium-based market for PV exists in the United States. Survey results pertaining to customers willingness to pay for PV are of limited use owing to inadequate methods of respondent selection and the framing of particular questions. Moreover, such surveys have tended to query consumers merely about likely premiums, which neglects altogether the question of whether they would commit to paying higher prices for the extended period of time that PV entails. In fact, premium costs on a kilowatt-hour basis for PV depend upon a number of factors, many of which are not even easily explainable to the typical consumer. The challenge facing development of the PV market is not only that PV costs more than conventional power—the way that PV is purchased is also quite different, requiring significant capital investment, hence a long-term commitment to pay a relatively fixed premium. This is a difficult sell at best.

All of this does not mean that a green niche market will not develop for PV. It is clear, however, that there will be competition for this market from other technologies—including grid-supplied renewables such as wind, as well as from relatively clean nonrenewables such as natural gas combustion and (perhaps) methane-powered fuel cells. These alternatives to PV will be able to provide similar environmental benefits for a smaller premium than PV without requiring long-term capital commitment from consumers.

Combined-cycle natural gas turbines, for example, now have combustion efficiencies of up to 60%, while emitting relatively little in the way of actual pollutants. They do produce 300 tons of carbon dioxide per gigawatt-hour (GWh), but this is a significant improvement over the 1,100 tons/GWh emitted by a typical coal plant. The United States still relies on coal to fuel some 57% of its generating capacity, so there is significant scope for the shift to gas to reduce pollution. As grid-based power becomes cleaner (with a shift to gas resulting from deregulation), the relative premium that the consumer would be paying for PV not to emit pollutants, as opposed to the premium per kWh, might go up dramatically. This means that a marketing strategy relying too much on the environmental benefits of PV may not be sustainable in the long run.

Summing up, *even if PV were to have the U.S. green market to itself, the scale would almost certainly be of insufficient to drive PV prices down to broadly competitive levels.* As it stands, there will keen competition for the U.S. green market, and in terms of carbon-emission offsets, PV is expensive.

B. Potential International Markets for PV

Some 2 billion people in the world still lack electricity. Thus, even at a low electrification rate of 250 watts per capita—the U.S. rate is 2,730 watts—there is a potential international market for PV of some 500,000 MW. In developing countries, PV does not have to compete with grid power, and can compete on the basis of cost/performance. Furthermore, PV's modularity is also an asset in developing countries, as power investments are scaleable—i.e., affordable—to an extent that large-scale conventional technologies are not.

With effective development of distribution infrastructure (including financing mechanisms) and products, international markets—especially, markets in developing countries—could help to accelerate demand for PV dramatically, thereby reducing PV's price to the level necessary to make it competitive in the United States and other developed (i.e., wired) countries. In other words, *PV markets in developing countries could provide a practical, cost-effective way to generate the level of demand necessary to make large-scale investments in PV production attractive*.

That PV isn't yet widely deployed in markets in developing countries suggests that there are barriers to their development. The main impediment to effective development of developing country markets is that they are enormous and culturally diverse, whereas PV manufacturers tend to be small, with very limited marketing organizations. Moreover, PV marketers must compete in those markets against much larger, better financed purveyors of conventional generation technologies. Such barriers result in a failure to develop effective and responsive marketing infrastructures; this, in turn, leads to high costs, poor presence, and lack of optimal (or perhaps even appropriate) products.

Such barriers are not insurmountable, even on a limited budget. Cooperation among PV firms and other interested organizations could yield effective strategies for more extensive development of foreign markets. One of the main points of this paper is that—given the tremendous potential of foreign markets—it is worthwhile, if not absolutely critical, to develop strategies for tapping them.

One particularly promising PV market in the world is the market for remote pumps. The *Solar Industry Journal* recently surveyed the world market for remote power, specifically for engine-driven pump and electrical generator sets. Its conclusion was that the potential for PV deployment in this market is enormous:

> Few would argue with the statement that there is some combination of PV and diesel generator that will provide the lowest lifecycle cost (or levelized energy cost) for a given application and geographic location which is currently being served by diesel gen-set and pump sets up to 50 kW in size. In this scenario, the PV would supplement the diesel, or the diesel would serve as backup for the PV system.[12]

Summary results from the *Solar Industry Journal's* survey are presented in the tables below. Table 5 shows the annual consumption of engine-driven pump sets; Table 6 shows the annual consumption of prime-power engine-driven generator sets. Both of these tables describe markets for primary power sources intended for more-or-less continuous duty, rather than back-up or standby units. By excluding standby power, the North American market, for example, is counted at only around 1/80th its total size, in terms of units sold.

[12]Robert Hammond and Kent Whitfield, "Worldwide Production and Consumption of Diesel Engines," *Solar Industry Journal* 9, 1st Quarter, 1998, pp. 24-32.

Table 5: Engine-Driven Pump Sets: Annual Consumption[a]

	Units by output range in kilowatts (kW)				
	<10	11-20	21-30	31-50	Total
Africa	436	148	352	368	1,304
Europe	34,985	20,992	16,955	61,475	134,407
Far East	137,779	95,933	45,986	97,892	377,590
North America	3	349	88	1,472	1,912
Near East	14,774	3,924	1,681	5,335	25,714
Central/So. America	-	1,260	1,121	964	3,345
Total	**187,977**	**122,606**	**66,183**	**167,506**	**544,272**
Average size (kW)	**8.1**	**13.2**	**22.7**	**34.6**	**14.5**
Total (MW)	**1,523**	**1,618**	**1,502**	**5,796**	**10,439**

[a]Prime power only; market for standby power in North America = approx. 80x larger.

SOURCE: *Solar Industry Journal*, 1st Quarter, 1998.

Table 6: Engine-Driven Generator Sets: Annual Consumption[a]

	Units by output range in kilowatts (kW)				
	<10	11-20	21-30	31-50	Total
Africa	68	208	4	17	297
Europe	1,652	3,977	515	11,350	17,494
Far East	53,125	40,014	1,642	6,121	100,902
North America	2	86	6	51	145
Near East	4,549	4,590	507	808	10,454
Central/So. America	79	132	25	255	491
Total	**59,475**	**49,007**	**2,699**	**18,602**	**129,783**
Average size (KW)	**7.2**	**14.6**	**24.8**	**37.2**	**15.1**
Total (MW)	**428**	**716**	**67**	**692**	**1,903**

[a]Prime power only; market for standby power in North America = approx. 80x larger.

SOURCE: *Solar Industry Journal*, 1st Quarter, 1998.

The world market for pump-sets is more than five times that of prime-power generators ("gen-sets"). Given its intermittency, PV is somewhat better suited for the pump-set market. Standard diesel power sources for both average about $600/kW of capacity. Thus, the pump market adds up to nearly $6.3 billion/year, with gen-sets another $1.1 billion. Although the North American market is relatively small by comparison—approximately $35 million for pumps and $2 million for prime power gen-sets—this market may be worth pursuing more aggressively as a test market for product refinements and market development strategies. The challenges and opportunities of the international pumps market is explored in more detail below.

C. PV Products: Potential Applications for U.S. Markets

A strong customer orientation will be important in the successful development of PV markets. Great emphasis must be placed upon figuring out what is needed, and how to provide it most effectively. PV offers little scope for marketing on the basis of, for example, conspicuous consumption, so "products" will to a large extent mean "solutions" to customer problems. PV marketers, whether manufacturers or other entities, must think beyond components to applications for which complete products could be developed.

A list of potential PV applications for U.S. markets compiled from various sources appears below in Table 7. Note that product differentiation is largely a function of perception, which may be heavily influenced by presentation, i.e., marketing. Thus, a market-based development strategy does not necessarily require novel products. It does encourage them where appropriate, but can also be served by effective, well-designed marketing activities.

Many of these markets, or perhaps submarkets, are more attractive when their geographic scope is enlarged. Thinking globally is, in fact, what PV marketers must do in order to devise successful strategies.

D. Seizing the Moment: U.S. Markets as Testing Grounds

To reiterate, there are U.S. markets for which PV-based products appropriate for the developing world could be developed. *We propose that the PV industry continue to identify and exploit U.S. equivalents of the most promising foreign markets*—markets for which PV-based products ("customer solutions") can be designed, refined, and aggressively marketed. The U.S. markets for the products may not be large enough to justify such investment and activity on their own but could serve as *testing grounds for new international products* and the development of an effective distribution infrastructure.

Experience gained in U.S. markets should translate into more rapid penetration of international markets, which would accelerate industry growth without the need to subsidize product purchases. This, in turn, will hasten the decline in price necessary to make PV competitive in the developed, grid-connected world. This approach, in other words, provides a practical, cost-effective way to generate the level of demand necessary to make large-scale investments in PV production attractive.

The motivation for this strategy is primarily economic efficiency: It simply boils down to finding the most cost-effective way to leverage existing demand, wherever it may be found, to help achieve economies of scale for PV production. But there is a particular imperative with respect to developing country markets. China and India, which between them contain over a third of the world's population, are rapidly electrifying. China is currently adding capacity at a rate equivalent to one new central station every 4 days; within 5 years, China is expected to accelerate capacity increases to one plant every other day. Despite such high-profile projects as the Three Gorges Dam, the majority of this capacity will, unless alternatives are more effectively presented, be fired by coal.

Table 7: Potential PV Applications in the United States

• Aerobic waste processing	• Microwave stations
• Airport beacons	• Mobile communications trailers
• Augmented ups (computer/network)	• Nautical navigation aids
• Automatic gate openers	• Oil spill detection buoys
• Back-up generators	• Park/campground lighting
• Battery charging	• Parking lot lighting
• Billboard lighting	• Pond and lake aeration
• Boat launch lighting and service	• Power for remote buildings
• Bus stop/shelter lighting	• Power plant warning sirens
• Cathodic protection	• Railroad signaling
• Cloud seeding	• Remote controllers
• Community facility lighting	• Remote fiber optic installations
• Display lighting	• Remote metering
• Dynamic thermal rating sensors	• Remote military installations
• Earthquake sensing	• Remote traffic flashing lights
• Electrified fences	• Rest stop lighting
• Emergency call/telephone boxes	• River level gauges
• End-of-feeder support	• Satellite TV systems
• EV charging stations	• School/playground lighting
• Facility sign lighting	• Sectionalizing switches
• Fire towers	• Street lighting
• Flow meters	• Stripper oil well pumping
• Highway sign lighting	• Telecom cell repeaters
• Hydro level gauges	• Tower obstruction beacons
• Insect control	• Tunnel lighting
• Insolation monitors	• Valve actuators
• Intruder detectors	• Ventilation fans
• Irrigation pumps	• Water pumping and control
• Isolated substation support	• Water purification
• Landscape lighting	• Water quality measurement
• Livestock watering/stock tank	• Water temperature
• Low-maintenance refrigerators	• Wind monitors
• Meteorological stations	

SOURCES: Utility Photovoltaic Group (UPVG), *UPVG Phase 1 Report* (Washington, D.C.: June 1994), and *UPVG Phase 2 Report* (Washington, D.C.: August 1995).; Electric Power Research Institute (EPRI); and Lucid, Inc..

Given the underdevelopment of copper grids in the developing world, a tremendous opportunity is being wasted. One of PV's main advantages is that it can be deployed close to the loads it powers, thus avoiding the need for expensive transmission and distribution systems. Once the grids are built, though, a significant element of PV's cost competitiveness is eliminated and the economic argument for additional conventional generating facilities is reinforced. The PV industry is currently too small and fragmented to market effectively against conventional power equipment vendors, which also have the advantage of needing to sell only to small number of customers (primarily government officials). On the other hand, PV's distributed nature allows it to benefit from the inability of many central governments to afford large power projects. In those situations, regional entities or individuals may make power purchasing decisions. The important thing is for PV to establish itself in those markets before grid construction eliminates a major component of its economic advantage.

III. A MARKET-BASED PARADIGM FOR PV INDUSTRY DEVELOPMENT

Effectively tapping large, developing country markets, in addition to domestic niche markets, to capture economies in production in the near term is as important as continued support for R&D in achieving more broadly competitive PV prices. Policy-makers need to work with industry partners to help them develop strategies aimed at improving the sales of cost-effective products which already exist, promoting product improvement and new product development, and building the necessary manufacturing, distribution and sales infrastructure within relevant product markets.

Most of the potential markets for PV in the developing world lack at least part of the essential infrastructure necessary to function efficiently. These gaps include key intermediaries and market players to serve critical functions at each point in the "value chain." The *Selling Solar* report produced by the Rockefeller Brothers Fund defined this key concept of product development:

> A value chain represents all the steps that occur in the chain of activities through which raw materials are transformed into finished products that are purchased by consumers...[this] includes manufacturing, distribution and retail sales, functions which are typically performed by different entities. Understanding how these activities and entities fit together is key to seeing how an industry develops. . . value-chain analysis examines the financing an industry requires to grow and prosper. . . value-chain analysis allows for the creation of a rigorous framework for thinking about development of all parts of an industry as well as the various links between the various components of the industry.[13]

We advocate *a market-based paradigm to support the development of sustainable businesses and functioning industry value chains in markets where PV already delivers unique value to the customer*. As in the case of traditional policy approaches, there are risks associated with the business development approach—namely that actions to address market barriers may fail to remove them. But the risks of the business development approach are not as serious as those associated with the subsidy approach for several reasons:

- First, the public investment required to test whether a program or action works and creates sustainable results is substantially smaller with a business development approach.
- Second, public funds are targeted to leverage private funds to a greater extent with a business development approach.

[13] Rockefeller Brothers Fund, *Selling Solar: Financing Household Solar Energy in the Developing World,*, Pocantico Paper No. 2.

- Third, actions are incremental, building upon each other to allow incremental learning and greater performance over time.
- Fourth, as a portfolio, not all programs and actions have to be successful to yield sustainable results with a business development approach.

Supply-side and demand-side strategies to support the development of sustainable businesses are typically presented as competing approaches and tend to be promoted by different sets of stakeholders. In reality, both must be pursued at the same time in order to achieve meaningful results. Larger, functioning markets for PV—the result of demand-side strategies—stimulate greater production levels, which justify investments in larger plants to reduce costs through scale economies and learning-by-doing. Lower prices in turn broaden markets for PV products, attracting new entrants at all stages of the PV industry value chain.

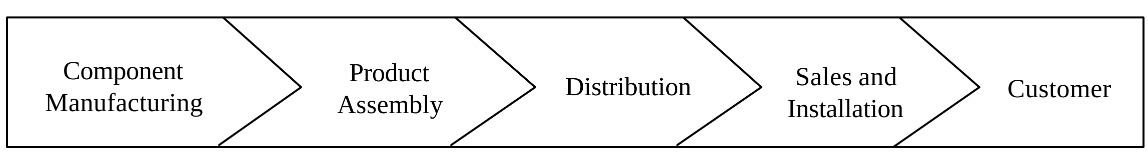
A. Value-Chain Analysis: A Tool for Industry Development

1. Conceptual Framework: What is Value-Chain Analysis?

Analyzing, designing, and implementing programs and business plans in markets that do not exist yet, or barely exist for products in the early stages of development, presents special challenges to analyst, policy-makers, and business people. Value-chain analysis can provide a framework for understanding *what is not there but should be* as well as what is. Thus, it highlights the question of market infrastructure, which is assumed in conventional markets and market analysis but which is missing and needs to be created as part of developing new markets for PV.

Value-chain analysis, in other words, facilitates the identification of weaknesses, missing functions, and absent actors in emerging industries. Analysis of comparable industries allows the translation of functional elements from one industry or market segment to another. It creates a framework for generating and evaluating strategies for industry development, as well as business development strategies aimed at individual firms or groups of firms. By focusing on the structure of the industry and the flow of value through it, the manager is able to transcend a firm-centered view. Although managers usually know what is in their firms' interests, it is a rare manager who can see the extent to which his business will need to transform as an industry grows. The companies that survive (and thrive) through this process are those which are able to adapt to this evolution of the value chain. A simplified value chain for a manufactured products industry such as PV is shown in Figure 1.

Figure 1: A Simplified Value Chain



At each step of the value chain, firms perform unique functions and add value. Each of the arrows represents a market in which the upstream companies are the sellers and the downstream companies are the buyers. (One can also conceive of the value chain as a flow of proprietary and public information created by the managers of the physical chain.[14]) At the simplest level, competition for market share takes place between firms at the same stages of the value chain. But increasingly companies are realizing that competition also comes from players from different industries and value chains that represent competing ways of meeting the same needs (for example: in the competition between food markets and restaurants, supermarkets have introduced ready-to-eat prepared foods). This competition is for the most efficient delivery of value to the customers in the markets that the firm serves. Vertical integration represents the combination by one business entity of two or more of these functions. In its simple form, this occurs through the acquisition of upstream or downstream firms; while this changes the appearance of the value chain, it does not substantially redefine the functions. Companies do this to capture value at more than one stage of the chain. The risk of vertical integration is that there may be more agile competitors who can perform each of the functions more efficiently than a vertically integrated company. The law of the value chain is "that which does not add value is waste."[15] This is true for suppliers, competitors, and customers of all firms.

New value propositions often emerge, based on new paradigms for delivering value to the customers. These transformations can radically redefine roles and functions, eliminating whole stages of an industry's value chain. An example of this type of transformation occurred when FedEx allowed companies to eliminate their own shipping departments and need for specialized distributors to give them direct access and relations with final customers.

2. How Value Chains Evolve: The Example of Personal Computers

The evolution of the personal computer (PC) value chain illustrates how the value chain for an industry evolves as an industry develops. The PC value chain example is useful because the PC value chain shares several characteristics with the PV industry, including rapidly evolving technology and technology that provides a new kind of value for customers that was not possible before.

- ***The Early Days: Custom Assemblers of PCs.*** In the early days of PCs, when there were no major brands, specialists and enthusiasts assembled PC products from components. Technology was not standardized, and knowledge about the value of the products was poorly distributed among potential buyers. The specialist-assemblers who sold PCs to end-users held much of the knowledge about who the customers were and how they used the products.[16]

- ***Evolution to Retail Computer Stores.*** As PC products became more standardized and there appeared computer applications that made computers accessible and useful to nonprogrammers, the end-user market for PCs was increasingly serviced by retail computer stores. As the retail market developed, chains of computer stores developed that could

[14]Jeffrey F. Rayport and John. J. Sviolka, "Exploiting the Virtual Value Chain," Harvard University, Cambridge, Mass., 1995.

[15]This is the mandate for increasing efficiency at Xerox Corporation.

[16]One of the things that helped Apple get around this bottleneck in the flow of information was their user groups, which were very helpful for new users in developing proficiency and provided an invaluable customer knowledge gathering and product development/testing environment. The PV industry might be able to develop similar mechanisms.

negotiate better prices with their suppliers, impose strict conditions ("you can't sell mail order if you sell through us"), and gain economies of scale in advertising. Thus, for example, when IBM finally entered the PC market, it made a major exception to its long-standing practice of marketing through IBM representatives by allowing PCs to be sold retail at the then-emerging computer stores.[17] The brand equity of the outlet was important to buyers, as the majority were first-time PC owners who wanted reliable and convenient local technical support.

- ***Mail Order PC Sellers.*** As PCs became more reliable, and applications and operating systems became easier to use, a new group of customers who had grown up with computers, or were buying their second computer, emerged. These customers were no longer willing to pay retail. Many of them, however, became "free riders," getting support from local retail stores but making their large purchases from low cost discounters and mail order houses. Eventually, traditional retailers' margins declined to the point where most of them exited the business. Apple made a strategic blunder when it stayed exclusively with retail stores and did not allow their products to be sold via mail order. With Apple's reputation for superior reliability and user-friendliness, they would have had an advantage in that channel.

- ***Discount Superstores for PCs.*** With retail consolidation, discount superstores emerged, combining ultra-efficient distribution and inventory systems with low overhead and low-price guarantees. As declining prices and increasing user-friendliness of PCs put them within reach of a larger segment of the population, they became an important product segment in large office and electronics superstores. These stores offered a chance to try out the product and yet could compete with the mail order houses on price due to sophisticated "just-in-time" inventory management systems and to their negotiating power with manufacturers. At this point, mail order retailers and large-chain discounters had all but eliminated the retail computer store, as well as the wholesalers who supplied them.

- ***Mass Customization of PCs.*** Customers' confidence in and knowledge about the PCs has developed to the point that there are a significant number of customers who feel comfortable ordering a custom configured PC through a Web site, entering their credit card number and having FedEx deliver the product the next day. This eliminates all the steps in the value chain after the product manufacturer. Dell and Gateway operate on this model and Compaq and others are following suit.

The evolution of the PC value chain offers several lessons for the PV industry. One key lesson is that *functions that are critical to the emergence of an industry at one stage of development may have a minimal role to play in the next stage of the industry's evolution* as more standardized products emerge and more efficient delivery structures develop for them.

Product manufacturers have maintained profitability in highly cost-competitive, declining cost-structure industries such as the computer industry by finding ways to move efficiently to acquire customers and deliver product to them. Sometimes other companies offered these more efficient methods and sometimes they were developed in-house. The evolution of manufacturers knowing more and more about what customers value in their products has culminated in direct sales by the manufacturer to the customer.

[17] William Meyers, *The Image Makers* (New York: Times Books, 1984), p. 165.

Another lesson from the example is that value chains are strengthened by the following:

- the collection of information to create best practices, market data, and knowledgeable customers;
- the creation of key infrastructure (e.g., providers of financial, marketing, and human resources);
- increased competition; and
- dependable markets.

B. Public Policy Precedents: "Market Transformation" for Energy Efficiency

The success of so-called "market transformation" strategies for energy efficient products and technologies provides some guidance. However, much of this has occurred within the regulated utility context, however, with utilities playing the key role to stimulate regional product markets, and may not apply directly to the situation of PV in the midst of a deregulating electric sector. In general, market transformation has meant a lot of things to a lot of people: from regulations which mandate; to labels and standards; to rebates and subsidies; to public sector purchasing initiatives; to information and education campaigns; to design contests. The market and industry development approach proposed here envisions an even broader set of activities aimed at national and international markets. One good example of a broad, national, voluntary program aimed at transforming a product market is the U.S. Environmental Protection Agency's (EPA) Green Lights program (see Box A).

Box A: The Green Lights Program

The U.S. Environmental Protection Agency's (EPA) Green Lights program for energy-efficient lighting had successes that have since been emulated for a whole range of other products segments—including computers, office equipment, and whole building energy systems.

The program began at a time when the energy-efficient lighting industry was still in the early stages of its development. There were good products (not great ones) that had been tested, although testing standards had not yet been well developed or standardized. Customers knew very little about the opportunities for using the technology. Vendors were not skilled in selling energy-efficient lighting and there were few, if any, credible third-party sources of information. No large customers had installed energy-efficient lighting products. Installers were predominantly specialists inexperienced in handling the long and complex sales cycle. There was little available market information and no standardized way of calculating benefits. And finally, smaller manufactures had difficulty expanding and larger ones did not take the market seriously.

The Green Lights program addressed all of these barriers, primarily offering companies free publicity in exchange for a public commitment to upgrade their lighting systems where it was economically prudent. Along with excellent educational materials and programs designed by EPA, this publicity made the firms real *customers*—not just potential demand. The Green Lights program helped managers understand how to buy the energy-efficient lighting technology; in many cases helped managers "sell" it to their supervisors by providing standard methodologies for calculating benefits; helped vendors identify customers who were likely to buy (decreasing selling costs); collected data on those sales to provide information on the market's development; and set up standards and testing programs. All of this led competing manufacturers to take the market seriously and to invest in new and improved products, and larger production facilitates. Growth opportunities attracted talented entrepreneurs and skilled professionals to the industry, dramatically increasing its capacity to make increasing profits. This growth also created the need for information products: newsletters, reports and other resources on energy efficiency upgrades for buildings have since come into being, all of which help define it as a specific market and make it more understandable and "dependable."

IV. DEVELOPING VALUE CHAINS FOR PV-BASED PRODUCTS

A. The PV Challenge

Opportunities to build the PV industry exist through the development of sustainable businesses serving market segments where PV is cost-competitive. Here we describe the challenges of commercializing technologies in general, and PV in particular, and explain why the value-chain approach provides guidance for analyzing and developing markets both for the PV industry as a whole and for individual companies.

A long history of PV spending on R&D to bring down the cost of PV cells and modules has created an industry focused primarily on component manufacturing. As a result, the majority of engineers employed in the PV industry are engaged in *technology development rather than product development*. A large percentage of PV sales to final customers flows through small systems integrators who assemble custom systems for individual customers. This market structure necessitates a large value-added component to each system, adding more than 50% of the final per-kilowatt cost of PV in many end-use applications. That is*, many different firms participate in the PV value chain, and each requires an acceptable profit margin, thus raising the price of the final product substantially*. More importantly, this market structure *insulates primary manufacturers from PV customers*. It keeps the markets small, because each small company lacks the economies of scale of the large manufacturer. The *small companies serving end-use markets do not have the resources to manufacture and further innovate standardized PV products* that serve whole market segments rather than just a few customers.

PV still resembles a developing technology—one that has not yet been well integrated into products and product markets. In considering the most effective way to expand the market for PV products, it is useful to consider the elements that reduce perceived risk for potential customers and investors. Elements related to perceived risk for potential customers and investors include the following:

- company size and perceived strength/stability;
- established industry and products (with third-party sources of information about products and companies);
- range of suppliers to chose from;
- local supplier and easy access to service;
- well-understood methodologies for evaluating and comparing products;
- certified (third-party) standards and certification (i.e., Underwriters Laboratories listing);
- satisfactory warranty; and
- product improvements to address customer needs.

Existing PV product companies and markets have the following attributes:

- small, young PV companies;
- nascent PV industry (few industry associations, trade shows, newsletters, etc.);
- few standardized PV products;
- PV products seen as unproven;
- no marketing of PV products—most potential buyers unaware of product's existence;
- few suppliers of PV products;
- small presence of PV suppliers and service outside local area;
- difficult for buyers to evaluate PV products: not part of the default purchasing process (i.e., lifecycle costing not incorporated into standard specs); and
- short or nonexistent warranties for products incorporating PV.

1. PV as a "Disruptive Technology"

While the ultimate goal of developing the PV industry is to lower costs through economies of scale, the immediate objective is to find ways to encourage demand for PV despite its high cost. The way to do this is to find correspondingly high value, primarily through the identification of applications where alternative energy supplies are expensive, or else where the special qualities of PV make it attractive despite its relatively high financial cost.

In his recent book, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Clayton M. Christensen lays out a useful framework for analyzing patterns of technology innovation, characterizing new technologies as either *sustaining* or *disruptive*. Christensen shows why established, successful firms, which can repeatedly introduce sustaining innovations, have failed in the face of competition from disruptive technologies:

> What all sustaining technologies have in common is that they improve the performance of established products along the dimensions of performance that mainstream customers in major markets have historically valued. Most technological advances in a given industry are sustaining in character.[18]

Occasionally, however, disruptive technologies emerge. According to Christensen, disruptive technologies often result in worse product performance, at least in the near-term:

> Disruptive technologies bring to a market a very different value proposition than had been available previously. Generally, disruptive technologies under-perform established products in mainstream markets. But they have other features that a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and frequently more convenient to use.[19]

Disruptive technologies, in other words, "don't make sense" from the perspective of established players due to either or a combination of: worse performance (initially), threats to status quo, markets which do not exist yet, lower margins, and different cost structure. While it is understandable that managers in large, established companies usually withhold making investments in such technologies, instead preferring to make investments to improve their core products for their best customers, this type of "common sense" management does not protect their companies in the face of the disruptive technologies' redefinition of the value proposition. Examples of this functional shift include radio tube manufacturers being swept away by transistors, mechanical excavators eliminated by hydraulics, integrated steel manufacturers driven from market after market by mini-mills, and mainframes eclipsed by minicomputers.[20]

In each of these cases, Christensen found that although disruptive technologies were often developed first by engineers within established companies, these technologies were "starved of resources" within the resource allocation frameworks of those firms due to lack of interest by the firms' existing customers. Disruptive technologies were commercialized successfully only by new entrants or autonomous firms spun off by large companies.

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[18]Clayton M. Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Boston: Harvard Business School Press, 1997), p. xv.

[19]Ibid.

[20]Ibid.

Consequently, it is clear that careful attention must be paid to understanding the needs of potential new customers as well as existing customers in established product markets for whom the integration of PV technology could create new value. Christensen points out that markets for disruptive technologies are not found but rather created through effective, learning-based marketing. Consequently, demand for these technologies and products cannot be predicted using conventional market analysis. In fact, not only are markets for these technologies "unknown at the time of their application, but they may be unknowable in advance."[21]

2. *Conflicting Business Paradigms: Existing Utilities vs. the PV Industry*

Utilities continue to provide the institutional context and framework through which most of the Federal funding for PV development and commercialization flows, despite the fact that restructuring may largely eliminate utilities in their current form over the next 5 years. As a disruptive technology, PV faces a challenge in that it does not fit into the existing business paradigm of existing energy companies—utilities, independent power producers, oil or gas companies. In fact, PV requires an approach substantially different from that which utilities have used to build up the electricity infrastructure in the United States.

Table 8 below contrasts two paradigms: 1) the business environment conducive to the development of, and market paradigm describing, PV in niche markets and 2) the market framework within which utilities currently operate.

Table 8: Conflicting Paradigms: Existing Utilities vs. the PV Industry

Element	Existing utilities' paradigm	PV industry's paradigm
Value embodiment	Large construction project (Power plant, delivery network)	Small standardized manufactured product
How value is delivered	Ratepayer at regulated price. Distribution is engineering issue only.	Customer at negotiated (market) price. Preferred load is hardest to serve for utility.
Cost structure	Unionized, vertically integrated, regulated rate of return, no marketing or selling costs	Declining cost structure, extreme cost competition, thin margins, significant cost of sales
Skill set	Large system engineering and management, regulatory affairs	Product development, manufacturing cost reduction, marketing and sales
"Control" paradigm	Utility decides (engineering, economics, and planning) or state utility commission decides	Customer decides, competition constrains
Product financing structure	Project financing: elaborate deals >$50M. Lowest commercial risks.	"Consumer" financing: low transaction costs, deals <$25k.
Company equity	Large amounts, low risk, lower nominal returns, institutional investors	Small amounts, high-risk, high nominal returns, venture funds
Learning rate	<1 new power plant per year	>1,000 (assuming 10 MW PV

[21] Ibid., p. 147.

(products per year)	increments in hundreds of MW	production facility) increments in hundreds of watts

B. Framework for a Comprehensive PV Industry Development Strategy

Table 9 below summarizes the approach to the development of the PV industry presented in this paper as a series of five stages for comprehensive PV industry and market development. The five-stage framework in this table offers a method for prioritizing and sequencing strategies.

In most cases, starting with Stage #1—existing PV products in existing markets—will create the most useful learning, and the learning from that stage can then be put to good use in subsequent stages. Because most barriers are identified with actors or processes in the PV value chain, and the framework starts with demand and progressively moves up through the network of suppliers, most of the strategies worth evaluating can be arranged in this framework and viewed as part of an integrated approach.

Table 9: A Value-Chain Framework for a Comprehensive PV Industry Development Strategy

Stage	Target	Primary goal	Action recommendations	Effects/Result	Additional benefits
Stage #0	Third-party funders, e.g., philanthropic foundations	Prioritization of markets; identification of key barriers and strategies.	Industry analysis and strategy design, stakeholder recruitment and consensus building	Clear strategy and specific program design ("who does what")	Leverage other resources and stakeholders
Stage #1	Existing sellers, potential customers of existing products	Increase sales of existing products	Education programs, institutional incentives, financing programs, documenting successes and best practices, information gathering	Increased customer awareness, more sales, better market information, more capable dealers, refined market transformation strategies	Growing market story generates information for stages #2, #3, and #4
Stage #2	Existing and potential distributors of existing products	Increase number of distributors and their ability to support products	Demonstration of "sellability," distributor education and support	Dramatically broadens market access	Reduces risks of over-reliance on a few distributors
Stage #3	Existing product integrators	Improve existing products	Provide information, competitive grants, free technical review, investment resources	Solves quality, performance, reliability problems, etc.	Creates feedback loop between customers and producers
Stage #4	Existing and new product integrators	Develop new products	"Golden carrot" type contests, provide market and customer information	Broaden range of PV markets; portfolio reduces risk	Builds capacity for future product development
Stage #5	Component manufacturers, manufacturers of component manufacturing technologies	Commercialize new technologies and manufacturing processes	Develop mechanisms to link created demand with investments in production to supply it[a]	Acceleration of learning curve effects to achieve lower cost points	Potentially opens up other markets and expands profits/markets of existing products

[a] See Eric Ingersoll, Robert DiMatteo, and Romana Vysatova, "Financing Large-Scale Increases in PV Production Capacity through Risk Management," *Expanding Markets for Photovoltaics* (Washington, D.C.: Renewable Energy Policy Project, 1998).

C. Applying the Value-Chain Framework to the Pump Market

By way of example, here we apply the value-chain framework and business development strategy to the international pump market. The international market for pumps—approximately $4.7 billion/year—represents a sizable opportunity for PV. According to the *Solar Industry Journal*, however, PV has been slow to penetrate this market.

Four primary reasons are given for why PV has made so little headway here despite the operational cost advantage of PV hybrid systems:

1. The remote market is highly distributed, fragmented, and remote, and diesel gen-sets and pump-sets are sold through a well-developed infrastructure which is currently unavailable to the PV industry;
2. The initial cost for gen-sets and pump-sets is low, while the initial cost for PV is high ($600/kW versus $8,000/kW for an equivalent PV system);
3. End users are typically familiar with gen-set and pump-set technology, and PV is perceived as exotic and technical; and
4. It is easier for users to install gen sets and pump sets than PV hybrid systems because the diesel infrastructure is well established and more familiar than the PV system infrastructure.[22]

All of these barriers to market penetration of PV hybrid pumps relate to missing pieces of the value chain and lack of information. In applying the value-chain framework, we begin by focusing on Stage #1—increasing sales of existing products in existing markets (retail). Then we consider Stage #2—extending these products to new markets (distribution). Next we focus on Stage #3, where market and customer information is gathered to improve existing products (product assembly), as well as to spur the development of new products. Finally, we consider Stage #4, increased demand for these new products ultimately leads to investment in more efficient production capacity, which in turn alters the economics of the technology and therefore of products throughout the value chain.

Using the value-chain framework, we arrive at several strategies for overcoming barriers to market penetration of PV hybrid pumps:

- Stage #1: Strategies might include working with companies that are selling PV pumps, to understand why customers do and do not buy the product, whether there are informational or financing barriers and developing programs to address these such as training and materials for USDA field staff in appropriate regions. Demonstration and marketing efforts would help potential users overcome their lack of familiarity and discomfort with the product. Lack of consumer finance could be addressed by working with existing financial institutions that provide consumer loans in rural area or through barter arrangements with end users. Demonstration could be combined with information about consumer loans that are available for purchasing hybrid systems.
- Stage #2: Inadequate market infrastructure could be addressed by coordinating with the existing value chain by creating joint ventures with pump-set distributors. This way, installation and service for hybrid systems could be handled through existing channels with adequate

[22] *Solar Industry Journal*, 1st Quarter, 1998.

training for technical personnel. Once there is better segmentation of customer segments, along with successful educational materials and other programs, a business case can be made to appropriate distributors that they should carry the product. In order to be effective, the business case will need to demonstrate a thorough understanding of how the farm equipment and distributors' business works and where profits come from.

- Stage #3: Based on the collection of information from customers and distributors, it may be possible to suggest changes to the product to improve quality, reliability, cost, and other aspects which are important to customers.

- Stage #4: The lack of manufacturers can be addressed by creating joint ventures with pump-set manufacturers. The development of data flows and increased interaction with customers and distributors is also likely to lead to suggestions for new products. The rationale for these will be easier to test with the availability of better market information.

D. Guiding Principles for a Market-Based Approach to Commercialization

Recent trends toward diminished public funding in favor of market forces implies the need for modification of traditional approaches to supporting renewable energy with greater leverage of public investment, increased potential for incrementalism and learning, greater involvement of business and private industry (beyond investor-owned utilities, and existing PV manufacturers and integrators), and the creation of sustainable businesses and industries.

Although the business development approach has been contrasted with the subsidy approach to stimulating the PV industry, the two approaches are not necessarily incompatible; however, the business development approach is *necessary whether or not subsidy programs exist*. Even in the event that production costs come down, *PV companies will still have to strengthen product development, marketing, sales, installation, financing, and other capabilities*.

Here we present some general principles that result from value-chain analysis and strategies for industry development. They are not meant to constitute an exhaustive list, but are useful for evaluating proposals and recommendations for action in fledgling markets.

- ***Principle 1: Aim to build sustainable businesses and industries.***

Sustainable businesses operate according to market forces, i.e., serve customers willing to pay prices that cover actual delivered product costs. Such businesses that are successful in getting renewables into the marketplace will have access to capital, customers, and skilled management and labor. They will have expertise in marketing and developing their products and services and a business model which can be reproduced and grown (within reason). These businesses will be profitable or have reasonable expectations of profitability. Avoid creating business that will depend on subsidies and other policy interventions. Businesses dependent on subsidies will have a harder time attracting private capital and quality personnel.

- ***Principle 2: Companies need profitable current markets to survive.***

Focus on markets that exist now rather than future markets that are based on projections. Cash flow is not generated by future sales. Don't waste time going after mass markets that don't exist when there are niche products and markets that do.

- ***Principle 3: Public programs should focus on creating, discovering, communicating, and refining opportunities for firms to deliver more value to customers.***

Value to customers must exceed cost. Sometimes this cost needs to be artificially reduced by third parties until the product is established in the market, but such interventions must be limited. Help companies develop marketing capacity rather than creating pseudo-markets for them through subsidies that orient them away from developing true, sustainable markets.

- ***Principle 4: Companies in emerging markets often need to build business competence.***

Companies in markets that are new and developing often do not always have sufficient capacity to identify customers, to develop them, to deliver consistently high quality products reliably. Distribution and sales are as important as product development and production. Public intervention can help build these capacities or it can seriously hinder their development.

- ***Principle 5: Help companies learn and create learning for the industry.***

With new technologies there is little market information available. Leaning can be expensive, risky, and slow. Well designed interventions designed to create industry and market knowledge can benefit a whole industry by 1) creating a consensus in the industry around key issues; 2) creating new knowledge about key issues; 3) permitting more effective distribution of knowledge to industry players and their potential partners in the financial and insurance community; and 4) involving and educating customers.

- ***Principle 6: Leverage public money as much as possible to achieve more with less.***

Leverage in this sense is achieved when others add money and other resources to your project. The higher the leverage, the more support is demonstrated for a project. Leverage is a good test for the effectiveness of a public investment. By reaching for higher leverage, radically higher levels of effectiveness for policy interventions can be reached.

V. ACTION RECOMMENDATIONS: INDUSTRY DEVELOPMENT STRATEGY FOR THE PV SECTOR

A useful method for diagnosing PV market barriers and development opportunities is *value-chain analysis*. Value-chain analysis involves explicit consideration of each step in a product's distribution chain—from product design to manufacturing to sales to service—thus providing a basis for detailed analysis of the entire value delivery process.

⇒ ***Our overall action recommendation is for public and private sector elements of the PV community to apply value-chain analysis to identify the best market opportunities for***

PV, to identify domestic analogs for these markets (where possible), and to work up strategies for their coordinated development*.* Considering PV markets from the standpoint of value delivery allows one to identify the issues critical to the successful development of such markets. As an example, the value-chain approach could be used to develop a strategy for PV penetration of the remote pump market. At over 10,400 megawatts/year, the remote pump market alone is some 70 times larger than total world output of PV. Given PV's performance characteristics relative to the dominant pump power technology (diesel engine), this should be a major opportunity—yet little has been achieved in this area so far.

⇒ ***A preliminary step for a value-chain analysis could be for the Renewable Energy Policy Project (REPP) to convene a meeting of potential funding organizations (e.g., Rockefeller Brothers Fund, Rockefeller Foundation, MacArthur Foundation, or agencies specific to a region such as the Massachusetts Technology Collaborative, the Massachusetts Department of Economic Development, etc.) in order to secure joint support of a program to apply the value-chain framework to the PV industry.*** The initial objective of the program to apply the value-chain framework to the PV industry would be to identify and prioritize commercially viable PV markets, then to develop strategies for pursuing those markets that are most promising. The ultimate goal would be to develop detailed plans of action for market development—that is, PV market development "scripts" specifying individual roles and activities.

Activities to develop a strategy for PV industry development would include the following:

- analysis of PV industry structure;
- analysis of submarkets by geographic region and application;
- identification of PV opportunities in these submarkets;
- mapping of existing value chains;
- identification of product development issues and opportunities;
- identification of relevant market barriers;
- identification of ways to address these barriers; and
- identification of specific stakeholder roles in development of the market.

PV market development activities to be undertaken according to the program we propose would depend upon particular circumstances but could include the following:

- organizing a pool of foundations to sponsor a contest with a significant cash prize for the best company proposal to learn about the needs of customers in key market segments and to develop/refine products and marketing strategies to meet these needs;
- developing a competitive export financing program through the Overseas Private Investment Corporations (OPIC) or the Export-Import Bank tailored to the needs of small equipment exporters; and

- developing a pool of funds from foundations or the World Bank that can be used to provide “money-back guarantees” to early distributors and customers to encourage them to try PV products, linked to the collection and dissemination of key information about customer and distributor satisfaction or lack thereof.