Facilitating Widespread Deployment of Wind and Photovoltaic Technologies

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As a result of technological improvements and increasingly attractive costs, wind and photovoltaic (PV) technologies, which provide electricity with near-zero emissions of air pollutants and greenhouse gases, are poised for widespread deployment.

Wind Power

At the global level, installed wind capacity has grown an average of 25 percent per year since 1990; by the end of 2000 it had reached 17.0 gigawatts of electrical capacity (GWe) and was generating about 0.24 percent of electricity worldwide. In the United States, average wind power prices (in 2000 dollars) fell from 47 cents per kilowatt-hour (kWh) in 1981 to 5.1 cents/kWh in 1995, as installed wind-power capacity expanded to about 1.5 GWe. For many large new wind farms in the United States, unsubsidized 30-year levelized life-cycle costs are currently about 5 cents/kWh-and less than 4 cents/kWh in areas of high average wind speeds.

Wind-power costs are expected to decline further as the industry gains experience, learns to exploit economies of scale both by using turbines with larger unit capacities and by building larger wind farms (more turbines per farm), sees reductions in project financing costs as developers and financial institutions gain confidence in the technology and its market prospects, and makes technological improvements (e.g., higher hubs to exploit the stronger winds aloft, materials that lower maintenance costs).

A decline of price as cumulative production rises characterizes a wide range of products that can be mass-produced, typically with "learning rates" of 10 to 30 percent: that is, the price falls 10 to 30 percent with each doubling of cumulative production. Learning-by-doing generates stocks of tacit and explicit knowledge that drive down costs and thus prices, in a manner that is captured by "experience curves." Historical learning rates for wind, PV, and gas turbine energy technology experience curves are indicated in Figure 1. Such curves can be used to gain insights about future price trends, although there is no guarantee that historical learning rates will persist. Indeed, Figure 1 shows that the learning rate for gas turbines in the United States declined from 20 percent in the early years to about 10 percent as the technology matured. But when they are combined with so-called bottom-up engineering analyses to guard against unrealistic cost estimates from blind extrapolations, these curves can help clarify future prospects.

Experience curves indicate that the more rapidly demand grows, the more quickly prices decline. Suppose favorable public policies are adopted that make it possible to sustain an average growth rate of 20 percent per year for wind electric generation throughout the first quarter of this century. Under this scenario installed wind power would grow to about 1,000 GWe by 2025, at which time wind power would account for about 12 percent of worldwide electricity generation. In both Europe and the United States, the historical learning rate for the price of wind electricity generation, as a function of cumulative electricity production, has been 18 percent. But even if it turns out that wind is such a mature technology that the future learning rate is only 8 percent, wind-power prices under this scenario would fall from an average of about 5.0 cents/kWh in 2000 to 3.9 cents/kWh by 2010 and 2.8 cents/kWh by 2025-projections consistent with bottom-up cost analyses.[ii]

The prospect of wind power below 3 cents/kWh has far-reaching implications. At such costs it will often be cost-effective to exploit the huge wind resources that are remote from major markets. Of the practically exploitable U.S. wind resources of moderate or better quality, 95 percent are located in the sparsely populated

12 states of the Great Plains, where the generation potential is three times total U.S. electricity generation at present;[iii] China has huge high-quality wind resources in Inner Mongolia;[iv] and a large fraction of the world's practically exploitable wind resource (about three times global electricity generation at present) is remote from major electricity markets.

To exploit these huge potentials, wind power must be deliverable at low incremental cost to major distant centers of electricity demand. This is feasible with fully loaded high-capacity (1-2 GWe) high-voltage transmission lines. Such transmission lines can be fully loaded if they are matched to large wind farms (3-6 GWe) that are coupled to appropriate electrical storage technology so as to provide "baseload" electricity to the transmission line. The least costly way of providing the needed day or more of storage capacity is to use commercially available compressed air energy storage (CAES) technology.[v] With CAES, power produced in excess of the line capacity during periods of strong winds would be used to compress air for storage in an underground reservoir. During periods of light winds, compressed air would be withdrawn from storage, some fuel would be burned in it, and the hot combustion products would be sent to a gas turbine expander to make extra electricity to "fill" the transmission line to capacity.[vi]

A large fraction of the wind power generated in such a system would go direct to the transmission line, but some would be stored. The cost of baseload electricity from a wind/CAES system would typically be less than 1 cent/kWh more than the cost of the intermittent wind electricity, so that if wind-power costs less than 3 cents/kWh, a wind/CAES power system would often be competitive with a natural gas-combined cycle on a direct-cost basis in providing baseload power. Because it requires some fuel burning, a wind/CAES system would not be emission free if that fuel were a fossil fuel, but the emissions would be tiny relative to those of conventional fossil energy systems. CAES requires suitable geology: bedded or domed salt formations that can be solution-mined, mined caverns in hard rock, or porous media (aquifers or depleted natural gas fields). About 85 percent of the U.S. land area has one or more suitable geologies.

Although wind farms occupy large areas, the turbines and infrastructure take up only 5-10 percent of these areas. The rest can be used for growing crops, ranching, and other activities. To the extent that large wind farms would be concentrated in farming/ranching regions (as would be the case in the U.S. Great Plains), wind-farm royalties would provide a major supplement to farming and ranching income: in the United States, royalty income per acre would typically be greater than the net income from farming or ranching.[vii]

Photovoltaic Power

Factory-gate PV module prices (in 2000 dollars) have fallen from $61 per peak watt (Wp) in 1976 to $7.5/Wp in 1990 to $3.85/Wp in 2000-closely following an experience curve with a 20 percent learning rate (see Figure 2). Cumulative PV power module shipments worldwide increased 20 percent per year on average from 1990 to 2000, when annual shipments totaled 250 peak megawatts (MWp). Some 1.0 peak gigawatts (GWp) of PV capacity is contributing 0.014 percent of global electricity.

At current prices PV electricity generated in a central-station power plant in areas of good insolation (received solar radiation) would cost several times as much as wind electricity generated in areas with moderate wind resources. This comparison is not a true reflection of the relative near-term market potentials for wind and PV technologies, however. Despite its much higher current cost, PV power that is generated at small scales where and when it is needed can be worth much more than central-station wind power. Small PV systems can be sited near users: on residential building rooftops, commercial building façades, and roofs of parking garages, as examples. Such decentralized generation is feasible because a PV system requires no system operators, causes no pollution, and is relatively quiet; in addition, its cost per kilowatt-hour is not especially sensitive to scale. Already PV is the least-costly means of providing electricity to households with modest levels of demand at sites remote from electric grids;

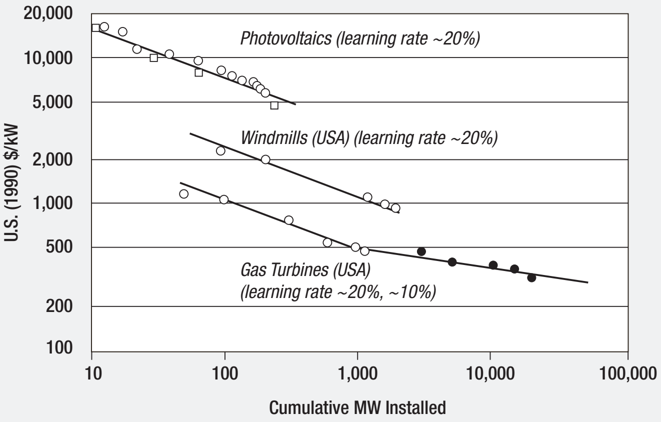
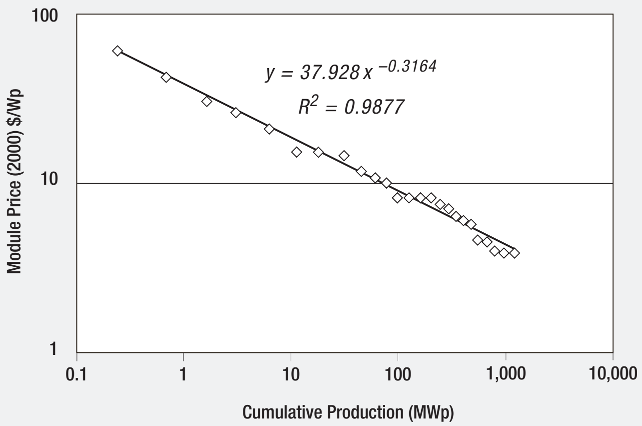


Figure 1: Experience curves for photovoltaics, wind generators, and gas turbines. These curves illustrate the well-established phenomenon that, for new technological products amenable to the economies of mass production, prices tend to decline with cumulative production. Source[i]

Figure 2: Experience curve for photovoltaic modules, 1976-2000. The points shown in this figure are PV power module prices for cumulative worldwide module sales in successive years. Prices (in 2000 dollars) are measured at the first point of sale (FOB the manufacturer's loading dock) to distributors and projects. The best fit of the historical data is the solid line, which corresponds to a learning rate of approximately 20 percent: that is, a 20 percent reduction in price for each doubling of cumulative production. Source[viii]



these include rural households in developing countries. PV systems for grid-connected applications are not yet competitive, but installed costs for grid-connected residential rooftop applications have been falling sharply: from $17/watt in 1984 to $9/watt in 1992 and $6/watt in 1996. According to various projections, costs for residential rooftop PV systems will fall to about $3/watt by the middle of this decade. At this cost, rooftop PV systems are expected to be fully cost-effective for U.S. consumers in several regions where net metering[ix] is allowed and PV systems are financed with home mortgages. The estimated U.S. residential rooftop PV market under these conditions could be as much as 40 GW[x]-160 times the global PV module production rate in 2000.

The findings of a bottom-up analysis[xi] of the near-term prospects for amorphous silicon (a-Si) PV technology are consistent with such projections. It shows that if factories are scaled up to produce 100 MWp of modules yearly (compared to 5-10 MWp per year for existing factories), modules based on present a-Si technology could be profitably produced during the middle of the decade at retail prices of $1.6/Wp. The corresponding installed-system cost in new residential housing would be $2.7-$3.0/watt. At such installed costs the 25-year levelized cost of electricity (with home mortgage financing, taking credit for income tax deductions of mortgage interest and assuming net metering) would be 9-10 cents/kWh in southern California and 12-13 cents/kWh in southern New York–in both instances less than the retail electricity prices.

The authors of this a-Si PV study estimate that module prices of $1.6/Wp (and the corresponding system costs of $3.0/watt or less) could be realized with the second factory that produces 100 MWp per year: that is, after about 2 GWp of modules are produced in factories that last 10 years. But according to the historical experience curve for all PV technologies (see the top curve in Figure 3), a retail module price of $1.6/Wp would not be realized until an additional 38 GWp of PV modules are first produced. This suggests that the historical PV learning curve may not be a good predictor of future PV prices and that, for thin-film technologies in particular, prices will fall more quickly. As competition develops among thin-film PV vendors and technologies (including cadmium telluride as well as a-Si) an experience curve for thin-film technologies to the left of the historical curve for all PV technologies may well emerge (see Figure 3). If that turns out to be the case, the cost of buying down thin-film PV module prices to a level as low as $1/watt (at which PV would be competitive in many markets besides new residential housing) would be only about one-tenth of that predicted by the historical experience curve for all PV technologies (see Figure 3).

This analysis is based on relatively inefficient a-Si PV units (module efficiencies of 8 to 10 percent and corresponding system efficiencies of 6.4 to 7.7 percent, which are expected to be typical of commercial products during the middle of this decade). Major improvements are expected in PV performance, energy payback, and cost. An assessment carried out jointly by the Electric Power Research Institute and the U.S. Department of Energy projects that, between 2005 and 2030, system efficiencies for thin-film PV will reach nearly 14 percent and system costs for central-station plants will decline to less than $1/watt.[xiii] Realizing such gains would enable PV to compete in many power markets throughout the world.

It is likely that PV will become widely competitive in distributed grid-connected markets during the next one to two decades. Small PV units might ultimately be deployed globally at an average rate of 1 kilowatt per person (which would require a collector area of about 7 square meters per capita near users in areas characterized by average insolation). For a world with 10 billion people that implies a PV electric-generation rate about 30 percent greater than present global generation from all sources. Such a deployment rate in grid-connected applications would probably require coupling PV to electric storage systems near users. Even if low-cost electrical storage technology (e.g., cheap batteries) does not emerge at the scale of the individual customer, small, above-ground CAES devices suitable for deployment on electric distribution feeders would probably be cost-effective in addressing such storage needs.

Overview

The prospects are good that central-station wind and distributed grid-connected PV power can be made broadly competitive during the next two decades and that over the longer term these technologies in combination could meet most global electricity needs.[xiv]

Intermittency. The intermittency of wind and PV technologies will not prevent these technologies from making major contributions in power markets. Gas turbines, combined cycles, and hydroelectric power supplies in various combinatons can provide effective backup during the next couple of decades. If, as expected, gas-fired generators account for a substantial fraction of new generating capacity in this period, it will become possible, even without new storage technology, to provide highly reliable grid power with 10-30 percent contributions to total generation from wind plus PV sources.[xv] Electric storage is needed to achieve higher levels of electric grid penetration. If coupled to appropriate storage technologies, intermittent renewables can provide either load-following or baseload outputs at all levels of electric grid penetration. Fortunately, technological breakthroughs are not needed. Although inexpensive microscale electrical storage (with batteries, for instance) remains an elusive goal, commercially available CAES technology solves the storage problem at the scales needed to enable intermittent renewables to make major contributions to electric grids.

Need for rapid and sustained market growth. Wind and PV technology will require nurturing by appropriate public policies until each accounts for several percent of electric power sales. And if these technologies are to make major contributions in this century, measures to promote their rapid market growth will be needed for much of the first quarter of this century.

A reasonable target for wind in this period is sustained market growth at 20 percent per year on average (versus 25 percent per year during the 1990s), which, as noted, would lead to a 12 percent wind share of world electricity generation by 2025. The corresponding global target over this period for PV might be 30 percent per year (versus 20 percent per year during the 1990s), which would lead to about a 5 percent world electricity market share by 2025. Such high growth rates over a period of 25 years are not unprecedented. Between 1956 and 1980, before nuclear power fell out of favor, global installed nuclear generating capacity grew at an average rate of 40 percent per year.[xvi] But, like nuclear power in its heyday, renewables will need strong supporting public policies to sustain such high growth rates.

Public Policy Issues

Wind and PV technologies require comprehensive public-sector support throughout the entire energy innovation chain: for research and development (R&D), demonstration, commercialization, and widespread deployment. Comprehensive treatments of public policies relating to the entire energy innovation chain are presented elsewhere.[xvii] Here the focus is on commercialization, which has only recently been given prominent attention.

Rationale for public-sector support of commercialization activities. Conventional wisdom holds that government should restrict its support for technological innovation to R&D and let the private sector assume the risks of commercializing new technologies. But for fundamental reasons the public sector should also support appropriate commercialization activities.

When new technologies are introduced into markets, their costs tend to be higher than the costs of the technologies they would displace. Early investments are needed to “buy down” the costs of new technologies along their experience, or learning, curves to levels at which the technologies can be widely competitive (see Figure 4). In principle, a firm introducing a new technology should consider experience effects when deciding how much to produce and consequently to “forward-price”: that is, it should initially sell at a loss to gain market share and thereby maximize profit over the entire production period. In the real world, however, the benefits of a firm’s production experience spill over to its competitors, so that the producing

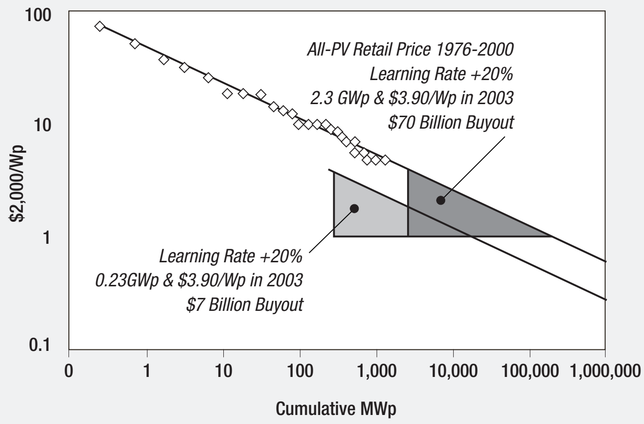
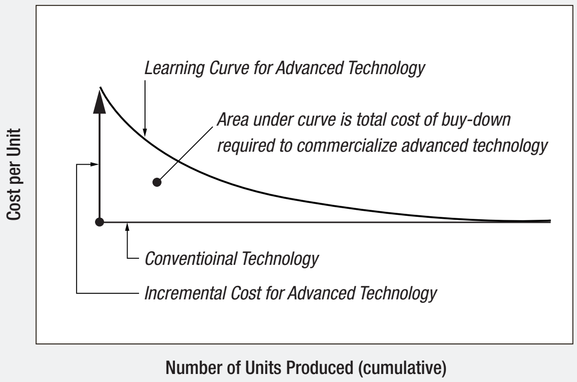


Figure 3: Costs of buying down crystalline silicon and a-Si:H modules to $1.0/Wp, from equal price levels in 2003. This figure shows projections of retail PV module prices based on both the historical PV experience curve for all PV technologies (dominated by experience with crystalline PV technologies) and a postulated a-Si:H curve assumed to have the same progress ratio and initial module price in 2003. Buy-down is defined here as the total incremental expenditure required to reduce module prices from their initial values to the $1.0/Wp target price (see, for example, Figure 4), without taking credit for niche market opportunities that would reduce the buy-down cost considerably. The module prices in the historical PV experience curve are the wholesale prices presented in Figure 2 augmented by a 20 percent retail mark-up. Source[xii]

Figure 4: Learning curve and buy-down cost for an advanced energy technology. This figure shows the incremental cost for buying down the cost of the advanced technology relative to the conventional technology, as the advanced technology moves along its learning curve. The triangular area between the curves indicates the total cost for buying down the cost of the advanced technology to the level at which the advanced technology is competitive with the conventional technology. The point at which the cost of the advanced technology equals the cost of the conventional technology is not necessarily the asymptotic (long-term) market price for the advanced technology. Source[xx]



firm will forward-price less than the optimal amount from a societal perspective. That phenomenon provides a powerful rationale for public-sector support of technology cost buy-downs.[xviii]

This rationale applies to a wide range of technologies. But the high costs of commercialization activities compared to R&D and the general scarcity of public-sector resources dictate that public-sector investments in such innovative activities be prioritized–with a focus on technologies that offer major "external" societal benefits. For energy technologies, a strong case has been made that public resources should be limited to those inherently clean emergent technologies characterized by steep industry experience curves, a high probability of major long-term market penetration once subsidies are removed, and high price elasticities of demand[xix]–conditions that both wind and PV technologies satisfy.

Toward a renewables portfolio standard: The emerging instrument of choice for buy-downs. In recent years several approaches have been tried throughout the world to encourage renewable-energy commercialization and to facilitate technology cost buy-downs. Such approaches have included subsidizing consumers directly, requiring electric utilities to pay relatively high fixed prices for renewables, requiring utilities to buy renewable electricity via auctions, and obligating electricity suppliers to include growing fractions of renewables in their supply portfolios. An example of direct consumer subsidies can be found in the California Energy Commission's Emerging Renewables Program, which receives funds from California's Systems Benefit Charge (a non-bypassable wires charge on retail electricity providers). Under the first two years of this program, the unit price of the residential PV systems receiving subsidies varied from 4 to 20 dollars per watt.[xxi] This scatter suggests that the residential PV market is currently not well informed about the available technological choices. The disappointing history of deploying the highly cost-effective compact fluorescent lightbulb suggests that it may always be difficult to educate residential consumers about energy market opportunities. Motivating cost-cognizant market participants (home builders who offer a PV option, for example) seems to offer more promise as a buy-down strategy.

Germany's Electricity Feed Law, requiring that wind generators be paid a high fixed price for electricity provided to utilities, has played a major role in making Germany the world leader in installed wind capacity (over 6.1 GWe, more than 40 percent of the world total, in 2000). Denmark and Spain have also had success with this approach. But, for the longer term, it may be more fruitful to focus on policy instruments that put stronger downward pressure on renewable-electricity prices so as to make more efficient use of scarce subsidy resources.

The United Kingdom probably has the most experience promoting renewables under competitive market conditions. Under its Renewables Non-Fossil Fuel Obligation (NFFO), launched as part of the 1989 Electricity Act privatizing the electric sector, renewable-energy projects were selected by competitive bidding in auctions. The proceeds of a levy on all fossil fuel electricity sales covered the difference between the bid price and the "pool price" at which generators sold fossil fuel power to distribution and supply companies. Although the NFFO fell short of its renewables capacity goal for 2000 and was not effective in developing a renewables equipment manufacturing industry in the U.K., it helped force down renewable-electricity prices, and the program had only a minuscule adverse impact on electricity tariffs. The U.K.'s Renewables NFFO has ended; its replacement will probably be a Green Certificate Market, discussed below.

Another way to introduce competition in renewables commercialization is the "reverse auction" of the California Energy Commission's New Renewable Resources Account program–another activity funded by California's Systems Benefit Charge. Under the NRRA, would-be renewable-electricity providers submitted bids, in three auctions, for subsidies for renewable-energy projects. Awards were made to qualifying bidders requesting the lowest subsidy rates. Subsidy awards, at an average rate of 0.93 cents/kWh, totaled $241 million for 78 projects involving 1.30 GWe of capacity. But there is growing concern that, even with guaranteed subsidies, many successful bids will not be followed up with projects because of the looming prospect of excess electricity supplies. Following the recent electricity crisis, the state of California committed itself to long-term electricity supply contracts (mostly for natural gas power). These are expected to lead to excess supplies, as a consequence of a subsequent grid exodus by many industrial firms to pursue independent electricity supply options.

A new option for advancing renewables in more competitive electricity markets is the Renewables Portfolio Standard (RPS), known in Europe as the Green Certificate Market (GCM). An RPS or GCM requires that each electricity provider include in its supply mix a small but growing fraction of renewables. Companies can either produce renewable electricity or purchase renewable energy credits (RECs or, in Europe, "green certificates") in a credit-trading market. The RPS/GCM would be phased out after a specified period during which new renewables industries are expected to be launched in the market. Several industrialized countries have introduced or are developing national RPS/GCM initiatives. China intends to explore the implementation of an RPS under its 10th Five-Year Plan.[xxii] Ten U.S. states have implemented an RPS, often in conjunction with electricity-market-restructuring initiatives, and a number of bills with provisions for a federal RPS have been introduced in the U.S. Congress.

Although there is little experience with implementing these initiatives, the embryonic Texas RPS provides a basis for optimism that a well-structured RPS can be an attractive option for promoting the commercialization of renewables in a competitive electric industry.[xxiii] The Texas RPS emerged as a key part of that state's 1999 electric-industry restructuring. RPS obligations begin in 2002 and end in 2019. The goal is to produce 0.40 GWe of new renewables capacity by 2003, rising to 0.85 GWe by 2005 and to 2.0 GWe by 2009 (when the new renewables share of power generated would be 1.5 percent) through 2019. All retail electricity providers in competitive markets have obligations based on their yearly electricity sales. Tradable RECs are issued for qualified electricity generation located within or delivered to the Texas grid. As a follow-up to the 1999 program announcement and the subsequent completion of implementing regulations, nine wind-power projects were brought under contract in 2001 with a total capacity of 0.93 GWe, exceeding the year 2005 obligation. There are good prospects that the year 2009 goal will be met.

The auspicious outlook for the Texas RPS reflects an outstanding renewable-energy resource base in Texas, strong public support for renewables, the sound structure of the program, and broad political support for it.[xxiv] The obligated electricity suppliers have been willing to sign long-term (10- to 25-year) contracts for RECs and the associated electricity. Those contracts give renewable-energy developers confidence to launch projects, by ensuring stable revenue streams and facilitating access to low-cost financing. The program offers credible and automatic enforcement. (Penalties are the lesser of 5 cents/kWh and 200 percent of the mean REC trade value for each missing kWh; REC prices are expected to be about 0.5 cents/kWh during 2002.) Retail electricity providers are protected against supply delivery failure on the part of renewable-energy developers-a problem encountered with the U.K.'s NFFO and expected with California's NRRA. Broad public support for renewables is key to the long-term success of the program because electricity ratepayers bear the cost. In this regard an important feature of the Texas RPS is that the 5 cents/kWh noncompliance penalty caps the cost of the program. If RECs were priced at this level, the cost of the program in 2009 would add 0.07 cents/kWh to the average retail electricity price (a 1 percent increase at the 2000 average retail price). There is no evidence that the price cap will be reached, however.

If the RPS does indeed become the buy-down instrument of choice, an important challenge in the U.S. policy arena will be how to encourage the exploitation of the enormous wind resource of the Great Plains and bring the wind power produced there to distant urban electricity markets. A national RPS with uniform rules across states would facilitate this process.

PV is usually not considered a major option for RPS programs because it cannot yet compete head-to-head with wind power in wholesale power markets. But with factories producing modules at a scale of 100 MWp per year, thin-film PV technologies may become competitive at the retail level by mid-decade in many new residential U.S. housing markets,[xxv] and as costs come down, market opportunities could extend to commercial buildings and retrofitted residential buildings as well. Such prospects suggest that ways should be found to include PV in RPS programs that are structured to give module manufacturers the confidence to build large (100 MWp per year) facilities. One option would be to allow home builders to generate and sell RECs based on the expected electricity generation from PV systems on houses they sell.

Many who are apprehensive about entrusting the government to "pick winners" insist that an RPS should be technologically blind except for the "renewables" requirement and that the market should determine which technologies win the largess of the subsidy. But there are serious problems with that approach. At the most fundamental level, different technologies are at different stages on their development paths at any one time. Less mature technologies can often make significant near-term contributions in niche markets (rooftop PV systems for new houses, for example, can be competitive at the retail level). A technologically blind policy might neglect such opportunities and give all or most of the available subsidy to the technology (wind, for example) that has advanced furthest along its experience curve. In effect, a "technologically blind" policy might end up picking a single winner. Also, some technologies that might be competitive under a technology-blind policy have limited overall potential (biogas and landfill gas come to mind), so that the leveraging effect of the subsidy would be modest. Moreover, as noted, the public sector has already made technological choices in its design of energy R&D programs: It has given considerable emphasis to technologies, such as PV, that have enormous long-term promise but limited near-term potential; excluding such technologies from suitable roles in an RPS increases the risk that such R&D investments might not lead to major commercial markets. And finally, because of the paucity of experience with truly radical clean technologies, public-sector decision-makers are unlikely to be less prescient than those in the private sector.[xxvi] An appropriate strategy for dealing with the winner-picking concern is to support a portfolio of clean-energy technologies that reduces the overall buy-down program performance risk through diversification.[xxvii] Such considerations suggest designing an RPS with a limit on the contribution that any single technology can make to the total RPS obligation; better yet, the RPS might have separate tranches for different technologies, including one for PV.

Other domestic policy issues. Despite the promise it offers for technology cost buy-down programs, the RPS by itself is not a silver bullet adequate to ensure the widespread deployment of wind and PV technologies. Putting in place an RPS or other comparably promising cost buy-down instrument ought to be complemented by appropriate supporting policies.

First, consider wind power. As has been pointed out, if wind is to become a major contributor to power generation worldwide, ways must be found to exploit the huge wind resources that are remote from major markets. CAES is a technology that can probably greatly facilitate such exploitation. Yet despite the availability in the market of both wind and CAES technologies, they have not yet been put together in commercial configurations providing the "baseload power" that would enable wind power to make major contributions to the global power supply. Commercial demonstration of this combination of technologies ought to be a high priority for wind-energy policy. Similarly, the successful exploitation of remote wind-power resources requires institutional mechanisms that would make it practical to build multi-GWe wind farms made up of thousands of turbines and to strengthen the associated transmission grid capability as needed. That would mean the development of wind-power systems on a scale that has not yet been pursued commercially. To address this challenge, a "wind-energy resource development concession," analogous to the concession used throughout the world to bring oil and gas and other mineral resources to market, has been proposed.[xxviii] It is a concept that warrants "institutional demonstration." Such a demonstration is being planned in China.

Pricing electricity properly to reflect its time-of-use value, distributed benefits, environmental costs not now included in market prices, and the risks associated with the volatility of natural gas prices would provide a powerful incentive for sustaining an accelerated market development for wind and PV over a period of decades. Alternatively, if efficient electricity pricing is politically or technically infeasible, surrogate incentives should be crafted for these technologies.

In the case of PV, a continuation of net metering long after an RPS phase-out might prove to be an effective surrogate. This policy, which has been implemented in 30 states as a mechanism for advancing PV, can significantly increase the homeowner's financial return on investments for large rooftop PV systems. With conventional energy cost accounting, net metering involves an implicit subsidy. But whether there would be a true subsidy for PV with full societal cost accounting is unclear. Studies ought to be carried out to clarify such issues.

In light of the potential of wind and PV for addressing the multiple challenges posed by conventional energy, the Energy R&D Panel of the President's Committee of Advisors on Science and Technology recommended that the federal R&D budgets for wind and PV be roughly doubled between 1997 and 2003.[xxix] R&D expenditures have not been ramped up as recommended, but such increases are warranted to enhance the long-term prospects for these technologies.

Renewables commercialization in developing countries? A concerted international effort is needed to speed up the rate of technological improvement and cost reductions worldwide for wind, PV, and other inherently clean-energy technologies that offer promise in meeting sustainable development objectives. Particular attention should given to developing countries, which will account for much of the world's future growth in energy demand and which face severe environmental problems caused by conventional energy. The effort should be aimed at channeling some of the enormous financial and technological resources of the private sector to the development and widespread deployment of such new energy technologies: for example, via international industrial joint ventures.[xxx] An institutional framework for channeling these resources to the process, with an emphasis on developing countries, is needed. Either a new multilateral institution should be created or an existing institution such as the Global Environment Facility should be equipped to take on this new responsibility.[xxxi]

The combination of rapid growth in energy demand plus emergent energy and environmental policy reforms could transform the energy markets of developing countries into favorable theaters for innovations in wind, PV, and other inherently clean energy technologies. With their sizable internal markets, large rapidly industrializing countries in particular have an opportunity to become market leaders for selected sustainable-energy technologies.

Conclusion

Both wind and PV technologies have evolved to a point where they can begin to make significant contributions to electricity supplies. But these technologies cannot become substantial contributors in electricity markets without two to three decades of sustained generation growth rates in the range of 20 to 30 percent per year. Such growth rates, in turn, cannot be realized without nurturing public policies. The appropriate policies should aim to induce a virtuous cycle of: expanded production; price reductions from learning-by-doing, production scale-up, and increased private-sector R&D; expanded market opportunities as a result of such price reductions; further increases in production to meet the higher demands at the lower prices; further price reductions; and so on. Over the last decade various experiments have been carried out to identify effective policy instruments for catalyzing this virtuous cycle. Of these the RPS has emerged as a potentially very effective instrument, especially when it is used in efficient and competitive electricity markets and complemented by appropriate supporting policies.

The electric-sector restructuring going on throughout the world offers a rare opportunity to put into place policies for advancing renewables. Fundamental policy changes such as the RPS are typically easier to make when institutions are in ferment, as they are now. Once the ongoing power-sector reforms have been carried out, the policy arena will become quiescent, and it will be more difficult to bring about the much-needed changes.

Endnotes

i N. Nakicenovic, A. Grübler, and A. MacDonald, Global Energy Perspectives, Cambridge University Press, Cambridge, U.K., 1998.

ii See R. H. Williams, Nuclear and alternative energy supply options for an environmentally constrained world, in Nuclear Power and the Spread of Nuclear Weapons: Can We Have One Without the Other? (a work arising from the 20th Anniversary Conference of the Nuclear Control Institute, 9 April 2001, Washington, D.C.), to be published in 2002 by Brassey's; W. Turkenburg, Renewable energy technologies, Chapter 7 (pp. 219-272) in Energy and the Challenge of Sustainability, World Energy Assessment of the U.N. Development Programme, U.N. Department of Social and Economic Affairs, and World Energy Council, New York, 2000.

iii Williams, 2002 (see Endnote ii).

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