Renewables:
A Promising Coalition of Many

The Story in Brief

Renewable energy technologies are most often spoken of and considered collectively. But wind, photovoltaic, solar-thermal, biomass, tidal, and wave energy options are largely unrelated technologically, each having its own discrete developmental and economic challenges. Understanding the place of these technologies in a clean, sustainable energy future requires an appreciation of their individual limitations and advantages and a familiarity with the expectations for advancements over the next two decades.

UNDERWATER TURBINE PHOTO COURTESY VERDANT POWER, INC.
PELAMIS WAVE ENERGY CONVERTER PHOTO COURTESY OCEAN POWER DELIVERY LTD.
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The importance of renewable energy resources has been recognized—and repeatedly rediscovered—since ancient times. By the first century, waterwheels were driving the bellows of blast furnaces to create cast iron in China, and the Greek engineer Hero had described a wind-powered organ. Archimedes reportedly used solar energy concentrated by mirrors to set Roman warships afire during the siege of Syracuse in 212 BC, and in 1839, a very young Edmund Becquerel discovered the photovoltaic effect. Even the Model T car was originally designed to run on either ethanol or gasoline, and Henry Ford actually constructed an ethanol fermentation plant to supply the fuel.

So why aren't we using more wind, solar, and biomass energy today? And what role are such renewable resources likely to play in the future? The answers to such questions are as diverse as the resources themselves—a group of largely unrelated technologies now being considered together because of their potential importance in helping limit carbon dioxide (CO_2) emissions, which contribute to global warming, and in reducing America's dependence on imported oil. As those concerns become more urgent, the drive to deploy non-emitting energy resources is accelerating rapidly, but success will depend on a wide variety of individual technology development paths.

Estimates of the contribution renewables will make to our energy future have been made by many different organizations, and the results vary widely, depending on the studies' assumptions and modeling approaches (see sidebar, p. 10). Still, one premise common to all estimates is that substantial research and development efforts will be needed in order for renewables to compete economically with other energy sources, such as nuclear power and coal plants with CO_2 capture and storage. In some cases, such as wind, the main problem is how to integrate an inherently intermittent resource into an electricity grid whose supply and demand must remain balanced within seconds and within very narrow voltage and frequency limits. Reducing costs will be the primary issue for photovoltaics, with several potential breakthroughs already being explored. And for biomass, fundamental questions remain about what approach to follow and which fuel stocks to use.

Wind power is now competitive with conventional electricity generation in favorable locations. Much of today's research is focused on dealing with the intermittency of the wind resource and integrating often-remote installations into the power grid.

Wind: Tackling Barriers to Grid Integration

With installed capacity in the United States of more than 11 GW and annual growth rates estimated by the American Wind Energy Association at more than 25% a year, wind energy continues to dominate renewable energy additions to the electricity generation mix. Indeed, for the last two years, wind has ranked second only to natural gas in terms of contributing new generating capacity. Much of this growth has been driven by steady improvements in generation technology, which have made the cost of electricity from wind resources competitive with that from fossil fuels in an increasing number of circumstances, both in this country and worldwide. Two inherent barriers remain, however, to the large-scale integration of wind energy into utility networks: the remoteness of many windy areas, and natural fluctuations in the wind resource in even the best locations. Recent progress has been made in addressing both of these problems.

Carrying power to load centers from wind farms in remote areas often requires construction of new transmission lines. Under previously common regulations, the addition of such lines raised a classic chicken-or-egg problem: typically, wind facilities weren't built unless connection with potential markets was assured, but the necessary power lines tended not to be added unless wind farms were already in place. Specifically, in California, power plant owners were required to pay all the costs of connecting new plants to the grid, which created a particular burden for small wind farms. To resolve this dilemma, the California Independent System Operator—with support from the California Public Utilities Commission and the non-governmental Natural Resources Defense Council—requested the Federal Energy Regulatory Commission (FERC) to allow shifting part of the cost to consumers. In

January 2007, FERC issued a unanimous decision saying that plant owners should pay for their share of the line but that all power consumers would assume the costs of unused line capacity until the capacity was fully subscribed.

The use of backup power or energy storage can substantially reduce the problems that resource intermittency brings to integrating wind into the power grid, but both of these options are relatively expensive today. To address the wind variability issue more cost-effectively, EPRI has been working with the California Energy Commission to develop and test regional and wind plant–specific wind energy forecasting systems that will allow better coordination of wind resources with a utility's other generating options. The recently completed project addressed both same-day and next-day hourly forecasts of wind speed and energy generation for the principal wind resource areas of California. Especially in regions with large concentrations of wind generation facilities, accurate forecasts are needed both to support green power markets and to assist system operators as they adjust other generation and transmission resources to follow load. In future work, EPRI is planning to implement the new algorithms in a real-time wind forecast workstation.

Meanwhile, the National Research Council—the research arm of the U.S. National Academy of Sciences—has published a report, *Environmental Impacts of Wind Energy Projects,* that proposes guidelines for evaluating the trade-offs between the benefits of new projects and their potentially negative impacts on the environment. Of particular concern is the death of birds and bats from collisions with the spinning blades. The report concluded that, at the current level of U.S. installed wind capacity, there is "no evidence of significant impacts on bird populations," with the possible exception of certain raptors that collide with older wind energy machines in one area of California. Nevertheless, the report recommends development of a more-extensive knowledge base that regulatory agencies can use to evaluate potential problems—an effort that would entail more-careful tracking of bird and bat populations to assess behavior, migration corridors, and other factors that could affect the risk of collisions.

Solar-Thermal Power: Renewing the Promise

Solar-thermal electricity (STE) is back. In spite of successful demonstrations of various STE technologies in the 1980s and early 1990s, the idea of concentrating solar power to heat a working fluid and generate electricity with a turbine or engine was largely ignored during the turbulent era of energy industry restructuring.

That has now changed, and more than a gigawatt of STE central station power plants are now in various stages of planning and early construction around the world. This shift is due not only to altered circumstances but also largely to the recognition that in multi-megawatt plants, STE provides the lowest-cost solar electricity available today. Advances in key plant components, as well as parallel advances in materials science, thermal storage, and computerized controls, have reduced the wholesale cost of electricity to close to 10¢/kWh for a large STE plant under the most favorable circumstances (see Further Reading, EPRI Report 1012731). Additional cost reductions are expected from plant scale-up and increased component production volume.

Actually, STE never entirely went away. The 354-MW Solar Energy Generating Station (SEGS) in California's Mojave Desert—built in stages—has been providing electricity for roughly two decades and is still the world's largest solar power plant. This facility uses long, trough-shaped mir-

Parabolic trough systems are considered the most reliable and least costly of today's solar-thermal electricity (STE) technologies. The Nevada Solar One plant—a 64-MW installation that lines up 760 parabolic concentrator arrays—began generating power in June. (photo: Acciona Group)

Sandia National Laboratories is evaluating solar dish–Stirling STE systems at its National Solar Thermal Test Facility in Albuquerque. The dish units, which are automated to track the sun, concentrate heat on a Stirling engine, which drives an electric generator. (photo: Randy Montoya)

Estimating Future Renewable Generation

While the technical capabilities of renewables and their contribution to the electricity generation mix are both growing steadily, estimating how much growth will be achieved—and by when—remains extremely difficult. Many uncertainties could affect the outcome, including possible mandatory restrictions on carbon dioxide emissions, introduction of a federal renewable portfolio standard (RPS), variations in fuel prices, offerings of deployment incentives, and changes in the rate of demand growth. The projections of renewable generating capacity presented in this article represent an assessment of current trends and expected technical potential, not predictions of what will actually happen in the future.

The following table, which compares estimates drawn from several sources and based on a range of assumptions and modeling approaches, illustrates the point. The NEMS model, produced by DOE's Energy Information Agency (EIA) and published in its *Annual Energy Outlook* (AEO), provides a baseline projection of 40 GW of additional renewable capacity by 2030 under a business-as-usual scenario that assumes no major changes in government requirements or incentives.

EPRI's technical feasibility estimates for CO_2 reduction (Prism model) also exclude external economic factors but assume substantial research and development activities and a balanced portfolio of high-tech generation technologies; under these assumptions, the analysis projects a possible 70 GW of new renewable capacity by 2030. Another EPRI assessment, based on the National Electric System Simulation Integrated Evaluator (NESSIE) model, considers the effects of fuel prices and CO_2 costs in its analysis; NESSIE projects a renewables capacity of 155 GW if natural gas prices are high and CO_2 constraints are imposed on electricity.

The NESSIE projections are relatively close to the projections for a 15% federal RPS. In contrast, significantly higher estimates come from renewables advocacy groups; their assessments were recently published in *Outlook on Renewable Energy in America*, from the American Council on Renewable Energy (ACORE). This outlook assumes the practical use of a very large portion of the country's natural renewable assets, focusing on the abundance of the resources rather than on technical and economic constraints.

Source of Estimate	Description of Estimate	Target Year	Renewable Capacity (GW)	Renewable Energy (TWh)	Method/Conditions/Assumptions
EIA AEO 2007	NEMS model	2030	40	177	Calculated from economic supply-demand model, no CO_2 tax, business-as-usual scenario
EPRI CO_2 Prism	Technical feasibility	2030	70	307	Estimates technical potential for renewables to reduce CO_2 emissions from electricity industry; no CO_2 tax
EPRI Renewable Energy Scenarios	NESSIE model	2030	155	737	Calculated from economic supply-demand model, with high CO_2-cost and gas-price scenarios
Calculated from demand	Federal RPS of 15%	2030	177	775	Simple multiplication of RPS by expected electricity sales or demand from AEO 2007
Calculated from demand	Federal RPS of 25%	2030	295	1292	Simple multiplication of RPS by expected electricity sales or demand from AEO 2007
ACORE *Outlook on Renewable Energy*	Resource availability	2025	635	1947	Assumes significant renewables deployment and incentives to bridge the cost gap

Notes:
Renewable capacity excludes conventional hydropower.
EIA and EPRI use a 50% capacity factor to convert between energy and capacity.

rors with a parabolic cross section to focus sunlight on receiver tubes filled with synthetic oil. This heat transfer fluid is pumped through a series of heat exchangers to produce superheated steam that powers a conventional turbine-generator. Natural gas can be used to provide up to 25% of the system output, enabling the system to generate dispatchable power when solar energy is not available.

Largely because of this experience, parabolic trough systems are considered the least expensive, most reliable STE technology for near-term deployment, and several new projects are under way. The Nevada Solar One plant, for example, went on-line in June near Boulder City, Nevada, covering a 350-acre site with 760 parabolic concentrators. The 64-MW plant, built and owned by Solargenix Energy, a subsidiary of Spain's Acciona Group, will sell electricity to Nevada Power Company and Sierra Pacific Power Company under a 20-year power purchase agreement. Among the technological improvements that have been developed since SEGS and incorporated into Nevada Solar One, better insulation will limit the plant's reliance on natural gas to only 2% of its backup power. Other major parabolic trough generating plants are expected to begin operation over the next two years, including installations in Spain, Morocco, Algeria, Egypt, and Mexico.

Another STE technology that was successfully demonstrated more than a decade ago has also recently been revived. Central receiver systems, or solar towers, use a field array of heliostats—large, flat mirrors that track the sun—to focus light onto a central receiver on top of a tower in the center of the array. In 1992, EPRI worked with the Department of Energy (DOE) and a group of utilities to demonstrate the use of molten salt as a heat transfer fluid and energy storage medium in a 10-MW power tower in southern California. Lessons learned from this project are now being applied to the development of similar systems elsewhere in the world.

A major advantage of both trough and central receiver systems is that their energy storage capabilities make them the most flexible of solar technologies. Current storage times of up to 18 hours enable such power plants to be dispatchable with load factors of 65–75%. Spain is currently the leader in solar tower development, with an 11-MW plant near Seville now being brought on-line in stages and two other projects planned for the near future. Meanwhile, Pacific Gas and Electric Company has signed a memorandum of understanding with Bright Source Energy to purchase at least 500 MW of power, beginning in 2010, from a series of power tower projects to be built in California.

To help support further development of these and other STE concepts, EPRI has formed the international Solar Thermal Electric Project (STEP), currently in collaboration with Electricité de France, Salt River Project, Energias de Portugal, and Public Service Company of New Mexico. STEP will model the cost and performance of various solar-thermal technologies, design novel applications, compare similar plant designs, and critically analyze vendor claims. The ultimate goal is to provide utilities with improved information and analytical tools, including engineering and economic models, for evaluating available STE applications, as well as to offer participants an opportunity to define and collaborate on demonstrations of new technologies. EPRI is also working on STE programs with DOE and the National Renewable Energy Laboratory and with global cooperative programs, such as the International Energy Agency's SolarPACES organization, to coordinate technology development activities and minimize redundancy.

Silicon photovoltaic systems engineered for low maintenance and long-term environmental exposure are being used increasingly on commercial buildings worldwide. This 457-kW array was installed on the roof of the Lufthansa terminal at Munich Airport in 2002. (photo: BP p.l.c.)

Thin-film photovoltaic cells, manufactured by depositing semiconducting materials on an inexpensive substrate, can be integrated with conventional building materials such as roofing tiles. In this 85-kW installation, CIS PV cells form an entire side of a business center in Wales. (photo: Shell Photographic Services, Shell International Ltd.)

Photovoltaics: Breakthroughs Worthy of the Name

More than a century passed between discovery of the photovoltaic (PV) effect and its first practical application in a power-producing solar array—on the Russian Sputnik 3 satellite in 1958. For years afterward, PV arrays remained so expensive that their use was restricted to such highly specialized applications. Since the 1970s, however, the price of photovoltaics has declined dramatically as efficiencies have improved and production volume has increased. By the late 1990s, installed capacity of grid-connected applications worldwide exceeded that of remote, off-grid installations, fundamentally changing the view of PV as a niche market. The first gigawatt of cumulative installed capacity was reached in 1999; total installed capacity now exceeds 5 GW.

The price of electricity produced by PV still needs to fall substantially before the technology can achieve widespread adoption as a conventional means of generation without subsidies. DOE estimates that the cost per installed watt of PV capacity must be reduced significantly to compete with fossil and nuclear generation. To meet this challenge, DOE has established a goal of reducing the average installed cost of all grid-tied PV systems to $3.30/W in 2015, from a median value of $6.25/W in 2000. The result, according to DOE, would be a reduction in the average wholesale cost of electricity generated by PV systems from the current 25¢/kWh to 9¢/kWh without subsidies.

For point-of-use generation, however, the economic competitiveness of PV systems is considerably different. As with any point-of-use generation technology, rooftop PV avoids the delivery cost and therefore can compete at a higher levelized cost of electricity. If substantial installation incentives are offered, as is the case in many states, a rooftop system in a residential or small commercial application may be able to compete at a cost of electricity 50% higher than would be acceptable for a central station generator. Because of this difference, some customers in favorable locations are already investing in PV rooftop systems to lower their utility bills.

Although part of the anticipated cost reduction in PV systems would probably occur anyway because of evolutionary improvements and increasing production volume, a far sharper drop in cost may result from fundamental breakthroughs in the underlying technologies. Such breakthroughs, based on use of new materials and nanotechnologies, represent the third generation of PV development.

About 95% of all PV installations still use first-generation technology—cells made from crystalline silicon, which are relatively efficient but very expensive. Usually a single crystal is drawn from a pool of molten silicon, or polycrystalline silicon is formed by cooling the molten material. In either case, the resulting block must be cut into wafers to produce cells, a process that is time-consuming and wastes a significant amount of the expensive material. Some manufacturers skip the sawing step by pulling ribbons of silicon from the melt or by solidifying thin layers on a ceramic substrate, but so far these alternatives have not resulted in significant cost savings. Individual PV cells made from crystalline silicon can achieve efficiencies of 20–25% in a laboratory setting, but commercial modules typically have efficiencies of 13–16%. If sunlight is concentrated on such cells, efficiency can be more than doubled, but the market for concentrating photovoltaics (known as CPV) is still emerging, mostly in large-scale applications.

Second-generation, thin-film PV cells are formed by depositing silicon or other semiconducting materials in layers less than 1% as thick as those in traditional solar cells onto an inexpensive substrate used to provide structural support. So far, record thin-film cell efficiencies have run in the 16–19% range, and module efficiencies of around 13% have been achieved. Commercial production, barely a decade old, is growing rapidly as potential cost savings are realized. Further improvements in thin-film technology are ultimately expected to enable it to replace crystalline silicon as the workhorse of the PV industry, particularly as the cells are integrated with conventional building materials, such as roofing tile.

Over the long term, however, technological breakthroughs based on the use of new materials and nanotechnology are expected to create a third generation of PV modules with efficiencies much higher than those typically achievable today—increasing from about 15% to more than 50%. Specifically, third-generation solar cells would substantially reduce one or more of the generic energy losses that affect both crystalline silicon and thin-film devices today. For example, creating multiple layers of cells would enable each to absorb a different part of the solar spectrum. Alternatively, optical frequencies could be shifted inside a cell to transform the solar spectrum in ways that increase absorption. The use of nanometer-sized "quantum dots" has been shown to produce more electrons for each photon of sunlight than bulk materials, and the energy of each electron might also be collected more efficiently. In addition, progress has been made in constructing carbon nanostructures that could potentially lead to new kinds of highly efficient PV cells.

In February of 2007, EPRI responded to growing utility interest in both central and distributed solar power by creating the Solar Electric Interest Group (SEIG). Two recently published reports are available that provide an update on the status of PV technology (EPRI Report 1010412) and examine the feasibility of achieving high-efficiency PV breakthroughs (EPRI Report 1012872). A major conclusion stated in both reports is that it is technically possible that PV resources will contribute about 10% of new U.S. capacity within 25 years. This conclusion is based on the assumption that at least one of the third-generation concepts just described will achieve commercialization in the coming decades, producing a three- to five-fold increase in module efficiency and a dramatic increase in economic competitiveness. To help accelerate the development process, EPRI has joined with Electricité de France in a joint research program that looks at three of the most promising new high-efficiency PV cell concepts.

Ocean Power: Harnessing Tides and Waves

Energy derived from the motion of ocean tides or waves has several potential advantages over other renewable resources, including higher power density, greater predictability, and closer proximity to major load centers. EPRI has established two collaborative programs to demonstrate ocean energy conversion in North America, involving 17 electric utilities, 2 federal agencies, several U.S. state and Canadian provincial agencies, and more than 30 technology developers. Already several participants have announced plans to build ocean energy demonstration plants, and approximately 40 preliminary permit applications have been filed with FERC, following publication of EPRI feasibility studies.

Tidal In-Stream Energy Conversion (TISEC) is leading the way, largely because the underlying technology is very similar to that of wind turbines, but with devices driven by moving water instead of moving air. As a result, TISEC turbines can benefit from decades of experience in refining and scaling up wind energy machines, including the use of advanced composite materials, power electronics, and underwater construction techniques used in offshore wind installations. In addition, because tides can be predicted years into the future, TISEC generators can sell electricity as firm power to the electricity grid, thus reducing the need for costly reserve power.

In 2005–2006, EPRI performed TISEC feasibility definition studies for seven promising locations in North America, using designs for both demonstration- and commercial-scale plants. A major conclusion of these studies was that, depending on location, plant size, and various financial assumptions, the wholesale cost of electricity for a TISEC generator at these sites would be in the range of roughly 5–12¢/kWh, making it competitive at the lower end with wind and well below the cost of trough solar-thermal technology. The studies also showed that the capacity factors of TISEC plants would be somewhat higher on the East Coast than on the West Coast because of lower diurnal inequalities—i.e., the difference between succeeding strong and weak tides.

Turbine designs of several very different types are currently being considered for TISEC application. An open-rotor turbine on a horizontal axis with 5.5-meter-diameter blades, for example, forms the basis of the Roosevelt Island Tidal Energy Project in New York City's East River. The first two of six turbines were installed in December 2006, and the 18-month experimental project will focus particularly on fish-turbine interactions and other potential environmental concerns. In contrast, the tidal project at Race Rocks in British Columbia uses a rotor assembly with an open center and no driveshaft or gearbox, mounted inside a duct that accelerates the water flow. This turbine was deployed in

Tidal In-Stream Energy Conversion (TISEC) has been studied favorably for application at seven promising sites in North America. Verdant Power's Free-Flow turbine is shown being transported for installation in New York's East River in late 2006. (photo: Kris Unger/Verdant Power, Inc.)

The Pelamis wave energy converter is a string of floating cylinders linked by hinged joints. The wave-induced motion of these joints pumps high-pressure oil through hydraulic motors that drive electric generators to produce power. (photo: Ocean Power Delivery Ltd.)

September 2006 and is expected to be fully operational by mid-2007. Other designs, including a turbine with helical blades, are also undergoing preliminary tests, but it's still too early to tell which technologies will eventually be the most successful.

Wave energy conversion lags somewhat behind TISEC, largely because the technology has no synergistic technological base, such as wind turbines, to draw on. Rather, a variety of designs are competing for initial attention, including heaving buoys that pump water to a generator, oscillating water columns in fixed structures that compress air for a turbine, and a snake-like series of floating cylinders whose movement generates electricity by means of hydraulic motors in the joints. A 2004 EPRI feasibility study showed that the potential wave energy resource in North America is considerably larger than the tidal resource. The study concluded that the cost of electricity from wave energy at a commercial scale in promising locations would now be in the range of 11–13¢/kWh, but that the cost could be expected to fall as more experience is gained. The main technical challenge is expected to be maintaining a high level of equipment reliability and plant availability for long-term energy production in a difficult environment.

Currently there are only a few megawatts of wave energy capacity deployed worldwide, and the first commercial, 30-MW plant is being installed in Portugal. The only wave project in the United States is a 40-kW buoy at the Kaneohe Marine Base in Hawaii. The first full license application for a domestic commercial wave energy plant was filed with FERC in November 2006, for a 1-MW installation at Makah Bay, Washington. Several preliminary permit applications have also been filed for other Pacific Coast locations.

Meanwhile, another key barrier to large-scale commercial development of ocean energy in the United States is regulatory. At present, both types of ocean energy conversion systems would have to go through the same licensing process that was designed more than half a century ago for conventional hydroelectric plants—although TISEC and wave energy conversion do not require any dam or water impoundment. FERC is waiving the license requirement for relatively small experimental ocean energy plants, but commercial projects are not able to move ahead as rapidly as those in other countries.

Biomass: Improving Power Options

Biomass fuel is the oldest renewable energy resource, going back to cave dwellers and their log fires. Literally before there was home, there was hearth. Even today, biomass represents the single largest source of electricity from non-hydro renewable resources, fueling more than 9700 MW of generating capacity. Most of this biomass comes from forest product and agricultural residues, with the raw material fired directly in a power plant boiler—either by itself or as a supplement to fossil fuels, particularly coal. The use of municipal solid waste for power generation is also growing.

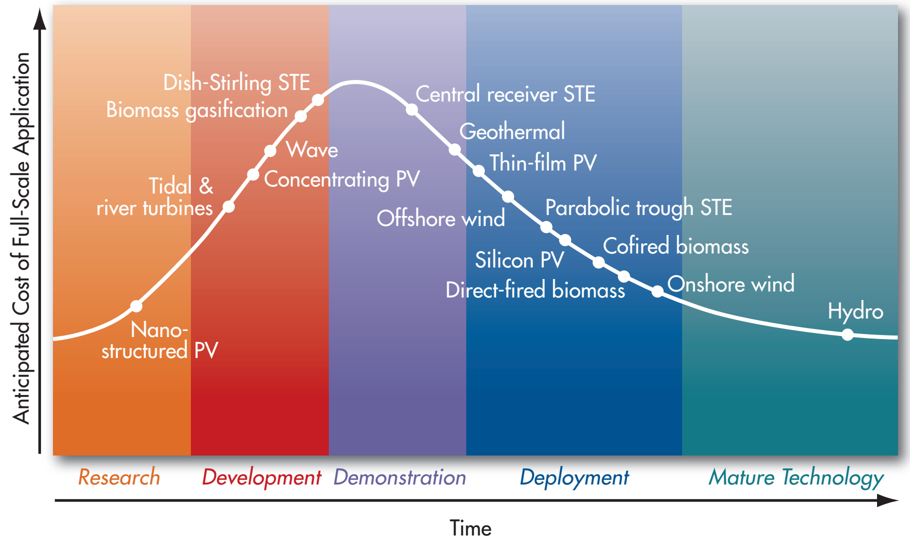
In addition, biomass provides the only renewable alternative for producing liquid transportation fuels, a prospect that has become the focus of much government-funded research. Indeed, the current Bush administration has established a goal of replacing 30% of gasoline used in the United States with biofuels by 2030. So far, most of the liquid biofuel for U.S. transportation has been in the form of ethanol, produced by conventional fermentation of plant sugars from crops such as corn. Since redirecting this much agricultural output places pressure on the supplies of crops—particularly corn—available for food, considerable research is now devoted to finding better ways of producing ethanol from other plant materials. The cellulose fibers that hold plants erect, for example, could provide a much more abundant source of ethanol, but the conversion process is still quite expensive.

While the ethanol biofuel issue has captured most of the headlines, the electric power industry has focused largely on finding ways to use biomass directly for power generation; these options include the cofiring of biomass in fossil fuel boilers, biomass gasification as a very-low-emission alternative, direct biomass firing, and combusting biogas from landfills and anaerobic digesters. Additionally, utilities have interest in bio-based combined-heat-and-power opportunities, assessments of local

Wood chip residues from Vermont forests and sawmills supply the bulk of the fuel for Burlington Electric Department's 50-MW McNeil generating station. Biomass can be fired directly, as at McNeil, or gasified before combustion for very low emissions. (photo courtesy National Renewable Energy Laboratory) resources, and characterizations of unusual biomass supplies. To aid in these efforts, EPRI has formed the Biomass Interest Group (BIG), which provides participants with technology assessments on key development issues for materials handling, biomass delivery, and environmental performance. It is anticipated that government funding of biomass-to-power research will remain at a very low level and that EPRI will therefore continue its leadership role in communicating and demonstrating technology advances in this area.

Additional research is especially needed in the near term to help biomass gain market share in power generation and in the long term to develop new biomass technologies with very low emissions. In particular, the current fleet of coal-fired plants could be evaluated for the potential to make use of biomass to cofire active units and to repower units slated for retirement in order to provide early reductions of net emissions. Longer-term reductions could result from increased public-private R&D collaboration on biomass gasification aimed at achieving higher performance and lower cost.

Renewables Technology Development



While the actual numbers vary, the cost of bringing new power options to the marketplace follows a similar trajectory for most technologies—increasing during research and development and falling off substantially after successful full-scale demonstration and as a large number of units are deployed. Investment values on the curve are positioned relative to each technology's anticipated final RD&D cost and should not be used to compare investments among different technologies.

Supporting "Green" Energy

Renewable energy technologies are playing an increasingly important role in the effort to limit global climate change by shifting to low- and non-emitting energy resources, particularly as concerns also rise over finding ways to reduce U.S. dependence on imported petroleum. Some two dozen states now have renewable energy requirements, and consumer interest in the use of clean and diversified energy resources is clearly growing. Meanwhile, utilities are faced with increasingly complex technical issues related to integration of more renewable energy into their power systems. EPRI is responding to these trends and needs by investing in further technological development in areas of particular interest to the industry and by providing strategic information to its members on emerging technologies. In the past, EPRI has made major contributions to renewable energy technology, including the development of power electronics for variable-speed wind turbines, high-efficiency cells for CPV in central plant applications, and fish-friendly turbines for hydroelectric facilities. Now, as renewable energy technologies are being developed and deployed on a large scale throughout the world, EPRI is focusing on how to address more-specific issues involved in utility adoption of these technologies.

"EPRI is uniquely situated to help its members assess the performance of renewable generation systems and resolve problems not being effectively addressed by vendors," says Tom Key, technical lead for renewable and hydropower generation. "In particular, we offer members vital performance and cost data in our *Renewable Energy Technical Assessment Guide,* opportunities to join renewable interest group activities, and regular updates on the status of technological developments around the world. The Institute will also continue its support of collaborative research in carefully selected areas of concern to our members."

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Further Reading

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