Distributed Power Generation: Technology, Economics, Environment*

The Interstate Natural Gas Association of America (INGAA) Foundation

Traditionally, economies of scale in electric generation and transmission and distribution gave rise to the vertically integrated electric utility. Today though, new generating capacity is available from small scale dispersed plants capable not only of satisfying particular localized loads but also of displacing generating capacity from the central station and of minimizing the need for extension and upgrades of the delivery capabilities of the integrated network. These small scale dispersed plants are referred to as **Distributed Generation**.

Distributed Generation is any small scale modular generation technology that is situated within a utility's service area and is usually interconnected to the transmission or distribution system. Figure 1 illustrates the placement of dispersed generation facilities within the existing utility network. Larger generators serve in utility applications along the transmission system or the subtransmission system. The transmission and subtransmission systems are used for distributing electric energy in bulk.

Placement may also be with ultimate consumers along the subtransmission system. Medium sized generators are placed along the subtransmission level or the primary feeder level. The primary feeder is between a substation, or other point of supply, and distribution transformers. Very small generators are placed along the secondary feeder level. The secondary feeder level is a system which connects distribution transformers to customers.

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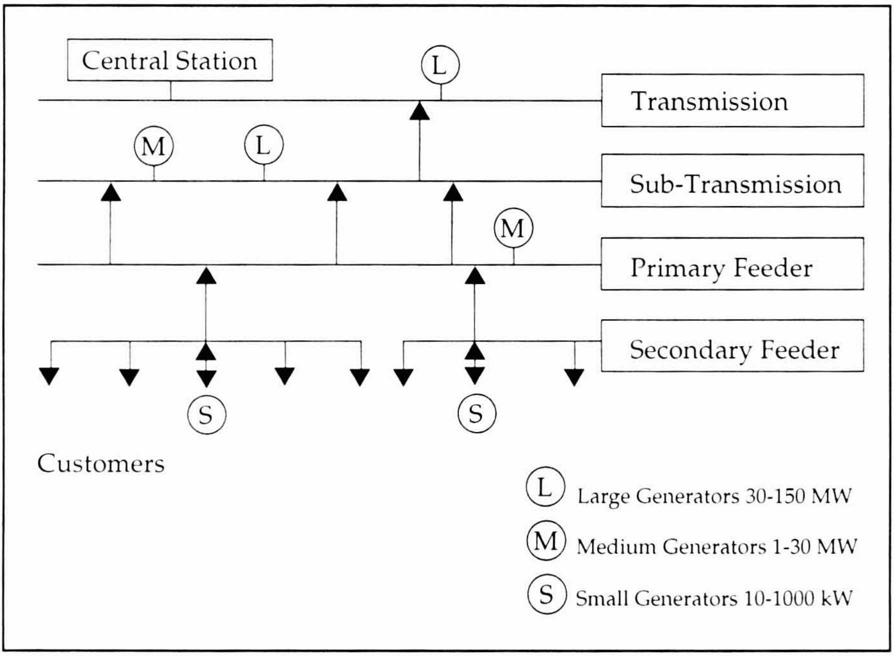
Figure 1. Distributed Generation Levels



Power is provided closer to customers and is generally of a relatively small scale in capacities ranging from about 500 kilowatts (kW) to 25 megawatts (MW) rather than being provided from central stations that may have capacities ranging anywhere from about 75 MW to more than 1,000 MW. Distributed generation can be a mechanism for deferring transmission and distribution upgrades and for improving power quality and reliability. A range of technologies are available such as internal combustion engine/generators, small combustion turbine generators, photovoltaic solar panels, wind turbines, and fuel cells. Some of these technologies utilize renewable sources of energy such as wind and solar. Others utilize fossil fuels including natural gas. The technologies in which natural gas is an appropriate fuel include engine generator sets, small gas turbines, and fuel cells.

DISTRIBUTED GENERATION TECHNOLOGIES

Some of the technology options for distributed generation are quite mature and are commercially available today. Others are still in the demonstration phase and may only be fully developed around the turn of the century. The emerging technologies require a greater investment in R&D and their adoption will only occur in the early decades of the next century. The technologies discussed here are those available in the immediate to near term.

Distributed generation may serve functionally as standby generation, as peak shaving capability, as baseload generation, or in cogeneration applications. Standby generation resources may be required by safety codes especially when there is need for high reliability. A common application of distributed peak shaving resources is to lower customers' billing demand; in certain partnership programs between the utility and the user (usually industrial), generation is installed "inside the fence" to reduce the need for bulk power capacity.

Distributed baseload generation is not very common since conversion efficiencies are lower than those of the somewhat larger combined cycle plant which appears to be the plant at the margin, hence establishing the market price of electricity in a competitive market. There also may be fuel cost disadvantages for distributed baseload generation when fuel delivery is from the local gas distribution company. These might be redressed though as the structure of the gas and electric industries becomes more unbundled.

Cogeneration packages may allow partial or total bypass of the utility. Highly efficient waste heat recovery systems contribute to fuel savings which compensate for the high capital investment and the efficiency disadvantage of distributed baseload operations.

COMPARATIVE ANALYSIS— TECHNOLOGIES AND ECONOMICS

Distributed generation is considered to cover capacity ranges from about 500 kW up to 25 MW. Of the technologies in Table 1, the combustion turbine covers the broadest range in capacity; it offers commercial units all the way to the upper end of that scale. Internal combustion engines greater than about 10 MW are not considered to

Table 1. Summary of Distributed Generation Technologies

	Engine Generator	Turbine Generator	Photovoltaics	Wind Turbine	Fuel Cells
Dispatchability	Yes	Yes			Yes
Capacity Range	50 kW - 5 MW	500 kW - 25 MW	1 kW - 1 MW	10 kW - 1 MW	200 kW - 2 MW
Efficiency(1)	35%	29 - 42%	6 -19%	25%	40 - 57%
Energy Density (kW/m2)	50	59	0.02	0.01	1.0 - 3.0
Capital Cost ($/kW)	200 - 350	450 - 870	6,600	1,000	3,750
O&M Cost ($/kWh)(2)	0.01	0.005 - 0.0065	0.001 - 0.004	0.01	0.0017
NO_x (lb/Btu)					
Natural Gas	0.3	0.10	n/a	n/a	0.003 to 0.02
Oil	3.7	0.17	n/a	n/a	
Technology Status	Commercial	Commercial	Commercial	Commercial	Commercial

Notes: (1) Efficiencies of renewable energy technologies should not be compared directly with those of fossil technologies, since the fuel is unlimited.
(2) O&M excludes fuel cost. There are no fuel costs for wind systems or photovoltaics but relative fuel costs should be considered in evaluation of the other technologies.

From Wan and Adelman 1995

be practical. Larger-sized combustion turbines do benefit from economies of scale and also experience greater efficiencies than do smaller-sized combustion turbines.

The modular nature of the renewable technologies—photovoltaic systems and wind turbines—makes them somewhat insensitive to economies of scale. Cost per kilowatt and efficiency are generally independent of total plant capacity. This is true also for fuel cells.

Figure 2 illustrates on a relative scale the capital cost for each of the technologies. Capital costs for photovoltaic systems, fuel cells, and wind turbines are quite high. For the renewable technologies, the capital costs are high but energy costs are essentially zero.

The technologies that utilize renewable sources of energy are the most environmentally acceptable in terms of emissions characteristics. Environmental permits are obtained relatively easily and in fact

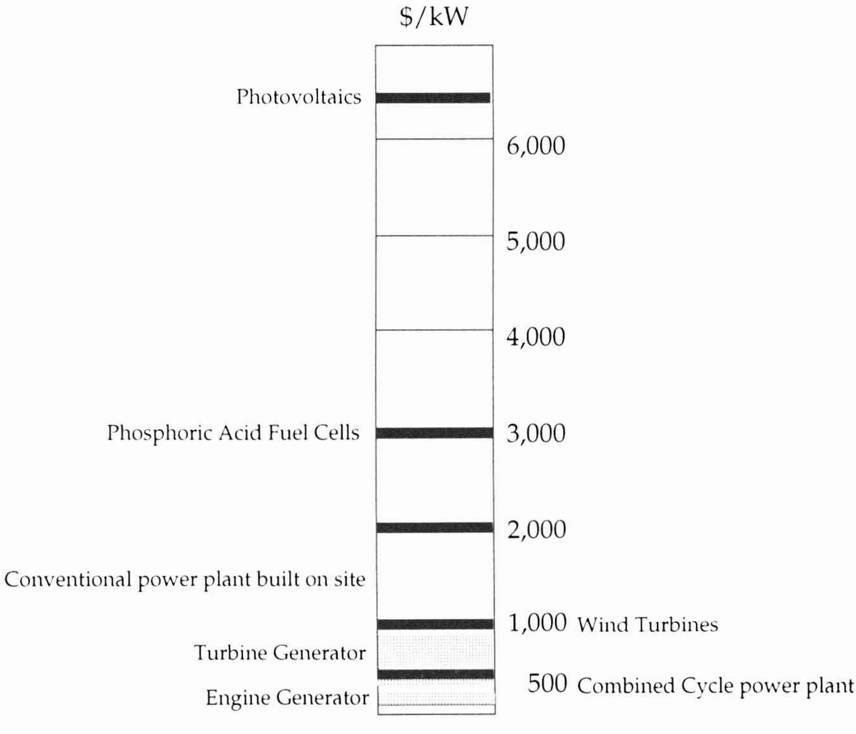


Figure 2.
Capital Cost for Distributed Generation Technologies

authorities often offer incentives for installation of solar and wind systems. Because of the absence of a combustion process, emissions from fuel cells are minimal; permitting of those facilities generally occurs without a hitch.

In Southern California, air permitting for phosphoric acid fuel cell installation is automatic. Combustion turbines and internal combustion engines experience more difficulties in obtaining environmental permits and often must do so with trading of emissions allowances and offsets, depending on the particular location of the facility. Only technologies fueled by hydrocarbons emit NO_X.

Combustion turbines are highly compact and internal combustion engines are slightly less so. These can be installed in small spaces even at the customer's site. Fuel cells require more space but are still reasonably compact and can also be located at customer sites. The renewable technologies require the most expanse of open space although photovoltaic systems can be integrated architecturally into structures. The energy density, or power density, expresses the power per unit area required for a facility.

Concerns with noise are more prevalent with distributed generation systems which are located closer to populated areas than with remotely located base-loaded plants. Noise is not a problem with fuel cells and photovoltaic systems because of the absence of moving parts. Noise may be mitigated for the internal combustion engine and the combustion engine but at a cost for buildings or sound proofing walls. Wind turbine systems are noisy but wind farms are generally located away from populated areas.

Each of the technologies listed in Table 1 has been able to carve out particular niches in the market for electric generation on a small scale. The genset has established a reputation for reliability in standby emergency applications and in remote locations. Photovoltaic cells and wind turbines are most appropriate where geographic attributes enhance their application and when incentives are offered that support their high cost. The fuel cell currently in use, the phosphoric acid fuel cell, has applications mostly in commercial settings which can make use also of the heated water by-product. Fuel cells will be important in applications where cleanliness is at a premium. Other fuel cells under development will be of larger capacity and will have applications for larger customers and at the utility level. The stiffest competition to all of the above comes from the small gas turbine. In fact, the different types of fuel cells do not compete with one another for stationary power applications as much as each competes with the small gas turbine. The gas turbine is relatively low cost and is improving in efficiency and environmental attributes.

FACTORS FAVORING, AND CHALLENGES TO, DISTRIBUTED GENERATION

Like other previously protected monopolies, the electric utility industry finds itself facing a much more competitive environment. This competitive environment is a major driving force for increased use of distributed generation. Technological advances and recent legislative and regulatory initiatives have supported the move towards competition. Growing concerns with environmental issues further enhance the attractiveness of distributed generation, especially those technologies that use cleaner fuels and/or renewable energy resources. Not only do the technology, deregulation, the economics, and the environmental attributes of distributed generation serve to encourage its implementation, they can also present certain obstacles.

Technological Advances

In Figure 3, technological advances in power plant generating facilities are illustrated over the period from 1930 to 1990. The march of technology contributed to exploitation of economies of scale; over time, larger and larger plant sizes became possible with steadily declining average costs per megawatt. The electric utility had a natural monopoly in the generation of electric energy. Between the 1980s and the 1990s though, the optimum plant size shifted to much smaller units.

This reduction in optimal plant size is one of the factors that has allowed the introduction of players other than the electric utilities into the generation market. The emphasis today is on utilization of energy resources that are more efficient and environmentally benign.

Challenges remain on the technological front, especially in terms of accommodating the small plants within the delivery network. The distribution network of an electric utility is not designed to accommodate local generation. Rather, the distribution network takes power from the high voltage transmission network, steps it down to a lower

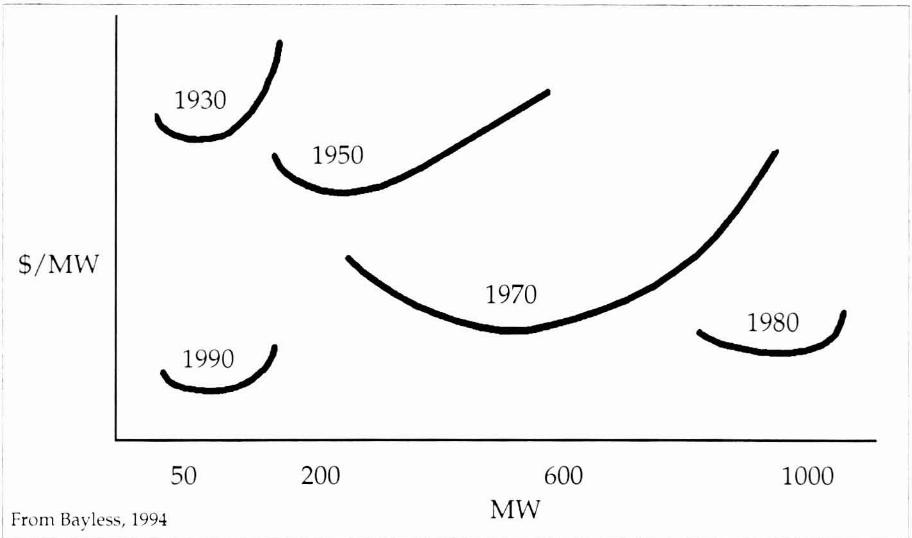


Figure 3. Optimal Plant Size
(Per-MW Cost Curves [1930-1990])

voltage, and then delivers electricity to end users.

Switches are installed on the network to assure that power flows in one direction only. With the introduction of generators into the distribution network, it is possible that direction of power flow on the distribution feeders may change. This may cause difficulties considering that certain protection and regulating controls are installed assuming power flows only from the substation to the loads.

The generation technologies mentioned in this article (Table 1) have been found to operate successfully when interconnected to the electric utility system. Each is able to be started, to be operated at a desired load level, and to respond properly to system emergency conditions. Standards have been developed for the interface to assure maintenance of safety, protection, and service. When only a few small, dispersed generation units are interconnected to the utility system, the impacts are small and geographically limited. Stability and performance of the existing power system are not impaired.

The level of penetration of distributed generation technologies connected to the distribution system influences the need for special techniques for handling those connected sources. At low penetration levels of less than 15 percent of circuit peak load, major issues are safety, system protection and the ability to dispatch. Distributed technologies generally affect only the local distribution system and its operations at these low penetration levels.

At medium penetration levels of 15-30 percent, technical concerns relate to generator/load interactions and power quality. At high penetration levels of more than 30 percent, concerns are for local stability issues. Many of the effects of distributed generators on the power system and the customers it serves can be anticipated but it is not yet known how severe some negative effects will be at higher penetration levels.

Service reliability is a concern and the cost of assuring reliability is very high. Comparable service to that provided by the utility must be maintained and consumers must be able to obtain electricity in the amounts they want and at the time they want it. Currently, not enough is known about the value of reliability but as the utility industries become restructured, the decision as to what constitutes adequate reliability for a consumer may increasingly be made by customers rather than by electric utilities. Customers will make this determination as they choose among suppliers and make decisions whether to contract for backup capability or interruptible services.

The work of utility dispatchers is facilitated by the use of sophisticated computer systems that monitor demand and communicate back to generation units. This technology is not available at the distribution level. Nor does the distribution system have sophisticated controls and protection systems.

Research is underway to identify the planning and dispatch and control tools that will be required as the penetration of distributed generation increases on a utility's system. With increased penetration levels may come the need for advanced distribution systems and communication systems for real-time monitoring and control.

Much of the benefits of distributed generation arise from the closer matching of supply with load, especially during periods of system peak demand. This matching requires the development of effective control and dispatch strategies which coordinate the local generation and load control with system generation control while maintaining the proper voltage profile and minimizing operating costs. Development of advanced distribution technologies that better accommodate distributed generation will involve substantial investments in both time and money.

Regulatory Issues

Deregulation of the electric utility industry got its start in November 1978 with the passage of the Public Utility Regulatory Policies Act (PURPA) which was one component of the National Energy Act. Further deregulation occurred with the National Energy Policy Act of 1992 (EPAct) which amends the Public Utility Holding Companies Act to make it easier for independent power producers and others to compete in the power supply market.

In March 1995, the FERC issued the Mega-NOPR (Notice of Proposed Rulemaking) for implementing the provisions of the EPAct. The NOPR encompasses two dockets: (1) *Promoting Wholesale Competition Through Open Access Non-Discriminatory Transmission Services by Public Utilities* (Docket RM95-8-000; Docket RM94-7-001), and (2) *Recovery of Stranded Costs by Public Utilities and Transmitting Utilities* (Docket RM94-7-001). As their names imply these are initiatives to provide for open access transmission and to allow for recovery of stranded costs. The FERC issued final rules on these issues as Order 888 on 24 April 1996.

While the FERC is not granted jurisdiction over retail wheeling, the public policy debate is beginning to focus on that topic. The dialogue today on the subject of retail wheeling is not *if* it will occur but rather *when* it will occur. State regulators and legislators are considering plans that would give power suppliers direct access to retail customers over existing, utility-owned transmission and distribution lines.

Since 1993 and 1994, there has been a relatively large increase in the instances in which states require, encourage, or permit retail wheeling. Pending legislation and/or regulation within the various states is more likely to permit competition rather than restrain it. All respondents to a survey of state regulators indicated that they expect to see retail wheeling for industrial and large commercial customers in their jurisdictions before long.

In response to both regulatory trends and market forces, the electric utility industry is expected to undergo a great deal of restructuring as has already occurred in the natural gas industry. Restructuring may include activities such as vertical disaggregation, asset spin-off and redeployment, and horizontal mergers and acquisitions. The time line for this is unclear but some restructuring activity is already underway. In this uncertain environment, small scale incremental capacity additions, such as distributed generation, are that much more attractive than are large scale capacity additions in the form of central stations.

Economic Considerations

The economies in power generation appear to be shifting from economies of scale to economies of mass production. Economies of scale, as illustrated previously in Figure 3, allowed for the building of the basic infrastructure of the electric industry, that is for the building of large central station generation resources and a bulk power network for distribution of the power. That infrastructure is now in place. Today, it is economies of mass production that serve to make standardized modular generation units a cost effective alternative to central station generation and/or transmission and distribution upgrades.

The economics of small scale power generation technologies stand to improve from continuing research and development efforts that have lowered costs of volume production of standardized units. Unit costs are expected to decline further with design experience and as the market matures allowing mass production of these units. Even so, one of the major obstacles to wider distribution of the renewable small scale generating technologies is their initial cost. The capital investments on a per kilowatt basis for photovoltaics, wind turbines, and also fuel cells are significantly higher than those costs for large, central station units.

But modularity and the small footprint of most distributed generation units allow power production close to customers' loads. Some of the most appropriate applications of distributed generation technologies are in remote areas where load density is low, growth is slow, and the cost of power delivery into the area is high.

This means that distributed generation may substitute for upgrades and additions to the utility's transmission and distribution system. Cost savings from deferral of transmission and distribution expenditures may compensate for the higher initial costs of smaller, distributed generation systems. Along with reduced need for transmission and distribution expenditures is the reduced need for rights of way. Operational savings also result from reduction in energy losses during transmission of electricity over distance.

The smaller size of facilities allows for incremental capacity additions which in turn allows for better matching of capacity to forecasted trends in load growth. Power production can be tailored to suit specific applications. Utility management is less likely to become locked into expensive large scale generation projects that are no longer cost effective as load conditions and forecasts of growth change.

As distributed technologies satisfy specific local demands, existing capacity may be released for alternate use. Lead time for planning and implementation is shorter for distributed generation projects than for central station planning; installation may be done relatively quickly. These considerations all lower financial risk to utilities at a time of great uncertainty due to pending restructuring.

As the electric industry moves to competition, customer satisfaction and retention take on a very high priority with the utility or other supplier of electricity. Potential customer benefits from distributed generation may be present in areas of power quality and improved reliability. Location-specific generation serves to improve service reliability especially for customers such as hospitals for whom reliability is of prime importance. A continuous flow of power is ensured regardless of disturbances or outages that may occur on the utility grid.

Some of the earliest applications of distributed generation have been for ensuring power reliability to customers. Some customers have great concern about power quality and reliability of the electricity they receive. Examples of such customers includes hospitals, electronics manufacturers, and customers using electronic equipment that is sensitive to voltage surges, frequency noise, and other electric interference in the power supply.

Other customers are relatively indifferent to quality and reliability as long as the cost reflects the level of service received. All customers are expected to have more choices about who will supply their electricity and how it will be produced, including the option of self-generation. It may become possible for energy services to be tailored to specific customers' needs.

Environmental Concerns

Environmental concerns have also been a strong driving force for commercial development of distributed generation technologies. These facilities release fewer emissions than conventional power plants so compliance with air quality criteria is more easily attained. These clean technologies are appropriate for locations within the community among residential and commercial establishments. The public's rising concern about electromagnetic fields from transmission and distribution lines makes siting such networks more difficult. Distributed generation that substitutes for additions to the transmission and distribution system alleviates some of that concern.

Federal and state environmental laws, and often even local regulations, govern the siting and permitting of distributed generation. Environmental impacts of a technology can be grouped into two categories, emissions characteristics and physical characteristics. Emissions characteristics relate to pollutants emitted when the facility is operating. Physical characteristics include such things as location, size, noise, and appearance.

The Clean Air Act of 1963 and the Clean Air Act Amendments (CAAA) established federal regulations for air pollutants. A primary goal of the CAAA is to reduce concentrations of criteria air pollutants to a level below the National Ambient Air Quality Standards in areas where those are exceeded and to prevent air quality deterioration in areas that already meet the standards. The states are granted responsibility for implementing and achieving the national standards; the rules and standards established by the states may be more restrictive than the federal guidelines, but not less restrictive. Some states have implemented more restrictive ambient air quality standards. Air pollution control officers at the local level are responsible for enforcing the air quality regulations.

The implementation plans formulated by the states must contain standards and rules for new sources of emissions. To permit a major new source, an air quality analysis must be performed to determine if the facility will cause a deterioration in air quality. In areas where emission standards are exceeded, that is in "nonattainment areas," emissions from a major new source must be offset at a ratio greater than one.

Offsets are created by reducing emissions from existing sources within the air basin by installing pollution control equipment or by decommissioning existing sources. This provision for offsets is designed to decrease total air basin emissions. Certain of the distributed combustion technologies may release emissions in excess of the trigger rate, causing this legislation to become applicable. The trigger rate differs depending on whether or not the area is a nonattainment area and also may be more stringent due to more restrictive state or local guidelines.

It may be that for installation of certain distributed generation plants, environmental assessments, analyses, or environmental impact statements are required. The National Environmental Policy Act of 1969 requires an environmental assessment for "significant" projects and if environmental effects are severe, more detailed analyses are required. Nineteen states and various local governments have similar legislation for considering environmental impacts of certain projects.

At the local level, this is more prevalent for large metropolitan areas; cities and counties that choose not to expend resources to develop programs that consider environmental impacts in decision making are more likely to opt for adoption of federal and state regulations. Emissions from small generation units, those less than 25 MW, are unlikely to trigger review by federal or state governments.

Therefore, it is expected that government at the county or city level will have the greatest environmental authority over such projects. These local agencies are enforcing federal and state standards unless local ordinances are more restrictive.

Obtaining a use permit from local planning commissions is often the first step in the permitting process for a distributed generator. Factors considered by the planning commission and by other local agencies instrumental in the process include current zoning status, land use plans, effects on vehicle traffic, required site improvements, and aesthetic concerns.

The public is given a voice in these proceedings. In recent years, the public has grown more hostile to the siting of energy facilities. Even while recognizing the benefits of the technology, people may not want the facility located nearby. This syndrome has been called NIMBY: "Not In My Back Yard."

One can expect that distributed generation technologies will face a certain degree of resistance from the public considering that many such projects will be located generally in heavily populated areas and closer to the end user than are central station units. The public must weigh its concerns related to NIMBY issues versus concerns related to transmission and distribution upgrades and perceived threats from electromagnetic fields. As these localized small scale generation technologies continue to penetrate the market, it is expected that NIMBY will be less of an issue as long as emissions, noise, and aesthetic concerns are addressed.

Numerous developments are responsible not only for the emergence of small scale and distributed generation but also for the emergence of a restructured electric utility industry. Some of these developments include market shocks that initially raised energy prices but ultimately gave rise to more competitive energy markets; legislation and regulation that was responsive to both a strong environmental movement and to a growing trend to deregulation of protected monopolies; and technological advances that stretched the limits on fuel utilization and generation efficiencies and on reduction of pollutant emissions.

Probably the major impetus to installation of distributed generation is the move to more competitive energy markets. Competitive markets imply increased supply options to customers. Customers' choice of small scale generation will be strongly influenced by the improved efficiencies of these technologies that translate to lower costs for power. The biggest challenges that remain are technical issues related to interconnection of distributed generation to the power grid when market penetration in an area exceeds 15 to 20 percent and technical issues related to demonstration of less mature technologies.

Table 2 captures some of the developments, along with challenges, that remain for wider implementation of distributed generation strategies.

Table 2.
Issues Impacting Installation of Distributed Generation

Technological & Technical

Favors Implementation

- Improved Generating & Fuel Efficiencies and Reduced Emissions
- Smaller Optimum Plant Size

Remaining Challenges

- Research & Development for some Technologies in the Demonstration Stage
- Grid Connection: Dispatchability/Safety/System Protection
  Generator/Load Interactions/Power Quality/Stability
- Planning, Dispatch, and Control Tools for Electricity Distribution

Legislation & Regulation

Favors Implementation

- PURPA—1978 and EPAct—1992
- Incentives for Environmentally Friendly Technologies

Remaining Challenges

- Clean Air Act and Clean Air Act Amendments
- FERC's Order 888—Wholesale Wheeling

Economics & Competitive Markets

Favors Implementation

- Lower Costs for Volume Production of Standardized Units
- Power Production Close to Loads
- Deferral of Transmission & Distribution Upgrades and Additions
- Incremental Capacity Additions & Shorter Lead Times means Cost Savings
- New Players in Generation Market: IPPs, NUGs, Self Generation, Power Marketers
- Electric Industry Restructuring and Natural Gas Industry Restructuring
- Cheap and Available Natural Gas

Remaining Challenges

- Some Distributed Technologies have High Initial Cost
- Determination of Localized Costs, Localized Benefits and Value of Service Reliability
- Wholesale Wheeling and Retail Wheeling on the Horizon

Environmental

Favors Implementation

- Cleaner Fuels Mandated and Reduced Emissions of Technologies
- Small Footprint and Modular Technologies Facilitates Siting

Remaining Challenges

- Availability of Renewable Sources of Energy
- NIMBY—Not In My Back Yard!