THE POTENTIAL MARKET APPLICATIONS OF DISTRIBUTED GENERATION OF ELECTRICITY

by

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Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

The electric industry is entering a new era with the advent of deregulation, high technology businesses that require exceptional quality of service, and increasing environmental concerns. The development of microturbine and fuel cell technologies is providing the ability to locate power sources on the customer site. In certain situations, this distributed generation architecture can prove to be an economically attractive alternative to the current centralized power generation architecture.

The situations in which distributed generation offers significant advantages were explored to determine the market opportunities of microturbines and fuel cells. The technologies were compared to the current standards for distributed and centralized power in four critical areas: environmental impact, quality of electricity service, interconnection to the existing distribution network and economic feasibility.

Opportunities for microturbines and fuel cells were found in market applications for customers with special needs. These opportunities are expected in increase as technologies improve, interconnection barriers are reduced, high technology business expands, and environmental awareness increases. In the future, microturbines and fuel cells should play an important role in minimizing environmental impacts, increasing service reliability, and providing immediate cost-effective electricity generation for capacity short-falls in the existing infrastructure.

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1. INTRODUCTION

Today, the separate trends of deregulation, environmentalism, growth of "high technology" business and increased security concerns are creating new demands on the electric industry. New distributed generation technologies offer solutions to address these changes.

Background

The current power generation and transmission architecture was developed in the early 1900's with the advent of transformers. These transformers converted direct current (DC) to alternating current (AC). AC electricity could be transported over long distances without unacceptable power dissipation, unlike DC. Transformers allowed cities to build large, centralized power plants, thus taking advantage of economies of scale.

Both the large capital costs involved in this system design and economic efficiency theories favored a monopolistic approach to energy generation that led to the electric utility. Utilities could raise large amounts of capital and distribute capital costs across a broader range of customers when they controlled service for an entire region. By being the only electricity supplier in a region, a utility was able to raise capital for investments simply by increasing electricity tariffs. Also, capital loans could be secured at a low interest rate because the utility's financial risk was low, as the regional customers were a captive market. Because the distribution infrastructure was already in place to serve existing customers, the incremental cost of additional customers was small. For these reasons, policy makers determined that a monopoly, which was required to service all the customers in a region, would be the most economically efficient use of capital investment for electrical generation and distribution. This organizational arrangement supported large, capital-intensive projects.

Economies of scale and low risk loans motivated the expansion of capacity for individual generation units through out most of the 20th century (See Figure 1.1). Utilities found themselves in a unique business position. They had guaranteed methods of raising capital by means of a market without competition. Consequently, planning departments were organized to build large facilities years ahead of full utilization because there was minimal potential for loss of demand. According to the Averch-Johnson hypothesis, the utilities invested in more capital intensive projects than was economically efficient because their allowed rate-of-return was greater than their capital costs.[1]

[1] Ackermann, 1999

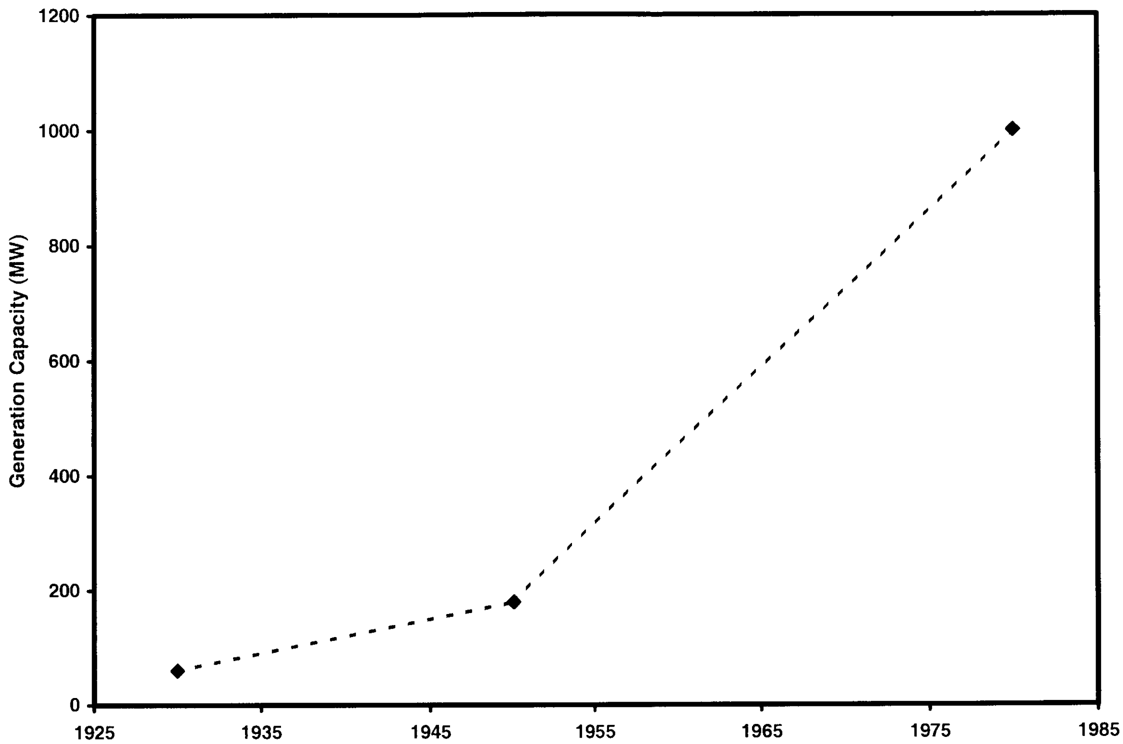

Figure 1.1. Generation Capacity of Individual Power Plants, 1930 to 1980
The generation capacity of individual plants increased because of economies of scale and the organization of utilities. Source: Ackermann, 1999.

This capital-intensive system began to change in the 1970's. The OPEC oil embargo spurred a re-evaluation of the energy industry. Fuel sources became an important consideration in the electric industry. The government started investing in and encouraging alternative fuel technologies to reduce their dependence on the Middle East oil supply. In 1978, the federal government officially introduced competition into the electric industry with the Public Utility Regulatory Policies Act (PURPA).[2] PURPA allowed independent power generators (known as Qualifying Facilities-QFs) with a production capacity of 50MW or less to be exempt from profit

[2] Curtis, 2001

regulations. Also, PURPA allowed QFs with renewable energy sources or cogeneration to exceed the 50MW limit.

The utilities were required to purchase the QF's power from renewable sources at the rate that it would cost them to incrementally generate that power (known as "avoided costs"). Although, the utility was able to determine the avoided costs, it was legally bound to base its customer tariffs on the same rate. Thus, a high avoided cost would help fund the QF market but generate more revenue for the utility; a low avoided cost would reduce the QF market but cut into the utility's revenue. Because of the high fuel prices in the 1970s, utilities chose to negotiate high avoided cost agreements with QFs; and, the independent wholesale market was created.[3]

Deregulation

In the 1990's the deregulation of the electric industry accelerated. Many states expanded the deregulation process by preparing to completely deregulate their wholesale energy markets. This shift in the structure of the industry has already had a significant impact on electricity generation.

The uncertainty surrounding the deregulation process caused many utilities to re-think their generation investment strategies. Unsure of their future demand loads, large capital investments became much more risky for utilities; new construction slowed dramatically.[4] Utilities needed more flexible investment strategies for a competitive market.

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[3] Although, QFs had only 58,000MW of installed capacity (less than 2% of the total capacity in the U.S.) as of 1999. Ackermann, 1999

[4] Romm, 2001. Romm is a former Energy Department official.

Today, distributed generation (DG) offers several benefits as a potential strategy: shortened installation and payback time, modular sizes to meet demand without excessive capital costs, and reduction of transmission and distribution (T&D) investments. This third benefit is important as many transmission networks in the U.S. are reaching capacity limits. One reason for the capacity constraints is the decreased rate of investment by utilities resulting from the transition to deregulation. A second reason is the increase in transmission volume by utilities as deregulation increases the inter-regional trading of electricity. A third reason is the dramatic increase in electronic technology.

Technology

The high tech economy in the U.S. experienced sensational growth in the 1990's. The implementation of microprocessors, data storage and processing facilities, Internet infrastructure, and other electronic equipment has dramatically increased the demand for electricity. Not only do businesses require more electricity, but also they need a higher quality of power than traditional businesses. Their electronic equipment needs electricity with a stable frequency and voltage in order to operate smoothly. These new demands strained the electric industry's infrastructure, which was not receiving the necessary re-investment in either generation or T&D infrastructure. Distributed generation offers a solution for power-intensive businesses that are unable to receive both high quality and reliable power from the local utility.

Technological advances over the past decade have also improved the performance of DG equipment. Fuel efficiencies for microturbines, fuel cells, wind turbines, and other technologies have increased. As their capital costs fall, commercial application of these technologies becomes more feasible.

Environment

In addition to fuel efficiencies, one of the greatest advantages of most DG equipment are the low emissions they emit. For example, fuel cells produce about 10,000 and 100 times less NO_x than new coal plants and centralized gas steam plants, respectively.[5] In the U.S., the increasing concern over the environmental impact of society has been primarily directed at stationary sources of pollution, such as electric plants. As society looks for a means to increase generation capacity while minimizing its environmental impact, DG technology may offer an immediate solution while renewable sources are being further refined developed.

Security

Other than shortfalls in capacity and power quality, the security of the electric system has become an unexpected priority since the terrorist attacks of September 11, 2001. Along with the rest of the nation, the electric industry is facing a new reality where security issues have a heightened importance. A mere four months after the attack, there had already been multiple security warning that specifically mentioned nuclear energy plants as potential terrorist targets.[6] A nuclear power plant disaster is now more probable with the possibility of sabotage and should be a primary concern for energy officials.

Nuclear power plants aside, any centralized power generation plant needs to be concerned about security. Because of our society's dependence upon electricity for everything from business transactions to criminal investigations to financial accounting, long-term power outages would create serious problems. In fact, business information and transactions lost because of power outages were a

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[5] Horton, 2000

[6] CNN, 2002; Reuters, 2001

significant part of the total financial losses in the attack on the World Trade Center.[7] Although central plants are easier to secure, the potential losses incurred from an attack are greater. A distributed generator may not be as secure, but most of the potential losses from a single generator would be restricted to the DG owner rather than hundreds of utility customers.

[7] Bruno and Stafford, 2002

2. DEFINITION OF THESIS OBJECTIVE

As discussed in the introduction, opportunities are being created by the simultaneous maturation of DG technology and the new demands placed on the electric industry. **This thesis will identify general market opportunities for microturbines and molten carbonate fuel cells (MCFCs), which are two commercially available forms of DG.**

Fuel cells and microturbines were selected because they can operate in the current energy industry infrastructure without climatic limitations.[8] Fuel cells offer tangible environmental improvements over current generation technologies. Microturbines are one of the most immediately feasible DG technologies and could serve as an environmentally superior alternative to the current distributed standard, internal combustion diesel engines.

General opportunities were investigated because the variation between markets minimizes the value of an individual market analysis. Even in a single geographic market, changes in interconnection standards of utilities, energy prices and DG technology cause specific market analyses to become out-dated in a short time. A more effective method is to recognize characteristic benefits and costs of DG technologies relative to the typical centralized power plants and back-up internal combustion generators. This thesis compares potential market needs to these characteristic benefits and costs to assess the potential commercial success of microturbines and fuel cells.

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[8] Molten carbonate fuel cells are commercially available and able to operate on natural gas with an internal reformer. Repp-Crest, 2001

The feasibility of commercialization will be based on the advantages and disadvantages of DG with regard to four key issues: environmental impact, service quality, interconnection agreements and economic costs.

Defining "Distributed Generation"

The term "distributed generation" has become a nebulous phrase that has several different meanings to different people. Definitions range from multiple mega-watt utility sub-stations to remote solar panels that provide electricity to a single household. In this thesis, **DG will refer to generation that is located on the property of an energy customer and primarily designed to service the customer's energy needs.**

This definition excludes generators for sub-stations and commercial wholesale electricity providers. Because most DG-owners are electricity customers and not providers, this thesis generally assumes the local utility will not own the DG equipment. However, it is possible for utilities to own DG equipment that is located on a customer site.

3. ENVIRONMENTAL IMPACT

In the U.S, the electric industry has been a primary target of air emission regulations. This scrutiny has been well deserved. According to the EPA, the electric industry was responsible for greater than 25% and 65% of the total U.S. nitrogen oxides (NO_x) and sulfur dioxide (SO_2) emissions in 1996, respectively. (See Figure 3.1.) These pollutants are sources of acid rain and smog. Although the electric industry has made significant progress in controlling its emissions since 1996, environmental impacts remain a critical concern for energy generation technology.

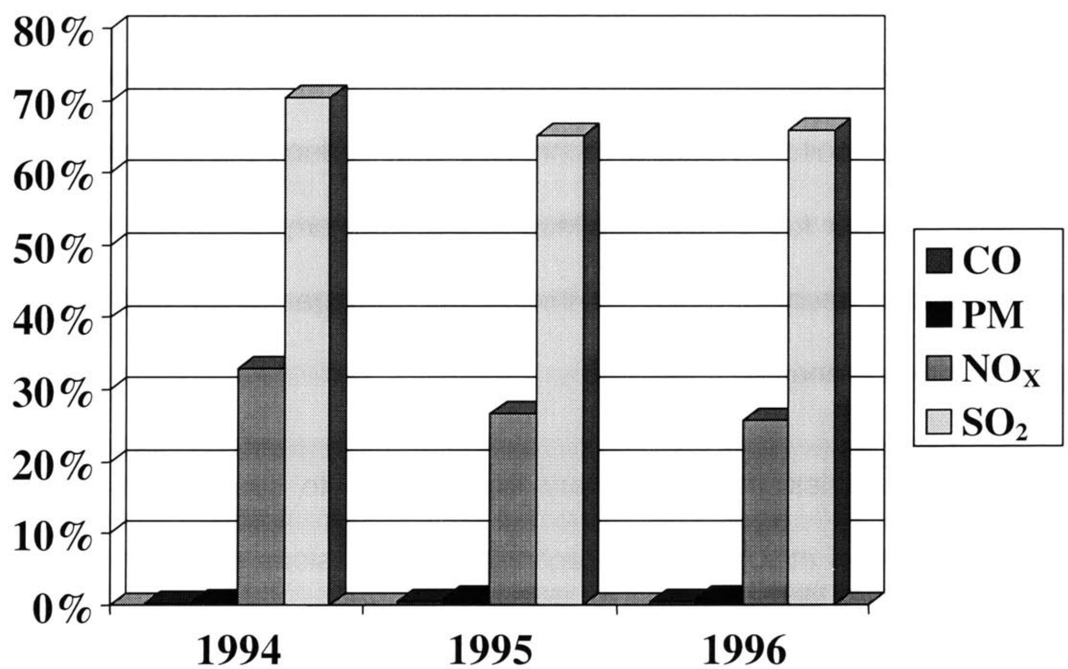

Figure 3.1. The Percentage of Total U.S. Air Emissions Attributable to the Electric Industry as Reported by the EPA
Emissions of nitrogen and sulfur oxides (NO_x and SO_2) are a serious problem for the electric industry, while carbon monoxide (CO) and particulate matter (PM) are not. Source: Horton, 2000

As the electric industry must significantly increase its generating capacity over the next few decades, it is critical to understand how distributed generation technologies can help contribute to or detract from the most environmentally sound method of increasing generation capacity. This analysis is especially critical because traditional power plants have operating lifetimes on the order of decades, creating a relatively inflexible environmental impact once the plant is built. For example, most current power plants are significantly more polluting than the latest technology because they were built decades ago. While pollution control technology helps mitigate this problem, there are several disadvantages to pollution control technology. For one, the pollution is not eliminated. The control technology simply collects the pollutants from the exhaust; the pollutants must be treated or else they will be land waste.[9] Also, the pollution control technology may reduce the fuel efficiency of the power plants. Lower fuel efficiencies lead to a greater amount of pollution per unit of energy produced because of the environmental damages caused by increased fuel extraction for non-renewable fuels.

Emissions

Although emissions values vary from source to source, critically reviewed values give a good indication of a technology's emissions performance. Reporting emissions of different technologies normalized by energy produced provides the best method of comparison. In Table 3.1, emissions are reported for molten carbonate fuel

[9] Most treatment methods involve combustion in kilns. Kilns are more polluting than power plants because of reduced emission restrictions and higher carbon concentrations in their fuels. Thus, treatment options are not as environmentally beneficial as new technologies that prevent the initial formation of pollutants.

cells, Capstone Microturbines[10], internal combustion (IC) generators, combined-cycle gas turbines (CCGT)[11], and coal power plants.

Table 3.1. Air Emissions by Technology
Internal combustion (IC) generators represent the current standard for distributed power. CCGT's and new coal plants represent the current standard for centralized power. Emission levels for CCGT's and coal plants include pollution control technology.

Lb/MWh	NO_x (Nitrogen Oxides)	SO_2 (Sulfur Dioxide)	CO (Carbon Monoxide)	PM-10 (10 μm Particles)
Fuel cell	0.0002	0	0.01	0
Microturbine	<0.15	0.02	3	0.1
IC generator	>1.5	0.03	4	0.2
CCGT	0.07	0.01	0.09	0.01
New coal plant	2	2	N/A	0.1

NOTE: SO_2 formation greatly depends on the sulfur content of the fuel.
Sources: CADER, 2001; Horton, 2000; Capstone, White Paper, 2000; Capstone, Media Notes, 2002; Wisconsin PSC, 2000

Fuel cells and microturbines demonstrate improved emissions performance over typical centralized power plants such as coal plants (which produce over 50% of the nation's electricity).[12] Because of pollution and efficiency considerations, most new power plants are CCGT's. New CCGT's out-perform microturbines. However, these plants require pollution control technology to achieve these low emissions, unlike microturbines. As stated earlier, the control technology does not eliminate the pollution. Without the control technology, the CCGT's may not be capable of matching the emission levels of the microturbines. The microturbines are designed to

[10] Capstone is a leading microturbine manufacturing company with a reduced emissions product.
[11] CCGT's are a combination of a gas turbine, which combusts natural gas, and a steam engine that utilizes the waste heat from the gas turbine. Wisconsin PSC, 2000
[12] Benka, 2002

have a long retention time for the fuel in their combustion chambers. This retention time allows a more complete combustion at temperatures low enough to minimize NO_x production.

Fuel cells have extremely low emissions because they produce energy without combustion. The MCFC is a high temperature fuel cell, which allows it to reform natural gas to hydrogen (H_2) internally. The hydrogen itself creates no emissions. Small amounts of NO_x and CO are produced from the heated air and the water-gas shift, respectively.[13] See Appendix A and B for further information about the energy production processes of microturbines and fuel cells, respectively.

One important distinction between air emissions from a centralized plant as opposed to DG equipment is the location of pollution. A centralized plant is generally located away from major population centers, while DG equipment emits pollutants on-site. Some concern has been raised that DG generators would be more detrimental to human health because they emit the pollutants in close proximity to people. This logic suggests that the dose of pollutants the population receives is higher for DG generators because dispersion processes reduce pollution concentrations from centralized plants before the general population is exposed.

This distinction between centralized plants and DG generators may not be appropriate for the problem at hand. The pollutants of concern (NO_x and SO_2) create environmental problems that primarily occur at great distances from the point of emission. Sulfur dioxide emitted from midwestern power plants travels thousands of miles before the environmentally damaging acid rain occurs. Nitrogen oxides

[13] The water-gas shift is the equilibrium reaction: $CO + H_2O \leftrightarrow CO_2 + H_2$. CO_2 and unreacted hydrogen combine to create the CO in small amounts. Carrette et al, 2001

contribute to smog formation through a similar acid deposition process that requires extended time scales. On the other hand, NO_x also contributes to ozone formation, which is a localized process.[14] It is important to remember that population centers are crowded with motor vehicles that also emit these pollutants, which may render DG emissions insignificant. Thus, the geographic distinction between DG and centralized plant emission locations might not create significantly different health or environmental consequences.[15]

Special exceptions to these arguments would include circumstances in which no amount of emissions would be acceptable. For example, regulators may make a policy choice that no level of emissions is acceptable within national parks. In this case, providing electricity from a centralized source that was outside of the national park would be preferable to siting fuel cells or microturbines within the park.

Current and Future Regulations

Currently, the environmental regulatory system is not prepared for DG. Today's DG regulations are designed for internal combustion engines, which produce high levels of emissions. The regulations specify a maximum number of operating hours to limit environmental damage; this limitation is not necessary for the cleaner DG technologies. Although they emit fewer pollutants, environmental regulators will have to study the effects of fuel cells and microturbines in order to determine the health risks associated with localized pollution sources. These studies should

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[14] Hemond and Fechner-Levy, 2000

[15] The geographic source of the pollution certainly has an impact on social justice issues. The siting of nuclear power plants is especially unappealing to people because of local radiation from these plants. Other centralized power plants are opposed for localized problems such as noise or land value degradation. Although this paper will not investigate this topic, it is clear that DG reduces social justice problems by bringing energy generation to the source of consumption.

contribute to a proper regulatory strategy that protects the public health and the environment.

Efficiency

In addition to the criteria air pollutants, the greenhouse gas carbon dioxide (CO_2) is a major environmental concern. The U.S. is responsible for approximately 25% of the world's CO_2 emission, roughly 3 billion tons annually.[16] Ideally, carbon emissions can be eliminated with renewable energy sources in the future. For the immediate present, the most effective means of carbon reduction is to increase fuel efficiency.[17] A more efficient energy source will decrease carbon emissions by requiring less fuel to achieve a constant power output. Higher efficiencies also reduce the pollution caused by extracting the fuel (whether it be fossil fuels or uranium oxide).[18] Fuel efficiencies for different technologies are reported in Table 3.2. See Appendix C for a discussion of the environmental differences between available fuels.

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[16] Benka, 2002

[17] While renewable energies (such as wind turbines) create no carbon dioxide, these technologies have limited applications for a variety of technical, political and geographic reasons. Therefore, the most significant reduction in carbon dioxide emissions currently available is increased efficiency of fossil fuel consumption. This should not detract from the important objective of increasing renewable energy use. Moniz and Kenderdine, 2002

[18] The type of fuel is also an important environmental consideration. For example, a 50% efficient microturbine is still more environmentally friendly than a 50% efficient coal plant.

Table 3.2. Fuel Efficiency and CO_2 Emissions by Technology.
Fuel cells and microturbines are capable of achieving fuel efficiencies above 85% by capturing waste heat for heating applications. This is not possible for centralized plants that would have to transport the heat significant distances to customers.

	Electrical Efficiency (%)	CO_2 Emissions (Lb/MWh)
Fuel cell	40-70%	800
Microturbine	30-40%	860
IC generator	35-43%	1100
CCGT	55-60%	800
New coal plant	36-39%	1900

Source: Curtis, 2001; Wisconsin PSC, 2000.

The fuel efficiencies reported in Table 3.2 are for continuous loads. Depending on the application DG equipment may be used as a base load generator (continuous) or as a peak load generator (intermittent). Peak load applications will reduce the fuel efficiency of the generator, subsequently decreasing the environmental attractiveness of the technology.

The change in fuel efficiency of intermittent loads can be small (microturbines) to large (fuel cells). Microturbines are capable of quick start-up times, on the order of minutes, and thus have minimal loss of efficiency from intermittent use.[19] The start-up process for fuel cells is much more involved. High temperature fuel cells require about a half hour to reach steady state operating conditions from a cold start.[20] If the fuel cells are already at operating temperature (~ 800 C), the start-up time is only a few minutes. Fuel efficiencies during the start-up period can be at least 5% below continuous operations efficiencies.[21]

[19] Capstone, Media Notes, 2002
[20] Fuel Cells 2000, 2000
[21] Klett, 2002

Environmental Analysis

The immediate need for new generation capacity coupled with the long lifetime of centralized power plants creates a unique market opportunity. The present is an opportune time to shift towards environmentally sound technologies.

Microturbines and fuel cells are both environmentally attractive technologies. Compared to the internal combustion engine (the traditional on-site generation standard), microturbines and fuel cells offer improvements in emissions and CO_2.[22] Comparison with CCGT's is a more difficult process because of the unknown environmental impact of the treatment for the pollutants that are trapped by the pollution control equipment for these centralized power plants.

In a conservative analysis, the microturbine fails to offer environmental advantages over the CCGT. Besides having higher emissions and lower fuel efficiency for generating electricity than CCGT's, microturbines create noise pollution (at 58dBA[23]) that may be unattractive for sensitive residences. However, microturbines that use uncollected natural gas emissions as fuel provide an environmental service that CCGT's cannot.[24]

In any analysis, the fuel cell is environmentally superior to CCGT's. Aside from the lower emissions, the fuel cell could be an important platform for transitioning the energy industry away from fossil fuels. Fuel cells are able to operate on a variety of fuels ranging from natural gas to hydrogen produced from renewable sources such as wind turbines and PV cells. Adopting fuel cells as a basic generation technology

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[22] In addition to higher fuel efficiency, natural gas is more environmentally friendly than diesel or gasoline. It has a lower carbon to hydrogen ratio so less carbon dioxide is produced. Klett, 2002

[23] Yet, this noise is less than internal combustion engines. Capstone, White Paper, 2000

[24] These emissions of natural gas are present at landfills, water treatment plants and fossil fuel extraction sites. If un-used, the natural gas contributes to global warming. FuelCell Energy, 2001

would enhance America's prospects for developing renewable energy sources without geographic and climate limitations.[25]

From an environmental perspective, fuel cells and microturbines have a market opportunity in replacing all of the current DG equipment. Fuel cells offer environmental advantages over all types of fossil fuel based electricity generation because of their ultra-low emissions and potential for incorporating renewable energy into the economy on a large scale.

[25] Hydrogen could store the energy that is intermittently produced from wind turbines and solar panels. If a hydrogen distribution network were constructed, the renewable energy could provide a continuous, clean power supply for fuel cells.

4. QUALITY OF SERVICE

Several factors are coinciding which augment the need for reliable, high quality power. For one, the integration of electronic equipment into practically every residence and business has heightened the American society's dependence on electricity. Many businesses require high quality power in order to keep production lines open or computer servers running. Second, the strained capacity of aging transmission and distribution infrastructure is increasing the frequency of power quality lapses. From the extreme case of blackouts to the more common case of drops in voltage, business customers are at risk to lose millions of dollars a year. Typical losses per hour for various businesses are reported in Table 4.1.

Table 4.1. Cost of Lost Business Caused by Lack of Electric Power

Industry	Average Cost of Downtime ($/hr)
Cellular Communications	$41,000
Telephone Ticket Sales	$72,000
Airline Reservations	$90,000
Credit Card Operations	$2,580,000
Brokerage Operations	$6,480,000

Source: Curtis, 2001

For decades, many companies have used on-site generators for stand-by power as insurance against lapses in power from the grid. These sources have primarily been internal combustion engines (diesel or gasoline) or batteries for smaller applications. These engines are effective for emergencies. However, their operating hours are limited by regulations in part because of their negative environmental impact.[26]

Recently, several businesses have invested in microturbines or fuel cells to ensure that their power quality needs are meet in a reliable fashion. In the Southwest, a computer microchip manufacturer has installed fuel cells to use as base-load power source. The manufacturer was motivated to install the fuel cells to provide a high quality power source for the microchip processing line that the local utility could not provide. The quality of the microchips depends on these fuel cells. In Omaha, a large financial bank is using fuel cells for a stand-by power source. The reliable power source is critical to its business transactions; and, it was more cost effective to invest in fuel cells than to upgrade the local utility's infrastructure.[27] In Chicago, a large clothing retailer has installed microturbines on its roof, and a fast food restaurant uses fuel cells as a supplemental power source.[28] All of these applications were motivated by the need for a reliable stand-by power source or improved power quality.

Frequency and Voltage Stability

Power stability is a difficult task for utilities. At all times, the generating equipment must match the shifting load demand. If an imbalance occurs, deviations are created in the customer's electricity frequency. Many industries have a frequency tolerance of ± 0.1 Hz.[29] Utilities have set up complex control systems to manage the

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[26] In addition to the high amount of pollutants that are locally emitted, IC generators are not fuel efficient, especially considering most generators have not been upgraded to the latest technology. See Table 3.2.
[27] Claeys, 2002
[28] Capstone, Media Notes, 2002; Claeys, 2002
[29] Ackermann, 1999

customer demands.[30] The generator configurations are changing on the time scale of a minute when loads are fluctuating. With power control equipment, utilities reduce the time scale of power fluctuations to seconds or less. While humans are usually not affected by events on these time scales, they are large enough to cause problems for electronic equipment. [31]

In addition to frequency variations, voltage drops must also be managed. Electricity travels from the high voltage areas of the generation to the low voltage customers. The voltage at the customer site should not vary more that ± 5-10%.[32]

Resistive and reactive impedances in the transmission and distribution networks cause most of the variations in voltage. Distribution lines match the voltage at the customer site and are thus at a lower voltage than transmission lines. This low voltage creates a much higher resistance per length than transmission lines. Because transmission lines carry high voltages, their only significant contribution to resistive losses is in rural areas where the lines are lengthy. In urban areas, where the transmission lines are shorter, the distribution network is primarily responsible for resistive losses. Yet, fluctuations in voltage for urban areas are generally dominated by reactive variations. Utilities normally use generators at sub-stations and series capacitors along power lines to ensure quality control.[33] The generators, in a spinning reserve mode, can be engaged to supply power or absorb excess power as needed. Capacitors perform similar functions of smoothing out voltage variations by storing

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[30] Spinning reserve, where a generator is operating but not supplying power to the grid, is a common technique. Generators on spinning reserve are able to quickly provide additional power as needed. Also, many generators are not run at full capacity, so that their production can scale up as demand rises. Ripple control is a method of automatically switching different loads on or off the grid in order to control total customer demand. It is not used very often. Kaminski, 2002

[31] Curtis, 2001

[32] Ackermann, 1999

[33] Kaminski, 2002; Ackermann, 1999

and releasing excess current as needed. With these engineering controls, most utilities offer 99.99% reliability (known as “4 nines”).

While 99.99% can satisfy the average residential consumer, many companies require 99.9999% (“6 nines”) reliability for their operations.[34] However, the power quality effects of a DG operation that is connected to the existing electric grid are ultimately dependant upon this interconnection. See Section 5 for a discussion on interconnection issues.

Blackouts

Besides inconsistent power, problems with reliability also include power outages. Reviewing the values in Table 4.1, one can see the economic consequences of a complete loss of power. Beyond the financial considerations, many life-critical processes in health care institutions are threatened by power outages. For these cases where electric power is “mission-critical”, stand-by gasoline or diesel generators have been in use for decades. However, many of these generators were manufactured before recent technical improvements and have low fuel efficiencies (less than 30%). This disadvantage is compounded by the pollution permit limitations on the number of operating hours.

As an alternative to these traditional generators, microturbines and fuel cells can provide operational flexibility in an economically feasible way. These environmentally superior technologies have no current pollution permit limits on operating hours. Both capital and operating costs for microturbines are comparable, if not advantageous, to diesel engines (see Table 6.1). Even the high capital costs of fuel cells are economically viable for some of the industries in Table 4.1. For

[34] For example, the microchip processing industry requires this degree of the reliability. Claeys, 2002

instance, an airline reservation business could recoup the capital cost of 170kW stack of fuel cells with avoided downtime costs assuming only 5 hours of power outages over the lifetime of the fuel cells (10-20 years).[35]

Stand-by power sources need to be brought on-line immediately in response to power outages, which are unpredictable. Microturbines are able to meet these needs; they have short start-up times (a maximum of minutes). Also, the natural gas fuel can be easily supplied through the existing natural gas distribution network without having to store fuel on-site, which diesel generators must do. On the other hand, MCFC's and other high temperature fuel cells may take as long as a half-hour or more to reach a steady state, unless the fuel cell is already idling at operational temperatures. Uncertainty in the start-up time could be a major hurdle for stand-by application of fuel cells. In certain situations, fuel cells could be run below capacity as a continuous source for power quality and then be available for stand-by generation.

National Security

Besides the typical reasons for power outages, natural disasters and human sabotage can eliminate people's access to electricity. One of these events causes much more damage, both in terms of dollars and human health, than typical power outages. Still, they are typically neglected because of their infrequency and unpredictability. However, the recent terrorist attacks on September 11, 2001, have changed that practice. Americans have recognized that terrorism is a real threat that must be accounted for in all aspects of society.

The electric industry is particularly vulnerable to such attacks. On October 17th, 2001, a "credible threat" to the Three Mile Island nuclear facility caused the

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[35] Assuming the fuel cell costs $2500/kw and interest is 5%. Government subsidies, which can range up to $1000/kw, are neglected. Information gathered from Curtis, 2001

Harrisburg airport to be shutdown and three F-16 fighter jets to circle the facility.[36] In January, building plans of U.S. nuclear facilities were found in caves previously occupied by the Al-Queda terrorist group.[37] This finding suggested that a terrorist attack on a commercial nuclear facility was planned. In fact, many experts agree that it is more likely for a terrorist group to create a nuclear event by attacking a nuclear facility rather than construct, transport and detonate a nuclear device:

"The security guards at half the nuclear power plants in the United States have failed to repel mock terrorist attacks against safety systems designed to prevent a reactor meltdown. These are so-called "force-on-force" exercises supervised by the Nuclear Regulatory Commission. The NRC refuses to take enforcement action in response to the failures, and is in the process of weakening the rules of the game in response to industry complaints. Sabotage of nuclear power plants may be the greatest domestic vulnerability in the United States today. This is the time to strengthen, not weaken, nuclear regulation."

Paul Leventhal
Commencement Address Franklin & Marshall College 2001

Attempting to reduce one's vulnerability to attack, most engineers favor a system of redundancy. Distributed generation offers a means of increasing the redundancy of the electricity infrastructure by reducing customers' dependence on the grid. Not only is the potential of a nuclear accident avoided with DG, but distributed generators also minimize the potential damages caused by an attack on any type of centralized power plant. Buildings with DG units would not be as negatively affected as those without DG units if a power plant was destroyed. Changing the target of a power plant from one central location to many distributed locations would significantly decrease the potential damage inflicted by any one terrorist attack. Decreasing potential damages reduces the appeal of an attack for

[36] Reuters, 2001
[37] CNN, 2002

terrorists who are seeking to create the greatest possible destruction. Thus, a dispersed generation architecture renders the electric industry more secure.

Quality of Service Analysis

The utilities are able to provide reliable, stable power for most residential customers. There exists a growing market of customers with exceptional needs for high quality, reliable power.[38] These customers depend upon electronic equipment to the point that either serious financial losses or health damages are risked during a power failure or even a momentary fluctuation in power. Microturbines provide an economic replacement for internal combustion engines in this application. The microturbines, unlike the engines, are not limited to small number of operational hours because of environmental concerns. Also, microturbines eliminate the need to store gasoline or diesel fuel on-site as they can operate on natural gas provided by the local gas company. Fuel cells, a more expensive option than microturbines, are currently feasible for only companies that have major financial interests in power quality such as investment banks and airlines.

DG also offers an alternative to costly T&D infrastructure upgrades for networks experiencing capacity constraints. These constraints can lead to lapses in power quality in they are not addressed. (This concept is further discussed in the Technical Benefits portion of Section 5.)

[38] Currently, 10% of the nation's electric load needs to be supplemented with DG to ensure reliability and power quality. Ten years from now, as much as 40% of the load may need to be supplemented because of the growth of industries with stringent power needs. Curtis, 2001

5. INTERCONNECTION

While not all DG applications require the on-site generator to be connected to the grid, the issues surrounding interconnection play a central role in the future commercialization of DG. Technical and political-economic barriers need to be addressed so that prospective DG owners fully understand the costs and benefits of a combined power supply from DG and traditional transmission and distribution systems.[39] While the Institute of Electrical and Electronics Engineers (IEEE) and other organizations have identified and are addressing the technical challenges of interconnection, only a few states have developed regulations governing the economic relationship between DG owners and utilities. Several variations of DG arrangements are depicted in Figure 5.1. The most complex interconnection arrangement occurs when there is two-way flow between the grid and the customer site with the DG equipment, Case IV in Figure 5.1. This type of interconnection will be examined here because it encompasses all of the relevant issues.[40]

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[39] Although there is over 60,000 MW of installed DG in the form of gas turbines and reciprocating engines, most of these units are not connected to the grid. Thus, there is not a precedent for widespread installation of interconnected DG from either a technical or economic perspective. ADL, System Interfaces, 1999

[40] For example, analyzing Case III in Figure 5.1 would not address certain technical system upgrades needed to enable two-way flow.

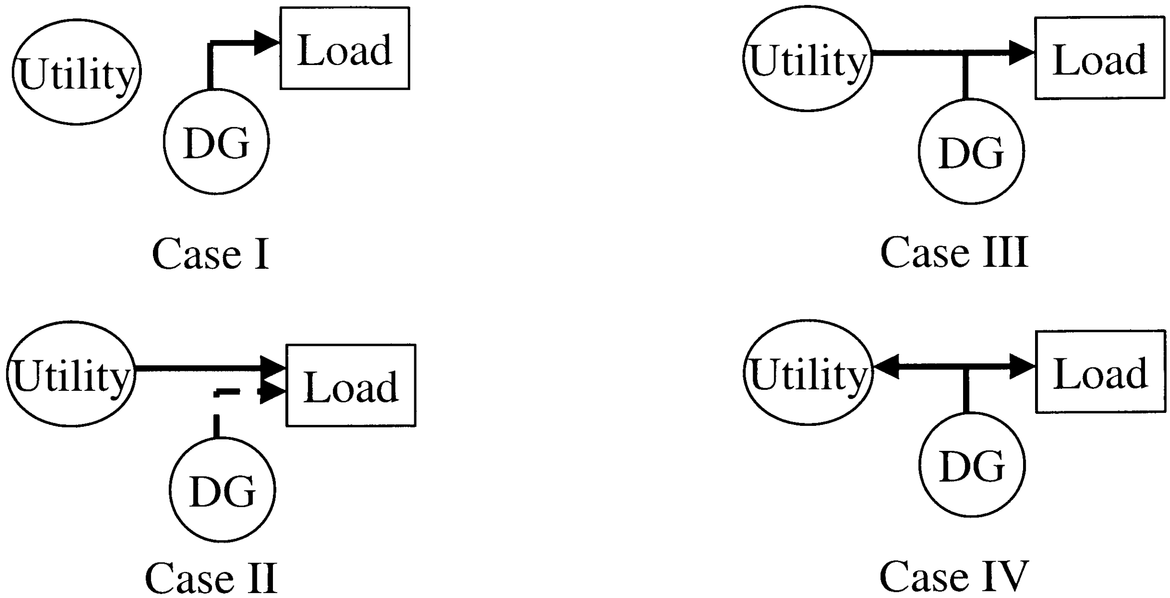

Figure 5.1. Schematics of Different DG Arrangements
Case I is an isolated arrangement where the DG provides all power needs. Case II is a stand-by arrangement where the DG provides emergency power. Case III is a supplemental arrangement where the DG provides power in parallel to the utility power. Case IV is a multi-flow arrangement where the DG provides parallel power and exports excess power to the utility.

Technical Issues

DG units that are designed to operate in parallel with electricity from a distribution network must not endanger the safety or power quality of the network. Engineering control for both the DG equipment and the grid infrastructure are necessary to meet those requirements.

Microturbines, fuel cells and most other DG equipment are active (asynchronous) power sources, as opposed to reactive (synchronous) sources. An active power source is not capable of starting without an initial energy input. Using either double-fed, asynchronous generators or grid power with an AC/DC converter can provide this energy input.[41] The converter is necessary because fuel cells and microturbines are direct current (DC) generators and the grid transports alternating

[41] Ackermann, 1999

current (AC). Additional controls have been developed to convert the DG power output to match the voltage and frequency of electricity from the distribution grid. These technical challenges are being met with available equipment that is incorporated into DG systems.[42]

For the distribution network, DG interconnection can require substantial infrastructure upgrades. While it is true that DG units can help to relieve the capacity demands of T&D networks (see Section 4), the DG equipment introduces a qualitatively different power architecture. Traditionally, networks carried one-way power flow from central power plants to customer sites.[43] Now, significant DG interconnection would create a distribution architecture with two-way flow. Many distribution lines would require upgrades to handle two-way power flow.[44] Power control systems would also need to be upgraded in order to maintain system stability with varying power inputs from DG sources.[45]

One important part of a control system is equipment that properly restricts a DG unit from exporting power to the grid during a power outage (or a scheduled maintenance task). Workers can be fatally injured when a power line thought to be inactive is receiving power from a DG source. The phenomenon of "islanding" is an advantage as long as the proper controls prevent the electrified segment of the distributed network from feeding power back into the rest of the distribution grid.[46]

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[42] Capstone, Media Notes, 2002; Williams, 2002

[43] Although interconnected distributed generation sites have existed for years, their numbers were so small as to be insignificant for power quality control. Also, they generally did not feed electricity back into the grid. Kaminski, 2002

[44] ADL, System Interfaces, 1999; Eicher and Larson, 2001

[45] Kaminski, 2002

[46] Islanding is the occurrence of an electrified segment of the distribution network when the rest of the network is experiencing a power outage. The "island" is created by DG units that continue to operate during a loss of power from the central power plant. The island can range in size from a single

Currently, the design of these control systems adds a significant cost to the installation of DG equipment. Depending on the type of equipment and the state of the grid, the additional costs can range from $50 - $200/kW installed.[47]

Technical Benefits

While infrastructure improvements are needed in many cases, DG equipment can also relieve capacity constraints for T&D lines that are reaching their capacity limits. In extreme cases, DG equipment could mean the difference between receiving power or not. For example, Transmission Path 15 is a critical transmission line between the northern and southern parts of California. In the energy crisis of 2001, there were times when the centralized generation capacity of the state and purchased power were capable of meeting energy demands, but some customers were without power because the transmission network was unable to provide the necessary capacity.[48] DG produced electricity would not be limited by transmission constraints, as it is already located at the customer site. Moreover, significant DG penetration could provide enough local energy sources so that new infrastructure would not have to be built. In the case of California, the $300 million cost for the new capacity along Path 15 could be avoided or significantly reduced.[49]

In addition to savings in capital investments, interconnected DG equipment can provide operational benefits to the T&D system. DG equipment reduces the load on the T&D power lines. Even when these lines are capable of handling a power load, their efficiency and operational lifetime is increased when the power load is

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customer site to several sites depending on the design of the distribution network. Wisconsin PSC, 2000

[47] ADL, System Interfaces, 1999

[48] WAPA, 2001; Romm, 2001

[49] WAPA, 2001

reduced. Transformer lifetimes have been increased by 2 years and maintenance costs decreased after significant DG penetration.[50] Power lines benefit from DG because a lower power load means less thermal and electric stress at contact points between wires. Failure at these points is a common cause of power outages.[51] In total, T&D costs sum up to about 50% of the customer's electricity costs, a substantial amount.[52]

Besides savings on T&D costs, DG equipment eliminates inefficiencies from the T&D process. Power lines can dissipate more than 10% of the power produced at a central power plant, according to the Department of Energy.[53] The specific causes of power inefficiency are listed in Table 5.1.

Table 5.1. U.S.A. Electric System Loss Distribution Analysis

Transport Process	**Percent of Total Power Lost**
Step-up Transformer T1	0.32 %
230kV and above transmission	0.53 %
Step-down transformer T2	0.37 %
69kV transmission	2.94 %
Step-down transformer T3	0.66 %
Meter	0.36 %
25 and 12 kV distribution	2.94 %
Distribution transformer T4	1.77 %
Meter	0.90 %
Total	**10.8 %**

Source: Wisconsin PSC, 2000 (from Department of Energy)

[50] Study in Western Sicily. Ackermann, 1999
[51] Ackermann, 1999
[52] For T&D systems capital costs average about $400-500/kW and O&M costs average $0.03/kWh. Curtis, 2001
[53] Other sources report a range from 7-13%. Curtis, 2001

Summing up the technical considerations, interconnection of DG equipment can be beneficial or problematic depending on the situation. The benefits for the T&D system and fuel efficiency are only significant if DG penetration reaches significant levels.[54] Yet, the system upgrades required to provide for a safe, stable distribution grid with DG installments could be a major investment for each customer site.[55] There is a disparity between DG benefits for the grid, which are dispersed through out the system, and DG costs for the grid, which are accrued on an incremental basis. Consequently, utilities commonly view the idea of DG interconnection as a threat to a stable and reliable electricity distribution network, even if they would benefit from a reduction in capacity demand. An Arthur D. Little survey of electric utilities identified power quality and worker safety as the two greatest concerns of interconnected DG.[56]

Political-Economic Aspects of Interconnection Agreements

Because interconnection of DG units for individual customers is an evolving concept and most utilities are primarily concerned with protecting their quality of service, interconnection agreements between DG owners and utilities have become a contentious topic.

Unlike the current movement for technical standards, no industry-wide standards are developing for the economic contracts for interconnection. The federal government is leaving this area of regulation up to individual states and their public utility commissions. Currently, only a few states, such as New York and Texas, have

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[54] One exception to this trend is large-scale industrial DG installations, which can create a noticeable reduction in the generation demands for a utility's central power plant.

[55] These upgrades are becoming easier as organizations standardize interconnection equipment and independent testing is performed to ensure products meet these standards. For example, the IEEE published an interconnection standard in early 2002. This standard should provide more predictability in interconnection costs.

[56] ADL, System Interfaces, 1999

developed standardized interconnection agreements that utilities must follow. Most states still allow the utilities to create individual agreements with each DG owner. This tradition comes from the fact that most interconnected DG operations in the past were so large and uncommon that custom agreements were appropriate.[57] In these large projects, testing the distribution network and making the necessary upgrades were insignificant parts of the whole project in terms of time and costs.

Fuel cells and microturbines are expanding the interconnected DG market to smaller operations (on the order of hundreds of kilowatts or less). A critical requirement for these DG projects is the ability to install generating equipment in a quick and cost-effective manner. Lengthy engineering studies and expensive upgrades can overwhelm a small project, increasing the installation time from days to years and doubling the capital investment costs.[58]

The details of an interconnection contract will most likely determine if the DG project is economically viable. In an extremely unfavorable contract, the DG owner would pay for testing of and upgrades to the distribution network and would not be compensated for any benefits provided to the grid. In an extremely favorable contract, the DG owner would be compensated for electricity exported back to the grid and avoided costs to the T&D system. State regulators will most likely have a decisive impact on the structure of these contracts.

Some of the interconnection issues that regulators should consider are listed in Table 5.2. These decisions will have to be made based on the particular situations of each utility and the regulators' determination of how to distribute costs and benefits

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[57] The interconnected DG units of the past were usually greater than 1MW. These included renewable technologies for QF's under the 1978 PURPA Act (see Section 1) and major industrial customers.
[58] Alderfer et al, 2000

among electricity customers. Thus, they are beyond the scope of this thesis. However, they will most likely determine the degree of DG adoption as a parallel electrical generation source. To make effective regulations, it is important that regulators have a solid command of the issues presented through out this thesis and a clear vision of a future electric industry architecture. In Appendix D, case studies are provided as examples of current problems with interconnection contracts.

Table 5.2. Issues to be Resolved for Interconnection Contracts

Issue	Potential Solutions
Who regulates interconnection?	• State commissions • Federal agencies • Trade association • No one
Should interconnection agreements be standardized?	• One standard • Several standards depending on technology/size of DG • No standards
Who pays for system testing?	• DG owner • Utility • Government
Who pays for system upgrade?	• DG owner • Utility • Government
What are the rates for stand-by power?	• Based on standard rate • Based on reliability of equipment
Are DG owners compensated for power exported to the grid?	• No • Yes, with net metering
Are DG owners compensated for avoided costs to T&D network?	• No • Yes • Only in capacity constrained areas
Who pays for stranded capacity?	• DG owners • Non-DG owners • Maybe certain assets are fully amortized

6. ECONOMICS

The interconnection contracts are a portion of the complete economic picture for DG technologies. The ideal economic analysis would convert all of the environmental, power quality and interconnection effects into economic values in order to compare DG and centralized electrical generation on equal terms. Several realities prevent this ideal analysis from happening. For instance, not all of the environmental impacts have been priced. Also, the incremental savings the DG units provide for T&D systems is difficult to quantify.[59]

Even if every aspect of electricity generation were priced, different situations would still produce different results. In cases where transmission lines are operating at full capacity, DG units can help utilities avoid expensive infrastructure upgrades (see Section 5). Yet, significant DG penetration would create excess capacity eliminating this benefit and causing the utility to retain un-utilized T&D infrastructure.

Because of the complexities involved in an economic analysis, this section starts at a basic level and considers supplement issues on an individual basis. First, an overview of capital, operation and maintenance (O&M), and fuel costs is presented. Second, a case study for a commercial customer is reviewed. Finally, the economic impact of subsidies and regulations will be discussed to highlight how the economic analysis depends upon political and social values.

General Costs

The cost of electricity generating equipment can be divided into three main categories: capital, O&M and fuel. The primary difference between a mature

[59]The difficulty arises because tariffs are based on average operating and capital costs, not incremental costs. The current "unbundling" of rates for states undergoing deregulation will help. However, debate will continue as to whether a reduction in demand is a savings for the utility or stranded capacity. Eicher and Larson, 2001

technology and a developing technology (e.g. microturbines or fuel cells) is the capital cost. As production volumes increase, production costs decrease due to economies of scale and manufacturing experience. Current cost estimates from the Consumer Energy Council of America are provided in Table 6.1. The DG technologies of fuel cells and microturbines can be compared to established technologies: internal combustion (IC) engines, coal plants and CCGT's.

Table 6.1. Energy Production Costs and Efficiencies by Technology

	Capital Cost ($/kW)	O&M ($/kWh)	Efficiency (%)
Fuel cell	$500*-3000	$0.005-0.01*	40-70 %
Microturbine	$450*-750	$0.003-0.01*	20-40 %
IC engine	$600-1100	$0.01-0.06	35-50 %
CCGT	$350-450	$0.006-0.009	55-60 %
Existing coal plant	$900-1300	$0.009-0.012	36-39 %

* Target prices
Note: The maximum fuel efficiency for IC engine is much greater than the general consensus of other sources sited in Table 3.2.
Source: Curtis, 2001

Capital Costs

More recent capital cost estimates for molten carbonate fuel cells in operation are $2000-$3000 per kilowatt.[60] This high capital cost is a significant barrier to the widespread application of fuel cells. The federal government subsidizes most current fuel cell operations. While the accuracy of the target price is debatable, one can certainly expect the cost of fuel cells to dramatically decrease as long as funding is available for development. As an analogy, the production cost of wind turbines decreased 20% for every doubling of global installed generation capacity from 1980 to 1995. Over that period, the cost decreased 80%; today, it is 90% below 1980

[60] Curtis, 2001; Wisconsin PSC, 2000; FuelCell Energy, 2001

levels.[61] The capital cost of fuel cells should be considered a temporary barrier as long as niche markets or subsidies are available to fund the high initial costs to achieve competitive production costs.

Microturbines have an immediate advantage over fuels cells in terms of capital costs because they are adapted from existing turbine technology. In fact, Capstone produces 30kW microturbines that cost only $500/kW.[62] This price is competitive with CCGT's, the state-of-the-art centralized power plants, and is at least $100/kW less than the existing distributed standard of internal combustion engines. Although microturbine technology is more developed than fuel cells, there is still room for production costs to decrease as manufacturing experience increases because the current production volume is low (~1,000 units per year).[63]

In addition to comparing capital costs on a per kilowatt basis, it is important to remember the true capital cost of an investment. DG units are generally 1MW or less, requiring much less capital than central power plants which generally have a capacity that is orders of magnitude greater.

Operation and Maintenance Cost

Unlike capital costs, O&M costs for microturbines and fuel cells should not present any barriers to market entry. In fact, as listed in Table 6.1 and from available operational experience, both DG systems should provide cost advantages in terms of

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[61] Similar cost declines have been reported for PV and biomass technologies, as well. Ackermann, 1999; Union of Concerned Scientists, 2001

[62] Klett, 2002 - Referring to Capstone microturbines installed at water treatment plants in New York State.

[63] Capstone, Media Notes, 2002

O&M costs.[64] This is certainly the case when comparing them to internal combustion engines.

Cost advantages for both microturbines and fuel cells are inherent in their designs. First, their size allows for simple servicing and diagnostic inspections. Inspections of new CCGT's may cost more than $1 million dollars, not including necessary repair work.[65] Second, microturbines and fuel cells do not require much maintenance. Microturbines are made with a single metal turbine and operate with air bearings, which eliminate the need for oil lubrications. This design reduces frictional aging and simplifies maintenance. Fuel cells also have minimal frictional aging, as they are stationary devices. However, fuel cell electrolytes must be replaced every 7-10 years.[66] The overall O&M cost for fuel cells should be comparable to CCGT's, and microturbines will likely have a cost advantage.

The O&M costs in Table 6.1 apply only to energy production. Other costs that need to be considered are transmission and distribution costs. As mentioned in Section 5, these costs constitute about 50% of the cost to deliver power to customers. This added cost comes in the form of power losses, maintenance, and amortized charges for new capacity in T&D power lines. Thus, a more thorough analysis would include economic costs of power losses in and maintenance for T&D systems in the O&M values for coal plants and CCGT's in Table 6.1. Typical T&D costs are presented in Table 6.2. The O&M cost of distribution alone is at least twice the amount expected for microturbines and fuel cells. Consequently, operational

[64] Klett, 2002; Williams, 2002
[65] Kaminski, 2002
[66] Electrolyte lives are targeted to eventually reach 10-20 years. Williams, 2001

saving could be generally achieved in fuel cell or microturbine installations, assuming that DG technologies will reach their O&M target costs.

Table 6.2. Typical T&D Costs

	Transmission	Distribution
Capital Investment ($/kW)	$100-150	$400-500
O&M ($/kWh)	$0.0005-0.0006	$0.02-0.04

Source: Curtis, 2001

Fuel Costs

At this time, natural gas powers most of the favored technologies – CCGT's, microturbines and fuel cells. When comparing the fuel costs for these alternatives, fuel efficiency and customer purchasing power provide distinction from otherwise identical fuel costs. As mentioned in Section III, the current rank of efficiency is first CCGT's (60%) followed by fuel cells (40-50%), and microturbines (35-40%). However, when considering co-generation possibilities, fuel cells and microturbines reach efficiencies in the 80%-90% range.[67] If fuel prices were equal, a higher efficiency would produce a lower cost per kilowatt-hour.

However, the price of natural gas is inversely proportional to a customer's consumption rate. Natural gas prices by customer type are shown in Table 6.3.

Table 6.3. Natural Gas Prices by Customer Type

Customer Type	2000 Price ($/MMBTU)	Average 1990's Price ($/MMBTU)
Electric Utility	$4.40	$2.50
Industrial	$4.50	$3.00
Commercial	$6.60	$5.00
Residential	$7.75	$6.00

* Estimated based on an average value of 1000Btu per cubic foot
Source: EIA, Natural Gas Prices, 2002

[67] Capstone, White Paper, 2000; Fuel Cells 2000, 2002; Wisconsin PSC, 2000

Clearly, DG owners are at a disadvantage compared to electric utilities in purchasing natural gas.[68] Only industrial customers consume enough natural gas to command prices that are similar to those for utilities. One exception to this pricing hierarchy is the case of recovering waste methane. Landfills, water treatment plants, coal mines and other sources emit methane that has traditionally been ignored. Microturbines and fuel cells are able to utilize these sources as free fuel because they are small enough to be sited at the source and operate on the relatively low volumes of methane available. Additionally, their low emissions are important for these methane recovery applications in air quality regions where internal combustion engine operations are limited.[69] This practice of recovering waste methane is a good example of the flexibility of DG generators, but is not a general indication of typical fuel costs for this equipment.

From the basic cost comparison, the present situation does not provide worthwhile economic advantages for DG owners in a general comparison to centralized power. Fuel cells have high capital costs that are a barrier for entry to markets without special circumstances. Microturbines, without co-generation applications, have significantly lower efficiencies than CCGT's that may negate savings accrued by eliminating T&D costs.

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[68] Although natural gas is more expensive than coal, the CCGT is a better standard for comparison to DG. CCGTs make up 88% of the new power plant orders because they are more cost-effective than coal plants. Even with lower fuel costs, coal plants are more expensive because of negative environmental effects and large capital and O&M costs. The average coal price for the electric utilities was $1.35/MMBtu in 2001. EIA, Coal Prices, 2002; Kaminski, 2002

[69] Several demonstration operations are currently underway in the Northeast and Southern California, where internal combustion engines would be limited by operating permits. These operations have "free" fuel, are eliminating methane emissions, and are reducing the need for gas exploration. Klett, 2002

This analysis does not consider niche markets for microturbines and fuel cells. Some niche markets are characterized by special needs for the customer: high quality power, increased reliability, co-generation of heat, and ultra-low emissions. Other niche markets are characterized by utility constraints: peak demand leading to premium rates, growing demand requiring significant capital investment in T&D infrastructure, and customer locations that are not grid accessible. These markets are opportunities to commercialize DG technologies.

ADL Analysis

Supplemental energy during hours of peak consumption (known as "peak-shaving") could be a large market for DG equipment. Arthur D. Little (ADL) performed a study of peak-shaving for a typical commercial customer in Boston, Massachusetts.[70] The economics of using a 50kW microturbine in the month of September to reduce the peak load from 96kW to 46kW were analyzed.[71] The load profile for the commercial customer is displayed in Figure 6.1.

[70] ADL, Understanding the Economics, 1999

[71] September is good test month, as it does not overly favor DG. Peak rates for electricity are highest in the summer from air conditioning demand. Heat from the microturbine would be most valuable in the winter.

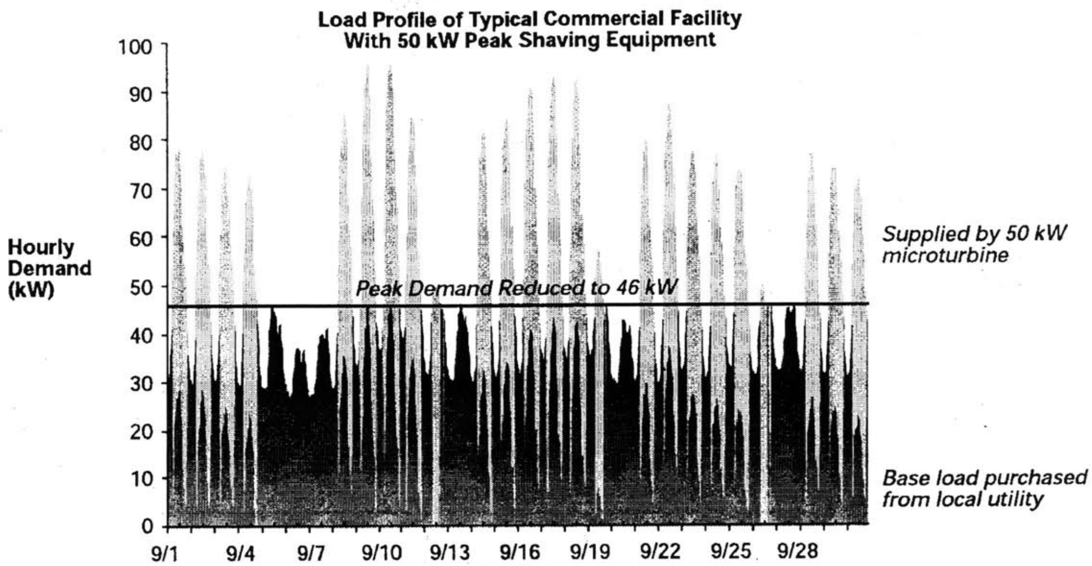

Figure 6.1. September Load Profile of Boston Commercial Customer
The gray profile represents the case without the microturbine. The black profile represents the reduced demand with the microturbine.
Source: ADL, Understanding the Economics, 1999

Using rates provided by Boston Edison, ADL calculated an annual savings of $28,600.[72] A breakdown of these savings is provided in Table 6.4.

Table 6.4. Annual Cost of Electricity Purchased from the Utility
This table sums savings in purchased electricity based on rates provided by Boston Edison. Costs for the microturbine are not included.

	No Microturbine	With 50kW Microturbine	Savings in Purchased Electricity
Peak Demand (kW)	75-95	25-46	
Demand Charges ($)	$13,700	$5,000	$8,700
Energy (kWh)	439,000	125,000	
Energy Charges ($)	$29,600	$9,700	$19,900
Total Cost ($)	$43,300	$14,700	$28,600

Source: ADL, Understanding the Economics, 1999

For the microturbine to be profitable, the fuel and O&M costs must be less than the savings from avoided electricity costs. Assuming $0.0075/kWh for O&M and

[72] See Appendix E for Boston Edison rate structure.

a conservative efficiency of 31.5%, the microturbine can provide a net savings. The magnitude of these net savings depends on the cost of fuel. From Table 6.3, a conservative estimate of the fuel cost for a commercial customer would be $6.60/MMBTU. In line is historical prices, ADL assumed the price of natural gas to be $5/MMBtu. In Figure 6.2, a natural gas cost of $5/MMBtu would translate to $7,500 in annual net savings.

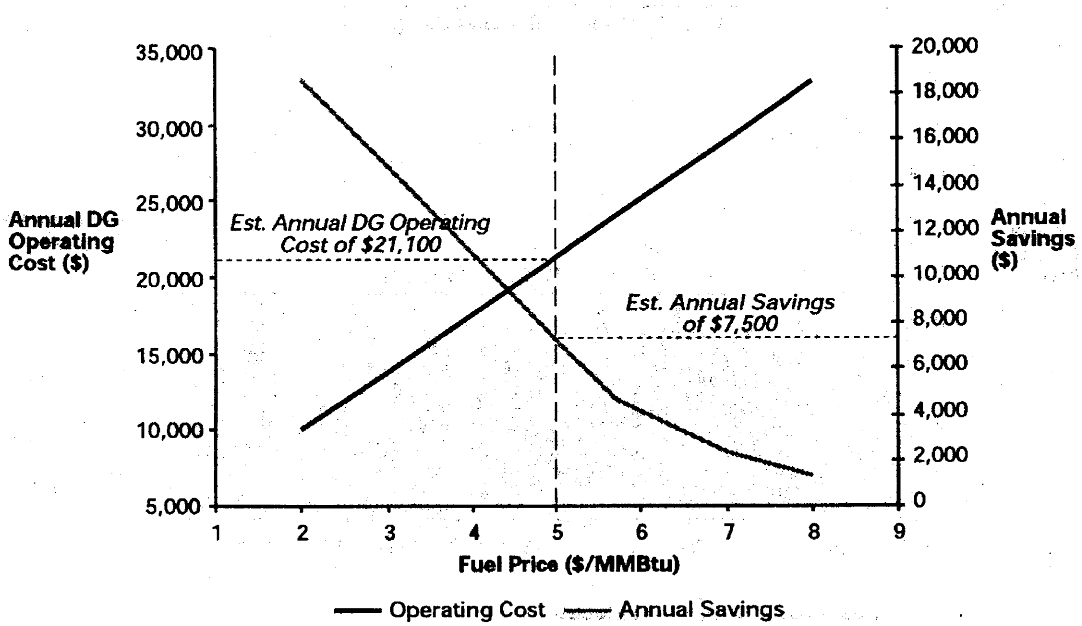

Figure 6.2. Determination of Annual Savings from 50kW Microturbine
This graph plots the operating cost of the microturbine based on fuel price. The annual savings are determined from the difference between the $28,600 saved in purchased electricity and the operating cost of the microturbine. In this case, the threshold for a positive annual savings would be greater than $8/MMBtu.
Source: ADL, Understanding the Economics, 1999

With a positive annual net savings, the microturbine will be an economically viable option. These savings can be used to recover the capital costs invested in the microturbine. If the payback period of the microturbine is an acceptably low number of years, the investment becomes an economically attractive one. Depending on the type of owner and the amount of capital invested, the appropriate number of payback years will vary. For the commercial customer in Boston, a payback period of less than 6 years may be acceptable. Assuming a capital investment of $550/kW and an interest rate of 10%, a payback period of just over 5 years is depicted in Figure 6.3.[73]

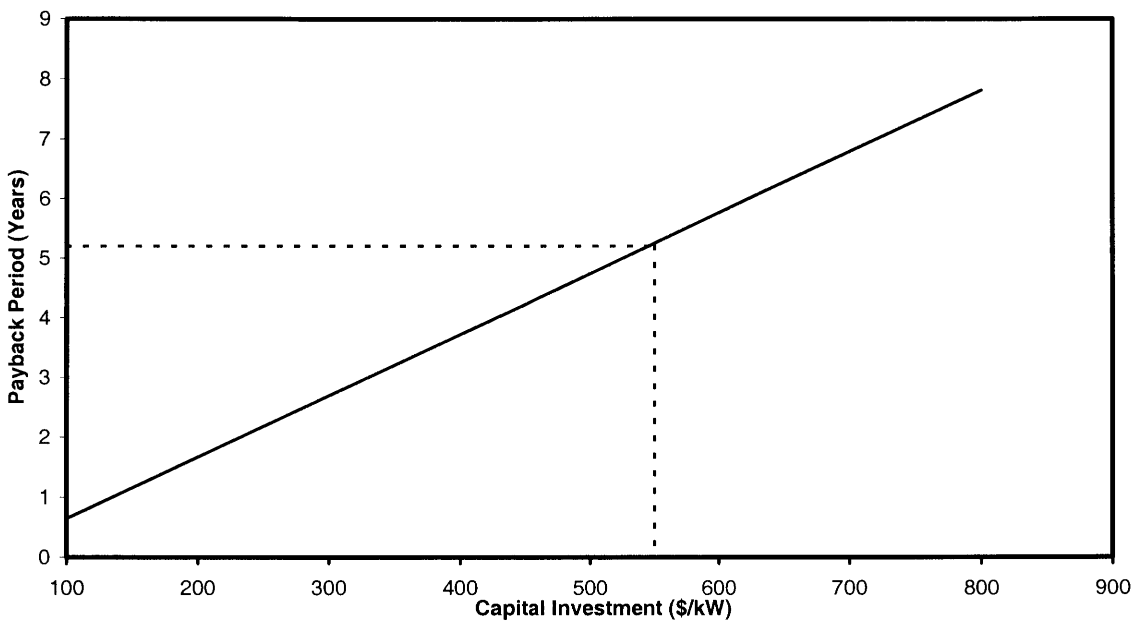

Figure 6.3. Simple Payback vs. Capital Investment
Holding O&M costs, fuel costs and interest rate constant, the payback period is a linear function of the capital investment. This capital investment included equipment and interconnection fees. For an investment of $550/kw, the payback period is just over five years.

From the figure, one can see how the payback period depends on the capital investment. For large interconnection fees, a capital investment of $700/kW would create an unacceptably long payback period of more than 7 years. Without an interconnection fee, the payback would only take about 4.5 years (65% of the time for

[73] Assume $500/kW for the microturbine, $50/kW for interconnection fees, $0.0075/kWh for O&M, 31.5% efficiency, $5/MMBtu, and capacity factor of 72%. The interest rate and interconnection fee were added to the ADL analysis to provide a more realistic scenario.

payback with a large interconnection fee). This two and a half year difference highlights the impact of interconnection fees on the economic appeal of DG.

While Figure 6.3 accounts for the immediate costs of the microturbine, ancillary costs and benefits need to be included for a complete analysis. These indirect effects are negotiated in interconnection contracts and can be categorized as either customer benefits, grid benefits or added customer costs. Because grid benefits are difficult to quantify on an incremental basis and are not recognized in many interconnection contracts, this analysis will conservatively neglect them.[74]

Customer benefits vary depending on the needs of the customer and the constraints of the local utility. Three benefits for the Boston commercial customer are listed in Table 6.5. The primary benefit results from the energy savings associated with the co-generation of heat (accounting for more than 50% of the customer benefits).

Table 6.5. Typical Customer DG Benefits
The prices depend on a customer's previous methods for acquiring heat and managing inconsistent power quality.

Customer Benefit	Savings @ 60% Capacity Factor ($/kWh)
Reduced Energy Cost for Heat (Co-generation)	$0.021
Decreased Exposure to Electricity Price Volatility	$0.010
Increased Power Reliability	$0.006
Total	**$0.037**

Source: ADL, Understanding the Economics, 1999 (from ABB, PG&E and ADL)

[74] Grid benefits are savings in centralized generation investments, T&D investments and T&D O&M costs.

Added customer costs are charges assessed by the utility to the DG owner. For the Boston commercial customer, added costs are listed in Table 6.6. Standby charges are fees to cover the utility's excess generation capacity that is reserved in case the microturbine fails. Competitive transition charges (CTC's) are the costs to cover "stranded" investments that a utility makes in preparation to serve the energy demand of the commercial customer. Securing generation capacity, T&D capacity, and fuel supply contracts are three examples of investments that the utility may have made. As discussed in Section 5, these charges may or may not be appropriate depending on whether one feels the DG owner is relieving the utility from a capacity constraint or the DG owner is leaving the utility with un-utilized capacity that has not been fully amortized. CTC's and stand-by charges vary between situations and would be arranged in an interconnection contract.

Table 6.6. Typical Customer Added DG Costs
These prices depend on the financial worth and amortization status of the utility's assets.

Added Costs	Cost @ 60% Capacity Factor ($/kWh)
Standby charges	$0.006
Competitive transition charges	$0.021
Total	**$0.027**

Source: ADL, Understanding the Economics, 1999 (from rates and interconnection contracts in CA, MA, IL, FL and TX)

Considering the rates for these ancillary factors in Tables 6.5 and 6.6, the economic attractiveness of the 50kW microturbine increases. In Figure 6.4, ADL determined the threshold natural gas and electricity prices necessary to have the net operational savings recover the capital investment in five years. This threshold was varied to include the customer benefits and the added costs. Locations below the threshold lines are attractive and have a payback period of less than 5 years.[75]

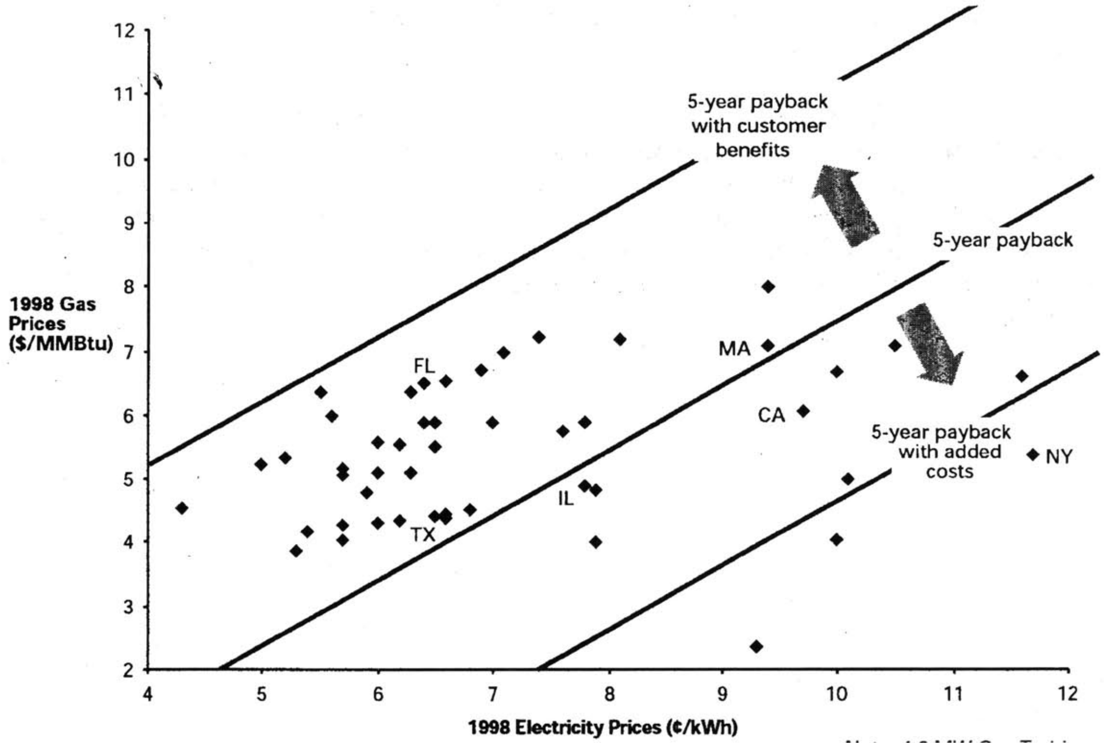

Figure 6.4. Payback Period as a function of Gas and Electricity Prices
Local prices of electricity and natural gas for commercial customers are plotted as of 1998. Five-year payback thresholds for a 50kW microturbine are calculated based on the savings from purchasing electricity at a given price and the operating cost of the microturbine at a given fuel price. Locations below a threshold line will pay for the microturbine in less than five years. The threshold line varies from extremely favorable when customer benefits are the only ancillary considerations to extremely unfavorable when added costs are the only ancillary considerations. The median threshold line represents the simple payback period without considering any ancillary costs or benefits.
Source: ADL, Understanding the Economics, 1999

Figure 6.4 highlights the uncertainty involved in the economic analysis of microturbines and DG units in general. Depending on the ancillary benefits and costs, the microturbine could be restricted to a few locations with high electricity prices or introduced in almost all locations, regardless of electricity prices. The current state of

[75] The assumptions for Figure 6.4 are the same as Figure 6.3, with two exceptions. They are: (1) ADL did not include an interest rate; and (2) the capital cost was $600/kW for Figure 6.4.

distributed generation requires a case-by-case analysis, rather than broad energy policy decisions, to determine economic feasibility. Other case studies of niche market opportunities for DG units are presented in Appendix F.

Government Influence

In addition to the state governments' potential role in setting interconnection standards, deregulation and subsidies are two tools government can use to shape the future structure of the electric industry. Allotting federal subsidies to different segments of the electric industry creates an economic landscape that reflects the government's preferences of generation technology. While subsidies are a well-understood mechanism of government intervention, deregulation is a new process that promises to have an important impact on the prospects for DG.

The federal government is the primary source of subsidies for the electric industry.[76] Nearly all forms of electricity generation are subsidized to some extent. The Department of Energy (DOE) and the Department of Defense (DOD) support fuel cells through the Climate Change Fuel Cell Program and Vision 21 Program, respectively.[77] It may be expected for the government to provide support for a developing technology that has potential benefits. For example, the government provided at total of $5.7 billion for wind and solar power, as of 1999. This relatively small subsidy contributed to an 80-90% reduction in the cost of electricity from these sources.[78] By comparison the nuclear power industry had received over $145 billion,

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[76] Private industry subsidies are substantial but do not influence the DG market as much as federal subsidies and will not be discussed here.

[77] The Department of Defense Climate Change Fuel Cell Program has been funding about 1/3 of the capital cost for select projects since 1996. Also, the Department of Energy provides subsidies through the Vision 21 Program. The Vision 21 Fuel Cells Program is a staged process of achieving maximum possible efficiency from fossil fuels. Williams, 2001

[78] Wind-generated electricity has decreased from 40 cents/kWh in 1980 to 4 cents/kWh in 2001. Union of Concerned Scientists, 2001

as of 1999, because of strong federal support.[79] The subsidies for oil and gas exploration and production are less well known. Congress has enacted legislation to provide $11 billion for these mature industries from 1999 to 2003.[80]

Regardless of the propriety of the relative magnitudes of these subsidies, two important conclusions can be drawn. One, the price of electricity is not an intrinsic value of the technology. Government subsidies modify the true cost of different forms of generation technology. Therefore, economic feasibility of DG depends on favorable government subsidies as well as technological improvements. In light of this, the economic analysis is also a question of social priorities. The second conclusion is that significant cost reduction for developing technologies can be expected with the help of government-supported research. The examples of solar and wind power demonstrate that investment in research and development activities of novel technologies is able to significantly reduce the costs of these technologies. Thus, not only does government support continue to subsidize the true cost of electricity for mature technologies, but also initial government support for a novel technology can dramatically and permanently reduce the technology's cost.

Deregulation

Even more than federal subsidies, deregulation promises to dramatically change the electric industry. Currently, 23 states are at some stage of the deregulation process (see Figure 6.5). Forecasts of the future electric industry have

[79] Although the nuclear subsidies have been provided over a longer period of time, the average annual nuclear subsidy is still greater than average annual subsidies for wind and solar combined. Union of Concerned Scientists, 2001

[80] The House of Representatives proposed another $38 billion for fossil fuels and nuclear power over the next ten years. As a mature industry, some people would argue that the oil and gas exploration does not qualify for as much preferential treatment as nuclear or renewables. Union of Concerned Scientists, 2001

ranged from a totally distributed, renewable power structure to a centralized, nuclear and coal fueled structure. Similar to interconnection agreements, the specific details of deregulation will help determine whether DG is promoted or not. However, there are three general features of deregulation that should encourage use of DG.

The first advantage for DG that deregulation offers is the change in the pricing structure. Most regulated utilities publish a single tariff that represents an average of capital and operating costs for generation, transmission and distribution. Deregulated prices should match the true cost of electricity delivered at the given time. These prices will reflect the extra costs associated with delivering electricity at peak hours. The niche market of peak shaving for DG units will expand as the peak electricity prices exceed the cost of electricity from the DG unit. Peak prices regularly exceed 10 cents/kWh, especially in the states that have chosen to deregulate.[81] Referring back to Figure 6.4, peak prices for delivered electricity of greater than 10 cents/kWh create an economically feasible opportunity for the simple, five-year payback of a microturbine with natural gas prices at about $7.50 or less. According to Table 6.3, this would apply to all types of customers - except residential customers at the unusually high prices in 2000.[82]

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[81] EIA, Retail Price Fact Sheet, 2002

[82] Another consequence of the high peak prices may be a reduced demand load during peak hours.

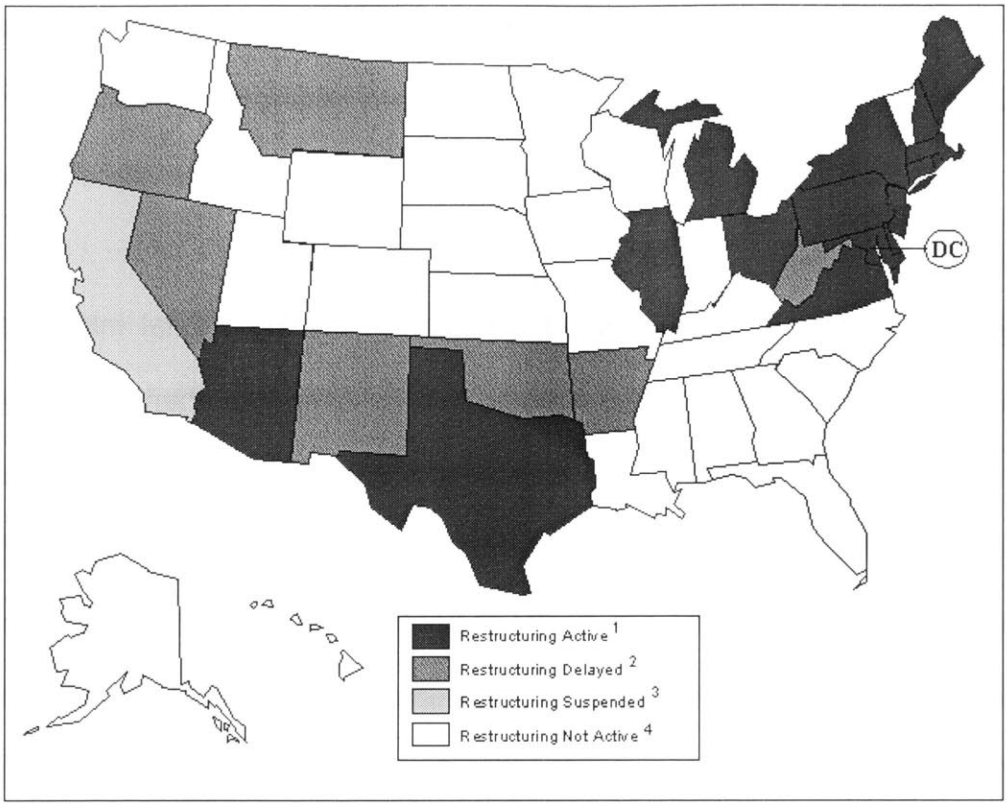

Figure 6.5. Current Status of Deregulation by State as of March 2002
Twenty-three states are either in the "active" or "delayed" status for deregulation. The District of Columbia is in the process of deregulation. California has suspended its deregulation.
Source: EIA, Regulatory Map, 2002

The second advantage for DG is the elimination of competitive transition charges for stranded generation assets. One of the goals of the deregulation process is to ensure that the regulated utilities are compensated for capital investments that have not been fully amortized before their monopoly power to recover invested capital is removed.[83] Regardless of a state's particular solution to this issue, a DG owner in a fully deregulated market will not be charged competitive transition charges for generation capacity. Although the DG owner may still be subjected to charges for

[83] Many states are solving this problem by encouraging or forcing utilities to sell their generation assets, as a means of recovering the utilities' investments. Alderfer et al, 2000

stranded T&D capacity, the competitive transition charges listed in Table 6.6 should be significantly reduced, if not eliminated. Because these charges are the primary added cost for DG owners, the economic feasibility of DG should be significantly improved.

The third advantage is the increased difficulty in funding capital intensive, large generation facilities. A deregulated market will increase the financial risk of capital investments because there no longer exists a captive market, as was the case for regulated utilities. This increased risk will lead to higher interest rates on loans for the electric industry. Rather than the old model of building high capacity generation facilities decades in advance of expected demand, electricity generators should strive to incrementally increase capacity as demand loads increase.[84] (See Figure 6.6.) Following the incremental model as closely as possible will maximize the utility of their capital investments.[85]

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[84] Regulated utilities preferred capital-intensive projects because they were able to achieve savings through economies of scale. Ackermann, 1999

[85] Also, new electricity providers in the deregulated market may not have the capital resources to invest in large plants with payback periods on the order of decades. DG units would reduce capital cost barriers for new market entrants.

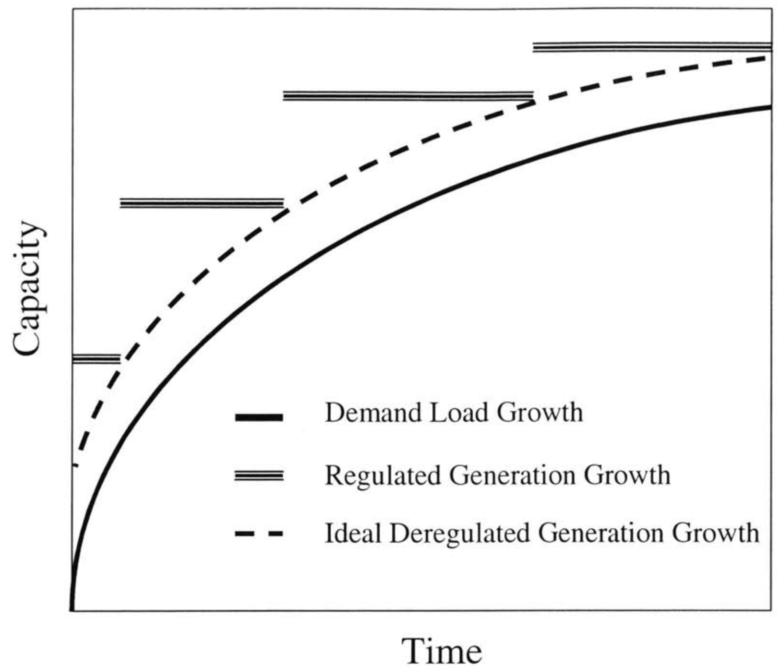

Figure 6.6. Comparison of Optimal Generation Growth Models
The regulated growth leaves large amounts of capacity unused. The deregulated growth maintains full utilization with the exception of an emergency safety margin. The demand growth is hypothetical and for illustrative purposes only.

The incremental model would require the installation of generation capacity relatively quickly in response to demand load growth. DG technologies offer advantages in a deregulated market through low capital investments, incremental increases in generation capacity and short installation time.[86]

Economic Analysis

An economic analysis of the market opportunities for fuel cells and microturbines depends on the specific ancillary benefits and costs of the target market. Without ancillary benefits, a significant economic advantage for DG owners is not apparent. The uncertainty involved in a general economic analysis is apparent in

[86] Large centralized power plants require customized engineering, resulting in long lead times for installation. DG units are designed to minimize engineering requirements for installation. DG arrangements achieve flexibility through modular arrangement of standardized units. Interestingly, Romm and other experts concluded that the California energy crisis was partially caused by an inability of utilities to quickly respond to an unexpected growth in electricity demand. Romm, 2002

Figure 6.4. Currently, there is no clear economic motivation for microturbines or fuel cells in typical situations.

On the other hand, there are a variety of "special" circumstances where DG technologies are financially advantageous compared to centralized generation.[87] Supplemental electricity during peak hours is one of the most common of these circumstances (and was investigated in the ADL analysis). Other opportunities include:

- Co-generation
- Utilities with over-constrained generation or T&D infrastructure
- Customers without grid access
- Recovery of waste methane
- Government subsidies

These markets represent an immediate opportunity for microturbines and fuel cells. The future impacts of deregulation will affect the feasibility of DG and the general structure of the electric industry. Precise predictions are not possible; yet, certain aspects of deregulation are inherently beneficial for DG penetration. It is reasonable to expect the market opportunities to increase as DG technologies improve and deregulation proceeds to re-organization the industry.

[87] Compared to the current DG standard (internal combustion engines), microturbines are less expensive as a general rule.

7. MARKET APPLICATIONS

Considering the four key areas of analysis - environment, quality of service, interconnection and economic feasibility - there exists under-utilized markets and the promise of future market expansion for microturbines and fuel cells. One of the important features of these technologies is that they do not inconvenience electricity consumers. They are able to operate on available fuels and provide continuous, reliable electricity regardless of one's climate. With these abilities, microturbines and fuel cells are well poised for immediate commercialization.

Current Prospects

Throughout this analysis, the market applications of microturbines and fuel cells have been discussed. In Tables 7.1 and 7.2, a general summary of these applications is provided. Competitive advantages for these technologies are also listed in the tables. Currently, fuel cells are not widely used because of associated capital costs. However, with government subsidies, hundreds of fuel cells are in operation through out the U.S. because of their superior environmental properties and high fuel efficiencies.[88] Other than demonstration value, fuel cells offer important benefits in areas where combustion is not acceptable or no new emissions are allowed (i.e. space shuttles and deep water ocean exploration).

Microturbines are further advanced than fuel cells. They are financially competitive with CCGT's and significantly less expensive than internal combustion engines. Noise pollution and relatively low electric efficiencies reduce the appeal of microturbines for some applications. However, the noise pollution is less than internal

[88]Primarily these installations are for demonstration purposes at military bases and private customer residences. However, commercial applications include hospitals and businesses with high heat loads and a need for reliable power. U.S. Fuel Cell Council, 2002

combustion engines.[89] Instead of these inherent characteristics of microturbines, interconnection barriers and CTC's assessed by utilities are the primary obstacles for widespread use of microturbines. This suggests that microturbines should be able to replace internal combustion engines as the DG standard for applications that do not require interconnection (i.e. emergency power for hospitals).[90]

Future Prospects

The prospects for fuel cells and microturbines are bright. While future changes are impossible to predict, it would be reasonable to expect several current trends to progress. In Table 7.3, these trends and their consequences are listed. Because these trends are addressing the present barriers, there is a good chance that microturbines and fuel cells will achieve a greater share of the markets in Tables 7.1 and 7.2.

Deregulation and interconnection standards are the most unpredictable trends because these are new phenomena for the electric industry. Preliminary attempts of deregulation have ranged from success in Pennsylvania to disaster in California. Even with California's problems, 16 states are still actively pushing deregulation forward. At the present, there is no reason to expect these states to abandon their efforts. Independent of deregulation, states should continue to develop interconnection standards. These standards are necessary to ensure public safety, common infrastructure and uniform business practices. The impact of the standards on DG will depend on the details of the standards. However, the presence of any

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[89] This noise is not noticeable in urban areas when the unit is placed away from people in a basement or on a roof. Claeys, 2002

[90] Critics may point out that microturbines would not be wholly independent, as they would require a natural gas from the gas distribution network. In fact, microturbines can run off of propane and other fuels that could easily be stored on site if complete independence was necessary for a back-up power source.

reasonable standard at the least will encourage increased consideration of DG. The standards will resolve questions of safety, reliability and potential charges or benefits for DG owners. Clarifying the consequences of DG installation will allow interested parties to evaluate the advantages and disadvantages without concern for unforeseen expenses. Thus, it appears that both deregulation and interconnection standards are likely to help promote DG as a viable generation option.

The most critical market factor for all novel forms of generation, including microturbines and fuel cells, will be the future regulatory framework of the electric industry. A market with clear and fair interconnection standards will allow customers to choose their form of fuel source and generation technology. Customers should benefits from increased options that will allow them to tailor their electricity service to their needs and preferences.

Table 7.1. Market Applications as a Replacement of the Internal Combustion Engine
Microturbines are referred to as MT; and, molten carbonate fuel cells are referred to as MCFC.

Commercial Markets	**Example Applications**	**MT and MCFC Advantages**	**Differences between MT and MCFC**
Replacement of current DG (Internal Combustion Engine)			
Remote Locations with Natural Gas Supply	• Rural customer w/o grid access • Semi-temporary location for construction, military operations or exploration	• Cleaner emissions • No fuel storage necessary	• MT less expensive than current DG • MCFC feasible with subsidies
Remote Locations without Fuel Supply	• Temporary locations in natural wilderness and scientific field work	• Limited benefits- difficult to transport natural gas compared to gasoline	• MCFC has potential future use of H2 from renewable sources
Reliability	• Hospitals, Internet data centers, entity with critical function in a power outage	• Quick start-up (MT only) • Unlimited operating hours	• MCFC needs time to reach operating temperature • MT less expensive than current DG

Table 7.2. Market Applications as a Replacement or Supplement for Centralized Power
Microturbines are referred to as MT; and, molten carbonate fuel cells are referred to as MCFC.

Commercial Markets	**Example Applications**	**MT and MCFC Advantages**	**Differences between MT and MCFC**
Replacement of /Supplement for Centralized Power (CCGT)			
Peak Shaving	• Utilities with constrained capacity (i.e. California, NYC) • Deregulated markets with real time pricing	• Reduce electricity costs and congestion for constrained networks	• MCFC quiet but need time to reach operating temperature, unless idling • MT cost effective, but moderate amounts of noise
Power Quality	• Manufacturing processes with high dependence on electronic equipment (i.e. microchip fabricators)	• Increase power stability from 99.99% to 99.9999%	• N/A
Environmentally Sensitive Areas	• Non-attainment areas with strict regulation of pollutants (i.e. LA) • Socially conscious user (i.e. California aqueduct)	• Meet strict air quality requirements in non-attainment areas	• MCFC cleanest power source that is not limited by climate • MCFC potential platform for renewable H2 production
Co-generation	• Customer that have large heat demands (i.e. hotels, apartment buildings, pools, manufacturing plants)	• Use exhaust for heating air or water	• MCFC provide heat at higher temperatures (~800C) than MT (~300C), allowing more heating options
Recovery of Waste Methane	• Landfills, water treatment plants, coal mines, natural gas and oil extraction sites	• Use small sources of methane that are currently un-captured	• N/A

Table 7.3. Current Trends Affecting the Electric Industry
Microturbines are referred to as MT; and, fuel cells are referred to as FC.

Trend	Future Consequences	Impact on Microturbines/Fuel Cells
Deregulation	• Capital intensive projects are more expensive • No guarantee exists for recovering investments • No stranded generation asset charges	• Providers switch to small-scale additions of capacity • MT and FC provide economic solution through on-site installation where capacity matches demand
Interconnection Standards	• Better grasp of the costs and benefits for DG as a supplemental power source • May include ancillary costs or benefits	• Potential DG owners are encouraged to investigate options because standards are set
Improved Technology	• Costs reduced as innovative technology matures • Operating properties improved	• FC achieve marketable costs, as wind and solar technologies have • Fuel efficiencies improve
Less Dependence Fossil Fuels*	• Increased motivation to maximize efficiency of fossil fuels • Increased interest in renewable energy	• Increased value for high efficiency FC • Support for FC as a climate-insensitive platform for utilizing current fossil fuels while offering a market for renewable H2 production

*Note: Even with the current Presidential focus on coal and nuclear power, initiatives for non-fossil fuels are supported by federal funding and members of Congress.

8. CONCLUSION

The electric industry is at a crossroads. Demand for additional generation capacity is high because of growth in consumption rates and new businesses that require high quality power.[91] Simultaneously, environmental and safety concerns have restricted the growth of traditional generating facilities. Also, the uncertainty of deregulation has halted many plans for large power plants, as utilities are unsure of their ability to recover capital investments. In the midst of this situation, microturbines have developed into a commercially viable alternative to additional power plants; and, fuel cells are beginning to enter markets with the help of federal subsidies.

Though each market may be small on its own, the various niche markets presented in Tables 7.1 and 7.2 sum to a significant portion of electricity consumers. Fuel cell and microturbine companies will be able to achieve commercial success by modularizing their products. Manufacturing the same basic set of products for all the niche markets will provide the necessary client base to achieve economies of production. Then, the products can be customized to specific applications with different arrangements of these modular components. [92]

Based on this analysis, microturbines and fuel cells may help to provide immediate improvements in national security, high technology business, and critical health services. DG can be one part of the solution to meet customer needs with

[91] Curtis, 2001

[92] For example, an industrial plant and a household would buy the same type of 30kW fuel cell; the industrial plant would simply buy many more fuel cells to achieve a greater generation capacity. This modular approach has worked well for the personal computer industry (Dell, Gateway, etc.). Williams, 2001

products that benefit the environment, increase reliability and provide cost effective generation for capacity short-falls in the existing in infrastructure.

9. PERSONAL NOTES

The outcome of this thesis was slightly surprising. I didn't realize the extent to which microturbines are already commercialized. I expected them to have capital cost barriers that were similar to fuel cells. (Although, I knew that they were more affordable than fuel cells.) From my perspective, I think that the utilities' control over the interconnection agreements is preventing significant adoption of microturbines, especially for commercial customers. I analogize this to the recent failures of competitive local exchange carriers (CLECs) in the deregulation of the local telecom markets. In that industry, the incumbents also owned extensive infrastructure to service customers. They prevented competition by introducing various hurdles for new market entries to interconnect to the central hubs of the incumbents.

This frustrates me because I feel that the best energy system would be a combination of centralized and distributed power to provide several benefits. Among these benefits would be improved quality of service, greater customer choice, diverse fuel sources, and greater investment into actual energy production rather than energy transmission.

As for fuel cells, I have an emotional attachment to them because of their environmental advantages, including the potential for reducing our dependence on fossil fuels. Currently, they are not ready for extensive commercialization. However, I would say that their greatest barrier is not capital costs. I feel that in a supportive environment for stationary and transportation applications fuel cells could rapidly become economically feasible. The main problem will be creating that supportive environment, while producers improve their technology.

APPENDICIES

A. MICROTURBINES

The microturbine was developed from jet engine technology. Capstone Turbine Corporation has become the market leader with an ultra-low emissions product. Thus, their product is used as a reference for general microturbine technology through out this thesis.

Individual microturbines range from 25-500kW.[93] For applications requiring more electricity, a system of microturbines can be arranged to provide megawatts of power. As mentioned in Section 3, the environmental advantage of microturbines is the long retention times for the combustion chamber. This allows a low operating temperature (about 300°C), which reduces nitrogen oxide formation. Figure A.1 diagrams a typical microturbine.

The combustion reaction drives a spinning shaft at 100,000rpm. [94] This energy is converted to electricity with a high-speed generator. The electricity is converted to the required frequency, usually 60 Hz, with internal equipment. The exhaust is carried through a recuperator, used to heat air entering the combustion chamber in order to increase fuel efficiencies. Electrical efficiencies can reach 40%. When the remaining heat from the exhaust is recaptured for heating air or water, efficiencies can be over 90%.[95]

Microturbines generally operate on natural gas. However, they are capable of operating on propane or methane from existing sources such as landfills, water treatment plants and coal mines. These microturbines operate with air bearings and

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[93] Curtis, 2001
[94] ibid
[95] The ultra-high efficiencies occur when the exhaust can be directly used, as with greenhouses. Capstone, Media Notes, 2002

are air-cooled which eliminates the expenses, complicated operations and pollution from oil bearings and water coolant systems.[96]

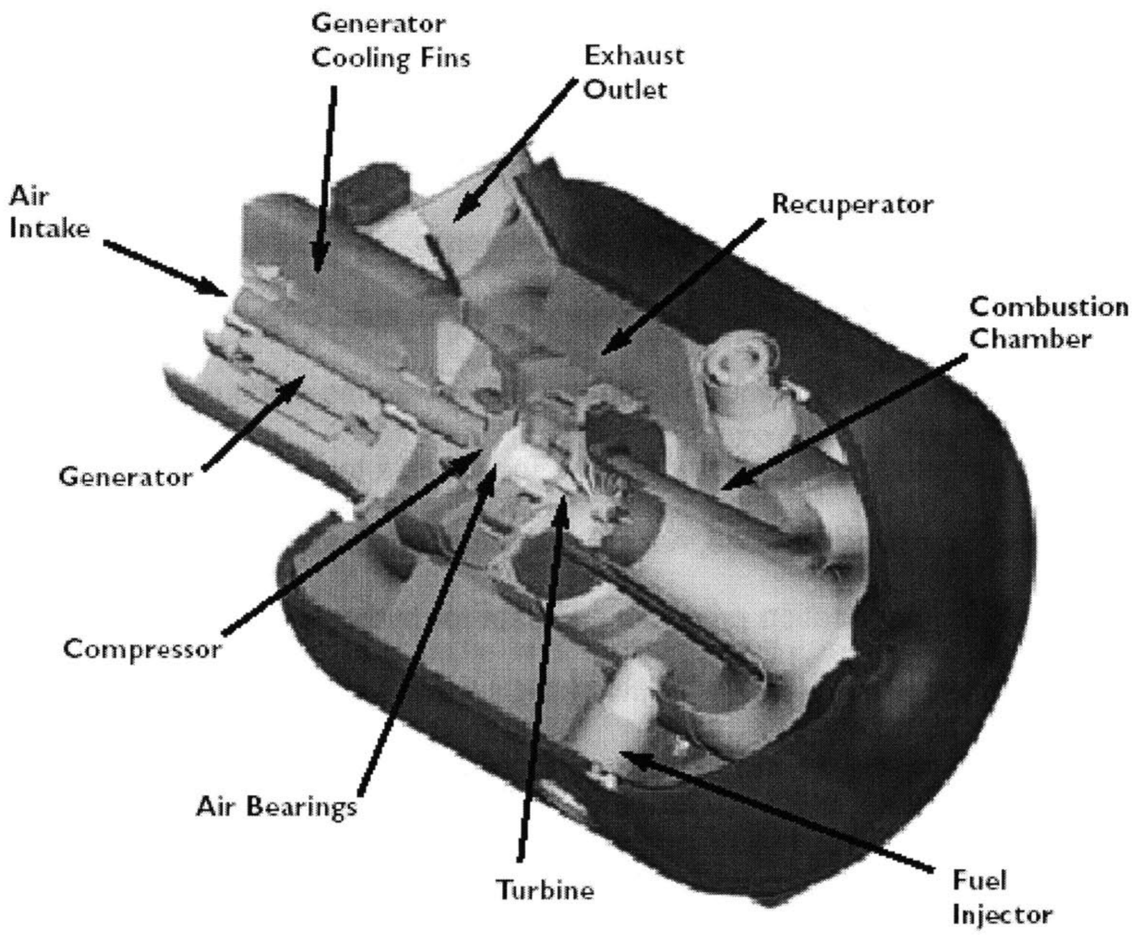

Figure A.1. Diagram of a Microturbine
Courtesy of Capstone Turbine Corporation

[96] Curtis, 2001

B. FUEL CELLS

Fuel cells are basically composed of an anode, cathode and an electrolyte between the two. As depicted in Figure B.1, fuel enters the fuel cell and attaches to the anode. Then, the protons diffuse through the electrolyte as a voltage potential carries the electrons to the cathode. The current of electrons produces the electricity. At the cathode the protons react with oxygen from air to produce water.

The distinctive property of a fuel cell is generally the electrolyte. Thus, fuel cells are usually categorized by the type of electrolyte. Molten carbonate fuel cells (MCFCs) have a molten alkali carbonate mixture for an electrolyte.[97] This mixture is solid at room temperature and liquid at operating temperatures – about 800°C.[98]

This high operating temperature allows the MCFCs to operate on a variety of fuels - hydrogen, carbon monoxide, natural gas, propane, landfill gas, marine diesel, and simulated coal gasification products.[99] Except for hydrogen, fuels are internally reformed with the high temperatures of the MCFCs in the water-gas shift discussed in Section 3. This method is called steam reforming. First, the fuel is thermally decomposed into hydrogen and carbon monoxide. Then, the water-gas shift produces more hydrogen by converting water and carbon monoxide to hydrogen and carbon dioxide.[100]The ability to operate on natural gas is critical, as a distribution network already exists for that fuel.

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[97] Curtis, 2001
[98] FuelCell Energy, 2001
[99] Fuel Cells 2000, 2000
[100] Other methods of reforming hydrocarbons are autothermal reforming and partial oxidation. Carrette et al, 2001

Internal reforming creates higher electrical efficiencies. Current operations have achieved electrical efficiencies ranging from 45-55%.[101] MCFCs should reach 70% efficiency in the near future.[102] In combined heat and power applications, fuel cells have achieved efficiencies greater than 85%.[103] This should also increase in the future.

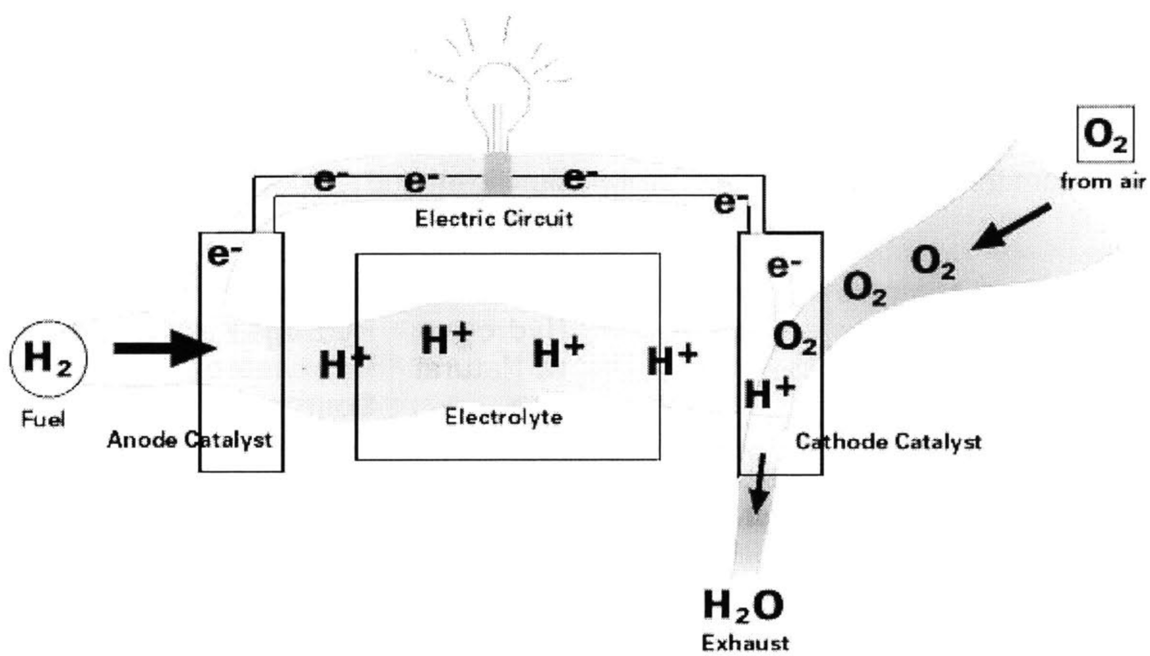

Figure B.1. Diagram of a Fuel Cell
This paper discusses fuel cells with molten carbonate as the electrolyte because of their ability to internally reform natural gas to hydrogen, and their high fuel efficiencies.

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[101] Carrette et al, 2001; Williams, 2001
[102] Wisconsin PSC, 2000; Carrette et al, 2001
[103] Williams, 2001

C. ENVIRONMENTAL ANALYSIS OF FUELS

Fuel use has an environmental impact that extends beyond emission of pollutants in electricity production. Life Cycle Analysis (LCA) is a process in which all of the environmental effects of a material are quantified in a measurement of its true environmental impact. For fuels, a LCA would include extraction, transportation from the site of extraction, processing, distribution, consumption and disposal of residual materials. Although a formal LCA for all of fuels that are used for electricity generation is beyond the scope of this thesis, a cursory overview is provided in Table C.1.[104] Transportation and distribution have been excluded from Table C.1 because pollution from these processes is relatively insignificant and difficult to quantify.

Table C.1. Environmental Impact of Fuels for the Electric Industry

	Natural Gas	**Coal**	**Hydrogen w/ Natural Gas**	**Hydrogen w/ Renewable Sources**	**Uranium Oxide**
Extraction	~1.5% of total gas extracted escapes to atmosphere	Pollution from mining waste; Uncontrolled emissions	Same as natural gas	Potential for visual obstructions	0.2% yield of uranium from mined ore
Processing	Negligible	Negligible	CO_2 (steam reforming)	Negligible	Radiation exposure
Consumption	Emissions reported in Section 3	Emissions reported in Section 3	Zero (for pure hydrogen)	Emissions reported in Section 3	Cancer for 1 in 280 workers
Disposal	N/A	200+ lb/MWh ash put on land or burned in kilns	N/A	N/A	Toxics leaking from storage; Radiation

Sources: Ashford, 2001; Spath and Mann, 2001; Boston Globe, 1990; Steinfeld et al, 2000; EPA, 1995

[104] The analysis of hydrogen from natural gas assumes the natural gas is processed to produce hydrogen at the source of consumption through a steam reformer. The analysis of hydrogen from renewable sources assumes the hydrogen is produced at the point of consumption because commercial distribution systems have not been developed.

This analysis imparts a more complete picture than emissions from production of electricity, which involves only consumption. The most environmentally attractive fuel is hydrogen produced from renewable sources, such as wind turbines or solar panels. Feeding this hydrogen to fuel cells offers the potential for an energy source with a negligible environmental impact. Currently, this alternative fuel is primarily limited by an inability to transport and distribute hydrogen from areas of renewable energy sources.[105]

The most important conclusions from Table C.1 involve coal and uranium oxide. These fuels create significant pollution during disposal. The environmental problems of nuclear waste have contributed to the lack of growth in the nuclear industry since the accident at Three Mile Island. Even if permanent disposal o nuclear waste at Yucca Mountain is approved, scientists are not prepared to say that there exists a safe disposal option for nuclear waste.[106] Although regulated by the EPA, the waste ash from coal plants has created environmental problems. Generally, this waste is combusted in a kiln to reduce its volume. These kilns have control equipment to reduce emissions. Yet, the standards for these kilns are not as stringent as that for power plants.[107] Ultimately, the disposal of coal ash creates additional pollution and opens up the possibility of environmental exposure to toxic leachate.

Extraction is another area of environmental exposure. Pollution is generated in this process by natural gas, as well as coal and uranium oxide. Uncontrolled

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[105] Other limitations are the relatively low energy density of hydrogen and the existing infrastructure base for fossil fuels. Moniz and Kenderdine, 2002

[106] New York Times, 2002

[107] Additionally, the remaining ash is disposed in landfills where the potential for leachate formation exists. Ashford, 2001

emissions (known as "fugitive emissions") from coal and natural gas extraction processes are primarily methane. This gas contributes to global warming.[108] Besides air pollution, the mining operations for uranium oxide and coal create land and water problems. The waste ore that is separated from the fuel emits radiation (for uranium mining) or creates acidic materials (for coal mining). While they have reduced their environmental impact, mining operations continue to pose risks for significant groundwater and surface water contamination of toxic metals and chemical mixtures.[109]

From this brief overview, the importance of considering the total environmental impact for these fuels is clear. For natural gas, the emissions from the consumption process may give a reasonable, although incomplete, indication of the pertinent environmental impact. Similarly, the damaging emissions from coal combustion are indicative of the negative impacts throughout its life cycle. On the other hand, an analysis of the consumption process for uranium and hydrogen reformed from natural gas gives a misleading conclusion of little or no environmental impact. This appendix highlights the full range of processes that should be analyzed. In a comprehensive analysis, ranking fuels on a scale of environmental impact will require policy decisions comparing different risks such as nuclear radiation and greenhouse gases.

[108] Hemond and Fechner-Levy, 2000
[109] Shogren, 2002

D. CASE STUDIES OF INTERCONNECTION CONTRACTS

The National Renewable Energy Laboratories (NREL) sponsored an investigation into interconnection barriers for on-site distributed generation (DG) power supplies from 1998 - 2000.[110] This study examined 65 DG projects and concluded that a majority of the cases experienced substantial barriers for interconnection.[111] Technical, business-practice and regulatory barriers were the most difficult to overcome. Potential DG projects were over-burdened with non-uniform technical standards and interconnection contracts.[112] Regulatory schemes were generally not designed to handle non-industrial scale DG projects. Additionally, most DG proponents felt that utilities transferred many costs onto and created unnecessary delays for DG owners without considering the benefits of DG to them.[113]

These barriers are partly caused by legitimate safety and power quality concerns of utilities and partly produced by utilities that view DG as a threat to their revenue base. Many of the safety related costs, such as engineering studies, cannot be scaled directly to the size of the DG equipment. As the capacity of the DG project decreases the engineering costs reach a minimum that is required for all new interconnected power sources. Thus, small DG projects are faced with an excessively large interconnection costs per kilowatt because the project capacity is

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[110] Alderfer et al, 2000
[111] ibid
[112] Technical barriers have been minimized with IEEE interconnection standards published in 2002. Also, DG producers add interconnection equipment to most new models. Capstone, Media Notes, 2002
[113] Alderfer et al, 2000

not large enough to justify the minimum engineering costs.[114] Yet, the record shows that many utilities use the disorganization surrounding interconnection to charge unwarranted fees to DG owners. Additionally, benefits to the grid are not credited to DG owners. For example, during peak hours, most of the DG owners that are credited for electricity provided to the grid receive credits at non-peak wholesale prices. Then, the utilities sell this electricity to other customers at peak prices, for a profit.[115]

Three case studies from the NREL report have been selected that apply specifically to on-site microturbines or fuel cells with generation capacities less than 1MW.

Case 1. Two Microturbines (130kW) Sited at a Truck Stop

A truck stop in Louisiana investigated the opportunity for cost savings from installing two microturbines. An engineer contracted by the city approved the project vendor's proposal for control and protective equipment. The vendor shipped the equipment to the truck stop at a cost greater than $100,000. Several days after the first shipment arrived at the truck stop, the city passed an ordinance applying to "customers who have installed equipment and self generate their own primary electric services." The ordinance introduced new stand-by charges that would have cost the truck stop $5,400 for the 25,000 kWh required from the utility each month. Previously, the truck stop was using 80,000 kWh per month at a cost of $6,000. This new tariff required the truck stop to generate 55,000 kWh per month at a cost of $600 just to

[114] As these engineers gain more DG experience and automated equipment is developed to perform the required tests, these costs will decrease.
[115] Alderfer et al, 2000

prevent operating losses with the microturbines. The truck stop decided to forego the microturbine installation.

Further investigations revealed that the city ordinance was a result of the city's wholesale electricity supplier. The city had been told that distributed generation undermined the viability of the supplier; and, the city would have to pay higher wholesale rates to cover lost revenue.

Case 2. Fuel Cell (200kW) Demonstration Project

A federal automobile testing facility with a low power factor was incurring penalties totaling 25% of the original cost of service from a local utility. In an effort to reduce energy costs, the facility undertook a series of measures. One measure was the installation of a fuel cell system that would pay for itself in a 10-year period. Concerned about reliability, the utility proposed a back-up charge of $50/kW-year (equivalent to $10,000 per year). As another incentive, the utility offered to reduce the facilities energy costs by $10,000 per year if the fuel cell was not installed. Thus, the utility was effectively providing a $20,000 per year interconnection charge.

The facility was opposed to the back-up charge because it saw the fuel cell as a benefit for the utility. The utility was frequency in a capacity constrained state in the summer. In fact, the testing facility had been credited $0.50/kWh to run its back-up diesel generator for two days the previous summer. The utility was unwilling to recognize any benefits provided by the fuel cell equipment. After the proposal of the stand-by charges, the fuel cell project was discontinued.

Case 3. Microturbine (75kW) Sited at an Oil Well

An oil well, at a public school, was producing natural gas as a by-product. In the past, the natural gas had been sold to the natural gas distribution system. The well owner decided to gain additional value from the natural gas by installing a microturbine to generation electricity for the oil derrick and residual heat for on-site heating at the school. The utility refused to interconnect the microturbine because it was not obligated to interconnection non-qualifying facilities (QF's).[116] The microturbine developer stated that because the microturbine would supply electricity only to reduce the oil derrick's load, the addition of the microturbine was no different than reducing the facilities electricity demand from the utility. Because the microturbines had been fully tested for safety and reliability concerns, the developer initiated a legal suit to have the microturbine considered as a "load reduction device". If the microturbine was a "load reduction device", the utility would be required to interconnect the equipment.

In negotiations, the utility's final offer was to "experimental[ly]" interconnect the microturbine if the developer would export all of the electricity to the grid without compensation. In other words, the developer would pay the capital and operating cost of the microturbine while giving the electricity to the utility. The developer would continue to purchase electricity from the utility to operate its oil derrick. The developer declined to install the microturbine for the sole benefit of the utility.

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[116] QF's are powered by renewable resources. They export electricity to the grid and are paid the same price that it would cost the utility to generate the electricity. Ackermann, 1999

E. BOSTON EDISON RATE STRUCTURE

In Table E.1, the rates from Boston Edison for the commercial customer in Boston are presented. These rates were used in the economic analysis in Section 6.

Table E.1. Grid Cost of Electricity

	Rates in October through May ($/kWh)	**Rates in June through September ($/kWh)**
Demand Charges (in excess of 10kW)	$10.54	$22.59
Energy Charges	$0.041	$0.041
Distribution Charges		
First 2,000 kWh	$0.011	$0.021
Next 150 kWh	$0.006	$0.008
Additional kWh	$0.005	$0.005
Transition Charges		
First 2,000 kWh	$0.043	$0.084
Next 150kWh	$0.022	$0.029
Additional kWh	$0.014	$0.016

Source: ADL, Understanding the Economics, 1999

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F. ECONOMIC CASE STUDIES OF DG APPLICATIONS

In addition the peak shaving application analyzed in Section 6, there are a variety of other specific uses where DG equipment provides economic benefits. The Consumer Council for America published case studies for a rural food processing facility, Internet hosting/telecom hotel, and a retailer with high power costs.[117] These case studies encompass the special needs of rural customers, power quality dependant customers, and customers with a need for back-up power. Replications of the summaries for these three uses are provided below.

Case 1. Rural Application – Food Processing Facility
Problem:

- Excessive cost to provide electricity from the grid
- Unacceptable flickers and voltage drops when large motors are started (>50 hp)

Traditional Solution:

- Install new high voltage line from utility substation to facility (3 miles)
- Install industrial grade substation at facility for voltage step down
- Total cost ~$3.0 million (charged to customer)

Distributed Energy Solution:

- Install multiple on-site microturbines
- Assume natural gas distribution is available
- Assume operational cost of power is competitive or cheaper than power supplied via traditional solution
- Redundancy of microturbines avoids need for back-up generator (~$600,000)
- Total cost ~$2.5 million

[117] Curtis, 2001. DTE Energy Technologies provided the information to the council for these case studies.

Bottom Line:

- Capital cost savings ~$1.1 million
- Operation electricity cost savings
- Improved power quality and reliability

Case 2. Internet/Telecom Hotel – High Power Quality Needs
Problem:

- Facility devoted to computer systems and data processing
- Requires high reliability and power quality 24 hours per day, 365 days per year
- Downtime from momentary outages and low power quality could result in losses of $400,000 per year
- Peak demand of 1550kW

Traditional Solution:

- Add 1600kW standby generator and un-interrupted power supply (combined $550/kW) to supplement utility power
- Total cost ~ $1.1 million plus ongoing cost to purchase electricity @ $0.15kWh average cost

Distributed Energy Solution:

- Add 1600kW micro grid with 4 microturbines (400kW) for $1.825 million
- Use utility grid as back-up for high reliability

Bottom Line:

- Higher power quality and improved reliability (99.99999 reliability)
- Annual savings of $300,000
- Simple payback of 4.1 years
- IRR of 26%
- If co-generation is used
    - Annual savings of $456,299
    - Simple payback of 3.7 years
    - IRR of 29.6%

Case 3. Retailer with High Power Costs

Problem:

- General retailer
- Normally occupied 12 hours per day, all year
- Peak demand of 170kW
- Business cost of $40,000/year due utility outages
- Utility offers generator capacity purchase program

Traditional Solution:

- Add 175kW stand-by generator, only permitted for less than 200 hours per year
- Total cost ~ $132,000

Distributed Energy Solution:

- Add 225kW of prime power natural gas fired units (150kW and 75kW) for $241,500
- Peak shaving applications, 8 hours per business day
- Sell back excess capacity under Utilities R13

Bottom Line:

- Annual Savings of $28,000
- Simple payback of 4.8 years
- IRR of 19.6%

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