FINAL DRAFT

Industrial Applications for Micropower: A Market Assessment

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EXECUTIVE SUMMARY

The market for power generation equipment is undergoing a tremendous transformation. Smaller facilities are soon to discover an array of new micropower technologies, while larger facilities will turn to these options to supplement their installed generation capacity. U. S. industry has traditionally used power generation technology on-site to meet some of their thermal and electric energy demands. While the U. S. industrial sector has experienced substantial growth in installed capacity during the 1980's, growth has slowed since the early 1990s. Micropower (electricity generation equipment less than 1 MW) such as microturbines, fuel cells, and reciprocating engines offer promise to renew this growth. Based on the analysis conducted for this study, these technologies can cost-effectively provide thermal and electric energy, while reducing national energy use and emissions.

Micropower State of the Art

With new technology comes new challenges. To date, micropower has minimal penetration in the industrial sector, despite the availability of reciprocating engines that can cost-effectively generate power. A number of market barriers exist and the technology does not currently meet the needs of most smaller industrial facilities that could potentially offer a sizeable market. Reciprocating engine manufacturers are aware of these needs, and are currently planning on developing more efficient, low emissions, lower cost units with less periodic maintenance requirements. To accomplish this, key developments are needed, such as advanced combustion, higher compression ratios, improved ignition systems, as well as better modeling, sensors, and controls.

Microturbines also offer much promise, but face a battle for commercial acceptance against "tried and true" alternatives such as grid power or reciprocating engines. Like for reciprocating engines, a number of market barriers exist. The technology can only establish itself as a viable option by successful commercial installations over time. Installed cost, efficiency, and reliability need to improve to give them advantages over the competition. To achieve such improvements, microturbine manufacturers are focusing lower cost production of recuperators, power electronics, and gas compressors, and high temperature materials to improve efficiency.

Fuel cells are emerging as potential contenders in the micropower market. Of all the generation options, they are affected most by a limited track record of commercial acceptance. Despite the experience gained from a few hundred phosphoric acid units in the field, the current pricing of fuel cells appears to be the most severe limitation. Successors to the phosphoric acid technology, including molten carbonate and solid oxide, offer much promise but are still in the development/demonstration phase and have yet to offer economically-priced units for sale. Other than continued cost reductions and experience from demonstrations, fuel cells need few advances to become a viable option: they offer extremely high efficiencies, very low emissions, no moving parts, and could potentially penetrate the market via several niche applications that focus on their "green" attributes.

The Market Potential for Micropower

The market for micropower depends greatly on the status of the micropower technology. Given current unit costs and performance levels, the potential U. S. industrial market for both continuous power and combined heat and power (CHP) applications is expected to reach 10 GW by year 2010 (see Table S-1). Most of this potential exists for reciprocating engines, which have a small but significant cost advantage and a clear efficiency advantage over current microturbines and a dominant cost advantage over fuel cell units. However, microturbines do offer some potential for CHP applications in the smaller size range (30-100 kW) that their manufacturers have targeted. Based on economics alone, fuel cells were unable to compete for any significant part of this market potential.

Table S-1. Estimated and Projected Market Potential for Micropower

Application	Capacity (MW)		Number of Units	
	Current Unit Performance	Future Unit Performance	Current Unit Performance	Future Unit Performance
Continuous Power	850	1,200	2,700	3,550
Combined Heat and Power	8,850	19,550	34,500	78,600
Total	9,700	20,750	37,200	82,150

When regional variations are considered, states with a high spark spread (difference between electricity price and the fuel portion of the cost to produce electricity onsite using natural gas) and a high number of sites of the type and size that favors DR are the best targets. California offers the most potential for micropower based on high electricity prices, moderate natural gas prices, and a significant number of possible sites. New York and New Jersey also offer potential, with Massachusetts and Pennsylvania rounding out the top five. Not surprisingly, these states are all relatively far along with electric industry restructuring, due to their relatively high state electricity prices.

The industry analysis revealed that the potential for micropower exists mainly in industries where traditionally on-site generation has not been a factor. Rubber and plastics, fabricated metals, and electronics are among the leaders in market potential, but have little installed base of onsite generation. On the other hand, food and paper are two of the traditional industries where on-site power generation has been used extensively and where micropower also has potential.

When future unit cost and performance was considered, the market potential doubled, to almost 21 GW. This represents year 2010 market potential, assuming that units with these future cost and performance improvements are available by year 2000. A sensitivity analysis (see Figure S-1) revealed that any one of the three micropower technologies could capture a significant share of the market potential if it were to improve while the other technologies did not. In addition, the future unit cost and performance improvements created more of a market for micropower among industries that do not currently use on-site power, including fabricated metals, machinery, rubber/plastics, and printers.

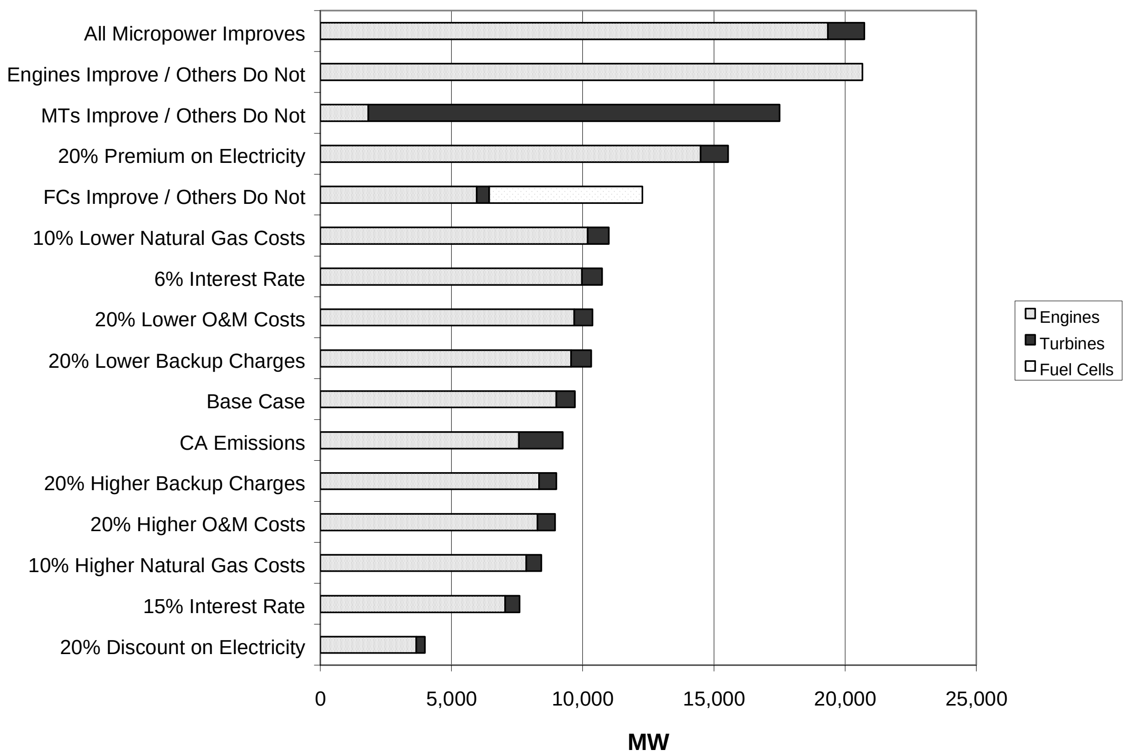


Figure S-1. Sensitivity of Market Potential to Changing Conditions

Market factors which would increase the potential market size include an increase in electricity prices or a decrease in natural gas costs. Factors which could decrease the market size include higher natural gas costs, higher interest rates, or a higher discount on electricity prices. In addition, including shaft power, peak shaving, and emergency generator applications, not included in this study, would likely add significantly to the size of the market. The market for shaft power, as well as for larger (above 1 MW) units will be examined in a follow-up study to be published in 2000.

Market and Technology Barriers

Applications of state-of-the-art microturbines, fuel cells and reciprocating engines in the U.S. industrial sector is currently limited, due to a combination of barriers in the following categories:

- Economics and Tax Treatment
- Product Performance and Availability
- Awareness, Information and Education
- Utility Policies and Regulation
- Planning, Zoning and Codes
- Environmental Regulation
- Supporting Market Infrastructure

These barriers can often make a micropower project uneconomic, and, even if economically or otherwise desirable, can frequently present such a confused and uncertain option to potential end users that more traditional purchased power approaches are favored.

Economics and Tax Treatment. Despite projected decreases in installed costs, first cost remains a barrier. Assistance in overcoming this barrier could be provided by the availability of a tax credit for selected micropower equipment to help defray project capital cost. Tax treatment of micropower equipment varies considerably based on asset use and generating capacity, and could improve market penetration if the tax code were to look more favorably on these investments.

Product Performance and Availability. Advances in technology, most notably in the areas of microturbines and fuel cells, as well as in the rapidly evolving power electronics, have also lowered the size threshold for economically viable power generation equipment. Notable advances are also being achieved with fuel cells, but a number of technical barriers must be overcome. Each of these technologies offers advantages and disadvantages in specific site situations, and there are very specific technology challenges associated with each option. The technology challenges can generally be organized in three areas: 1) reliability and efficiency goals are not quite being realized as of today; 2) products are commercially available on a limited basis; and, 3) other performance considerations.

Awareness, Information and Education. Industry and business owners have a limited understanding of the range of benefits associated with micropower technologies. Frequently following the path of least resistance, industry decision makers will often stay with grid purchased power, typically not realizing the full value of the micropower benefits. Further exacerbating this situation, and contributing to rather than breaking down the cost barrier, is industry’s frequent focus on capital cost versus life-cycle cost.

Utility Policies and Regulation. Many utilities have designed backup power rates that penalize "part-time" customers. While these rates may accurately reflect the higher cost of "reserving" capacity for these part-time customers, they effectively act to restrain micropower implementation. Interconnection is another critical issue, with utilities often requiring protective relaying on the utility side of the meter to ensure that the grid is protected from any problems caused by the distributed generator. Interconnection requirements can raise the cost of an on-site generation package by as much as 15 to 20 percent. Also, as deregulation begins to make its way across the country, customers choosing to leave the grid of the local energy supplier are required to pay "transition charges" or "exit fees" designed to help the local utility recover investments in "stranded" generation or transmission assets no longer producing revenue for the utility. Burdening the distributed generator with these exit fees and competitive transition charges is a disincentive to project implementation.

Environmental Regulation. Micropower projects can experience drawn out siting and permitting requirements at the state and local level. Some micropower, such as reciprocating engines, microturbines, and fuel cells are exempt in many or all regions due to small size and/or lower emission levels. Streamlined siting and permitting procedures would provide a major boost to larger micropower technology penetration. Additionally, output-based emission factors accounting for overall fuel utilization efficiency would recognize the inherent efficiency advantage of power generation technology located close to the load, eliminating T&D lines losses, and possibly taking advantage of CHP applications.

Supporting Market Infrastructure. Micropower is an example of a classical emerging technology with regard to its market distribution status. The lack of easily reachable channels of distribution for microturbines and fuel cells naturally limit their applications. Reciprocating engines offer a clear market advantage in the extensive dealer and service network available, with a ready supply of trained diesel mechanics and spare parts on a nationwide (and even worldwide) basis. The widespread transportation and machinery applications for diesel engines has provided a foundation for the power generation applications of this technology. The initial lack of trained maintenance staff, and lack of spare parts support for microturbines and fuel cells will slow down the penetration of these technologies. Microturbine manufacturers have made some progress in establishing a maintenance infrastructure, but to date they have not demonstrated the ability to dependably support this new technology. Other applications (e.g., transportation) that would build volume and help establish a service infrastructure for microturbines and fuel cells are needed. Fuel cells may accomplish this over time in the automotive transportation market. Other market infrastructure issues that are potential barriers to micropower development include the need to: encourage the development of an export market to achieve quantities of scale in production costs, and advance the standard engineering design practices to include micropower as part of an integrated plant design to lower installation costs.

Technology R&D Implications

Micropower has the potential to cost-effectively improve energy efficiency and reduce emissions in the industrial sector, but further R&D is needed to allow these technologies to compete with more conventional options. Micropower technologies share the need for lower costs, increased electrical efficiency, reduced maintenance, greater reliability, and lower emissions, but specific needs vary by technology.

Most reciprocating engine R&D is designed to improve efficiency and lower emissions. Lean-burn technology, favored by most new applications, has helped to meet these goals but requires research into ignition and turbocharging to meet future performance targets. To help lower emission levels further, non-traditional (non-NSCR) post-combustion emission control may be developed. Microturbine needs include improved efficiency and lower costs. Improved efficiency is most dependent on high-temperature operation which may require advances in temperature resistant materials (ceramics) for the recuperator and turbine hot section. All system components are targets for cost reductions as many auxiliary components including power electronics and fuel compressors add significantly to the total cost. Fuel cells will need efficient fuel reformers and support systems with increased reliability. Additionally, both fuel cells and microturbines will need to be demonstrated in order to verify manufacturer’s claims of efficiency, emissions, and reliability.

Section 1
INTRODUCTION

The market for power generation equipment is undergoing a tremendous transformation. Smaller facilities are soon to discover an array of new micropower technologies, while larger facilities will turn to these options to supplement their installed generation capacity. Meanwhile, the traditional electric utility industry is restructuring, promising new opportunities and challenges for all facilities to meet their demands for electric and thermal energy. In addition, global climate change concerns are creating new policies that may favor the use of combined heat and power. Together, these trends are motivating U.S. industrial facilities to reevaluate their current mix of energy services.

DOE Objectives

The U.S. Department of Energy's Office of Industrial Technologies (OIT) sponsored this work in support of their goal to significantly improve the resource efficiency and productivity of the energy and waste-intensive industries in the United States. To accomplish this, OIT will help industry develop technology solutions to critical energy and environmental challenges. Among the solutions being pursued, microturbines, fuel cells, and reciprocating engines offer promise to industry to cost-effectively provide thermal and electric energy to meet their needs. In addition, these technologies have the potential to reduce national energy use and emissions.

The purpose of this study is to assess the market for micropower technologies in the U. S. industrial sector and their potential impacts on national energy use and emissions. Micropower is defined as power generation technologies less than 1 MW electric output, and includes reciprocating engines, microturbines, and fuel cells. It does not include technologies which operate from renewable energy sources. Specific objectives of this study were to:

- ✓ review the technology state of the art, in terms of cost, efficiency, environmental performance, and other important characteristics,
- ✓ assess the potential market for these technologies by size, region, and industry,
- ✓ discuss market and technology barriers that could hinder significant market penetration, and
- ✓ estimate national impacts in terms of energy, emissions and economic development.

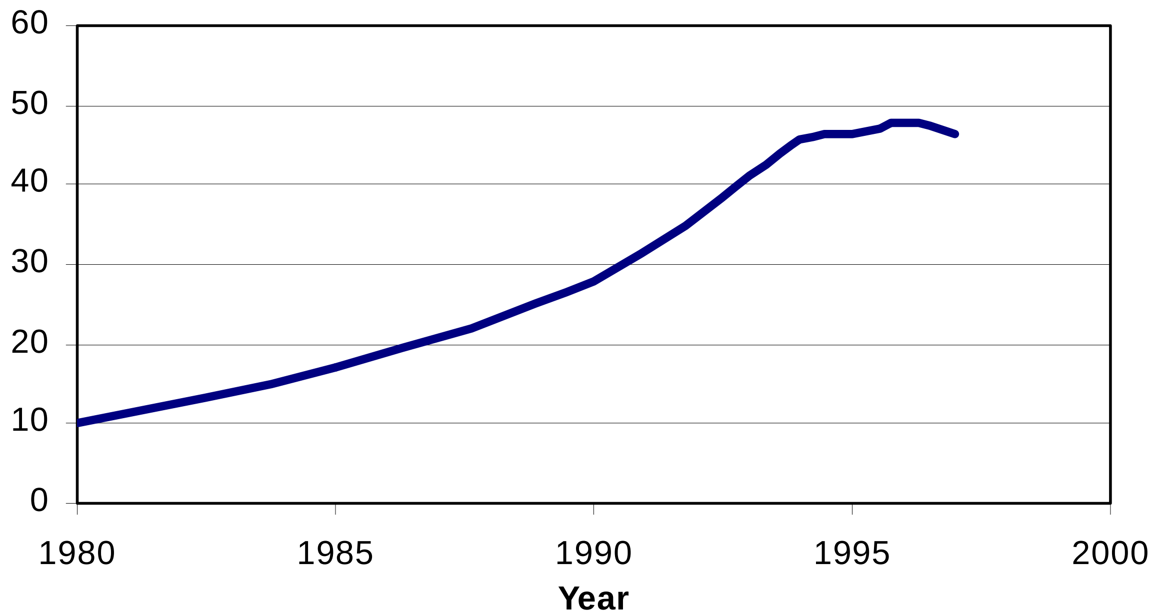
It should be noted that the focus of this study is the industrial sector in the U. S. However, for many of the micropower manufacturers, the commercial and residential sectors represent large, untapped markets that will likely be their initial focus as they rollout their production. Furthermore, the global market offers opportunities that are potentially many times the size of the U. S. market, particularly in developing countries without a central electric grid for power transmission and distribution. As a result, the U.S. industrial market size estimates developed for this study represent only a fraction of the total market for micropower technologies.

In addition, the study focuses on using micropower for electric power generation, both in electric only and in combined heat and power (CHP) applications. Shaft power applications exist for these units, but these applications are typically reserved for electric motors. Pumps, fans, compressors, and other driven equipment can benefit from the cost savings of micropower, particularly where electric rates are high and gas prices are moderate or low. While there is a potential market for these applications, this study does not account for this market. A subsequent effort, planned for publication in 2000, will examine this market along with the market for larger (above 1 MW) applications of onsite power generation. Additionally, peak shaving remains a potential market for equipment manufacturers, but due to either limited hours of operation these applications were not targeted by the market potential analysis.

Current Status of Micropower

U. S. industry has traditionally used power generation technology on-site to meet a portion of their thermal and electric demands. In the late 1970s, Congress passed the Public Utility Regulatory Policies Act (PURPA), which was intended to spur the use of on-site generation for both thermal and electric needs (i.e. cogeneration). While this resulted in substantial growth in installed capacity during the 1980's (see Figure 1-1), growth has slowed since the mid 1990s.

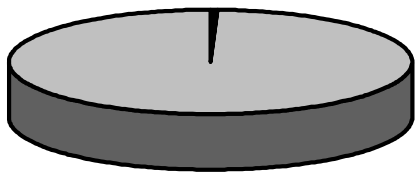
Figure 1-1. Growth in Industrial Generation (GW)



Source: Edison Electric Institute, Non Utility Sources of Generation

Mainly large installations have been able to realize the economies of scale required to generate power less expensively than purchasing power from the local utility. In 1997, less than one percent of all non-utility generation capacity was from micropower technology (see Figure 1-2).

Figure 1-2. Current Penetration of Micropower in Non-Utility Generation



Slowing growth and minimal penetration of smaller units can be attributed to a number of barriers, including environmental permitting difficulties, costs associated with interacting with utility systems, unfavorable tax treatment of generation plant investment, and lack of technology options for smaller facilities.

A number of trends, however, have surfaced that may renew the growth in industrial generation:

- ✓ Global concern over greenhouse gas emissions has placed an increased emphasis on total energy efficiency, which would favor combined heat and power over utility central plant generation. This may create interest in changing environmental regulations to be less emission based, and more output based, thus favoring CHP. Furthermore, creation of a global carbon permit trading market would provide new incentives for CHP.

- ✓ Electric utility restructuring has heightened concerns over grid reliability and thus is renewing interest in on-site generation. Stranded cost treatment, including exit fees, threatens to counter this interest by deterring non-grid sources of power.

- ✓ New micropower technologies are surfacing, including microturbines and fuel cells. In addition, a new generation of reciprocating engines are entering the market with better efficiencies, decreased costs, and lower emissions. In combination, these technologies provide smaller users with an unprecedented set of options from which to potentially satisfy their needs for both thermal and electric energy on-site.

This study assesses the market potential for these new and improved micropower technologies, and examines the potential impact that these barriers and trends have on the ultimate penetration of these technologies in the industrial sector.

Approach

The analysis was performed using RDC's DIStributed Power Economic Rationale SElection (DISPERSE) model, which estimates the achievable economic potential for distributed generation by comparing on-site generation economics with competing grid prices. The analysis determines whether on-site generation appears to be more cost effective than purchasing from the grid, and also which technology and size appears to be the most economical. As a result, double counting of market potential for a variety of competing technologies is avoided. This model has been developed over the past five years, and has been applied on a variety of projects for utilities, equipment manufacturers, and research organizations.

Using data on number of facilities in each size range in each state, the number of potential applications is determined. Results are aggregated and summarized to show key information on where the potential applications are (e.g., the top state for industrial sector applications of 25-75 kW microturbines is California, and almost all the applications are cogeneration, with the top sector being rubber/plastics). To consider the market impacts from planned improvements in micropower technology, a future scenario was also analyzed with substantial improvements in micropower cost and performance. Appendix A provides a discussion of the DISPERSE model inputs, analysis, and output.

Section 2
MICROPOWER STATE-OF-THE-ART

A number of micropower technologies are becoming available to facilities that have traditionally had only a limited set of options to satisfy their thermal and electric needs. Combined with electric utility industry restructuring, these options will challenge the ways that facilities meet demands for electricity and thermal energy. This section reviews the current status of these new micropower technologies, and examines key developments that are needed to improve their cost and performance.

Reciprocating Engines

Of the micropower technologies, reciprocating engines were commercialized first (more than 100 years ago) and have long been used for electricity generation. Both Otto (spark ignition) and Diesel Cycle (compression ignition) engines have gained widespread acceptance in almost every sector of the economy, and are used for applications ranging from fractional horsepower units for small hand-held tools to enormous 60 MW baseload electric power plants. Reciprocating engines in the micropower size range (<1 MW) are primarily designed for transportation and are converted to power generation, usually with little modification. This trend is due to the relative size of the transportation market versus the power generation market. For example, in 1995 North American production of diesel gensets (<1 MW) was approximately 28,000 versus 714,000 diesel engines produced for on-highway use (Source: *The Future of Diesel Engines*, Rhein and Associates, Inc. 1996.)

Courtesy of Caterpillar Inc.

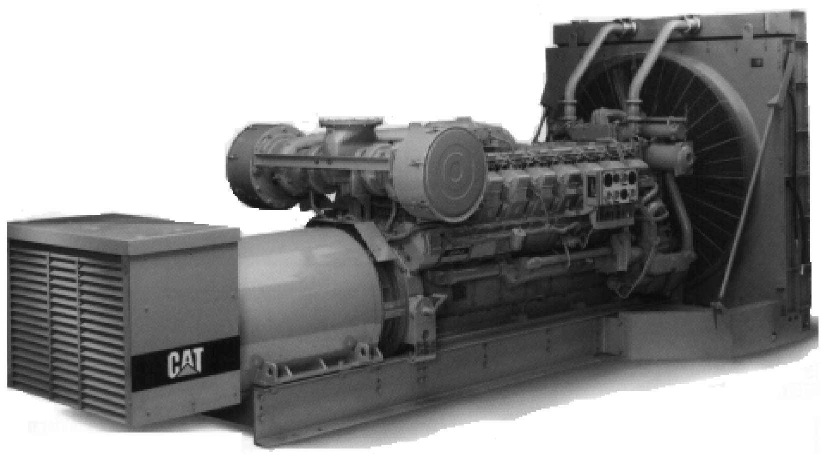


Figure 2-1. Reciprocating Engine Genset without Heat Recovery System

Almost all engines used for power generation are four-stroke and operate in four cycles (intake, compression, combustion, and exhaust). The process begins with fuel and air being mixed, usually before introduction into the combustion cylinder for spark ignited units (see Figure 2-2). In turbocharged applications, the air is compressed before mixing with fuel. The fuel/air mixture is introduced into a

Representative Manufacturers
Caterpillar
Waukesha
Kohler Co.
Jenbacher
Cummings
Detroit Diesel
Cooper Energy Services

combustion cylinder that is closed at one end and contains a moveable piston. The mixture is then compressed as the piston moves toward the top of the cylinder. For diesel units, the air and fuel are introduced separately with fuel being injected after the air is compressed. Near the time when the piston reaches the top of its stroke (timing is optimized for the most efficient power generation or to reduce emissions), a spark is produced igniting the mixture (in a non-spark ignited diesel engine, the mixture is ignited by the compression alone). The pressure of the hot, combusted gases drives the piston down the cylinder. Energy in the moving piston is translated to rotational energy by a crankshaft. As the piston reaches the bottom of its stroke the exhaust valve opens and the exhaust is expelled from the cylinder by the rising piston.

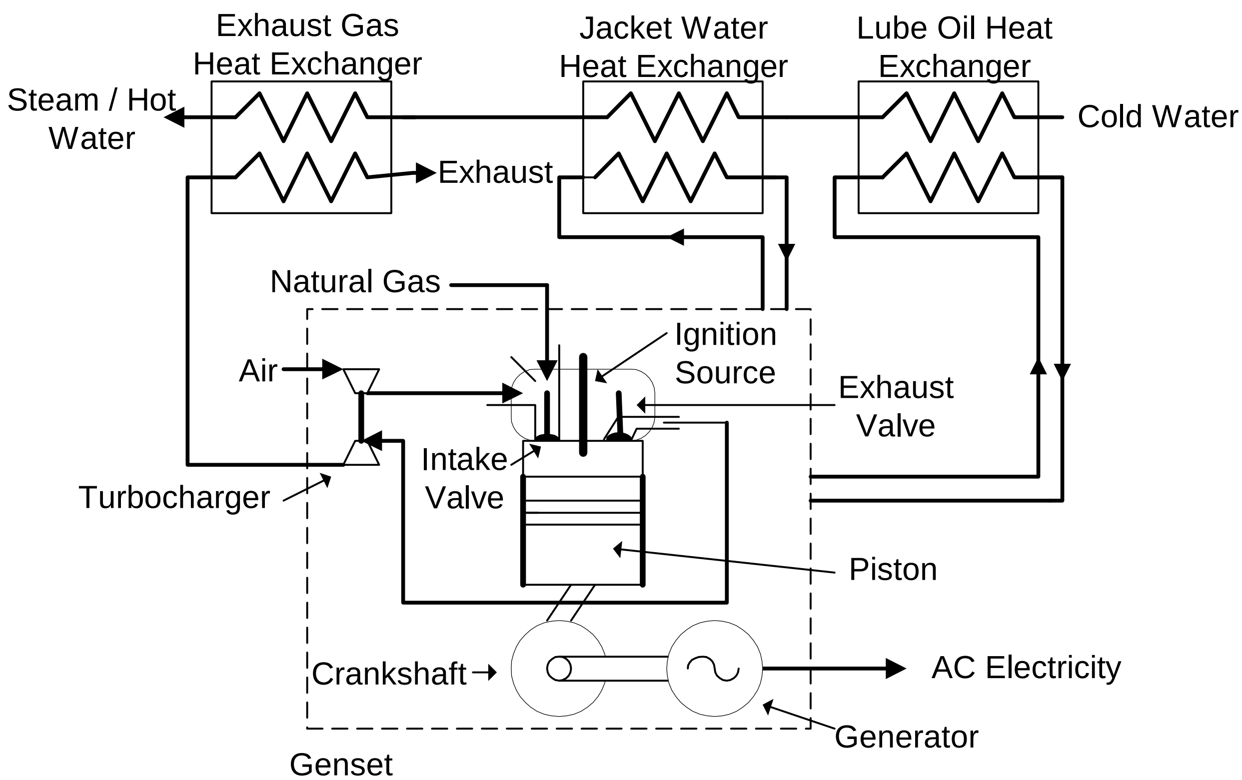


Figure 2-2. Schematic of a Typical Spark Ignited Engine Genset.

Most engines used for micropower are four-stroke, water cooled, transportation derivatives. Both diesel (compression ignition) and natural gas (spark ignition) engines are widespread, but it is becoming increasingly hard to site diesel generators, especially in larger sizes, due to emissions regulations. Most installed natural gas units are stoichiometric, though newer units, especially in larger sizes, focus on lean-burn technology which allows for increased efficiency and lower emissions from the combustion chamber. Table 2-1 summarizes some of the development issues that are currently a focus of major engine manufacturers. The developments all center around meeting the main goals of increased efficiency and lower NO_x emissions. Other areas of research to better understand, monitor, and control the combustion process include modeling, sensors, and controls.

Table 2-1. Key Development Issues for Micropower Reciprocating Engines

Issue	Developments
Stoichiometry	Much current development work is centered on lean-burn technologies for natural gas engines. Lean-burn engines have much higher efficiencies than conventional, stoichiometric engines. Lean-burn engines also offer lower NO_x emissions out of the combustion chamber mostly due to reduced peak combustion temperatures. Stoichiometric engines often have three-way catalyst exhaust after-treatment that lowers NO_x levels beneath those achievable in lean-burn engines. Three-way catalysts need exhaust oxygen content to be in a very narrow range close to stoichiometric levels and are therefore not effective in lean-burn engines with higher levels of oxygen in the exhaust. Research is ongoing to achieve cost effective NO_x emissions reducing catalysis for lean-burn engines. Another difficulty in lean-burn engines is getting the lean mixtures to ignite. Design implements that can be employed to overcome this difficulty include adding a precombustion chamber and influencing combustion chamber airflow.
Ignition	Most diesel and dual-fuel engines are compression ignited. Some advanced diesels and all gasoline and natural gas units are spark ignited. High efficiency engines will operate at higher pressure levels which will require high-energy spark ignition systems with durable components. Glow plugs and lasers are also employed as ignition sources for natural gas engines. Laser ignition has the potential to improve fuel efficiency and lower emissions by improving ignition timing and placement in addition to reducing maintenance requirements and increasing reliability.
Aspiration	Effective turbocharging is key to increasing Brake Mean Effective Pressure (BMEP) which leads to increased efficiency. Turbocharged engines which compress intake air before injection into the combustion cylinder can achieve a greater power to size ratios (power density), allowing the unit to be sited in a smaller area and/or lessening foundation reinforcement requirements. The pressure ratio of a typical turbocharger ranges from 1.5 to 4. Naturally aspirated engines take intake air in at atmospheric pressure, and thus have a lower power density. Turbocharging is especially important for lean-burn engines which require high air to fuel ratios. Increased turbocharging coupled with improved ability to ignite lean mixtures will be key to efficient lean-burn engines.
Combustion Chamber Design	Combustion chamber design is important to the efficient and complete combustion of fuels and the reduction of NO_x emissions. Advances such as a precombustion chamber to mix air and fuel or partially combust fuel prior to introduction into the main combustion chamber may be key to successful low NO_x, lean-burn engines.
Cylinder Head/Valves	Cylinder head and valve design has significant influence on engine power, efficiency, and emissions. Intake systems need to provide substantial airflow to produce proper airflow patterns to facilitate combustion. Exhaust systems must be designed to allow the exhaust to be pumped out of the cylinder with a minimum of work and minimal heat transfer to the cylinder head and coolant.
Fuel Injection/Timing	How fuel is injected and when in the cycle it is injected play important roles in how the fuel is combusted and therefore influence power, efficiency, and emissions.

Microturbines

Microturbines are an emerging class of small-scale power generation technology in the 25-300 kW size range. The basic technology used in microturbines is derived from aircraft auxiliary power systems, diesel engine turbochargers, and automotive designs. A number of companies are currently field-testing demonstration units, and commercial units are available from several manufacturers. There are currently four manufacturers of microturbines and another six potential manufacturers examining the market. This contrasts with over 40 manufacturers of large industrial turbines.

Courtesy of Allied Signal Power Systems

Figure 2-3. Allied Signal 75 kW Microturbine

<u>Representative Manufacturers</u>
AlliedSignal Power Systems
Bowman Power Systems
Capstone Turbine Corp.
Elliot Energy Systems
Northern Research and Engineering Corporation

Simple microturbines consist of a compressor, combustor, turbine, and generator. The compressors and turbines are typically radial-flow designs, and look much like automotive engine turbochargers. Most designs are single-shaft and use a high-speed permanent magnet generator producing variable voltage, variable frequency alternating current (AC) power. An inverter is employed to produce 60hz AC power. One manufacturer's design uses a split shaft. Most microturbine unit designs are currently designed for continuous-duty operation and are recuperated to obtain higher electric efficiencies. Air bearings reduce system complexity and are employed by several of current microturbine manufacturers.

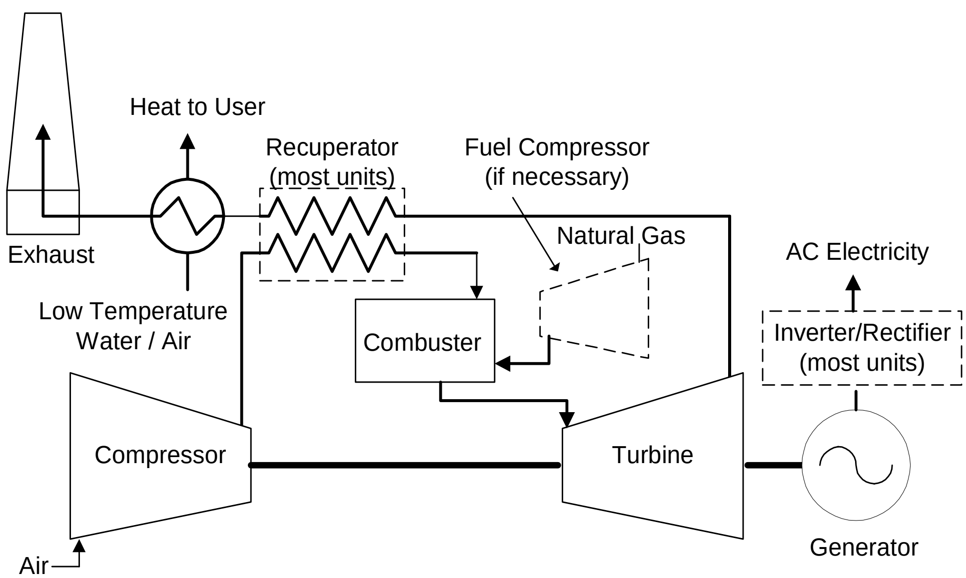


Figure 2-4. Schematic of a Typical Microturbine

Microturbines have good fuel flexibility and can be run in conjunction with gasifers which can provide gaseous fuels for the microturbine from liquid or, more commonly, solid fuels or wastes. When microturbines are run on natural gas, as they are most commonly, they often require a gas compressor to deliver fuel into the combustion chamber at specified pressures. Key development issues are summarized in Table 2-2.

Table 2-2. Key Development Issues for Microturbines

Issues	Developments
Recuperation	Recuperators are air-to-air heat exchangers that use a microturbine's hot exhaust gases to preheat the combustor inlet air after it has been compressed. Recuperators are key to the electrical efficiency of microturbines. With recuperation electric efficiencies are typically 26-32% versus 15-22% for non-recuperated units. To attain higher levels of efficiency, higher engine temperatures and hence, improvements in recuperator materials (i.e. ceramics) may be necessary.
Single Shaft vs. Split Shaft	Two different ways of producing AC power with microturbines are currently being evaluated in the demonstration units. The first and more common uses a single shaft with a high-speed permanent magnet generator spinning at the same speed as the turbine. This generator produces very high-frequency AC power that must be converted to 60 Hz using an inverter. The second design uses a two-shaft configuration with a reduction gearbox and a 2-pole, 3600 rpm induction generator that directly produces 60 Hz power and does not require an inverter. The development of the single-shaft has allowed for simpler design and construction which can lead to reduced maintenance requirements. However, split shaft design is necessary for mechanical drive applications.
Air Bearing vs. Oil-Lubricated	Microturbines are high-speed (40,000+ rpm) rotating equipment that require high-reliability bearing systems. Two different configurations are currently being used. The first uses air bearings with a compliant foil system that requires no oil lubricant. The second uses a pressurized lube-oil system with a pump, similar to that used by a car engine. Systems with air bearings eliminate the oil system and are simpler, require less maintenance, and have no parasitic oil pump load. However, oil bearings generally last longer and are perceived by many to be less prone to catastrophic failure, especially in situations when turbine power is ramped up and down frequently.
Gasifiers	Gasifiers produce gaseous fuel from solids, such as coal and biomass. Small-scale gasifiers for use with microturbines are still in the development stage. Gasifiers could help microturbines gain wider acceptance, especially in international markets and where no natural gas supply exists. Gasifiers potentially also can lower operation costs by allowing the microturbine to be run on less expensive fuels. However, gasifers generally use fuel with impurities and/or contaminants, and thus require expensive fuel gas cleanup that can severely compromise efficiency.
Power Electronics	Cost of electronics for power conditioning and grid connections is high. Standard interconnect or mass production may help reduce these costs.
Microturbine / Fuel Cell Hybrids	Power generation systems utilizing fuel cells combined with microturbines are also being developed by several manufacturers. These systems typically run the hot gas produced by certain types of fuel cells (primarily SOFC) through a microturbine to generate additional electricity. Hybrid systems are predicted to have exceptionally high electric efficiencies (60%+).

Fuel Cells

Courtesy of ONSI Corporation

Figure 2-5. ONSI 200kW Phosphoric Acid Fuel Cell

Fuel cells are an emerging class of small-scale power generation technology in the 25-1000+ kW size range. The first fuel cell was developed in 1839 by Sir William Grove. However they were not used as practical generators of electricity until the 1960's when installed in NASA's Gemini and Apollo spacecraft. One company, International Fuel Cells/ONSI, currently manufactures a 200 kW fuel cell that is being used in commercial and industrial applications. A number of other companies are currently field testing demonstration units, and commercial deliveries are expected to begin in 1999. Although fuel cells were first designed as purely electric generators, there are transportation applications. Automobile manufacturers through in-house R&D and alliances with fuel cell manufacturers are increasingly funding fuel cell development. Currently most transportation fuel cell efforts focus on Proton Exchange Membrane (PEM) fuel cells which have a good power to volume ratio. PEMs also have some potential for providing residential power. However, for the most part, fuel cells primarily used for power generation such as Phosphoric Acid and Molten Carbonate, are not suited for transportation use.

There are a number of types and configurations of fuel cells, but they all use the same basic principle. A fuel cell consists of two electrodes separated by an electrolyte. Hydrogen fuel is fed into the anode of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode. With the aid of a catalyst, the hydrogen atom splits into a proton and an electron. The proton passes through the electrolyte to the cathode. As they flow through an external circuit connected as a load the electrons create a DC current as they return to the cathode. At the cathode, electrons combine with hydrogen and oxygen producing water and heat. The part of a fuel cell that contains the electrodes and electrolytic material is called the "stack" which is major component of the cost of the total system. Stack replacement is very costly but becomes necessary when efficiency degrades as stack operating hours accumulate.

Representative Manufacturers
ONSI
Ballard Generation Systems
Energy Research Corp.
M-C Power
SOFCo
TMI
Siemens Westinghouse
Energy Partners
Analytic Power
H-Power
Electrochem Inc.
Mechanical Technology Inc.
Dai Fuel Cells

Fuel cells require hydrogen for operation. Since it is often impractical to use hydrogen directly as a fuel source, it must be extracted from other hydrogen-rich sources such as gasoline or natural gas. Cost effective, efficient fuel reformers that can convert various fuels to hydrogen are necessary to allow fuel cells increased flexibility and better economics. Fuel cells have very low levels of NO_x and CO emissions, all resulting from the reforming process. Using gasifiers to produce hydrogen fuel from sources such as biomass could help to increase flexibility and market share of fuel cells.

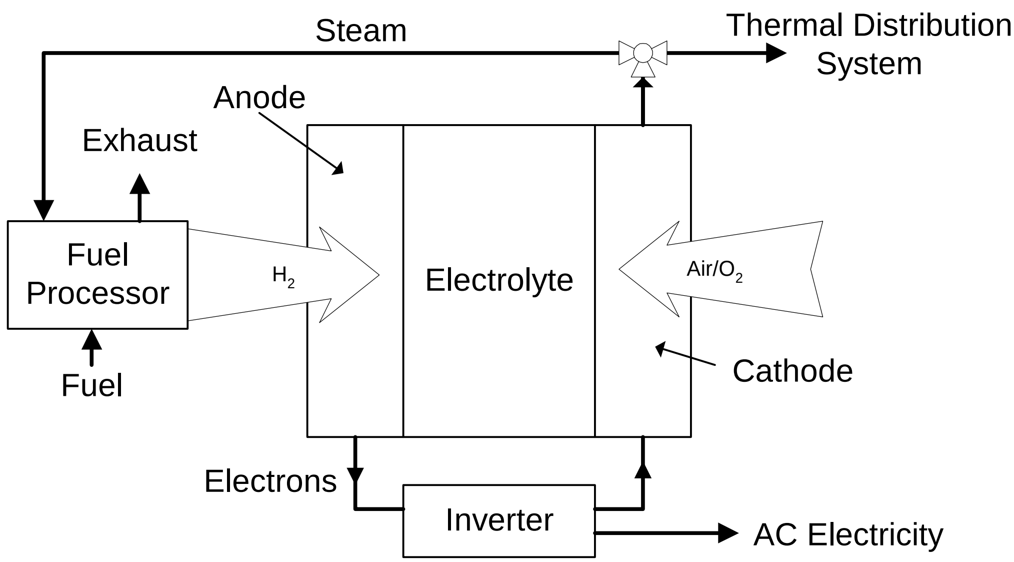


Figure 2-6. Schematic of a Typical Fuel Cell

The main differentiation among fuel cell types is in the electrolytic material. Each different electrolyte has benefits and detriments based on cost, operating temperature, achievable efficiency, power to volume (or weight) ratio, and other operational considerations. Currently only Phosphoric Acid fuel cells are being produced commercially for power generation. Other types have entered the testing and demonstration phase. Unlike the development other micropower technologies, fuel cell development is focused more on getting units to work and demonstrating effectiveness rather than refining current models. Table 2-3 summarizes key issues for the different fuel cell types.

Table 2-3. Key Issues for Micropower Fuel Cells

Configuration	Explanation
Phosphoric Acid	Phosphoric acid fuel cells generate electricity at around 40% efficiency – and nearly 85% if steam this fuel cell produces is used for cogeneration. Operating temperatures are in the range of 400°F. Phosphoric Acid Fuel Cells are fed with a hydrogen-rich gas in the anode, where gaseous hydrogen is oxidized to proton and electron. This proton then travels through a matrix layer, made of Teflon-bonded silicon carbide, soaked with phosphoric acid, to the cathode where it combines with oxygen and free electrons to produce water. Hydrocarbon fuels are steam reformed to produce required hydrogen gas. Since a PAFC system operates at a relatively high temperature, water and heat rejection is easier than for other technologies.
Proton Exchange Membrane	These cells operate at relatively low temperatures (about 200°F), have high power density, and can vary their output quickly to meet shifts in power demand. Most units being developed are for small-scale applications like those found in the transportation and residential sectors. The PEM fuel cell uses a proton exchange membrane (also know as polymer electrolyte membrane) sandwiched between two electrodes to form the fuel cell. The membrane is made of polyperfluorosulfonic acid, and is somewhat similar to DuPont Teflon. This material is used in fuel cells for its ability to conduct hydrogen atoms. PEM fuel cells operate at lower temperatures than most other fuel cells, and they contain no harsh chemicals, such as liquid acids or bases. This makes this type of fuel cell compatible with many common engineering materials.
Molten Carbonate	Molten carbonate fuel cells promise high fuel-to-electricity efficiencies and the ability to consume coal-based fuels. This cell operates at about 1200°F (up to 1400°F). Molten carbonate stacks have been proven, and demonstration units are currently being tested. Molten carbonate fuel cells are most applicable to large industrial and central station electricity generation. Minimal polarization losses allow the cells to use less expensive, non-noble metal catalysts. Because of their high operating temperature MCFCs also produce high quality waste heat, which can be used in fuel processing and cogeneration.
Solid Oxide	Another highly promising technology, the solid oxide fuel cell, could be used in big, high-power applications including industrial and large-scale central electricity generating stations. Small units (25-100 kW) are currently being demonstrated. A solid oxide system usually uses a hard ceramic material instead of a liquid electrolyte, allowing operating temperatures to reach 1,800°F. Power generating efficiencies could reach 60%. One type of solid oxide fuel cell uses an array of meter-long tubes. Other variations include using compressed discs. Carbon monoxide can also be used instead of hydrogen in these fuel cells to produce carbon dioxide and electrons in the anode.
Microturbine / Fuel Cell Hybrids	Power generation systems utilizing fuel cells combined with microturbines are also being developed by several manufacturers. These systems typically run the hot gas produced by certain types of fuel cells (primarily SOFC) through a microturbine to generate additional electricity. Hybrid system are predicted to have exceptionally high electric efficiencies (60%+).

Micropower Price and Performance

While price and performance data on reciprocating engines is fairly well established, data for microturbines and fuel cells is based on a limited number of demonstration projects. As a result, comparisons of price and performance should be interpreted with some uncertainty. The price and performance of engines, microturbines, and fuel cells is characterized by Table 2-3. This information was collected from a number of manufacturers and their distributors, and has been presented for review at a number of DOE workshops. The market analysis presented in the next section is based on representative units taken from this data.

Table 2-4. Cost and Performance of Micropower Technologies

Technology	Engine	Microturbine	Fuel Cell
Size	30kW – 60MW	30-200kW	100-3000kW
Installed Cost ($/kW)[1]	200-800	350-900	900-3300
Elec. Efficiency (LHV)	27-38%	15-32%	40-57%
Overall Efficiency[2]	~80-85%	~80-85%	~80-85%
Variable O&M ($/kWh)	.0075 - .02	.004-.01	.0019-.0153
Footprint (sqft/kW)	.22-.31	.15-.35	.9
Emissions (lb / kWh unless otherwise noted)	Diesel: NO_x: .022-.025 CO: .001-.002 NG: NO_x: .0015-.037 CO: .004-.006	NO_x: 3-50ppm CO: 3-50ppm	NO_x: <.00005 CO: <.00002
Fuels	Diesel, NG, gasoline; larger units can use dual fuel (NG/Diesel) or heavy fuels	NG, diesel, kerosene, naphtha, methanol, ethanol, alcohol, flare gas	NG, propane, digester gas, biomass and landfill gas

[1]Cost varies significantly based on siting and interconnection requirements, as well as unit size and configuration.
[2]Assuming CHP

Keys to the successful market penetration of micropower technologies were determined from a variety of sources, with additional input from the Advanced Stationary, Reciprocating Natural Gas Engine Workshop (San Antonio, Texas – January 1999) and Microturbine Technology Summit (Orlando, Florida – December 1998) and are discussed below.

Both microturbines and fuel cells are challenged by an unproven track record. More operational hours and better reporting of data are needed to prove these technologies. Microturbines are still an emerging technology, and have had limited field-testing. Data on longevity, actual efficiencies, and O&M costs of tested units are not widely known, and in many cases, complete and reliable information is not available. Fuel cells, especially developing variations such as the solid oxide fuel cell, are affected by the same limitations. This uncertainty makes it difficult for an accurate comparison to be made between microturbines, fuel cells, and other options. These technologies will continue to fight an uphill battle against the "tried and true" alternatives of purchasing grid power or a reciprocating engine genset until more data from field tests becomes available and they meet or surpasses current expectations.

Some of the critical price and performance issues are as follows:

Installed Cost. Installed cost is a critical consideration for many sites, and drives the economics of on-site generation. As the incumbent technology, *reciprocating engine* manufacturers must continue to reduce prices, especially if microturbine and fuel cell manufacturers meet their cost targets. *Microturbines*, on average, are currently more expensive than competing reciprocating engine units, but are projected to become lower within the next five years. Meeting these cost projections will be crucial to obtaining market share outside of areas where microturbines have an advantage from lower emissions. Supplemental equipment needed for fuel processing, gas compression, recuperation, and control systems is a significant portion of overall costs, so improvements here may go a long way toward meeting overall price targets. *Fuel cells* have, by far, the highest capital costs of micropower options. Substantial cost reductions are needed to allow fuel cells to compete with other generating technologies and the grid.

A key contributor to installed costs is the interconnection package. Connecting a genset to the grid can be very costly. The cost for engineering and equipment necessary to meet utility interconnection requirements can vary substantially from utility to utility, and may increase capital costs significantly. Additionally, since many of these costs are often fixed, price per kW is very high and often prohibitive for smaller units. These costs are likely to be reduced as the Institute of Electrical and Electronic Engineers (IEEE) is working toward standardizing interconnection as mandated by federal legislation. For *fuel cells* and most *microturbine* designs, direct current power is produced by the unit which must be converted to AC power, thus creating power quality concerns for some host utilities and introducing potential complexity for these manufacturers

Efficiency. For *engines*, electrical efficiency is high compared to microturbines. Improvements in design of combustion chamber, cylinder heads, and fuel injection are slated to increase BMEP and improve efficiency and emissions. This may prove to be necessary if the cost of fuel cells becomes competitive. *Microturbines* currently possess the lowest electrical efficiency of the micropower options. Improved recuperator designs and materials are crucial to increasing efficiency. Increasing electric efficiency to 40% or greater will almost certainly require effective recuperation or multi-staged designs, and is important to microturbine success. Additionally, incorporating high temperature materials such as ceramics can allow microturbines to operate at higher temperatures and increase maximum achievable efficiency. *Fuel cells* promise to offer the highest efficiency of all micropower options, but again are challenged by lack of demonstrated performance. For each of these options, better efficiency also means lower emissions, particularly carbon emissions, which is critical for success in the U. S. market.

Emissions. *Engines* have higher emissions of CO, NO_x, and particulates than competing technologies and are thus at a disadvantage in geographic areas with stringent emission criteria, or when the customer wants to be perceived as "green." Using catalysis to reach acceptable emissions levels is often expensive. *Microturbines*, like larger turbines, have a strong advantage over engines in terms of emissions. Current expectations for NO_x emissions are already below those of engines, and future improvements call for single digit emissions (ppm). Coupled with the fact that areas with strict emission limits tend to have relatively high electricity costs, low emission units will have a strong advantage in gaining market share. *Fuel cells* by nature of their lack of a combustion process have extremely low emissions of NO_x and CO. As emissions standards become increasing stringent, fuel cells will offer a clear advantage, especially in severe non-attainment zones. Fuel cell CO_2 emissions are also generally lower than other technologies due to their higher efficiencies.

Reliability / Availability. *Engines* require more periodic maintenance than competing technologies and thus have more mandatory downtime. Due to the often very high cost for utility backup power, downtime can be very expensive. In addition, reliance on outside service providers or in-house staff for this maintenance can be a concern for some facilities. *Microturbines* have the potential to have lower maintenance requirements than engines due to their simpler construction and few moving parts. However the longevity of the main components has not been fully proven and currently projected maintenance costs of approximately 1 cent / kWh are nearly the same as for engines. If these units can achieve the 0.4 cents / kWh level of larger turbines they could become much more competitive with reciprocating engines. *Fuel cells*, themselves, have no moving parts and therefore have the potential to have very low maintenance. However, support systems such as pumps and fans necessary for the operation of the fuel cell can be costly to maintain and result in increases in both scheduled and unscheduled downtime. Also stack replacements, required at 40,000 hours (estimated) to keep efficiency high, add significantly to maintenance cost. Again, both microturbines and fuel cells have not been demonstrated long enough to validate these expectations.

Useful Thermal Output. From *engines*, usable thermal output comes from the jacket water, exhaust gases, and the oil. The ability to capture and utilize all available thermal output is dependent on effective heat exchangers and conducive site thermal load. In order for a majority of an engine's thermal output to be utilized, the output must be used for either hot water or low temperature steam. All *microturbine* thermal output is in the exhaust, which gives it an advantage over engines in that heat recovery is from only one stream. Microturbines thus have a greater potential to generate steam, and can be advantageous in sites with high steam requirements. However, as with engines, some of the microturbine thermal output needs to be utilized in the heating of relatively low-temperature water to achieve high overall efficiencies. In addition, recuperated units have relatively low exhaust temperature and cannot produce significant amounts of steam. Currently, only one microturbine offers a packaged cogeneration system. Some *Fuel cells* are designed to produce heat of higher quality than are reciprocating engines or even turbines. Fuel cells are better suited than engines or turbines to meet the thermal needs of sites with a high quality steam demand.

Future Improvements

Based on technical literature and interaction among manufacturers and other industry participants during the workshops, expectations of future cost and performance improvements were formulated (see Figures 2-6 and 2-7). Each micropower technology is expected to improve substantially in the next 5 to 10 years and could result in significantly improved economics and greater market potential.

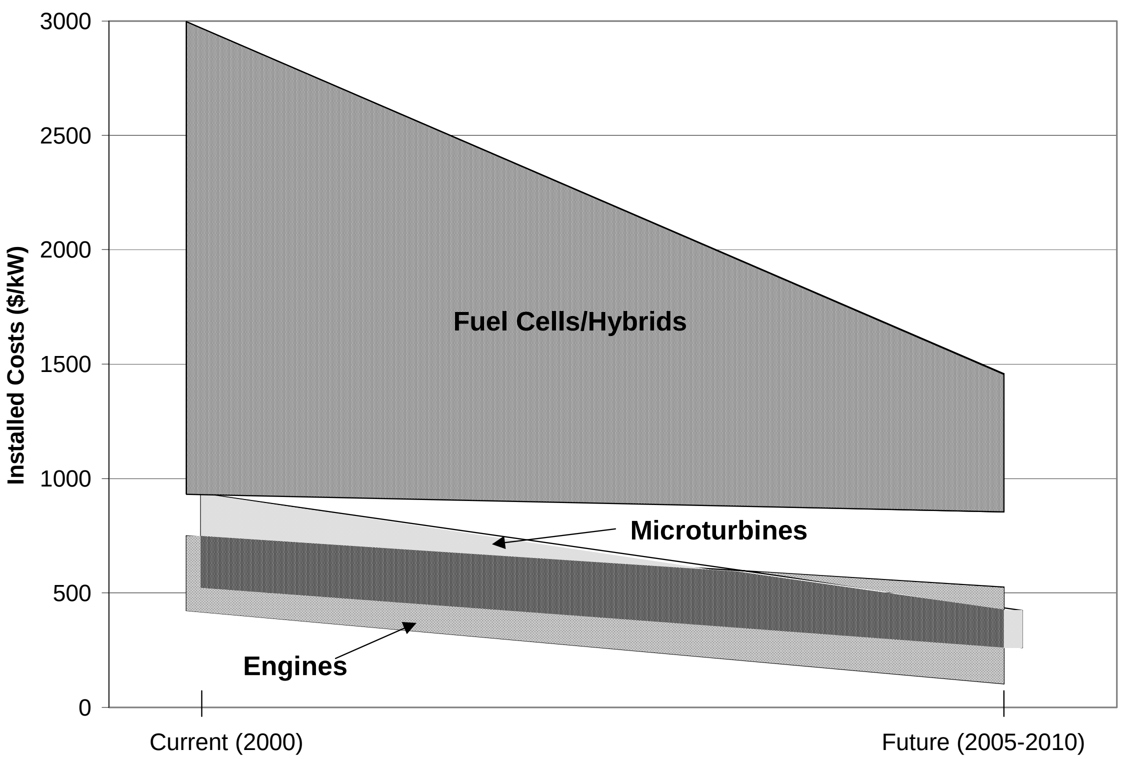


Figure 2-7. Expectations of Current and Future Installed Costs

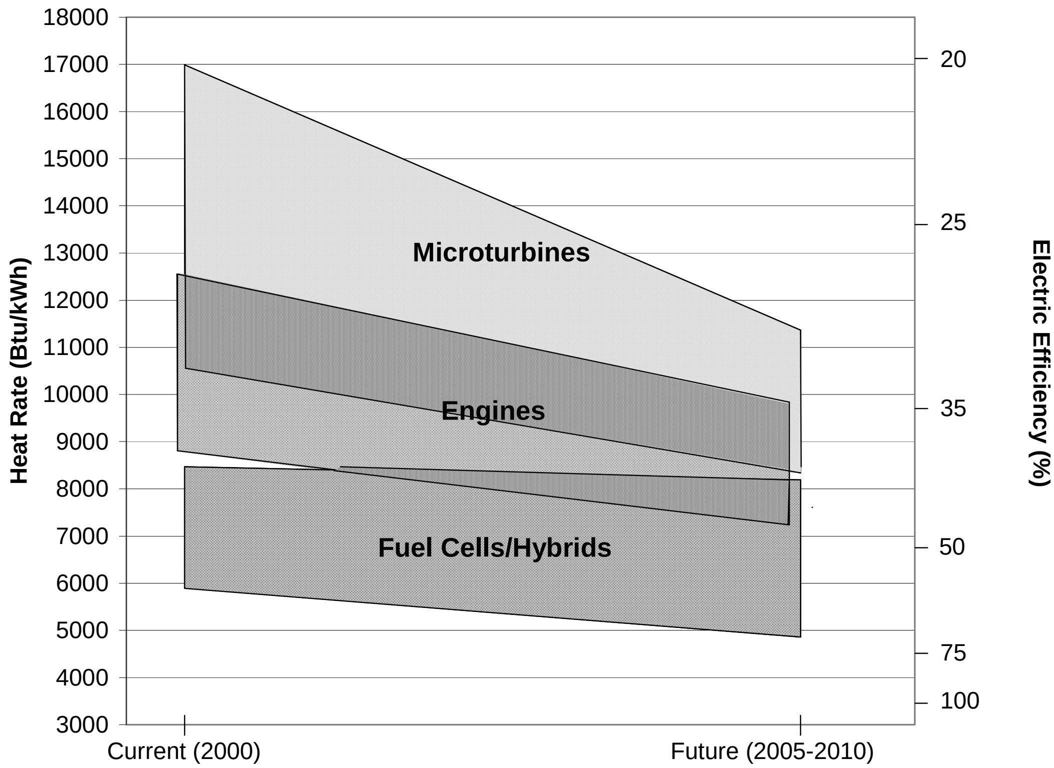


Figure 2-8. Expectations of Current and Future Heat Rates

Section 3
MARKET POTENTIAL FOR MICROPOWER

Due to their small size, economic capital cost, useful thermal output, and ability to adjust relative thermal to electric output, micropower technologies can be used for a variety of potential applications, including:

- **Continuous Power**. This application requires power on a nearly continuous basis, typically at least 6,000 hours per year. Competing grid price, as well as installed cost of the unit largely drives these applications. Operating cost, power quality, and reliability of grid power are each contributing factors. In non-attainment areas, emissions can provide a strong barrier to these applications.

- **Combined Heat and Power (CHP)**. CHP applications utilize the otherwise wasted exhaust heat as useful thermal output, typically steam. Again, grid price provides a strong driver, as well as installed cost. As with continuous power applications, these units will run on a nearly continuous basis, typically at least 6,000 hours per year. In non-attainment areas, emissions can provide a strong barrier to these applications.

- **Peak Shaving**. Driven primarily by high utility demand charges, peak shaving applications (sometimes called peak clipping) are also affected by installed cost, perceived unit reliability, and low fuel prices. These units operate much less frequently than do continuous power or CHP applications, and are used as few as several hundred hours annually.

- **Standby/Emergency Generation**. Applications requiring standby or emergency power are typically driven by the reliability (perceived or real) of the grid. Some business types (hospitals, airports, etc.) are required by code to install and maintain these units. For others, high cost of outage drives the application. Other factors which affect their application are installed cost, time required to start (i.e. black start response), fuel access/storage, and size/weight of unit.

- **Mechanical Drive**. Shaft-driven equipment such as gas compressors, air compressors, refrigeration units, chillers, and pumps can be directly driven by micropower units with the exception of fuel cells. Grid price, demand charges, and fuel availability drive these applications. Barriers include installed cost, maintenance frequency, and efficiency/operating cost.

Other potential uses of micropower technologies include direct current (DC) power and “green” power applications. Fuel cells initially generate DC power, and later convert it to AC grid power. Additionally, several microturbine designs generate DC power prior to grid synchronized AC power. Some applications, including welding and semiconductor production, require DC power that is usually produced from grid power with added expenses for power electronics required. Alternatively, fuel cells or microturbines could serve these applications. In addition, "Green" power has been successfully marketed in parts of the country, and fuel cells, with their near-zero emissions, may be attractive to users that value a positive environmental reputation.

Given the study objectives of assessing the potential to reduce national energy use and emissions, the focus of the analysis was on both continuous power and combined heat and power (CHP) applications. The peak shaving, standby, mechanical drive, and niche applications all remain potential markets for equipment manufacturers, but due to either limited hours of operation or a small number of potential applications, these applications were not targeted by the market potential analysis. A follow-up effort, slated for publication in 2000, will examine the market for shaft power as well as larger (>1 MW) units.

Market Potential Projections

To determine the micropower potential in the U. S. industrial sector, the distributed generation model was configured to evaluate a wide range of units up to 1 MW in size. The model was directed to focus on those units that are either available now or are planned for production by year 2000 (current scenario) or are planned for production by year 2005-2010 (future scenario). Table 3-1 provides a description of the units that were considered for each size range within the micropower market. For reciprocating engines and microturbines, substantial improvements in price and performance were projected for the future scenario, as well as the emergence of solid oxide fuel cells and fuel cell hybrids. Appendix A details the cost and performance data used for the analysis.

Table 3-1. Micropower Options Evaluated

Size Range (kW)	Technologies Considered
30-74	50 kW reciprocating engine and microturbine
75-149	100 kW reciprocating engine and microturbine (solid oxide fuel cell added for future scenario)
150-249	200 kW reciprocating engine and microturbine (solid oxide fuel cell, fuel cell/microturbine hybrid added for future scenario)
250-749	500 kW reciprocating engine and microturbine (solid oxide fuel cell, fuel cell/microturbine hybrid added for future scenario)
750-1000	1 MW reciprocating engine, miniturbine, and phosphoric acid fuel cell (solid oxide fuel cell/microturbine hybrid unit added for future scenario)

The analysis determines not only whether on-site generation appears to be more cost effective than purchasing from the grid, but also which technology and size appears to be the most economical. As a result, double counting of market potential for a variety of competing technologies is avoided. Using data on number of facilities in each size range in each state, the number of potential applications is then determined. Appendix A provides a discussion of the model inputs, analysis, and outputs.

Key assumptions inherent in this approach are:

- **Facilities will make an economic purchase decision**. While some facilities make purchases based on first cost, the industrial sector in general applies a more sophisticated approach to its decision making. In addition, it should be noted that many facilities use a capital budgeting process that could affect whether a micropower investment makes better business sense that other potential investments. Furthermore, growth industries are more likely to invest in growing the business, rather than adopt cost saving measures such as on-site generation.

- **Micropower units will apply to smaller facilities**. Larger facilities have a host of power generation options (such as larger turbines and reciprocating engines) available to them that offer, in general, superior economics to micropower. Thus, the analysis focuses on the smaller facilities that have no such options. While it is anticipated that some larger facilities will adopt micropower units to supplement existing generation, the methodology makes no provisions for these units.

- **In the current scenario, thermal and electric loads will remain unchanged**. While it is acknowledged that a facility's thermal and electric loads will change over time, the amount of change is unknown and depends on many factors. These factors include adoption of efficiency measures, replacing steam heated equipment with either electrically driven or direct fired units, growth/decline in production levels, or change in product slate. These factors are extremely industry- and site-specific, and no adjustments have been made in the current scenario to account for such changes. The future scenario includes efficiency improvements, which in turn decrease facility energy demand.

Other assumptions that have been made are described in Appendix A.

As shown in Table 3-2, the market potential for both continuous power and CHP applications of micropower in the U. S. industrial sector is estimated at 10 GW of capacity by year 2010. This total could increase twofold to almost 24 GW by 2010, assuming that units meeting these future cost and performance targets are available by year 2000, and the industrial base grows and efficiency improvements are realized as is forecasted. Similarly, the number of potential unit sales is estimated at almost 40,000 units, with sales projected to more than double to 94,000 units if future cost and performance expectations are met. These figures represent the total achievable economic potential, with the market penetration expected to be a portion of the potential market. The actual market penetration will depend on a number of factors, including the growth in the economy, improvements in unit cost and performance, and removal of both technical and market barriers that exist (see Section 4).

Table 3-2. Estimated and Projected Market Potential for Micropower

Application	Capacity (MW)		Number of Units	
	Current Unit Performance	Future Unit Performance	Current Unit Performance	Future Unit Performance
Continuous Power	850	1,350	2,700	4,500
Combined Heat and Power	8,850	22,250	34,500	89,100
Total	9,700	23,600	37,200	93,600

In addition, Table 3-2 shows that the dominant application in the U. S. industrial sector is combined heat and power. These applications represent over 90 percent of the market potential for installed capacity and new unit sales, and the potential for almost 9 GW of new CHP applications. With the future scenario, this potential grows to over 22 GW of new CHP capacity.

Figure 3-1 illustrates the composition of the market potential, in terms of micropower technology and unit size. From this figure, it is apparent that reciprocating engines dominate the market, with competition from turbines only in the 50 kW and 1 MW size ranges. This is consistent with the microturbine manufacturers' statements regarding strategy, which has been to focus on the U. S. commercial sector and later on international applications. Most of the current microturbine units that are planned for distribution in 1999 are not configured for combined heat and power (one manufacturer had partnered with an overseas firm to develop combined heat and power packages).

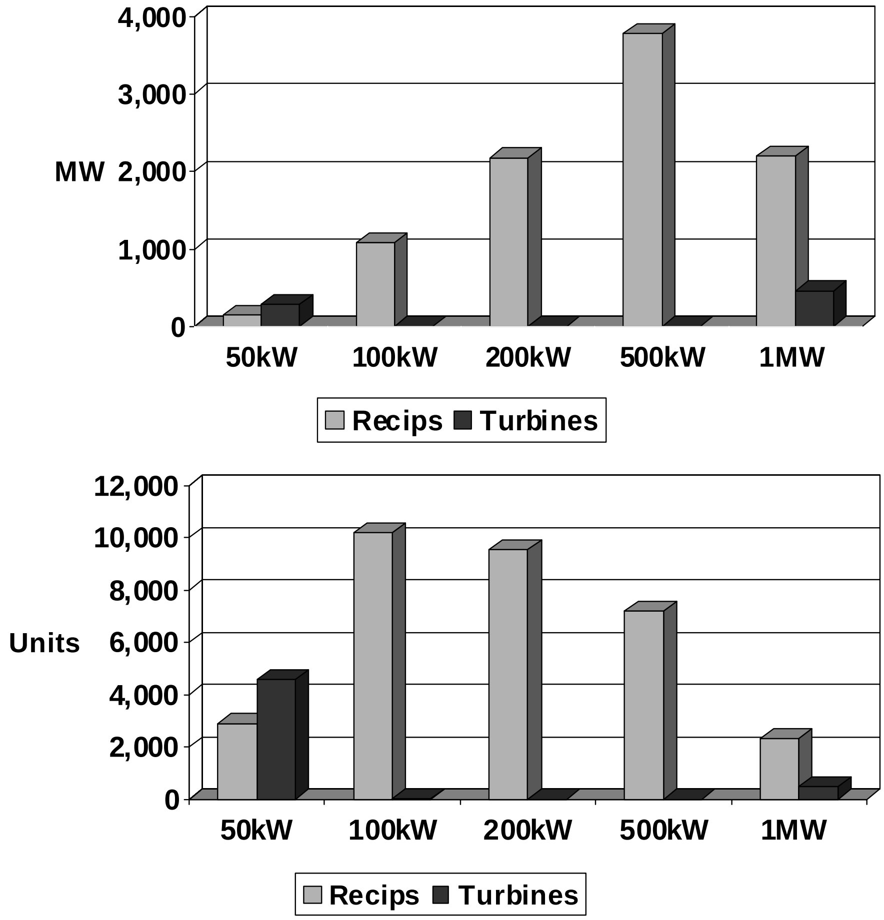


Figure 3-1. Market Potential for Micropower Technology, by Unit Type and Size Range (Current Scenario)

In addition, the microturbine units that are currently slated for distribution are all in the 50 kW size range, and thus are not as competitive with larger reciprocating engines. In the larger (750kW – 1 MW) size range, smaller industrial class turbines, or "miniturbines" are somewhat competitive with the megawatt class reciprocating engines. Overall, within the micropower size range and using current estimates of unit performance, reciprocating engines hold a small but significant advantage over microturbines in terms of electrical efficiency and cost, whereas microturbines offer a higher overall efficiency (thermal and electrical efficiency combined). The analysis revealed that fuel cells are not competitive with these two options when economics alone are considered, using current estimates of cost and performance. Fuel cells appear to be competitive only when installed costs can be lowered to be competitive with other micropower options.

When expectations of future cost and performance are realized, the market potential increases significantly, doubling both in terms of potential capacity and new unit sales.

As illustrated by Figure 3-2, performance improvements could enable microturbines to make more inroads in the 50 kW, 100 kW, and 200 kW size ranges. Again, fuel cells and hybrids are expected to be limited by economics due to high installed cost.

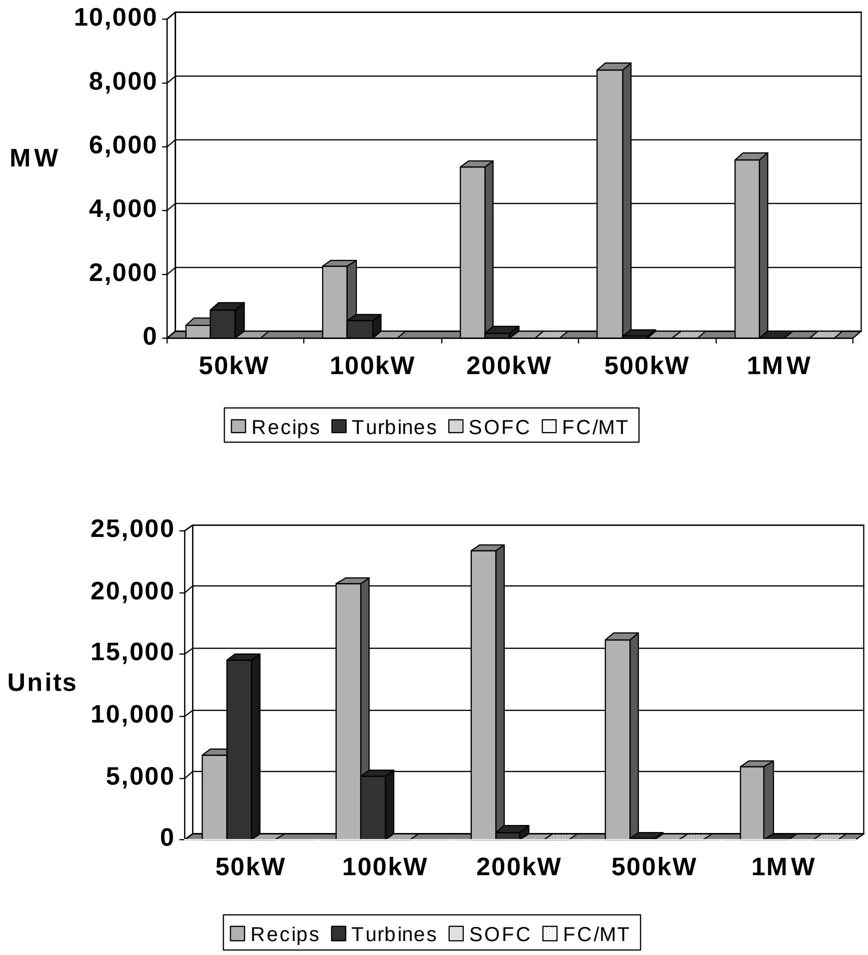


Figure 3-2. Market Potential for Micropower Technology, by Unit Type and Size Range (Future Scenario)

Regional Analysis

The distributed generation model provides regional results which facilitates a state-by-state analysis of the micropower market potential. As shown in Figure 3-3, sites in California dominate market potential. New York and New Jersey follow, with Massachusetts and Pennsylvania rounding out the top five. The next three are Illinois, Texas and Connecticut, the order of which varies depending on potential capacity or new unit sales. After these eight, the state potential drops off quite a bit.

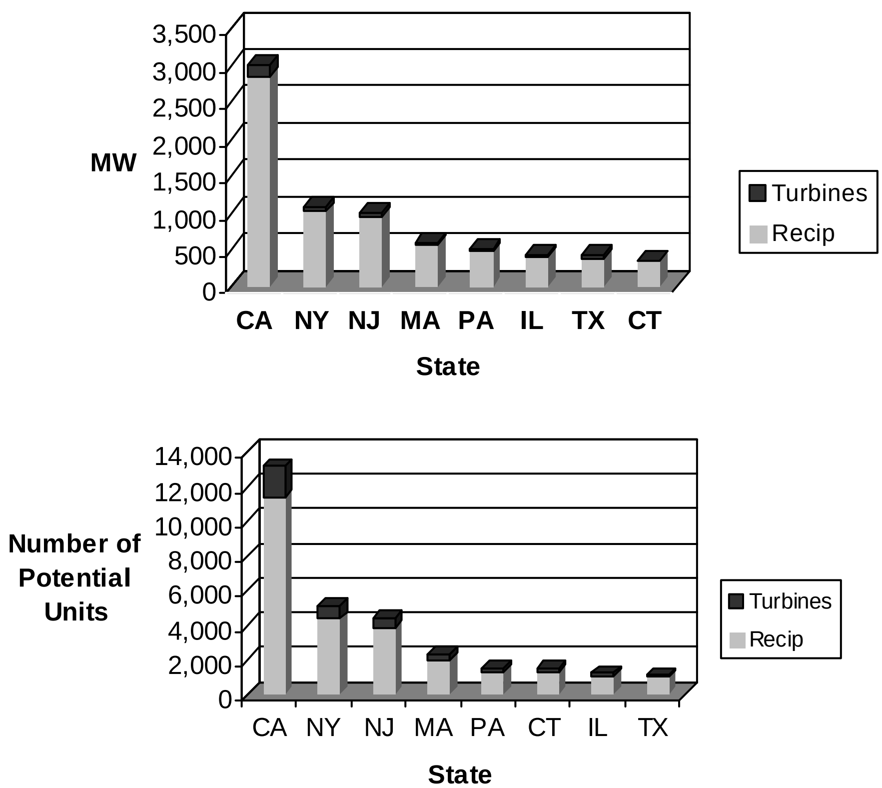


Figure 3-3. Top States by Micropower Market Potential

Much of this market potential can be attributed to higher than average electric prices as compared with gas prices: high electricity prices value output and low gas prices reduce operating cost. The top states shown in Figure 3-3 are states with these characteristics.

Figure 3-4 illustrates the electric and gas prices using a term coined in wholesale energy markets: "spark spread". Spark spread is defined as the difference, or spread, between grid electricity prices and the fuel cost necessary to generate electricity using natural gas. Figure 3-4 illustrates the "spark spread" for micropower technologies in these states, using a typical microturbine as the generating option. This figure shows that the top states offer from 3 to 5 cents per kilowatt-hour spread in a continuous power application, and when the value of the byproduct thermal output is considered (the CHP spread), the spread climbs even higher. States such as Pennsylvania, while not offering much of a continuous power spread, offer significant CHP spreads. Ohio was added as an example of a state without a significant spark spread. Not coincidentally, most of these top states (excluding Ohio) have made significant progress towards electric industry restructuring.

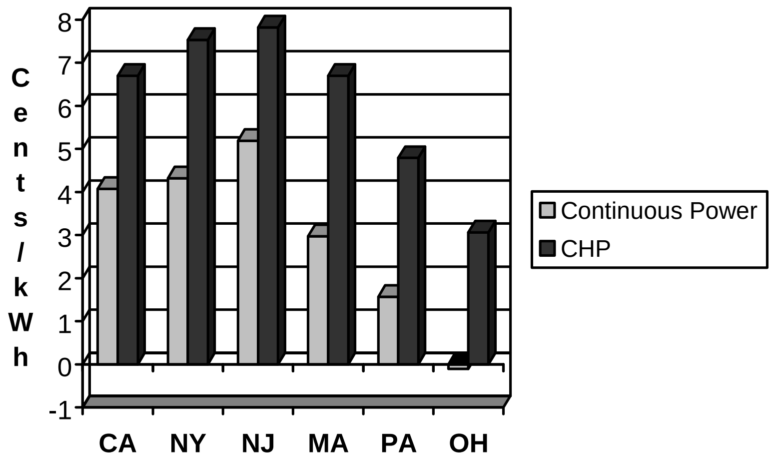
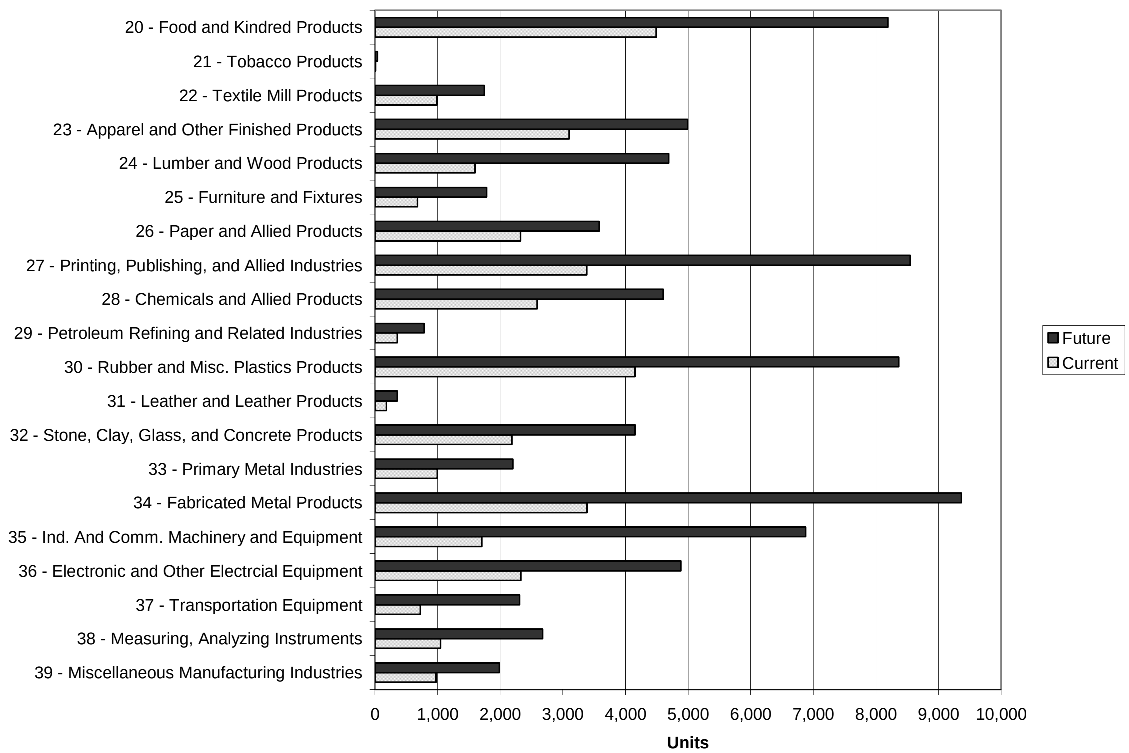


Figure 3-4. "Spark Spreads" for Top Micropower States

Industry Analysis

To date, industrial power generation has been concentrated in industries with high combined heat and power potential. These facilities generally have high steam demands and/or available waste fuels, and are led by pulp and paper (SIC 26), chemicals (SIC 28), petroleum refining (SIC 29), primary metals (SIC 33), and food (SIC 20) (Source: MECS 1994). While these industries continue to show potential for micropower, especially food, chemicals, and paper, they do not dominate the industrial sector. Figure 3-5 illustrates that, in terms of potential new capacity for micropower with current unit cost and performance, rubber/plastics (SIC 30) is the leader, along with food.   Others top industries include chemicals, fabricated metals (SIC 34), paper, and electronics (SIC 36).

In terms of potential new unit sales, the food industry is the leader, with rubber/plastics, with fabricated metals, printers, and apparel also showing significant potential. For many of these industries, including fabricated metals, printers, apparel, and electronics, a large base of smaller facilities have had few options in terms of affordable on-site generating options or have had little incentive to install capacity. Now, with more micropower options and improving economics, these facilities are expected to enter the market and become more self sufficient and less reliant on grid power.



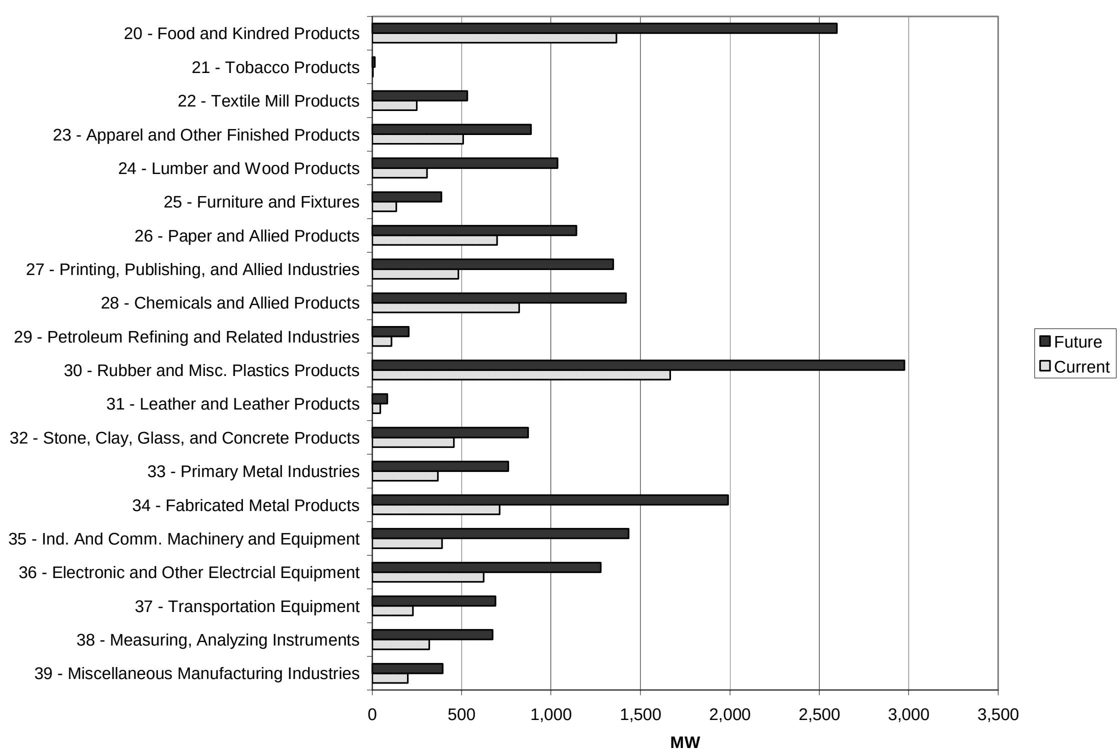


Figure 3-5. Market Potential for Micropower by Industry

With realization of future unit cost and performance improvements, fabricated metals, machinery, printers, and rubber/plastics are expected to install more micropower capacity. Again, large numbers of smaller facilities coupled with improving onsite generation economics drives these potential applications. The food industry is also expected to react to improved micropower economics, should they surface.

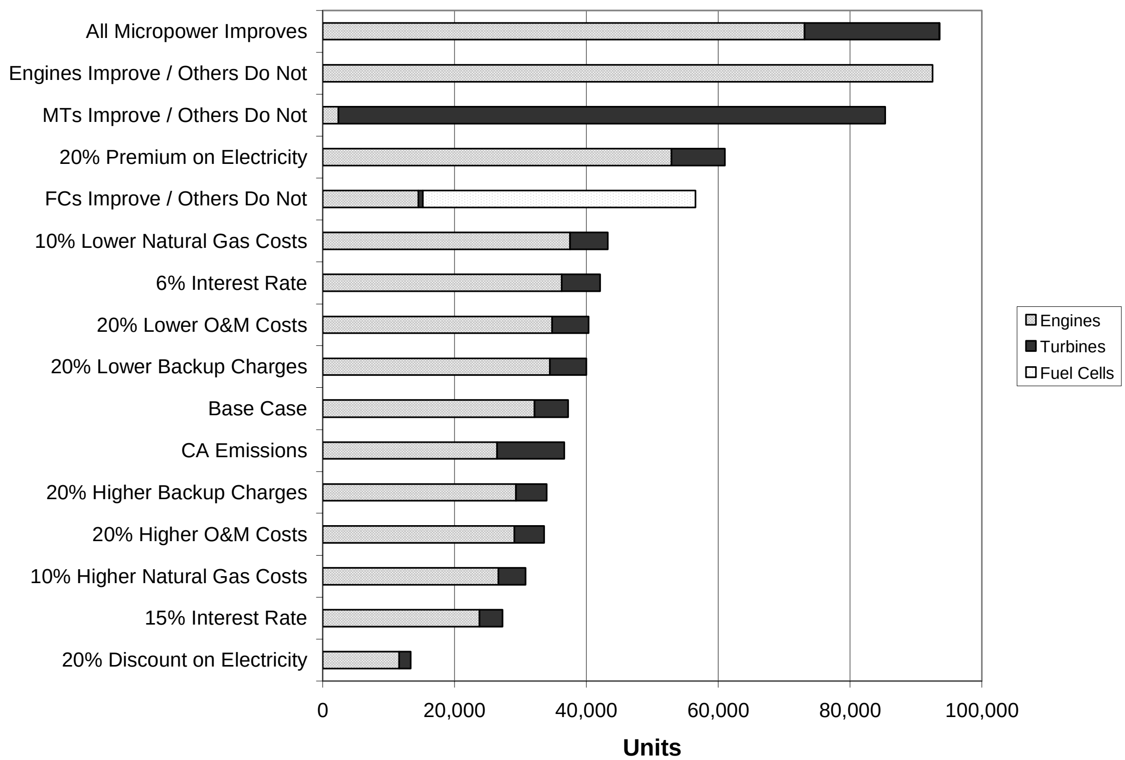
Sensitivity Analysis

The market potential for micropower technologies is dependent on many conditions, including installed cost, efficiency, gas and electric prices, operating and maintenance costs, and interest rates. The sensitivity analysis was conducted to determine which of these market factors have significant influence on potential, and how reasonable swings in these factors are reflected in increased or decreased market potential.

As shown in Figure 3-6, the largest single contributor to increased market potential is improvements in the cost and performance of all micropower technologies, with the potential to double the potential market for micropower. As discussed in Section 2, each of the micropower technologies has several key issues that are under development which could, if successful, improve cost and performance and thus expand market potential. Table 3-3 summarizes these potential improvements (see Appendix A for a detailed summary of cost and performance assumptions).

Also shown in Figure 3-6 are three scenarios where one of the three micropower technologies improves while the other two do not. The largest impact of the three scenarios is where reciprocating engines improve, while the cost and performance of other micropower options stay as is, effectively doubling the overall market potential. This would position engines to capture all of the new capacity for micropower, on an achievable economic potential basis (other factors such as emissions and maintenance would likely limit their penetration somewhat). The scenario where microturbines improve and others do not yields a similar projected impact where microturbines offer most of the market potential for micropower (18 of 20 GW), while still allowing a small share for engines. Microturbines, however, would not likely be limited by emissions and maintenance as compared with reciprocating engines. Finally, if fuel cells improve while others do not, they would capture 40 percent of the micropower market potential, with mostly engines and few microturbines constituting the remainder.

Of the non-micropower technology related factors, a 20 percent premium on electricity by far provides the most significant boost, increasing the potential market from 10 GW to over 15 GW. Some of the demonstration facilities for micropower have cited a premium value placed on on-site generation compared with grid power, based on the perceived improvement in reliability.



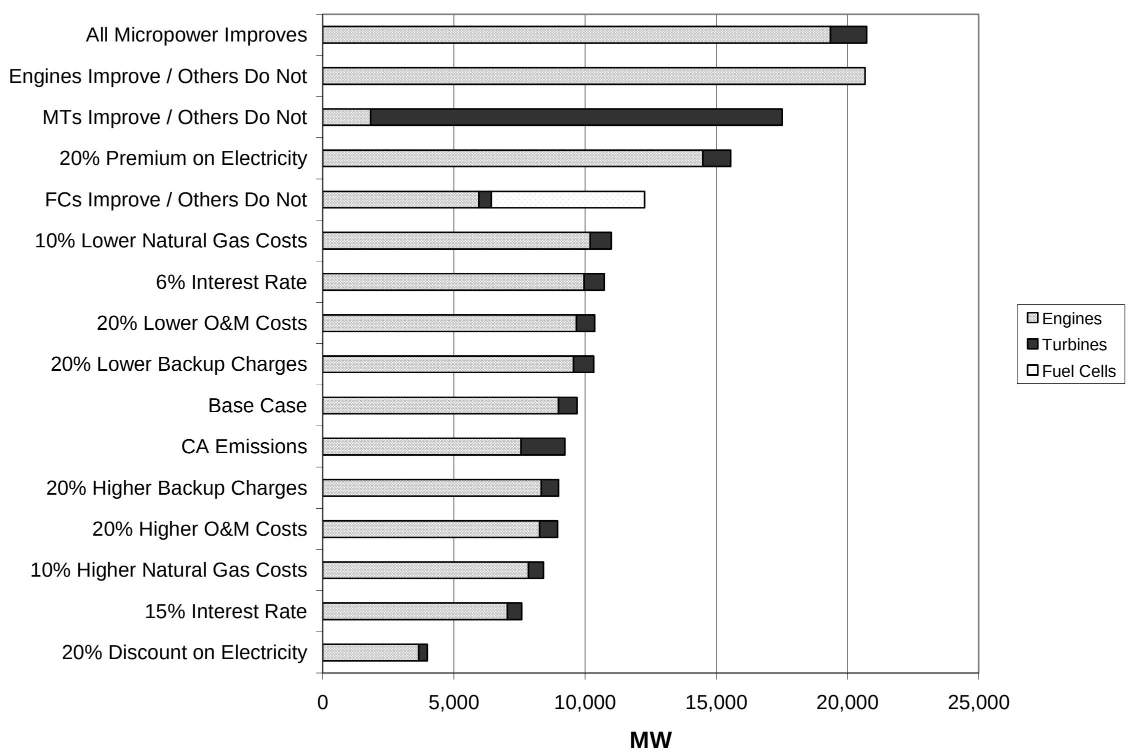


Figure 3-6. Sensitivity of Market Potential to Changing Market Conditions

Table 3-3. Potential Improvements in Micropower Cost and Performance

Technology	Size Range (kW)	Installed Cost ($/kW)		Electric Efficiency	
		Current	Future	Current	Future
Engines	30 to 1MW	600-770	450-540	31-38%	40-48%
Microturbines	30 to 750kW	700-800	400-440	20-32%	30-42%
Fuel Cells	30 to 750kW	1500-3310	900-1000	40-42%	42-55%
FC/MT Hybrid	250 to 1MW	N/A	900-1000	N/A	50-70%

Of the other scenarios shown in Figure 3-6, 10-20 percent changes in O&M costs, natural gas prices, and backup charges as well as a decrease in interest rate have limited impact on the market potential, each within 1.3 GW of the base case. An increase in interest rates up to 15 percent, as well as a significant drop (20 percent) in electricity prices could drop the market potential to as low as 4 GW, with all other factors unchanging.

The CA emissions scenario has little impact on overall market potential but offers an indication of the impact of more stringent emissions regulations. In this scenario, it was assumed that the four counties in California with strict ozone non-attainment area status would not permit any more reciprocating engines for continuous use due to more stringent emissions regulations. In this scenario, microturbines would account for most of the potential in those areas, and would double their potential nationally. Should similar regulations be passed in other areas of the country, microturbines would have a significant increase in their market potential.

Macro Impacts

In order to better understand the potential impact of micropower technologies on energy use, waste production, and production cost, the aggregated study results have been used as inputs into DOE's GPRA model. This model estimates the potential benefits and impacts which may accrue from the results of research, development, demonstration (and related) projects, and quantifies the potential energy savings, types of energy saved, types of emissions reduced, and economic benefits. As shown in Table 3-4, the micropower technologies have the potential to save 360 trillion BTU in energy, displace almost 150 billion kWh, and consume an additional 700 bcf of natural gas by 2020, as calculated by the GPRA model. In terms of environmental impact, these technologies could potentially save 15 million tons carbon equivalent of carbon dioxide, 270,000 tons of sulfur oxides, and 140,000 tons of nitrogen oxides.

Table 3-4. Macro Impacts from GPRA Model

Output Used for GPRA Data Call		
Impact By Year	2010	2020
Energy Metrics		
Total primary energy displaced (trillion Btu)	36.53	359.59
Direct electricity displaced (billion kWh)	63.80	144.43
Direct natural gas displaced (bcf)	-486.71	-718.84
Direct petroleum displaced (million barrels)	0.00	0.00
Direct coal displaced (million short tons)	0.00	0.00
Feedstock energy displaced (trillion BTU)	0.00	0.00
Renewable energy used (trillion BTU)	0.00	0.00
Waste energy displaced (trillion BTU)	0.00	0.00
Other energy displaced (trillion Btu)	0.00	0.00
Cost		
Energy-cost savings ($MM/yr)	5851.53	12,553.80
Non-energy cost savings ($MM/yr)	0.00	0.00
Environmental Metrics		
CO Displaced (MM tons)	0.00	0.01
Carbon Dioxide emissions displaced (MM TCE)	4.28	15.41
Other greenhouse emissions displaced (MM TCE)	0.00	0.00
SO2 displaced (MM tons)	0.11	0.27
NOx displaced (MM tons)	0.05	0.14
Particulates displaced (MM tons)	0.00	0.01
VOCs displaced (MM tons)	0.00	0.00
Hydrocarbons displaced (MM tons)	0.00	0.00
Solid Waste (MM tons)	0.00	0.00
Other environmental benefits (MM tons)	0.00	0.00

* TCE = Tons Carbon Equivalent

** MM = Million Metric

Section 4

TECHNICAL AND MARKET BARRIERS

The restructuring of the electric utility industry promises to transform the delivery of power and energy services. The micropower technologies comprising the focus of this report offer a potential combination of performance and flexibility that is creating interest among end users. Current trends in the U.S. clearly favor micropower, particularly from the standpoint of increased energy efficiency and reduced emissions. Meeting the increasingly competitive challenges of the U.S. marketplace will require harnessing the full resource capability of available and emerging technologies with characteristics of high efficiency, low cost, extreme reliability and low environmental impact. A number of barriers, however, stand in the way of realizing the benefits inherent in implementing micropower on a wide scale and applications in the U.S. industrial sector are currently limited, due to a combination of barriers in the following categories:

- Economics and Tax Treatment
- Product Performance and Availability
- Awareness, Information and Education
- Utility Policies and Regulation
- Planning, Zoning and Codes
- Environmental Regulation
- Supporting Market Infrastructure

These barriers can often make a micropower project uneconomic, and can frequently present such a confused and uncertain option to potential end users that more traditional purchased power approaches are favored. Table 4-1 identifies examples of each of the barrier categories.

A number of forces are driving the interest in micropower technologies. Industry restructuring is opening the door to new business arrangements and non-traditional suppliers, and customers in increasing numbers are taking the lead in meeting their ultimate energy requirements. The pace of this change, and the degree to which the benefits of micropower are realized, depends on the ability of all stakeholders to overcome these barriers to adoption of micropower technologies in the industrial sector. Each category of barriers is discussed in detail below.

Table 4-1. Barriers to Micropower Development

Category	Example Constraint
Economics and Tax Treatment	Lack of available tax credit to help defray capital cost; treatment as 39-year property under current tax laws
Product Performance and Availability	Lack of technology maturation; uncertainty in ability to meet cost and performance targets
Awareness, Information and Education	Limited industry understanding of range of benefits associated with micropower technologies
Utility Policies and Regulation	Costly grid interconnection requirements; "transition charges" or "exit fees"
Planning, Zoning and Codes	Local requirements for operator licensing and 24 hour supervision, resulting in delay/increased costs for many micropower projects
Environmental Regulation	Lack of recognition and credit for overall efficiency in determination of compliance with Clean Air Act requirements: drawn out siting and permitting procedures at state and local level, stretching to 24 months or longer
Supporting Market Infrastructure	Lack of easily reachable channels of distribution; limited availability of trained maintenance staff

Economics and Tax Treatment

Current production cost goals for microturbines place these relatively new technologies on a comparable cost footing with reciprocating engines. Fuel cells represent much higher capital and operating costs today. Projecting into the future, however, microturbines have the potential to attain a capital cost advantage over reciprocating engines. Fuel cells will continue to reflect relatively higher capital costs – however the hybrid solid oxide fuel cell/microturbine design offers a tremendous efficiency advantage of approximately 65 percent compared to 40 to 45 percent for the other micropower technologies.

First cost remains a barrier nevertheless. Assistance in overcoming this barrier could be provided by the availability of a tax credit for selected micropower equipment to help defray project capital cost. Tax treatment of micropower equipment varies considerably based on asset use and generating capacity (see Table 4-2).

Product Performance and Availability

Advances in technology, most notably in the area of microturbines and fuel cells as well as in the rapidly evolving power electronics, have also lowered the size threshold for economically viable power generation equipment. Notable advances are also being achieved with fuel cells, but a number of technical barriers must be overcome.

Table 4-2. Tax Treatment of Micropower Property

<table>
<tr><td rowspan="3">For Customer Use</td><td colspan="2">>500kW</td><td colspan="3"><500kW</td></tr>
<tr><td>Cost Recovery Period</td><td>Depreciation</td><td colspan="2">Cost Recovery Period</td><td>Depreciation</td></tr>
<tr><td>15 yrs</td><td>150% DB</td><td colspan="2">5-10 yrs</td><td>200% DB</td></tr>
<tr><td rowspan="4">For Sale to Others</td><td colspan="2">Separate Project</td><td colspan="3">Part of Structural Components of Building</td></tr>
<tr><td>Cost Recovery Period</td><td>Depreciation</td><td></td><td>Cost Recovery Period</td><td>Depreciation</td></tr>
<tr><td rowspan="2">15 or 20 yrs</td><td rowspan="2">150% DB</td><td>Non-Res</td><td>39 yrs</td><td>SL</td></tr>
<tr><td>Res</td><td>27 ½ yrs</td><td>SL</td></tr>
</table>

Each of these technologies offers advantages and disadvantages in specific site situations, and there are very specific technology challenges associated with each option. The technology challenges can generally be organized in three areas: 1) reliability and efficiency goals are not quite being realized as of today; 2) products are commercially available on a limited basis; and, 3) other performance considerations may be a barrier.

Reliability and Efficiency. Meeting an electric efficiency goal of at least 30 percent is a challenge for microturbine technology, with early field reports indicating current efficiency levels from 15 to 20 percent. Recuperation is needed on most units for higher efficiencies, but will increase costs. With the reliability of grid power an issue in the minds of many users, some customers are planning on multiple units (at a higher total cost) to provide their own reliability and availability of electric power supply.

Commercial Availability. Users are beginning to accept micropower technologies as a viable power supply option, albeit on a limited basis thus far. Reciprocating engines and larger-sized turbines are the only non-renewable technologies fully commercialized, although the major commercial rollout of microturbines is underway. It will be several years before commercialization is fully realized with microturbines, and even longer for the more advanced molten carbonate and solid oxide fuel cells.

Other Performance Considerations. The lack of technology maturation contributes to the underlying uncertainty in the ability of microturbines and fuel cells to meet cost and performance targets. This presents an obstacle to aggressive implementation of these technologies.

While the focus of this report is on continuous power and combined heat and power applications, additional micropower standby and emergency power market opportunities may increase overall sales, allowing an increase in production capacity and an associated decrease in first costs. As an example, reciprocating engines have penetrated the standby and emergency power markets with lighter duty models designed for limited annual operating hours. Current microturbine technology (and to some extent fuel cells as well) is being designed for long service life (up to a

40,000 hour lifetime for microturbines) with annual expected operating hours in the 4,000 to 6,000 range. Design of a lighter duty microturbine for markets with fewer operating hours may help overcome the first cost barrier.

Maintenance practices are still being developed as field experience grows. Maintenance cycles are being recommended by manufacturers (e.g., 5,000 hours for microturbines), but are not yet proven in operating practice, and synchronization of maintenance requirements for the turbine components and the gas compressor still needs to be accomplished. Lack of standardized maintenance practices and confidence in longer-term maintenance costs may tend to delay application of these technologies, although manufacturers are offering maintenance contracts to help allay these concerns.

There are a number of technical challenges in fuel cell technology that need to be overcome in order to gain market acceptance. The energy cells are stacked together in series to provide the needed power output. Results to date indicate that the life of these stacks is between 15,000 and 20,000 hours with fuel cell power output degrading over time, requiring periodic stack replacement during the unit's lifetime. The short stack-lives lead to life-cycle costs that that make the resulting power output noncompetitive with grid-purchased power in most parts of the country. The solid oxide fuel cell with an estimated stack life of up to 5 years may help minimize this constraint.

Awareness, Information and Education

Industry and business owners have a limited understanding of the range of benefits associated with micropower technologies. Frequently following the path of least resistance, industry decision makers will often stay with grid purchased power, typically not realizing the full value of the micropower benefits. Further exacerbating this situation, and contributing to rather than breaking down the cost barrier, is industry's frequent focus on capital cost versus life-cycle cost.

Utility Policies and Regulation

Many utilities have designed backup power rates that penalize "part-time" customers. While these rates may accurately reflect the higher cost of "reserving" capacity for these part-time customers, they effectively act to restrain micropower implementation.

Interconnection is another critical issue, with utilities often requiring protective relaying on the utility side of the meter to ensure that the grid is protected from any problems caused by the distributed generator. In these cases, the utility does not accept the protection functions provided by the electronic interface package included with many micropower systems, a package providing many, if not all, of the utility-required protective relaying functions. This duplication of interconnection requirements raises the costs to the distributed generator, with interconnection costing as much as 15 to 20 percent of the installed cost of the on-site generation package.

As deregulation begins to make its way across the country, customers choosing to leave the grid of the local energy supplier are required to pay "transition charges" or "exit fees" designed to help the local utility recover investments in "stranded" generation or transmission assets no longer producing revenue for the utility. Burdening the distributed generator with these exit fees and competitive transition charges is a disincentive to project implementation.

Planning, Siting and Zoning

Micropower technologies are and will be affected by local zoning policies, building codes and standards, and other issues including union labor and 24-hour attended operation. For example, microturbines require natural gas input at 55 to 85 psig, compared to the typical gas distribution system pressure of 1 to 50 psig. Accordingly, a gas compressor is frequently required as part of project initiation. If this unit is located within a building, local codes may require 24-hour attended operation for a pressure vessel of this rating. Many of the microturbine installations are expected to be outdoors, which may mitigate this constraint.

Environmental Regulation

Micropower projects typically experience drawn out siting and permitting procedures at the state and local level which can stretching to 18 to 24 months or longer. Streamlined siting and permitting procedures would provide a major boost to micropower technology penetration.

Additionally, these projects do not currently receive credit for overall efficiency in determination of compliance with Clean Air Act requirements. Output-based emission factors accounting for overall fuel utilization efficiency would recognize the inherent efficiency advantage of power generation technology located close to the load, eliminating T&D lines losses, and taking possible advantage of CHP applications.

Emissions control technologies (e.g., SCR) are being approved as meeting emissions limits, but no consideration of efficiency and net environmental benefits is currently given to most micropower technologies.

"Green" power generation technologies are approved for use in a non-attainment area under current environmental regulations. Most micropower technologies do not qualify as "green" under today's definitions. Broadening the "green" renewables standard to encompass an overall efficiency standard would offer expanded market reach to non-renewable micropower options.

Supporting Market Infrastructure

Micropower is an example of a classical emerging technology with regard to its market distribution status. The lack of easily reachable channels of distribution for microturbines and fuel cells naturally limit their applications. Widely varying approaches are being used to get the micropower products to the customer. Players are now jockeying for market position, with a diverse group of product manufacturers, distributors, packagers and sales representatives entering the scene. One microturbine vendor has established a comprehensive distribution network on a regional basis, with each distributor required to purchase the units from the manufacturer as a separate transaction from the customer sale. Other microturbine vendors are relying on their own sales force. The approach to market will impact customer contact with the equipment supplier. The uncertainty at this point in market development is to what extent the distribution approach will impact the customer's buy decision.

Reciprocating engines offer a clear market advantage in the extensive dealer and service network available, with a ready supply of trained diesel mechanics and spare parts on a nationwide (and even worldwide) basis. The widespread transportation and machinery applications for diesel engines has provided a foundation for the power generation applications of this technology. Other applications (e.g., transportation) would help build volume and establish a service infrastructure for microturbines and fuel cells. Fuel cells may accomplish this over time in the automotive transportation market.

Other market infrastructure issues that are potential barriers to micropower development include the need to 1) encourage development of a small power export market to achieve quantities of scale in production costs, and 2) advance typical engineering design practices to include micropower as part of an integrated plant design to lower installation costs.

Section 5

RESEARCH AND DEVELOPMENT NEEDS

For micropower to realize its full potential to meet the energy needs of industrial facilities, a number of technology improvements are needed in order to compete with conventional options. Achieving improvements such as increased electrical efficiency, reduced maintenance, greater reliability, and lower emissions – all at lower costs – will require substantial research and development in a range of areas. Specific R&D needs differ by micropower technology, and are dependent on the maturity of that technology.

Reciprocating Engines

Most of the current R&D focused on reciprocating engines is designed to increase efficiency or lower NO_x emissions. Most new applications are lean-burn which gives the advantages of increased efficiency and lower NO_x emissions but has the disadvantages of difficult ignition, inability to use three-way catalysts to reduce emissions, and having a lower power to volume ratio. Additional R&D is being pursued in the areas of improved models, sensors, and controls.

To facilitate proper ignition and combustion, a pre-combustion chamber or high-energy/precise ignition sources can be employed. Research is ongoing into how changes in the pre-combustion and combustion chamber design can influence air flow and combustion which in turn influence power, efficiency, and emissions. Additional research on ignition sources such as lasers promises to achieve ideal combustion through the precise placement and timing of ignition.

Lean-burn engines cannot use three-way catalysts which are employed in rich-burn engines such as those of gasoline fueled automobiles to simultaneously remove CO, NO_x and unburned hydrocarbons. Although all emissions are typically lower from the combustion chamber of a lean-burn engine, research on new types of catalytic emissions reduction is needed to achieve lower emission levels to be more competitive with turbines.

Effective turbocharging is key to increasing Brake Mean Effective Pressure (BMEP) which leads to increased efficiency. Turbocharging is especially important for lean-burn engines which require high air to fuel ratios. Effective turbocharged applications require efficient turbochargers and components that can withstand increased pressure ratios.

Additional research is being conducted on improved sensors and models to better understand the combustion process inside an engine and better controls to effectively manipulate the combustion process on-line to achieve ideal combustion.

Microturbines

Microturbine development needs are focused on increasing efficiency, reducing costs, and providing fuel flexibility. In addition the technology needs to be tested and demonstrated for commercial applications.

Efficiency improvements hinge upon developing effective recuperators. Recuperators use part of the exhaust from the microturbine to heat inlet air into the combustor. With recuperation, electric efficiencies have been increased to 26-32% from 15-22%. In order to approach the current targets of 40%, higher temperature inlet air will be required, necessitating higher temperatures in the recuperator, combustion chamber, and turbine section. Withstanding the higher temperatures will require advances in temperature resistant materials (e.g. ceramics) for the recuperator, combustor, and turbine hot section. Another way to improve microturbine efficiency is to couple with a fuel cell (usually solid-oxide). The future of these microturbine/fuel cell hybrids is dependent on fuel cell development as well as research into the best performing thermodynamic cycle to employ.

To reach cost targets of $400/kW microturbine developers will need to focus on reducing costs of the main unit as well as the packaging and support equipment. Microturbines typically employ a single shaft which leads to simplicity and ease of mass production which will be key to lower costs. However the single, high-speed shaft requires the use of an inverter/rectifier to provide standard AC power and any reductions in the cost of this equipment, such as thyristors and inverters, would improve overall system economics. When microturbines are fueled by natural gas, as they are with current models, gas compression is often necessary to increase the pressure over what is typically available from the local gas main. Compressors of the size necessary for microturbines are not prevalent and can be costly (leading to higher capital costs as well as associated O&M expense). Research into reproducing the characteristics of larger compressors for smaller units will be a key to the success of microturbines.

Microturbines potentially offer greater fuel flexibility than other micropower technologies. Gasifiers produce fuel from solid sources such as coal or biomass but are currently expensive and often provide gas with impurities or contaminants which may require costly cleanup. Reductions in gasifier expense, lower cleanup costs, or the ability of the microturbine to burn contaminated fuel would help alleviate these problems.

Overall, microturbines are new and untested. Published efficiency and emissions levels have not been verified independently and it is not clear whether current O&M projections are accurate. Independent field testing along with computer modeling will go a long way toward alleviating uncertainty and allowing microturbines to be considered a viable power generation alternative.

Fuel Cells

Fuel cells are an emerging technology with currently only one manufacturer offering commercial units. As such, most of the research and development issues for fuel cells are centered on demonstrating units under real-world conditions. However, research is needed for improved fuel reformers to efficiently provide necessary hydrogen fuel from hydrogen rich sources such as natural gas or gasoline. Additionally, fuel cells themselves have a high degree of reliability and availability due to their lack of moving parts but are limited to the reliability of support systems such as pumps and fans needed for operation and therefore improvements in these areas would increase the attractiveness of fuel cells. Future research and development into microturbine/fuel cell hybrids is also expected.

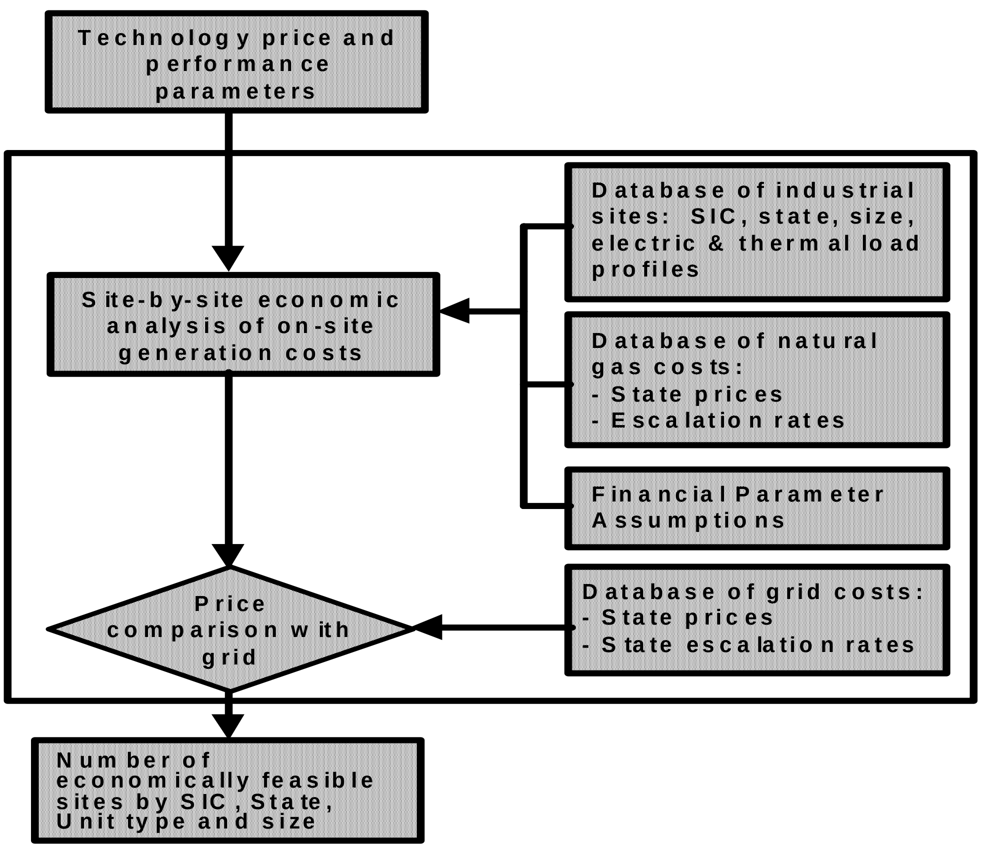
For fuel cells currently under development the major obstacle is cost. The one current commercial offering costs over $3000/kW which prevents it from competing with grid power or other micropower technologies on an economic basis, other than for niche applications such as "green" power or premium power. If fuel cells are to have success in the market, they will most likely need to reach the current solid oxide (SOFC) target of $900/kW. This will require substantial cost reduction, especially for the electrolytic material.

Appendix A
METHODOLOGY

The analysis was performed using RDC's DIStributed Power Economic Rationale SElection (DISPERSE) model. This tool is a spreadsheet-based model which estimates the achievable economic potential for distributed generation by comparing on-site generation economics with competing grid prices. The model not only determines whether on-site generation is more cost effective, but also which technology and size appears to be the most economic. As a result, double counting of market potential for a variety of competing technologies is avoided. This model has been developed over the past five years, and has been applied on a variety of projects for utilities, equipment manufacturers, and research organizations.

Using data on number of facilities in each size range in each state, the number of potential applications is determined. Results are aggregated and summarized to show key information on where the potential applications are (e.g., the top state for industrial sector applications of 25-75 kW engines is California, and almost all the applications are combined heat and power). Figure A-1 provides an overview of the model inputs, analysis, and outputs.

Figure A-1. DISPERSE Model



The model run begins with a database of industrial sites, which are organized by state, SIC code, and size (in terms of number of employees). Based on its location and the natural gas costs database, the model determines whether natural gas is available to the site. In addition, based on the site SIC code, a load profile which is representative of that industry is assigned. The size of facility is used to “scale” up or down the magnitude of the load profile.

Using this information, combined with the unit price and performance data, the model performs a life-cycle cost economic analysis, based on the unit life as well as the cost and performance data, and state fuel prices. The model determines year 1 distributed power competing electricity cost based on yearly costs to generate and expected escalation rates. The best technology option is selected based on the lowest year 1 distributed power competing electricity price.

The model then compares the annual cost to generate with costs of purchasing from the grid (from the grid pricing database), and counts the application if it beats the grid price. This process is repeated tens of thousands of times, once for each group of sites with the same state/size range/SIC code in the database of industrial sites, and the results are then aggregated to obtain market potential. By varying the important parameters individually while keeping other parameters fixed during a model run, sensitivity analysis is conducted.

The following key inputs are used by the model:

1. **Technology price and performance parameters**. The model requires data on the mix of technologies that are being made available to the sites analyzed. This data includes their installed cost, fuel type, heat rate, electrical efficiency, useable thermal output, fixed and variable operating and maintenance costs, and other key parameters. This data is derived from manufacturer-provided data, and is validated by comparison with published data in journals, technical papers, and other sources.

2. **Database of industrial sites**. Data on number of customers in each SIC and size range are from the Department of Commerce Country Business Patterns and the Manufacturing Energy Consumption Survey. Electricity use per employee is taken from the Annual Survey of Manufactures (U. S. Bureau of the Census). Industrial sector potential for combined heat and power is based on process level steam and hot water demand data from the RDC Industrial Market Information System (IMIS). Load profile data is from RDC-collected load profiles as well as Lawrence Berkeley National Laboratory data on electric and thermal profiles, by SIC and climate region.

3. **Database of fuel prices**. Natural gas costs are based on state prices for the industrial sectors, as reported by Department of Energy’s Energy Information Administration (EIA). This averaging is done to approximate the rate that

would be paid be a small industrial facility. Natural gas escalation rates are based on EIA projections from the Annual Energy Outlook.

4. **Financial parameter assumptions**. Ownership parameters are based on RDC experience with typical DG projects, and expectations for financial structures of projects in the future. Much of this information is based on experience from operating RDC's lease financing subsidiary company, EFS Finance, which finances energy projects including on-site generation. See Table A-2 for a list of these assumptions.

5. **Database of grid prices**. Year 1 electricity prices are based on projections from the EIA. Typical grid backup charges are included. Escalation rates are based on EIA projections from the Annual Energy Outlook, with adjustments for the progress of deregulation in the state and the current electricity prices in the state.

Table A-1: Unit Price and Performance Characteristics

	Size Range (kW)	30-75		75-150			150-350				350-750				750-1000		
	Type	Engine	MT	Engine	MT	FC	Engine	MT	FC	FC/MT	Engine	MT	FC	FC/MT	Engine	T	FC/MT
Current (Year 2000)	Cost ($/kW)	766	800	727	800	N/A	687	700	3310	N/A	636	700	3310	N/A	596	550	N/A
	O&M ($/kWh)	.01	.01	.009	.01	N/A	.0085	.009	.015	N/A	.008	.009	.015	N/A	.0075	.004	N/A
	Electric Efficiency	31%	27%	32%	27%	N/A	33%	27%	40%	N/A	35%	27%	40%	N/A	38%	25%	N/A
	Heat Rate (Btu/kWh)	11,000	12,600	10,750	12,600	N/A	10,500	12,600	8620	N/A	9,750	12,600	8620	N/A	8,980	13,900	N/A
	Thrm. Output (MMBtu/hr)*	.27	.36	.54	.73	N/A	1.08	1.46	.75	N/A	2.53	3.65	.75	N/A	4.46	8.41	N/A
	Overall Efficiency	80%	85%	82%	85%	N/A	84%	85%	83%	N/A	87%	85%	83%	N/A	88%	85%	N/A
Future (Year 2000-2005)	Cost ($/kW)	535	440	510	440	1000	485	400	900	1000	475	400	900	900	450	550	900
	O&M ($/kWh)	.006	.008	.0055	.008	.0075	.005	.0070	.0075	.0092	.005	.0070	.0075	.0092	.005	.004	.0092
	Electric Efficiency	40%	40%	42%	40%	45%	44%	40%	45%	65%	46%	40%	45%	65%	48%	25%	65%
	Heat Rate (Btu/kWh)	8,530	8,530	8,120	8,530	7,580	7,760	8,530	7,580	5,250	7,420	8,530	7,580	5,250	7,110	13,900	5,250
	Thrm. Output (MMBtu/hr)	.20	.19	.38	.38	.34	.71	.38	.34	.31	1.74	.38	.34	.31	3.34	8.41	.31
	Overall Efficiency	87%	85%	88%	85%	90%	90%	85%	90%	95%	93%	85%	90%	95%	95%	85%	95%

N/A = technology not anticipated to be available for this size range and period of time

*Thermal output at rated electric output

Table A-2: Financial Parameters

Project Length (years)	10
Federal Income Tax (%)	35
State Income Tax (%)	5
Property Tax (%)	1.5
Insurance Rate (%)	0.5
Debt Repayment Period (years)	10
Common Equity Fraction	0
Debt Fraction	1
Return on Debt (%)	9.1
Discount Cash Flows (%)	7

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Appendix B

DETAILED MARKET PROJECTIONS

Table B-3: Future Market Potential by SIC (number of units)

	Engines					Turbines				
SIC	50kW	100kW	200kW	500kW	1MW	50kW	100kW	200kW	500kW	1MW
2010	145	196	452	207	184	0	0	0	0	0
2020	141	189	309	270	0	0	0	0	0	0
2030	140	208	240	214	119	0	0	0	0	0
2040	45	280	494	461	184	33	0	0	0	0
2050	49	441	270	270	140	15	0	0	0	0
2060	134	156	108	102	7	0	0	0	0	0
2070	14	54	66	108	54	0	0	0	0	0
2080	240	210	269	231	59	0	0	0	0	0
2090	0	518	361	249	38	379	17	0	0	0
2110	0	1	1	1	0	0	0	0	0	0
2120	1	4	3	2	0	0	0	0	0	0
2130	1	1	4	4	0	0	0	0	0	0
2140	2	1	3	3	0	0	0	0	0	0
2210	0	1	16	16	9	0	25	0	0	0
2220	0	3	3	7	20	0	18	12	9	0
2230	0	7	18	13	7	12	0	0	0	0
2240	0	0	28	32	30	32	0	0	0	0
2250	58	111	205	169	48	119	3	0	0	0
2260	46	69	82	65	0	0	0	0	0	0
2270	0	19	20	42	30	0	0	0	0	0
2280	0	22	15	27	3	22	0	0	0	0
2290	34	126	128	102	25	18	0	0	0	0
2310	31	30	32	19	13	2	0	0	0	0
2320	6	158	176	83	2	152	0	0	0	0
2330	522	873	552	236	43	634	0	0	0	0
2340	0	38	49	17	3	53	0	0	0	0
2350	44	25	29	9	3	10	0	0	0	0
2360	59	65	34	9	0	22	0	0	0	0
2370	0	0	0	0	0	0	0	0	0	0
2380	32	50	41	8	4	13	0	0	0	0
2390	121	533	315	170	64	33	0	0	0	0
2410	26	9	3	0	0	6	0	0	0	0
2420	0	231	545	301	43	508	211	0	0	0
2430	465	377	353	208	81	0	0	0	0	0
2440	47	326	86	26	5	0	0	0	0	0
2450	7	46	138	57	0	0	0	0	0	0
2490	50	285	236	125	67	0	0	0	0	0
2510	2	80	60	123	7	289	189	116	0	0
2520	0	38	27	42	0	64	50	27	0	0
2530	0	27	23	21	14	27	0	0	0	0
2540	0	90	54	68	3	66	145	68	0	0
2590	0	88	66	24	4	27	0	0	0	0
2610	2	0	4	4	8	0	0	0	0	0
2620	0	28	3	5	0	0	0	0	0	0
2630	0	5	1	6	0	0	0	0	0	0
2650	270	647	561	674	36	0	0	0	0	0
2670	348	194	542	442	187	71	0	0	0	0
2710	0	300	286	128	54	646	0	0	0	0
2720	0	102	38	14	13	152	0	0	0	0

SIC	Engines					Turbines				
	50kW	100kW	200kW	500kW	1MW	50kW	100kW	200kW	500kW	1MW
2730	0	122	62	41	33	147	17	0	0	0
2740	0	56	31	9	0	91	7	0	0	0
2750	0	1574	693	396	97	559	166	0	0	0
2760	0	98	97	61	0	64	5	0	0	0
2770	0	0	8	6	5	11	0	0	0	0
2780	0	101	78	25	1	190	5	0	0	0
2790	0	121	64	8	1	318	0	0	0	0
2810	0	12	181	333	0	0	0	0	0	0
2820	38	89	80	54	20	10	0	0	0	0
2830	0	227	176	181	32	150	0	0	0	0
2840	113	225	189	198	87	76	0	0	0	0
2850	98	19	2	1	0	0	0	0	0	0
2860	156	14	131	93	183	0	0	0	0	0
2870	89	128	162	100	27	63	0	0	0	0
2890	409	421	467	206	35	101	0	0	0	0
2910	0	34	0	14	15	0	0	0	0	0
2950	0	142	138	66	0	209	0	0	0	0
2990	0	75	39	34	0	66	0	0	0	0
3010	0	14	15	10	0	17	0	0	0	0
3020	6	12	13	14	0	0	0	0	0	0
3050	133	167	116	89	33	0	0	0	0	0
3060	251	149	540	105	112	0	0	0	0	0
3080	0	584	3116	2258	1544	1582	0	0	0	0
3110	25	0	51	0	14	6	0	0	0	0
3130	10	5	1	1	0	1	0	0	0	0
3140	1	8	37	15	1	20	0	0	0	0
3150	0	5	5	4	0	0	0	0	0	0
3160	0	26	16	18	3	0	0	0	0	0
3170	0	13	7	2	0	0	0	0	0	0
3190	21	11	9	1	1	10	0	0	0	0
3210	0	4	1	6	0	8	0	0	0	0
3220	0	70	39	26	10	4	0	0	0	0
3230	0	123	156	92	62	0	0	0	0	0
3240	0	0	38	31	0	0	0	0	0	0
3250	46	17	148	68	25	0	0	0	0	0
3260	92	75	53	37	4	0	0	0	0	0
3270	597	1128	235	175	10	0	0	0	0	0
3280	124	23	8	1	1	0	0	0	0	0
3290	162	221	259	158	58	0	0	0	0	0
3310	25	128	108	157	90	13	0	1	0	0
3320	0	36	64	103	36	6	0	0	0	0
3330	0	0	29	17	13	0	0	0	0	0
3340	0	21	25	34	30	0	0	0	0	0
3350	0	75	125	141	130	49	0	0	0	0
3360	0	67	216	50	69	135	0	0	0	0
3390	0	105	159	79	20	52	0	0	0	0
3410	0	14	34	44	16	11	11	0	0	0
3420	0	137	139	110	2	221	122	0	0	0
3430	0	35	55	35	13	26	17	0	0	0
3440	756	825	482	219	10	507	73	0	0	0
3450	0	329	209	161	13	117	136	0	0	0

SIC	Engines					Turbines				
	50kW	100kW	200kW	500kW	1MW	50kW	100kW	200kW	500kW	1MW
3460	0	0	288	208	26	311	373	24	0	0
3470	0	308	848	313	63	700	0	0	0	0
3480	0	10	26	9	15	22	9	0	0	0
3490	0	332	356	229	42	453	304	45	48	0
3510	0	8	22	17	8	12	0	0	0	0
3520	0	4	45	36	5	101	72	5	0	0
3530	1	10	79	79	32	215	184	57	17	0
3540	0	902	362	208	22	199	103	0	0	0
3550	0	402	211	160	52	297	45	6	0	0
3560	0	50	262	276	59	330	255	73	23	0
3570	162	187	106	120	27	6	0	19	0	0
3580	0	10	126	116	9	210	161	15	0	0
3590	0	120	421	195	24	65	1508	27	0	0
3610	0	83	64	53	3	101	49	0	0	0
3620	0	167	258	249	116	57	74	0	0	0
3630	0	30	26	42	9	42	21	0	0	0
3640	83	215	247	179	82	81	70	0	0	0
3650	0	79	56	53	15	35	19	0	0	0
3660	0	72	110	156	45	288	20	106	9	0
3670	0	923	849	704	145	520	310	0	0	0
3690	0	165	148	92	17	266	43	0	0	0
3710	5	102	406	221	249	413	5	0	0	0
3720	0	37	161	70	76	107	8	0	0	0
3730	0	71	74	42	16	141	32	0	0	0
3740	0	4	22	15	0	14	16	0	0	0
3750	0	0	11	7	2	33	0	0	0	0
3760	0	10	14	10	10	0	1	0	0	0
3790	0	93	57	38	9	20	5	0	0	0
3810	0	75	48	65	0	52	0	0	0	0
3820	0	319	303	201	42	507	19	0	0	0
3840	0	386	277	236	100	192	0	0	0	0
3850	0	51	33	37	10	0	0	0	0	0
3860	0	122	96	55	33	0	0	0	0	0
3870	0	12	12	3	1	12	0	0	0	0
3910	104	11	51	18	2	8	15	0	0	0
3930	0	0	10	9	0	29	20	0	0	0
3940	0	7	139	66	53	75	131	11	0	0
3950	0	36	44	28	5	53	9	0	0	0
3960	0	33	50	22	19	35	20	1	0	0
3990	247	138	195	88	16	309	46	13	0	0