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Natural Gas Power Systems For The Distributed Generation Market

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NATURAL GAS POWER SYSTEMS FOR THE DISTRIBUTED GENERATION MARKET

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Abstract

Natural gas dominates the fast-growing non-utility power generation market. This market is composed mainly of large-scale simple-cycle and combined-cycle gas turbine power plants followed by smaller Distributed Generation (DG) systems. This paper explores the small-scale DG industry, current state of products, and future technology and product trends.

Independent Power Generation

The natural gas industry has a long track record of developing and expanding the market potential for independent natural gas power generation systems. This market ultimately helped contribute to electric restructuring in the 1990s and provides lessons for emerging small-scale power generation products aiming to expand sales over the next decade. Figure 1 shows some of the key events for independent natural gas power generation systems since the 1960s.

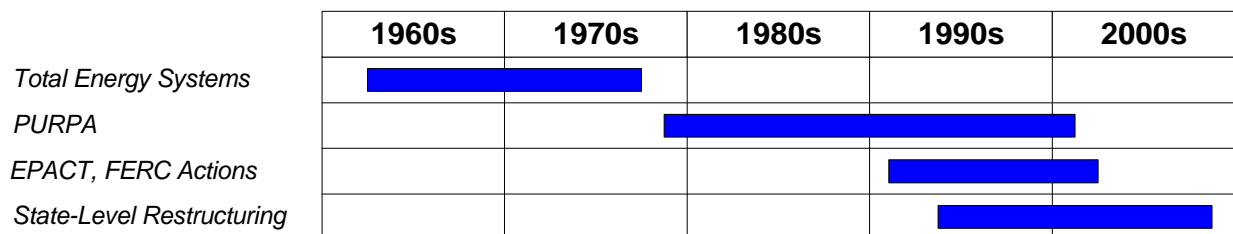


Figure 1

Going back three decades, the gas industry’s TARGET initiative (Team to Advance Research on Gas Energy Transformation) promoted fuel cells and Total Energy Systems (TES) using gas turbines and gas engines. Total Energy installations were combined heat and power (CHP or cogeneration) applications normally operated as grid-independent systems. This tactic achieved electric utility *bypass* and avoided difficult issues like interconnection, but had its shortcomings. TES applications peaked in interest and faded during the mid-1970s.

In 1978, PURPA legislation opened Pandora’s Box and revolutionized the U.S. power generation market. PURPA was an energy conservation measure meant to address the defining energy issue of the oil crisis decade. PURPA required electric utilities to: allow PURPA power plants to interconnect with the grid, buy excess power purchases from these facilities at “avoided cost,” and provide non-discriminatory back-up power. The interconnection and back-up power requirements addressed shortcomings of the Total Energy System concept.

PURPA spurred a tremendous wave of cogeneration systems during the 1980s and introduced many new terms to the power generation market -- QFs, Small Power Producers, PURPA machines, NUGs, IPPs, EWGs, etc. PURPA succeeded in achieving its energy conservation objective by increasing energy efficiency and enhancing use of renewable and waste byproduct

resources. This is a modest statement, though, of PURPA’s legacy. In retrospect, PURPA’s more significant impact was breaking a decades-long electric utility monopoly in power generation and fostering the birth of a substantive independent power industry.

During the 1980s, independent power producers (and others) pushed for rights to “wheel” power across transmission lines. Actions to address this market demand began with EPACT (1992) and were further bolstered by subsequent FERC actions on “open access” of power transmission lines. This cascaded to state-level modifications to the integrated generation/transmission/distribution electric utility model. Competition and choice were interjected into the industry. Federal and state-level changes will continue over the next 5-10 years as the regulatory compact governing the electric power industry is reshaped.

The U.S. power generation industry has changed dramatically in the past two decades. Historically, most power generation capacity was owned by utilities operating under regulatory control and oversight. In 1997, about 11 percent of capacity (Figure 2) was owned by non-utility entities; GRI projects this number to grow to 35 percent by 2015 (including new capacity and sale of existing capacity from utilities to non-utilities).

Most independent power generation capacity is natural gas fired equipment (Figure 3). Figure 4

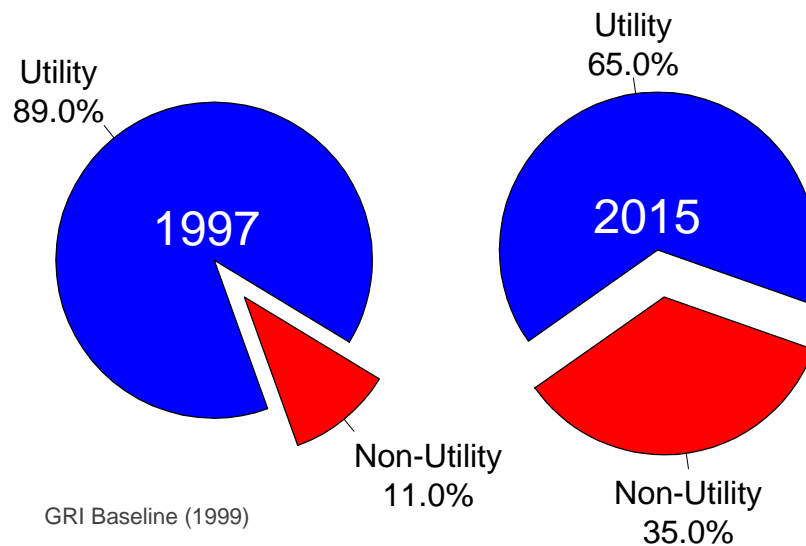


Figure 2

shows the mix of cogeneration fuel choices in the industrial market. Most capacity is concentrated in major process industries (chemical, paper, and petroleum). Much of the gas-fired equipment are large (over 25 MW) simple-cycle and combined-cycle gas turbine power plants.

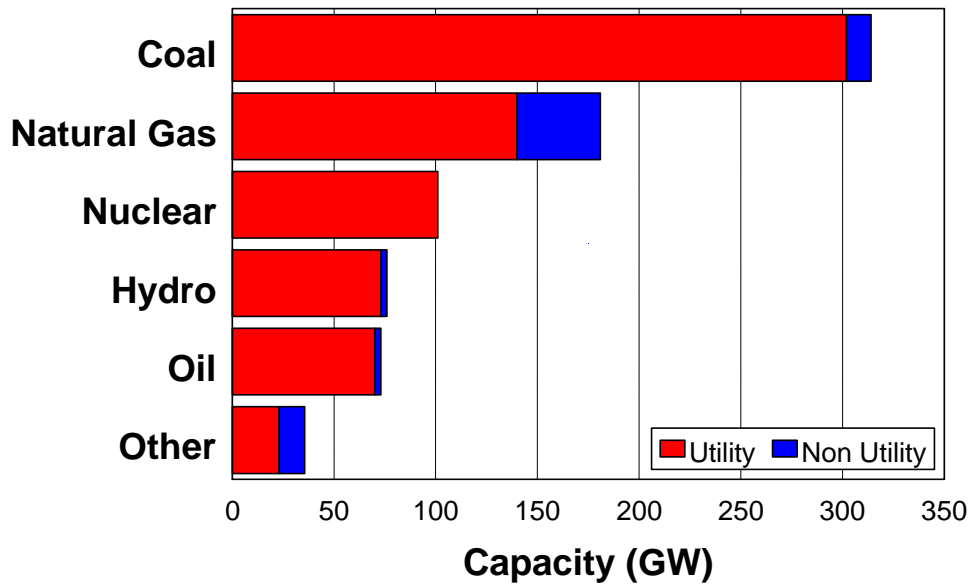


Figure 3

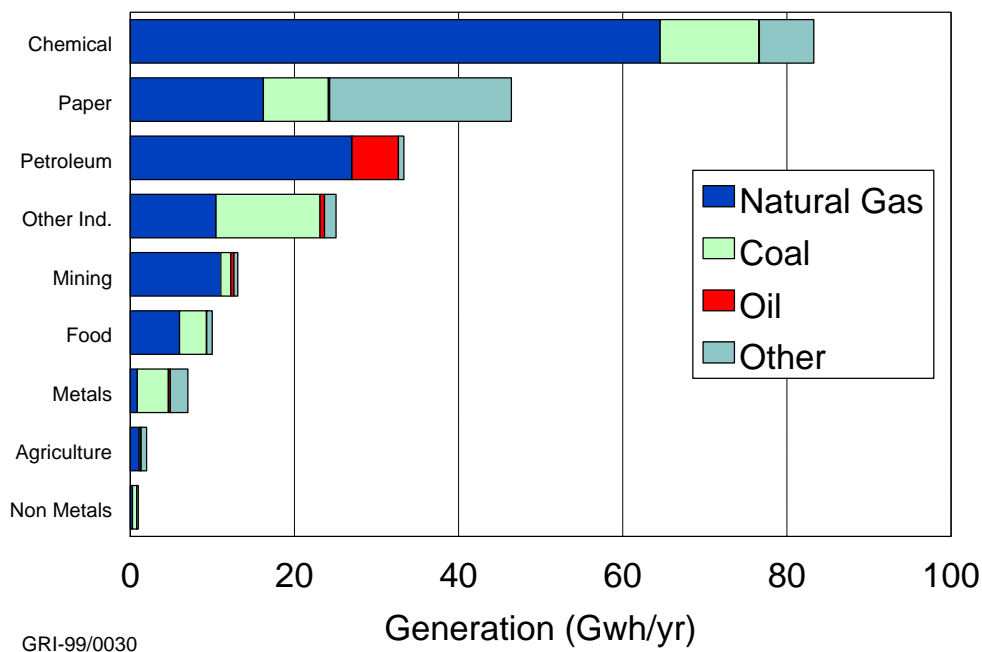


Figure 4

There are fundamental drivers favoring large gas turbine power plants. Most important are low up-front costs -- gas turbines are inexpensive and can be installed at a fraction of the time and cost of a coal-fired thermal power plant. Second, gas turbines offer low environmental impact -- cascading down to 5-25 ppmv of NO_x in the past decade. Third, combined-cycle systems are highly efficient plants (50-60 percent). Finally, these systems have improved availability compared to conventional power plants (Table 1, based on circa 1992 GRI data). Large-scale gas turbine power plants establish the industry benchmark in nearly all key categories.

Table 1

Operational Reliability Measure	Gas Turbines >25 MW	Electric Utility Average 1986-1990
Availability Factor, %	93.3	85.9
Forced Outage Rate, %	2.1	24.7
Scheduled Outage Factor, %	4.8	9.9

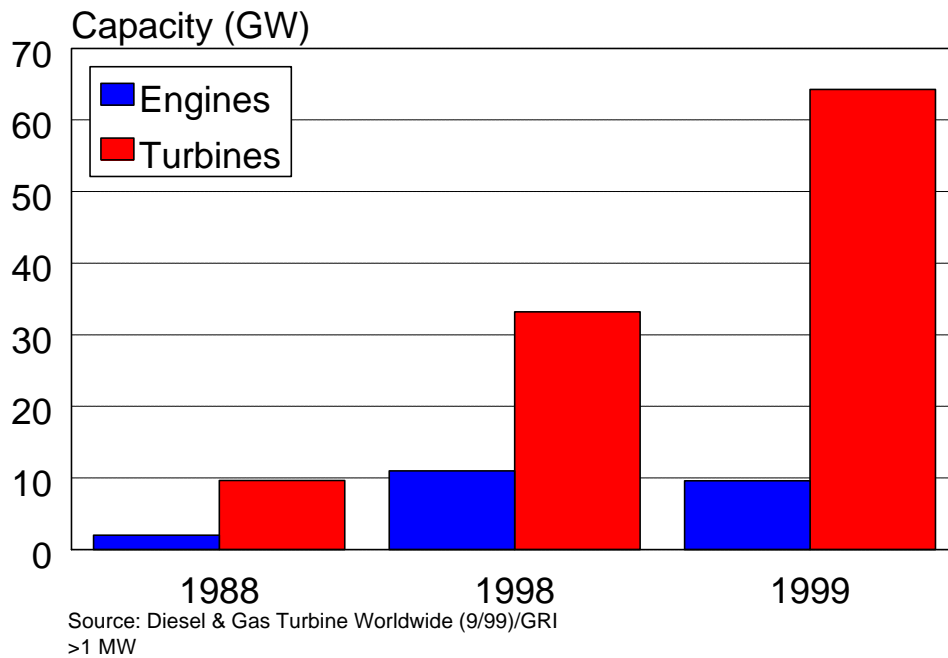


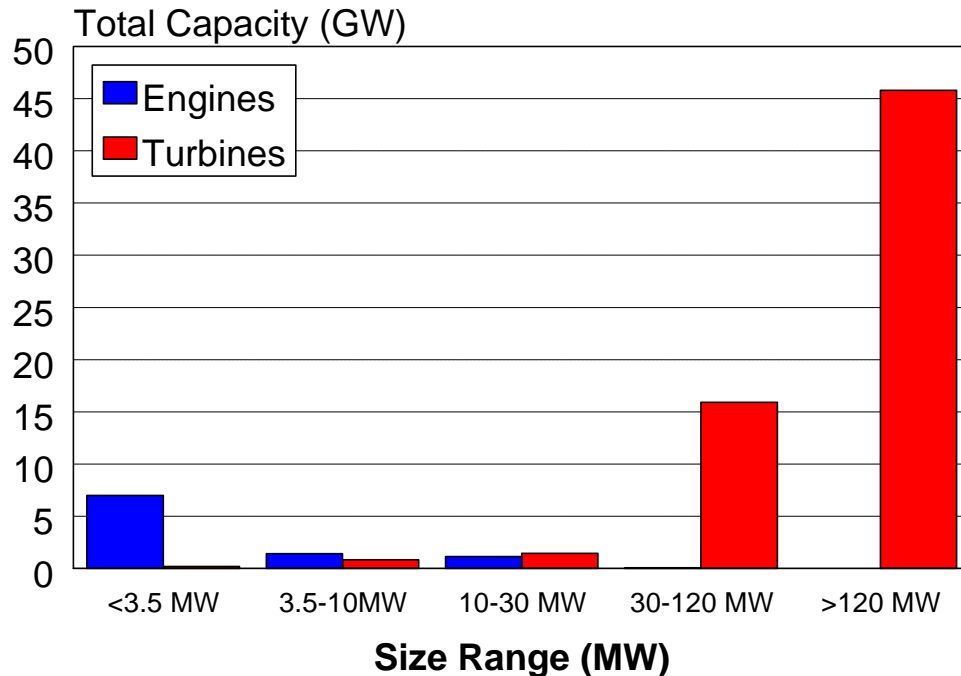
Figure 5

Growth in the U.S. independent power industry closely mirrors a worldwide growth trend in turbine and engine sales (Figure 5). In the past ten years, prime mover sales (over 1 MW) have increased substantially.

Small-Scale Distributed Power Generation

Today -- with electric utility restructuring -- unique opportunities exist for new approaches to generating electricity and satisfying on-site customer energy needs using smaller (under 25 MW) Distributed Generation power systems. GRI has been actively involved in advanced natural gas DG power systems for over twenty years. These efforts included conventional products (gas turbines and gas-fired reciprocating engines), emerging technologies such as microturbines and fuel cells, and other novel power systems such as rotary and Stirling engines.

The market for small-scale power generation has not developed in the past two decades like that of larger systems. There are many reasons for this, including negative scaling effects (i.e., higher total costs with decreasing size), legitimate technical issues, and competitive responses from



Source: Diesel & Gas Turbine Worldwide (10/99)/GRI

Figure 6

electric utilities trying to avoid customer loss. Examples include long approval time and high cost for interconnection and incentive rates to prevent customer loss.

The diversity of existing and emerging products vying for this segment is evidence of an under-developed market and lack of clear product winners. Gas turbines, the dominant choice above 25 MW, begin to lose their supremacy in the 1-10 MW size range (Figure 6). Below 3.5 MW, diesel and gas-fired reciprocating engines become a dominant market segment player.

Microturbines and fuel cells are emerging products mainly addressing the under 5 MW range. Unlike large turbine systems competing against higher priced coal-fired power plants, these emerging DG products are competing against products that presently feature lower capital costs. Differentiation for these emerging products is thus achieved through secondary attributes like lower emissions, lower maintenance needs, lower noise emissions as well as factors such as branding and image.

With the power generation market opening to competition and choice, financial resources are being deployed to improve both existing and emerging products. Product positioning, inter-technology competition, distribution channels, and new product adoption rates are key considerations going into the new decade for DG product manufacturers and their customers.

Overall Product Positioning

Natural gas distributed generation products include existing (turbine and engine) and emerging (microturbine and fuel cell) products. These products face unique technology, market, and regulatory challenges. The challenges for emerging technologies are additionally complex due to

historically low new technology adoption rates in the power generation and energy markets. Low adoption rates are likely due to various factors: conservatism of customers making large capital purchases, high level of time and cost required to develop reliability growth in new products, challenges in developing suitable sales channels and service infrastructure, and the difficulty of overcoming the price-volume *chicken and egg* dilemma.

Existing Products - Gas Turbines.

The early history of gas turbines dates to the 1930-1950 time period. Stationary market application moved relatively steadily during 1950-1980, but accelerated significantly from 1980-1999. With reasonable natural gas prices in the future, the dominance of large gas turbines will continue.

Combustion turbines (or gas turbines) are a popular DG option for power generation due to their general simplicity, reasonable efficiency, and suitability for high-temperature heat recovery. Most gas turbines in this size range are used in a simple-cycle operating mode (Figure 7); fewer small-scale (under 25 MW) combined-cycle systems are installed.

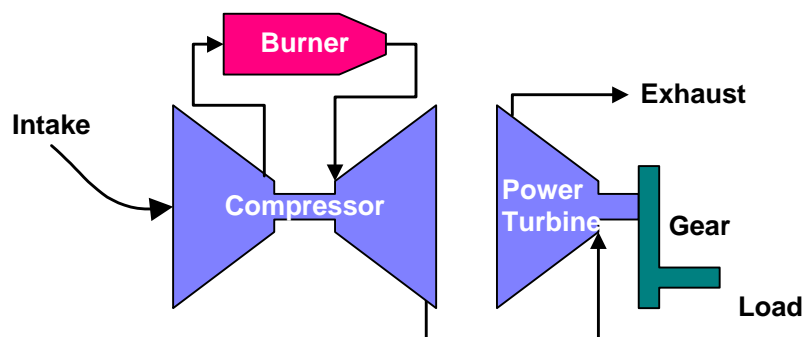
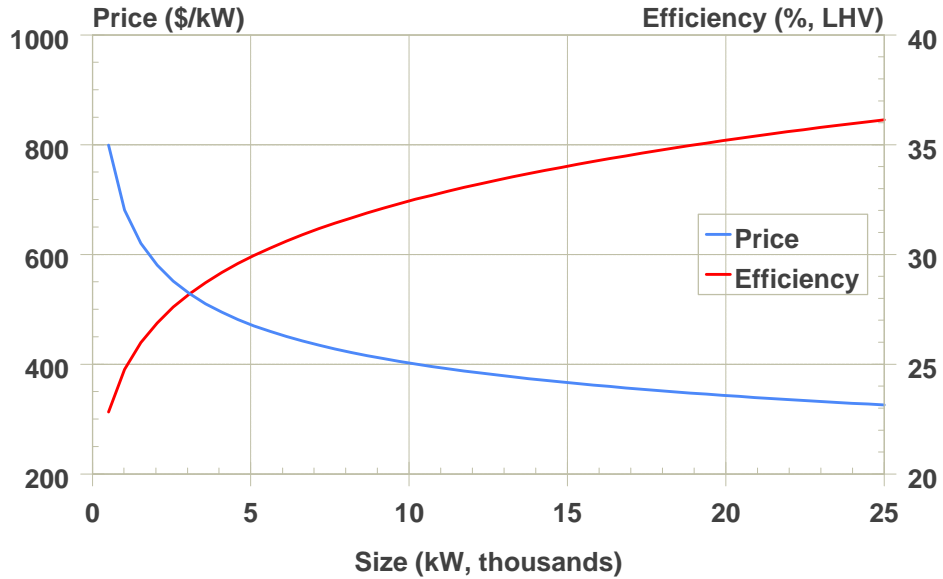


Figure 7

Figure 8 shows characteristic price and efficiency levels for 0.5-25 MW gas turbines. Turbines have higher specific prices and reduced efficiency at levels below approximately 5 MW due to scaling effects. This graph illustrates why small gas turbines (below 1-2 MW) lack appreciable market share.

Gas turbine power and efficiency are largely defined by pressure ratio and turbine inlet temperature (Figure 9). The quandary for gas turbines is that higher firing temperature and pressure -- while raising efficiency -- also increase product cost.



Actual purchase prices may vary due to market conditions and other factors
 Source: Gas Turbine World/GRI

Figure 8

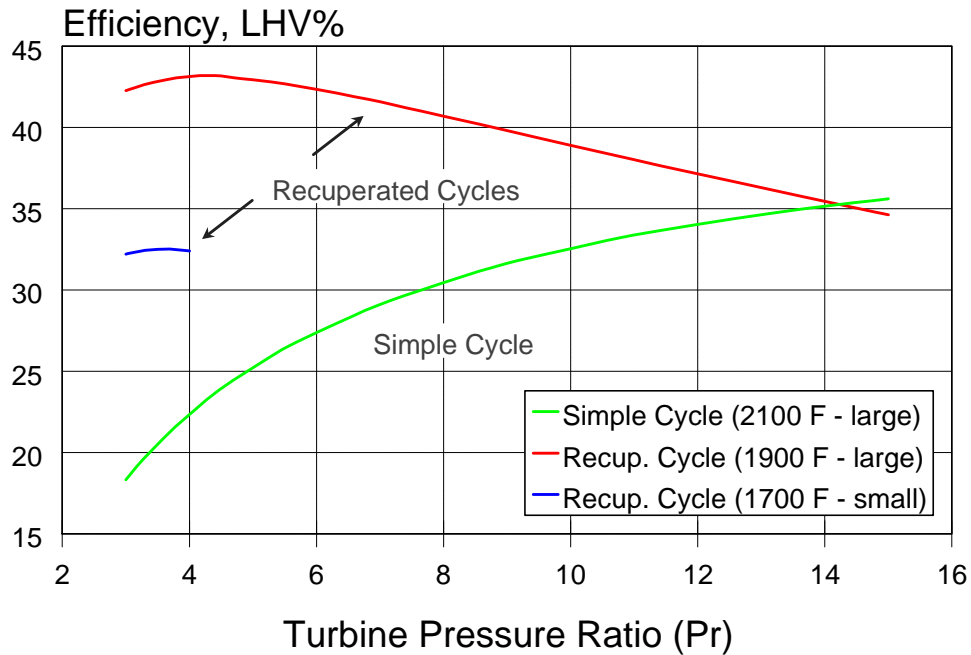


Figure 9

In an effort to skirt this limitation, Solar Turbines -- with support from the U.S. Department of Energy -- recently developed the Mercury 50 gas turbine. This uniquely designed machine is a purpose-built recuperated gas turbine. A recuperated gas turbine violates the simple-cycle turbine *rules of thumb* by achieving higher efficiency at lower pressure ratios. The Mercury 50 is a 4 MW machine achieving 40 percent efficiency -- a significant improvement over comparable simple-cycle machines and competitive with diesel and gas engines in that size range.

Until the Mercury 50, the stationary market experience with recuperated gas turbines included several hundred converted turbines -- mainly in the gas compression market. The market acceptance of this new product will be an interesting case study. Along with recuperated microturbines, the Mercury 50 may significantly increase the portion of turbines produced with recuperators.

Gas turbines have experienced a downward trend in emissions over the past decade. There was a period where steam or water injection was popular to reduce emissions on turbines with conventional diffusion burners. Through this decade, though, a number of manufacturers introduced dry low-NO_x combustors. GRI supported efforts with Allison (Rolls-Royce), General Electric, and Solar Turbines. These have achieved NO_x emissions in the range of 9-25 ppm. This technique seems to reach a practical limit in the range of 5-15 ppm. [For reference, a gas turbine at 25 ppm NO_x and 33 percent efficiency emits about 0.38 g NO_x/hp-hr].

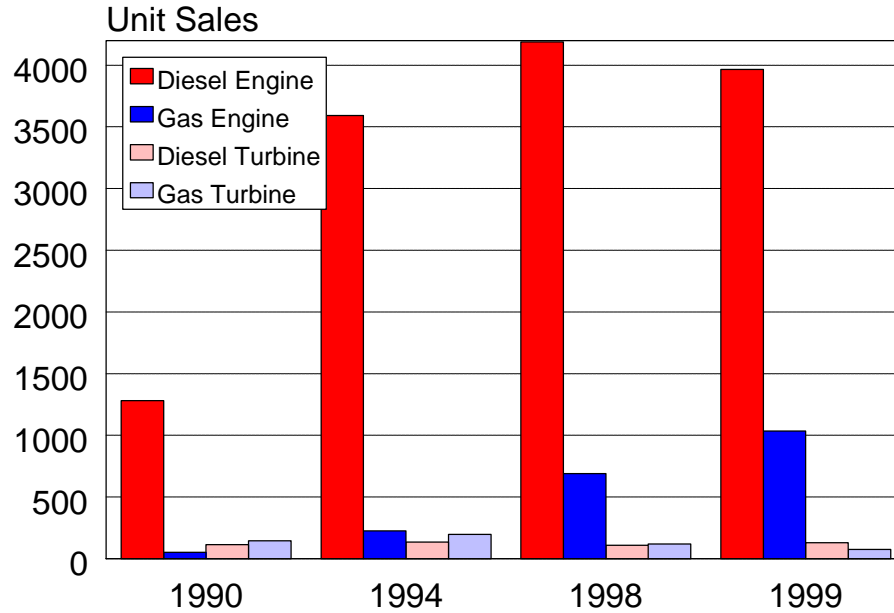
GRI, and others, have long supported catalytic combustion development for gas turbines and other industrial applications. GRI, DOE, and the California Energy Commission are working with Catalytica Combustion Systems to develop and validate the XONON catalytic combustion system. Early full-scale test results on a Kawasaki gas turbine appear promising. Continued development is planned as well as verification of long-term durability. Catalytic combustion holds the promise of being a next-generation emission avoidance strategy for gas turbines.

The future outlook for gas turbines is promising. These units will continue to be the prime mover of choice for larger distributed generation applications -- particularly those involving heat recovery. The prospect for other new recuperated gas turbines or market acceptance of novel concepts such as catalytic combustion will depend on market conditions, pricing decisions, and new product adoption behavior.

Existing Products - Gas Engines.

The formative history of reciprocating engines dates to the 1880-1920 time period. Stationary engine applications have grown consistently over the decades -- including significant growth in the past ten years. With continued product advancements and a reasonable regulatory environment, reciprocating engines will continue as a low-cost and competitive prime mover.

Reciprocating engines in general -- and gas engines in particular -- have emerged in the past 10-15 years as very competitive prime movers for the power generation market. This is evidenced by the tremendous worldwide growth in engine sales (Figure 10, units 1-5 MW in size). Diesel engines are the leading prime mover in this range due to their low first-cost position and popularity in emergency and standby power applications. However, gas engines have grown from 4% of engine sales in 1990 to over 20% (of a substantially larger market) in 1999. This trend is expected to continue into the future. The positioning of gas engines has improved vis-a-vis diesel engines and gas turbines.



Source: Diesel & Gas Turbine Worldwide/GRI (9/99)
 Segment: 1-5 MW; Share based on engine sales

Figure 10

The growth in gas engine popularity is due to across-the-board improvements in cost, efficiency, reliability, and emissions. As gas engines raise their specific output (kW/L), they close the gap with diesel engines on an output and specific cost (\$/kW) basis. This also improves their positioning relative to gas turbines.

Gas engine generator sets can typically be obtained for prices around \$250-400/kW through a distributor. GRI is working with Caterpillar, Cooper, and Waukesha to develop high-output gas engines in the 0.5-4 MW size range that should achieve generator set pricing in the \$225-300/kW range. These products should be positioned to capture opportunities in the higher-end peakshaving market (500-3500 hours per year).

Gas engines achieve shaft efficiency of 30-44% (LHV). Stoichiometric engines have lower efficiencies while the higher numbers apply to larger lean-burn or dual-fuel/micropilot engines. Lean-burn engines in the 0.5-4 MW size range typically achieve efficiency in the 37-41% range.

Gas engines use two basic emission control strategies – stoichiometric operation or lean-burn combustion. Stoichiometric combustion with a three-way catalytic emission control system simultaneously lowers NO_x, CO, and unburned hydrocarbons. Stationary power applications are good applications for this technology due to their steady-state operation. Stoichiometric operation is capable of achieving emissions below 1.0 g/hp-hr and may, with tight controls, achieve NO_x emission levels in the range of 0.15-0.3 g/hp-hr.

The other main gas engine emission control strategy is lean-burn combustion. This employs a large excess of air (50-100% more than required for stoichiometric combustion). The presence of high levels of excess air translates into two beneficial effects:

- NOx emissions can be significantly reduced
- Cycle efficiency can be significantly increased

For stationary applications, lean-burn combustion typically becomes available at sizes above 300 kW. There are a variety of lean-burn engine designs. Larger gas engines often use ultra-high-energy ignition strategies such as a pre-combustion chamber or micro-pilot ignition system using a small (1% of energy) injection of diesel fuel. The practical limit for lean-burn gas engines are NOx levels in the range of 0.3-0.7 g/hp-hr. Ultra-low-NOx gas engines may also use oxidation catalysts for control of CO and unburned hydrocarbon emissions.

While reciprocating engines are characterized as maintenance intensive, prior GRI efforts documented that gas engines can provide high levels of availability -- even in high load factor applications (Table 2).

GRI actively worked during the 1980s and early 1990s to support development of combined heat and power (cogeneration) systems based on smaller (under 500 kW) gas engines. In particular, efforts focused on 5-75 kW systems using low-cost automotive engines and packaged systems to lower total installed costs. Units in the 30-75 kW range were made by Tecogen (Thermo Power Systems) and a robust 5 kW system was jointly developed by Kohler and GRI to target the residential and light commercial markets; based on extensive technical and market research, Kohler and GRI elected not to introduce this product.

While many small cogeneration systems were installed in the past, the overall market acceptance and product adoption rates were modest. There are many reasons for this, some of which are *technology neutral* considerations that others (e.g., microturbines and fuel cells) will need to contend with to develop the small cogeneration/distributed generation market segment. Following are some of the issues:

- Long project lead times
- High sales expenses
- High costs for environmental and interconnection approval
- High costs and complexity for thermal system integration
- Lack of suitable service infrastructure
- High total installed costs (lack of economy of scale)
- Long payback periods
- High maintenance costs

Table 2

	Gas Engines 80-800kW	Gas Engines >800 kW	Gas Turbines 1-5 MW	Gas Turbines 5-25 MW
Availability Factor, %	94.5	91.2	92.7	90.0
Forced Outage Rate, %	4.7	6.1	4.8	6.5
Scheduled Outage Factor, %	2.0	3.5	3.0	4.1

- High back-up/standby power costs
- Ratcheting demand charges
- Competitive pricing responses from existing electricity suppliers

Emerging Products - Microturbines.

Microturbines date back to the 1950-1970 time period, with the automotive market looking at gas turbine products. Stationary market interest was spurred by PURPA in the mid-1980s and accelerated during the 1990s as the automotive market re-assessed small gas turbines in hybrid vehicles and several manufacturers pursued opportunities in the distributed generation market. Several high profile emerging products will significantly shape the microturbine market during the next five years.

Microturbines are unique, small gas turbines being pursued in the under 300 kW size range. These products are high-speed units with shafts rotating at 50,000 - 120,000 rpm, mainly using recuperation to boost efficiency, and integral high-speed alternators that produce an electrical output transformed to more conventional 50 or 60 Hz power. As shown previously (Figure 9), these units tend to be low-pressure-ratio machines ($P_r=3-6:1$). Leading manufacturers include AlliedSignal, Capstone, Elliott, and NREC. The NREC microturbine is different since it is a split-shaft design that uses a power turbine rotating at 3600 rpm and a conventional generator.

The microturbine concept is not new, having been pursued for many decades in the transportation market and since the mid 1980s for the stationary power market. Current products are generally sized at 25-75 kW and achieve efficiencies of 24-30% (LHV). The expectation is for units with higher capacity ratings to emerge over the coming years. NO_x emissions are estimated to fall in the 9-25 ppm range (about 0.15-0.4 g/hp-hr).

Microturbines have generated significant interest and curiosity in the past four years. Several manufacturers are working in this area and using somewhat unique packaging and branding strategies to differentiate their products from conventional competitors such as reciprocating engines.

How the market responds to these products poses a very interesting case study in the power generation and energy markets. Will customers be attracted by this branding and choose these “high tech” alternatives over conventional products? Will manufacturers and other stakeholders be able to establish suitable national and international sales and service channels? Will the equipment exhibit high reliability and long mean time between maintenance? Will these products be capable of moving down the price-volume curve at a suitable pace? Stay tuned.

Emerging Products - Fuel Cells.

The origin of fuel cells dates back to 1839, while the formative history was based on the work of Sir Francis Bacon (circa 1948) and later efforts in the space program. The gas industry’s TARGET effort and other developments by DOE,

GRI, and EPRI during the 1980s and 1990s led to the first commercial fuel cell product in 1991 (International Fuel Cells/ONSI). Today, ONSI is striving to move beyond the early adopter market while a large number of companies and organizations pursue competing products based on alternative fuel cell concepts. Along with ONSI, several high-profile, emerging fuel cell products (e.g., Ballard, Plug Power) will – during the next five years -- meaningfully shape the market's perception and attitudes toward fuel cells.

Fuel cells are unique electrochemical devices that convert fuel into electricity in ways completely different from the thermodynamics of the Carnot cycle and prime mover technology. In fuel cells, hydrogen and oxygen (typically) are separated by an electrolyte – inducing an electrochemical potential that is converted into direct current electricity by hydrogen protons moving through the electrolyte (to combine with oxygen and form water) and electrons flowing through a separate electrical circuit.

This is the basic fuel cell concept, but a practical operational fuel cell system for the stationary power generation market that uses economic fuels such as natural gas require a balance of plant to operate. Figure 11 illustrates this basic system composed of a fuel processing and conditioning subsystem, the fuel cell, a heat and water recovery subsystem, and a power conditioning subsystem to convert DC into useable AC power. These subsystems may include an array of pumps and compressors to move fuel, air, and water.

In practice, there are several different approaches to fuel cell design:

- Molten Carbonate Fuel Cells (MCFC)

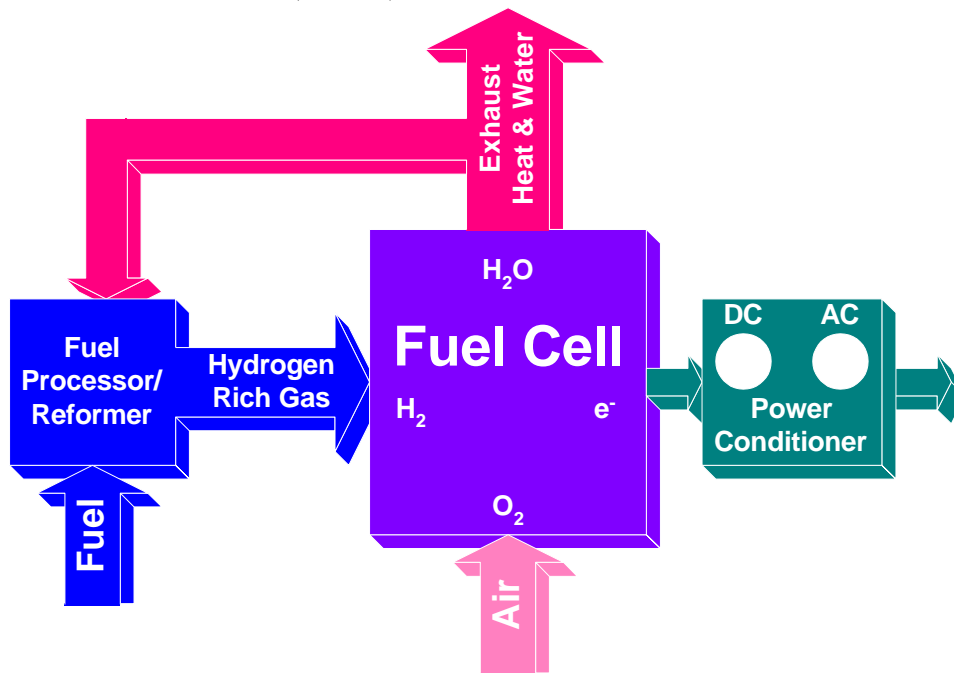


Figure 11

- Phosphoric Acid Fuel Cells (PAFC)
- Proton Exchange Membrane Fuel Cells (PEM)
- Solid Oxide Fuel Cells (SOFC)

Fuel cells have long been a highly attractive power generation concept. Fuel cells feature the potential for high efficiency (35-60 percent), low (to zero) emissions, low noise emissions, and high reliability due to (theoretically) limited moving parts. However, the sobering fact remains that existing engine and turbine technology were actually invented after fuel cells. That is, the rate of technology development and market acceptance for prime movers has been considerably greater than fuel cells. Prime mover technologies have moved far down the price-volume curve, with equipment readily available at prices of \$200-400/kW. The only commercially available fuel cell, the ONSI PAFC introduced in 1991, is priced 10-20 times higher.

Fuel cell technology development challenges and subsequent market development challenges are significant. Several hundreds of millions of dollars (likely billions) have been put into the development of PAFC, SOFC, and MCFC in the past twenty years. In recent years, significant resources have moved into developing PEM fuel cells. These are backed by statements of near-term commercial availability (2001). Based on fuel cell history, this would be a remarkable achievement

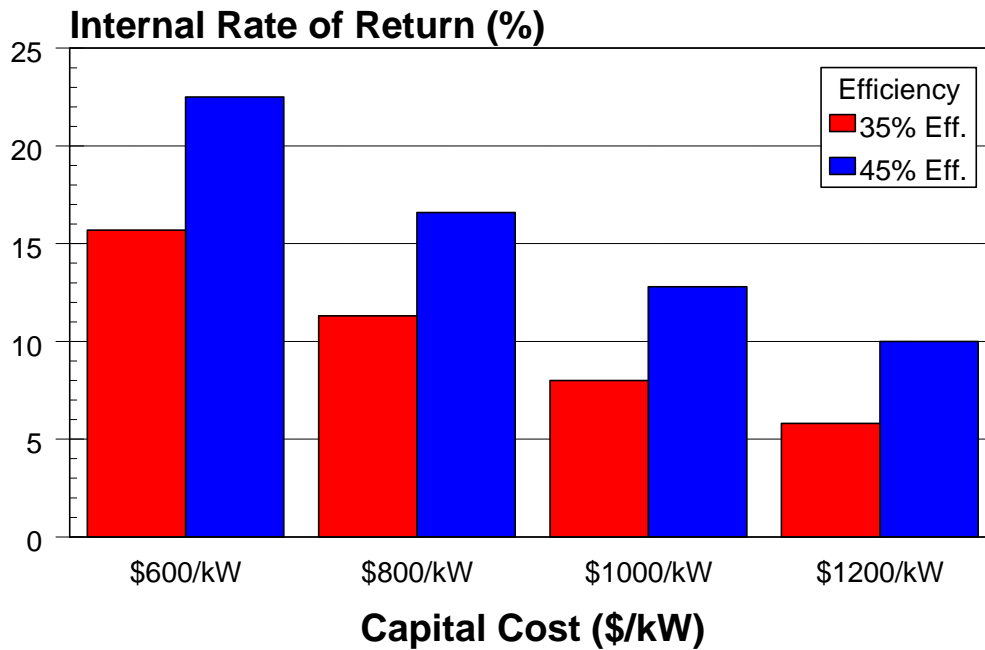
Today's energy economics cannot support significantly high capital costs. Moderately high first costs are acceptable if maintenance costs are low and efficiencies are high (in others words, variable operating costs are low) to justify a baseload operational profile. Figure 12 illustrates how these parameters affect the project rate of return. [It is worth remembering that conventional economics do not convey all aspects of why a power project might be done. Factors such as reliability, security, and power quality are real project decision making factors].

The fuel cell area is rich with opportunity – and risk. GRI's focus has been on pursuit of solid oxide fuel cells due to their potential for low first cost and high efficiency. Low first cost is achieved by a simplified balance-of-plant system – including use of internal reforming and reduced need for fuel clean-up (e.g., SOFC are more tolerant to CO). Manufacturing cost studies indicate the potential for system prices of \$700/kW.

Until fuel cell prices decrease, their market application is likely to be focused on unique or niche markets where customers are willing to pay a premium for quality power or reliability. Major pushes to commercialize PEM fuel cells over the next five years will demonstrate the ability of companies to simultaneously address technical, market, and business challenges.

Summary

The independent power generation industry in the U.S. has come of age in the past fifteen years – particularly with larger gas turbine systems. Restructuring in the electric utility industry opens the prospect for even greater opportunities for non-utility generators – large and small. The challenges, however, are significant. Electricity is a ubiquitous commodity that, with restructuring, is projected to decrease further in average price. This places a challenge on



Maint. \$0.005/kWh; Gas @ \$3/MMBTU; Elec. @ \$0.05/kWh, \$7/kW (peak, 3200 hours), \$0.05/kWh (off peak 5400 hours), 15 Year Depreciation, 35% incremental tax rate

Figure 12

equipment suppliers to squeeze out value in the form of lower capital costs, lower operating costs (i.e., higher efficiency), or lower maintenance costs.

Existing gas turbine (over 3 MW) and gas engine (0.3-3 MW) products are well positioned to provide cost-effective onsite and grid connected power in many regions. Their track record is established and the sales and service distribution channels firmly in place. Emerging products such as microturbines (under 0.3 MW) and fuel cells will need to prove themselves as cost-effective and reliable power generation devices.

Utility restructuring has accelerated capital flow into development of small-scale emerging products, increasing their chances to succeed. With the opportunity, though, comes risk in the form of technical challenges and market challenges. In the coming five years it will be interesting to observe technology development, risk taking, and technology adoption characteristics in the small-scale power generation market.

Like horses in a race, people have predictions about who the winning horse (technology/product) will be. It should be evident that in the independent power industry, large-scale gas turbine power plants will be the clear winner. Every other “horse” is vying to Place or Show. Whether the runner-up will be existing products (smaller gas turbines or gas engines), emerging products (microturbines and fuel cells), or other contenders in the field (solar, wind, Stirling engines) remains to be seen. In either case, competition and choice is coming to the power generation market. Enjoy the race.

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