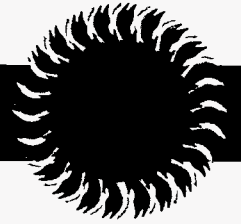


TOPICAL ISSUES BRIEF



**Small Turbines
in Distributed
Utility Application:
Natural Gas Pressure
Supply Requirements**

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H. Lawrence Goldstein



National Renewable Energy Laboratory
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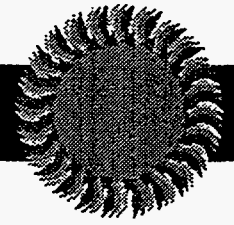
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Small Turbines in Distributed Utility Application: Natural Gas Pressure Supply Requirements

H. Lawrence Goldstein

Prepared for:

Office of Utility Technologies
Energy Efficiency and Renewable Energy
U.S. Department of Energy



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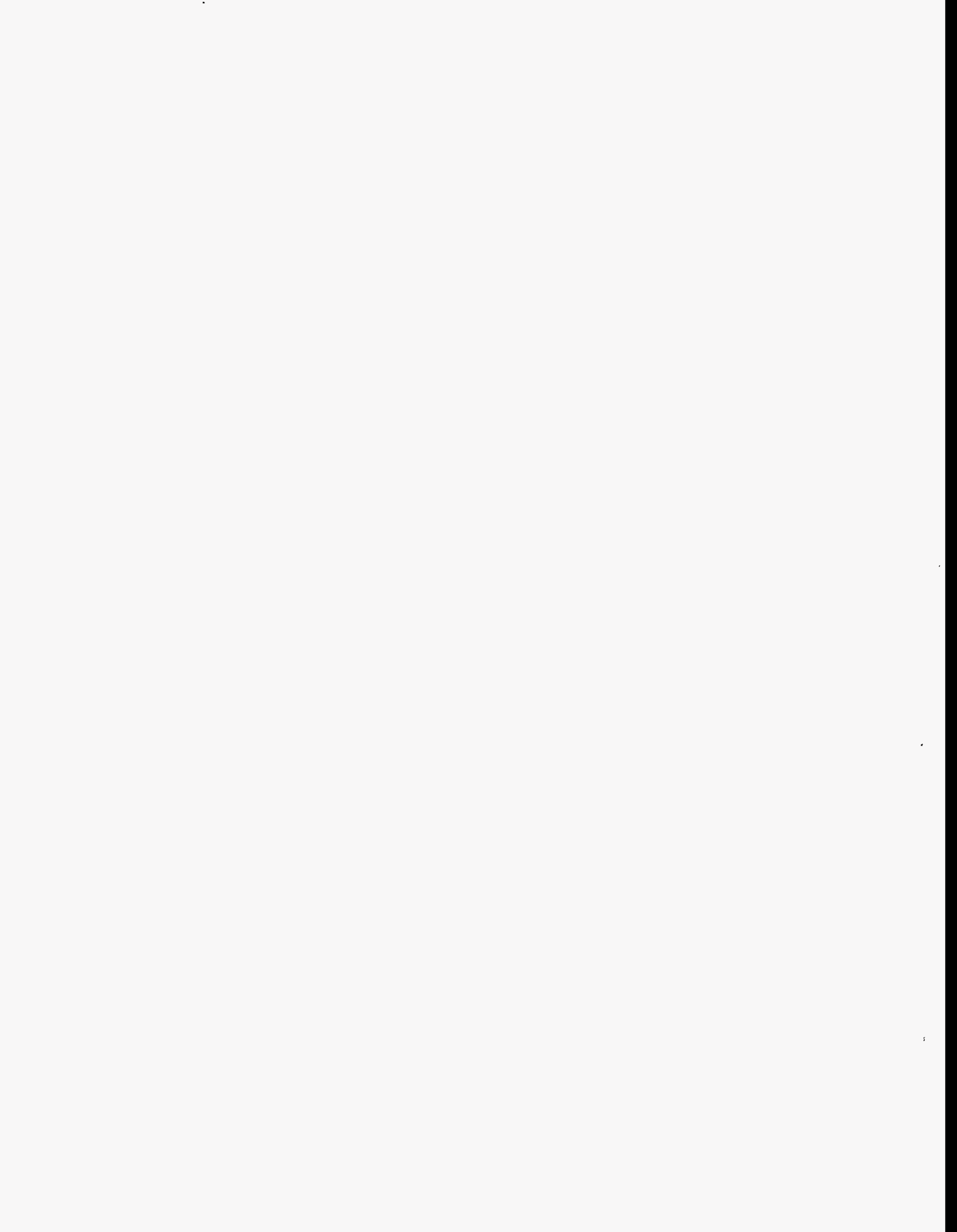
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Abstract

Distributed Utility (DU) is an emerging concept that places small, modular electricity generation and storage systems near customer loads to help meet energy service needs. Implementing DU can strengthen the local distribution system and help avoid or delay the expense of upgrading transformers and feeders. DU options include small, modular fossil and renewable technologies, such as gas-fired combustion turbine-generator sets, diesel/gas-fired engine-generator sets, photovoltaic systems, wind systems, and other emerging technologies including fuel cells, solar thermal dish-Stirling systems and battery storage systems.

The gas turbine-generator set is an attractive option based on its low front-end capital cost, reliable performance at unmanned stations, and environmental performance characteristics. However, one critical aspect of turbine operation that could prove to be a significant obstacle to its widespread adoption in DU applications is the need for a reliable, high-pressure natural gas fuel supply. This report assesses gas turbine utilization issues from a perspective of fuel supply pressure requirements and discusses both cost and operational factors.

A primary operational consideration for siting gas turbines on the electric distribution system (e.g., an electric substation site), is whether the local gas distribution company (LDC) can supply gas at the required pressure. While the issue of a reliable fuel gas pressure supply is very site specific, currently available gas

turbine engines require gas supply pressures of at least 150 pounds per square inch gauge (psig), and, more typically, 250 to 350 psig. Although each LDC configures its system differently, few LDCs maintain line pressure in excess of 125 psig. One option for meeting the gas pressure requirements is to work with the LDC to upgrade or extend an existing pipeline and connect that pipeline to a high-pressure supply source, such as an interstate transmission line. However, constructing new pipeline is expensive, and the small volume of gas required by the turbine for the application offers little incentive for the LDC to provide this service.

Another way to meet gas pressure requirements is to boost the compression of the fuel gas at the gas turbine site. Fuel gas booster compressors are readily available as stand-alone units and can satisfactorily increase the supply pressure to meet the turbine engine requirement. However, the life-cycle costs of this equipment are not inconsequential, and maintenance and reliability issues for boosters in this application are questionable and require further study.

These factors may make the gas turbine option a less attractive solution in DU applications than first indicated by just the \$/kW capital cost. On the other hand, for some applications other DU technologies, such as photovoltaics, may be the more attractive option.

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Small Turbines in Distributed Utility Application: Natural Gas Pressure Supply Requirements

I. Statement of the Issue and Implications

Distributed Utility (DU), an emerging concept that locates electricity generation and delivery systems near the customers, can strengthen the local distribution system and avoid or delay expenditures for upgrading transformers and feeders.¹ One way to implement DU is to place small (e.g., below 5 MW), modular systems that can generate or store electricity at peak demand times at targeted electric utility substations. Research has indicated that DU technologies applied in this way may provide system capacity and energy benefits, improve power quality and reliability, and reduce losses on the distribution system.^{2,3} In practice, as an area's electric load grows and uses up the local distribution system's operating margin, the supporting delivery system (e.g., substation and feeders) becomes stressed and therefore less reliable. DU technologies can provide utilities with another option for maintaining the service reliability of the local distribution system, thus delaying the need for capacity expansion, and may serve as a platform for providing further system benefits.

Technology options for DU application include small, modular fossil fuel and renewable supply and storage technologies, such as gas-fired combustion turbine-generator sets (GTs), diesel/gas-fired engine-generator sets, photovoltaic (PV) systems, wind systems, and several emerging technologies including fuel cells, solar thermal dish-Stirling systems, and battery storage systems. Battery systems are included because they may be charged during the off-peak hours and then dispatched, similar to a generation supply source, during the system or local feeder peak hours, thus offering a similar array of benefits. Because these technologies would be sited at unmanned locations (primarily substations) to provide peaking service, a primary consideration is reliable operation with minimal maintenance. The price of fossil fuel becomes a factor in this application only with increasing hours of operation.

The lower front-end capital cost requirement of both engine-generator sets and gas turbines appears on the surface to give these technologies an edge over most other DU options for substation application. However, superior operational and environmental performance characteristics favor the gas turbine engine. In locating this technology at the electric substation level, one critical aspect of turbine operation that could prove to be a significant obstacle to widespread utilization is the requirement for a reliable, high-pressure natural gas fuel supply.

Although the issue of natural gas supply pressure will be site specific, currently available industrial gas turbines for electric power generation below 5 MW generally require fuel gas supply pressures in excess of 150 pounds per square inch gauge (psig), and typically, depending on the engine manufacturer's model and size, pressures in the range of 250 to 350 psig. At the electric distribution substation level where this technology will be deployed, the issue is whether high-pressure service is available from the local gas distribution company (LDC)—and whether providing that service to solve local reliability problems in the electric distribution system creates reliability problems in the local gas distribution system. While each LDC's system is configured somewhat differently, few local distribution systems maintain line pressure in excess of 125 psig.⁴ In contrast, interstate transmission company pipelines routinely operate at pressures of 1200–1300 psig, because high pressures are more economical for moving gas over long distances.

Several options are available to provide the requisite service pressure at the targeted electric utility substation site; for example, reinforcing an existing LDC service main or constructing a new high-pressure line to the site. Either of these options would then be connected to a source of reliable high-pressure gas, possibly an interstate transmission line or the LDC's own principal supply main that connects the city gate station to the distribution system mains. Another option would be to add fuel gas booster compression at the site.

However, each option is burdened by substantial up-front capital investment requirements. Also, the maintenance and reliability of natural gas booster compressor equipment injects other variables. One last issue is the impact of concurrently operating many gas turbine generation units (e.g., located at several sites on the same or an interconnected gas distribution main). Individually or in combination, these factors may make the gas turbine a less attractive solution in DU applications than first indicated by just the \$/kW capital cost. On the other hand, for some applications other DU technologies—in particular, peak-load-following renewable technologies such as photovoltaics—may be the more attractive option.

This report provides an assessment of gas turbine utilization issues from a perspective of fuel supply pressure requirements and discusses both cost and operational impacts.

II. Gas Turbines and Fuel Supply Pressure Requirements

Gas Turbines

A simple-cycle gas turbine engine consists of three totally integrated components: an air compressor, a combustion chamber (combustor), and a power turbine. In most industrial turbine engines, the compressor and power turbine are normally on the same shaft. This arrangement allows a part of the power output to drive the compressor also, as illustrated in Figure 1. To produce electric power, the remaining shaft output, after the compressor's requirements, is used to drive an electric generator (not illustrated).

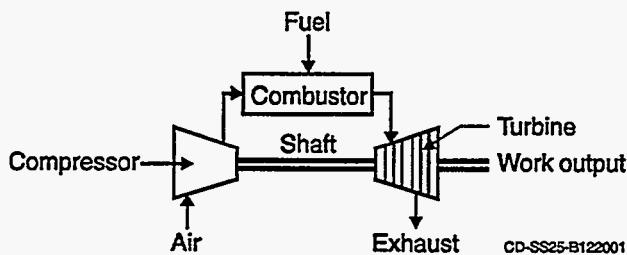


Figure 1. Simple-Cycle Gas Turbine

A more detailed description of the three main gas turbine elements, engine efficiency trends, and pricing considerations are provided in the Appendix.

Fuel Gas Pressure Supply Requirements

The gas turbine uses large amounts of high-pressure air, which is heated in the combustor by burning natural gas or other fuels. The resulting hot, pressurized gas stream is then expanded in the turbine section to produce power. To inject the gas fuel supply into the combustor, the gas must be at a pressure higher than the air stream being discharged from the compressor. Therefore, the compressor discharge pressure sets the minimum requirement for fuel supply pressure. Furthermore, an extra operating margin is required to compensate for pressure drops in the fuel system piping and regulators and across burner nozzles, and to provide for flow control such as engine ramping and other engine-specific factors. The actual fuel pressure margin is typically between 75 and 150 psig more than the maximum pressure developed by the air compressor.

The fuel gas pressure requirements are best illustrated by considering a small industrial turbine engine with an overall air compressor pressure ratio of 6:1 (90 psig). Based on a survey of manufacturers and vendors published in the *1995 Gas Turbine World Handbook*, this level of pressure ratio would be at the lower end of the compression scale for gas turbine engines.⁵ Assuming a sea-level site, the fuel gas supply pressure required for reliable operation of this engine would be between 165 and 240 psig.

III. Local Gas Distribution System

Configuration of Gas Distribution Systems

The distribution system of a local gas utility is designed to move gas at relatively low pressures from city gate or border stations to the end user. The city gate or town border station serves as the primary interconnect between the supply source (e.g., an interstate transmission line connected to a gas field) and the LDC's distribution system. Gas is normally received at a sufficiently high pressure (up to 1300 psig from a transmission system) to require pressure reduction rather than boosting at the city gate. From this point it flows into the LDC's distribution service mains, which are made up of pipe of various diameters. The distribution system also connects the LDC's load-balancing and peaking supply sources (e.g., gas manufacturing or producing facilities, underground or aboveground holder-type storage, and peakshaving facilities).

Although the configuration of each LDC's distribution system is unique in physical layout and operating pressures, the piping systems have common elements. For example, an LDC gas delivery system may typically include several principal *transmission or supply mains*, which are connected to various gate stations and will normally carry the highest system pressures (100–300 psig). These in turn are connected to the *distribution service lines*, which are commonly designed and configured to accommodate two or three levels of service pressure. In a three-level system, "high-pressure mains" (30–100 psig) typically deliver gas to the perimeter of the various local load centers. Gas then flows into feeder or "medium-pressure mains" (5–30 psig) and from there, through distributor or "low-pressure mains" (several inches of water pressure—5 psig) to the service customers. Normally, low pressure is required by all residential and certain commercial and industrial customers. Figure 2 provides an illustration of an LDC system.

As an LDC system expands to meet customer load growth, a major consideration is its ability to meet peak-hour customer demands on a peak day with the pressure that is available at system input points. The distribution network is analyzed from time to time to determine when the system should be reinforced. Common methods for reinforcing or increasing pressure of the local distribution system include boosting pressure at the system input points, adding compressor facilities, enlarging or paralleling (with tie-in) existing high-pressure or feeder mains, and constructing new supply mains.

Distribution Service Supply Pressure

The Gas Research Institute (GRI) conducted a survey of LDCs to determine the available gas supply pressures in *distribution service lines* in the contiguous United States.⁶ It found that distribution pressures generally vary from a few inches of water up to 100 psig. The older industrial cities in the East and upper Midwest tend to have operating pressures ranging from a few inches of water to 10 psig. The newer Sun-Belt cities tend to have higher pressures, varying from 30 to 50 psig.⁷ The survey identified that the most common distribution system supply pressure is in the range of 30 to 60 psig (Table 1).

This survey information is important to siting small gas turbines in DU electric substation applications because in most cases the gas supply pressure available on a local distribution system and offered by the LDC will be considerably lower than the supply pressure

Table 1 - Distribution of Service Line Operating Pressure

Pressure Range	Percent of Total
Low Pressure (inches of water)	26.1
1 to 10 psig	9.8
10 to 30 psig	18.4
30 to 60 psig	42.3
60 to 100 psig	2.6
other	0.8

required by the engine's fuel system. In essence, the distribution gas line pressure that will be most likely available at targeted DU generation sites will be too low to be used directly. In this situation, the turbine facility is at a significant disadvantage. Because the gas volume consumed by a single turbine unit, even in baseload operation, is very small, there is very little leverage in negotiating higher supply pressure with an LDC. However, several different generic approaches can be used to obtain adequate pressure at a site. These approaches are discussed in the next section.

Another issue of potential concern is the reliability of the system's supply pressure when *multiple dispersed gas turbine facilities* are operated in parallel. Simulation studies have looked at the impact on transmission-type pipeline facilities of operating several dispersed, high-pressure, gas turbine generation loads.^{8,9} The general findings from these studies extrapolated to the local distribution system suggest that starting and stopping these units could cause local gas main pressures to fluctuate. If the problem is sufficiently severe, additional line compression will be required to restore pressure reliability. This in turn suggests that an LDC will need to be more actively engaged in the siting and management (e.g., number of units and hours of operation) of dispersed gas turbine generation loads on its distribution network, if it is to avoid localized pressure supply problems. This involvement will require a degree of communication and cooperation between the affected gas and electric utilities that has heretofore been lacking.

IV. Meeting Fuel Pressure Requirements of Gas Turbines

Increasing Local Pipeline Pressure

One method available to an LDC for increasing fuel supply pressure at a site would be using an existing pipeline—either upgrading or extending it, or both—and

interconnecting it to a high-pressure supply source. However, as noted previously, because of the very small volume of gas involved—a 5-MW turbine will consume only about 60 Mcf per hour—there is little incentive for the LDC to provide this service. On the other hand, if the LDC needs to provide additional pipeline capacity in the vicinity of a targeted site to meet its firm customers' peak-demand requirements, then it would more likely accommodate the request. The gas turbine owner/operator will be required to charge the LDC system's firm ratepayers for costs from schedule acceleration as well as incremental construction and operation costs. These payments normally consist of an up-front or annual installment payment in aid of pipeline construction and a monthly reservation or demand charge to cover the expense of providing the required high-pressure service and "interruptible" supply of gas.

Construction cost trends for various diameter, high-pressure-rated steel pipes are presented in Table 2. As might be expected, cost per mile fluctuates considerably with geographic location, terrain, population density, and other factors. Generally, material and labor for constructing land pipelines make up the bulk of the cost. Material costs include those for line pipe and pipe coating. Right-of-way (ROW) costs include expenses for obtaining the ROW and for restoration of land and any damages. Miscellaneous costs include allowance for funds used during construction, engineering, surveying, supervision, administration, overhead, contingencies, and state, local, and Federal Energy Regulatory Commission filing and permit fees. Not included are costs for valves, regulators, and interconnection to an interstate transmission pipeline, metering station, or compressor station.

The table indicates that capital costs for construction of even a few miles of small-diameter pipeline can rapidly equal or exceed the capital outlay of the turbine/generator system. Accordingly, in all but a few cases

where a high-pressure gas supply source is located adjacent to or very near a targeted site, it will not be economically justifiable to utilize this option. As a point of reference, 6-inch pipeline operating at an inlet pressure of 125 psig with only a nominal pressure drop is capable of delivering about 3 times the hourly gas volume required by a 5-MW turbine.

Fuel Gas Booster Compressors

1. Equipment Options

If the supply pressure of LDC pipeline gas is not sufficiently high to be used directly, an alternative option is to boost the compression of the fuel gas at the gas turbine site. In 1991 GRI researchers conducted a survey of manufacturers and suppliers of booster compression equipment and found that compressors are readily available for small gas turbines below 5 MW.¹⁰ Equipment options include both stand-alone, reciprocating (single- or two-stage) and single-stage, oil-flooded screw compressor models. Both types of equipment are capable of providing the required gas fuel system delivery pressure when the LDC pipeline supply pressure is as low as 3 psig. Generally, higher pipeline pressures will significantly lower the cost of compression. For example, at 3 psig a two-stage reciprocating compressor will be required, while at 30 psig only one stage may be necessary. In this case equipment costs (as indicated by one vendor) may be reduced by as much as 30%.¹¹ In practice, the supply contract negotiated with an LDC will provide for some guaranteed minimum level of gas pressure. The latter provision is necessary to successful turbine operation, because the booster compressor operates at a fixed compression ratio and low inlet suction pressure (e.g., pipeline supply pressure) harms performance.

Table 2 - Current Land Pipeline Economics (1995 dollars)

Average Cost Trend, \$ per mile

Pipeline Size inches	ROW \$/mile	Material \$/mile	Labor \$/mile	Misc. \$/mile	Total \$/mile	Low \$/mile	High \$/mile
6 in	6,600	92,800	159,400	78,800	337,600	107,700	1,086,700
8 in	29,200	111,000	164,000	106,600	410,800	84,600	1,676,700
20 in	16,700	182,400	455,800	208,200	863,100	428,600	1,302,200

Source: *Oil and Gas Journal*, November 27, 1995.

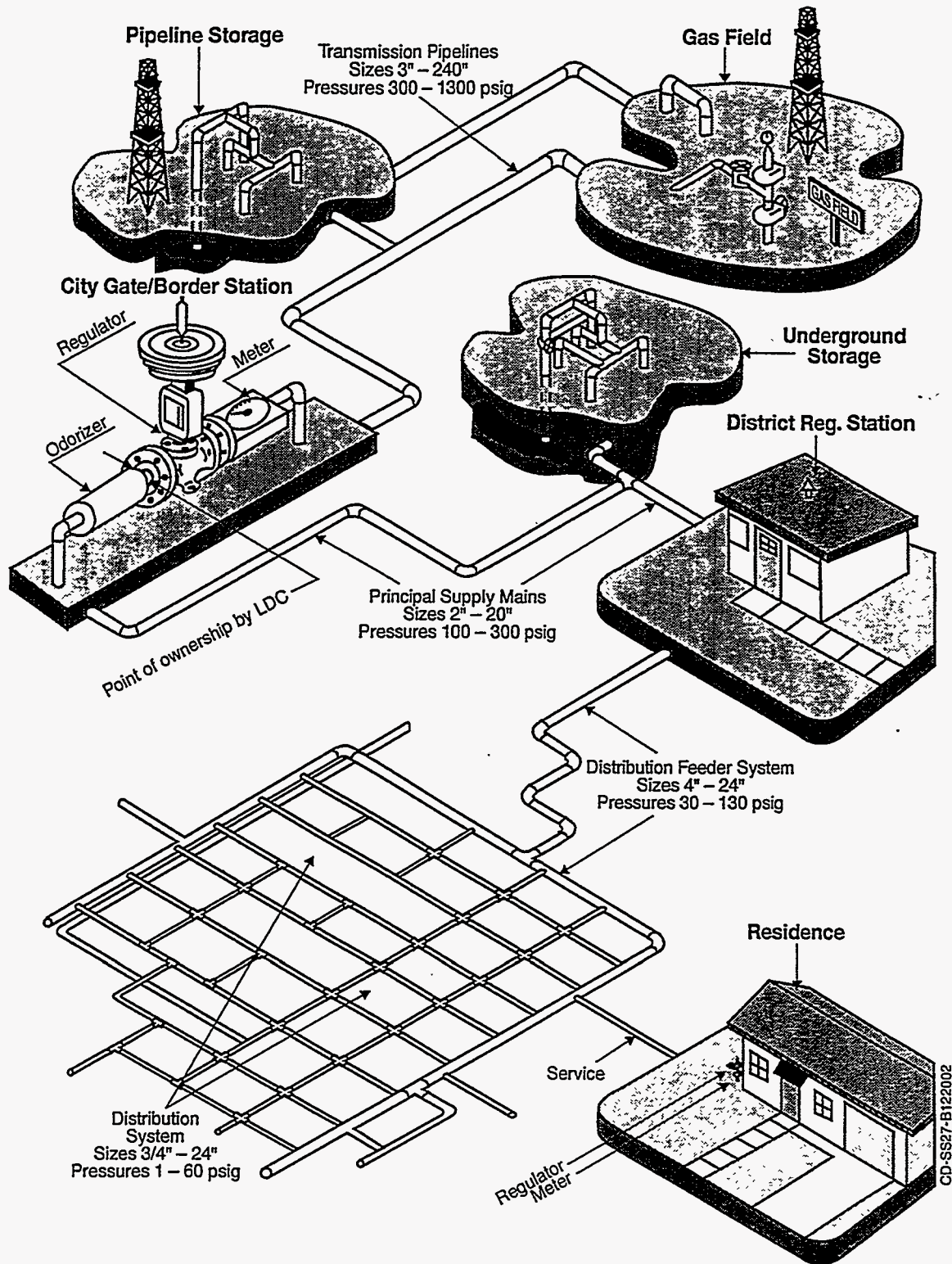


Figure 2. Local Gas Distribution System

Table 3 - Representative Prices of Stand-Alone Fuel Booster Compressor Equipment (1991 dollars)

Gas Turbine Manufacturer	Base Rating (at ISO), kW	Booster Compressor Price Range, \$	Booster Price Range per Unit Power Output \$/kW
Garrett	548	30,000-90,000	55-165
Solar Turbines	1,080	50,000-150,000	45-135
Allison Engine	3,925	70,000-220,000	18-56

Source: *Alternative Systems for Fuel Gas Boosters for Small Gas Turbine Engines*, GRI 92/0239.

2. Equipment Price

The price range of available screw-type booster compressors (based on 30-psig supply pressure) is illustrated in Table 3. Reciprocating compressors typically cost up to 20% more than the comparable size rotary screw compressor. Generally, economies of scale result in the booster compressor cost per unit of power output declining with increasing size range. However, in the size range below 2 MW, the unit costs are significantly higher because the manufacturing economies of scale are not as great and because the smaller number of turbine installations at this size means that fewer production units are sold.

3. Reliability and Maintenance

Manufacturers of both types of booster compressors claim that their products offer unit reliabilities and availabilities of between 90% and 95%, provided that both preventive and routine maintenance are carried out at frequent intervals. However, because the experience base using this equipment in small gas turbine facilities is still rather limited, it is not known how valid the RAM (Reliability, Availability, Maintainability) claims really are. A gas turbine engine is developed through years of careful engineering, testing, and integrating the three major components. In contrast, a booster compressor is manufactured to provide a wide range of uses, and in this particular application it is primarily an off-the-shelf, stand-alone item. Therefore, simply wedding the two may not provide satisfactory reliability and availability. GRI has indicated that a joint study with the Electric Power Research Institute (EPRI) on this issue is planned for 1997.

Annual expenses for maintaining booster compressors are typically in the range of 2 to 4 mills per kWh.¹² This cost represents a significant addition to normal gas turbine operation and maintenance (non-fuel) expenses, which are in the range of 5 to 7 mills per kWh.¹³

4. Other Considerations

The most efficient way to drive a booster compressor is by direct power takeoff from the turbine, which typically consumes about 5% to 10% of the engine power output. Also, a source of compressed fuel gas is required to start the engine. For these two reasons, an electric motor is the most commonly used drive. However, as noted in Section II, providing black-start capability precludes this option and instead requires the installation of a second gas-fueled motor/generator set dedicated to powering the fuel gas booster compressor. This feature can increase initial booster equipment costs by 30% to 40%.

The fuel gas booster compressor is physically separate from the gas turbine and is normally installed on its own skid within a building. The footprint of this facility is roughly the same as that of the gas turbine facility. In addition, the motor/generator set for black-starting the booster compressor usually requires a separate, explosion-proof, dog-house-type structure.

V. Conclusions

1. The study findings suggest that the need for a reliable and firm high-pressure fuel gas supply may be a significant barrier to widespread deployment of small gas turbine/generator sets, under 5 MW, in DU applications involving the electric distribution network.

2. Although the issue of adequate supply pressure will be site specific, survey information indicates that the typical range of gas pressures available in local distribution systems across the United States is substantially below that needed for gas turbine operation.

3. Fuel gas booster compressors are readily available as stand-alone, add-on units and are capable of increasing supply pressure at a turbine site from as low as 3 psig to the required operating pressure, which may be as much as several hundred psig. However, the life-cycle costs of this equipment are not inconsequential, and maintainability and reliability in this mode of application are questionable and require further study.

4. Extending a high-pressure gas supply main to the site is another option, but in most cases it is significantly more costly. Depending on distance and other considerations, extending the supply main may easily exceed the capital cost of the turbine/generator set. Furthermore, because the gas volumes consumed will be very small there is little incentive for an LDC to undertake this type of project.

VI. Notes

1. EPRI, PG&E, and NREL. *An Introduction to the Distributed Utility Valuation Project*, Monograph, 1993.

2. Coles, R.L., et al. *Analysis of PV Benefit Case Studies: Results and Method Used*, NREL Draft Report, May 1995.

3. Telephone conversation with a representative of Solar Turbine Company, 16 December 1995. Solar Turbine Company and San Diego Gas and Electric are now completing a joint DU test program to define the operating benefits of using a small advanced gas turbine to provide peaking-load generation in support of substation operations. Results are expected to be published this year.

4. Faulkner, H.B. *Currently Available Fuel Gas Booster Compressor Equipment for Small Gas Turbine Engines*, GRI Report 91/0328, November 1991.

5. *1995 Gas Turbine World Handbook*, Vol. 16, (Connecticut: Pequot Publishing), 4:05-15.

6. Jasionowski, W. J., et al. *Assessment of Excess Flow Valves in Gas Distribution Service Lines*, GRI Report 85/0150, August 1985.

7. Faulkner, H.B. *Alternative Systems for Fuel Gas Booster for Small Gas Turbine Engines*, GRI Report 92/0239, November 1991.

8. Energy Ventures Analysis, Inc. *Pipelines to Power Lines: Gas Transportation for Electricity Generation*, EPRI TR-104787 and GRI-94/0057, January 1995.

9. Jensen Associates. *Gas for Electric Generation: The Challenge of Gas and Electric Industry Coordination*, EPRI TR-101239, September 1992.

10. Gas Research Institute Report, GRI 91/0328.

11. Conversation with a representative of U.S. Turbine Company, 14 November 95.

12. Vendor quotation for a typical preventive and regular maintenance service contract based on a cost of \$70 to \$10 per month per hp for up to 2,000 hours of operation.

13. Wan, Y. and Adelman, S. *Distributed Utility Technology: Cost, Performance, and Environmental Characteristics*, NREL/TP-472-7844, 1995.

Appendix: Gas Turbine Technology and Price

This Appendix briefly describes small gas turbine technology and provides a perspective on price and related factors.

Gas Turbine Engine Components

As noted in Section II, a gas turbine engine comprises three main elements:

1. Compressor

The compressor takes in large amounts of air, compresses it to the high pressure required by the power cycle, and delivers it into the combustor. Compressors are designed to operate at a specific combination of air flow and pressure. The combustor operates at nearly constant pressure, which is determined by the pressure of the compressed air entering the chamber. Based on a 1995 survey, published by *Gas Turbine World*, of performance specifications for electric power turbines by manufacturer and model, most industrial gas turbine engines require pressure in the range of 10 to 25 atmospheres (approximately 150 to 375 psig).¹ For the fleet of small gas turbines in the size range below 5 MW, the overall pressure ratio developed by the compressor (the ratio of the compressor discharge pressure to the inlet suction pressure) is between 6:1 and 15:1, or roughly 90 to 225 psig. The larger gas turbines, up to several hundred megawatts, have compression ratios of between 15:1 and 25:1 (about 225 to 375 psig). Lastly, aeroderivative turbines have compression ratios significantly higher than their industrial counterparts, typically between 20:1 and 30:1 (about 300 to 450 psig).

While any type of high-efficiency compressor may be used, the axial-flow compressor is normally chosen for its design flexibility and greater air-handling capacity. Typically, multiple stages are used to develop the high-compression pressure ratios required, because each stage of an axial-flow compressor develops a pressure ratio between 1.2:1 and 1.4:1. As an example of this practice, the ABB Type 8 industrial turbine (52.8 MW, ISO base rating) uses a 12-stage compressor to develop an overall compression ratio of 15.5:1.²

2. Combustor

In the combustor, the fuel gas and a portion of the compressed air burn at nearly stoichiometric conditions (flame temperature approximately 3500°F) to produce a high-temperature combustion product gas stream. The remainder of the air is then efficiently mixed with the gas stream to reduce its temperature to the permissible first-stage turbine inlet temperature. Generally, the higher the first-stage turbine inlet temperature, the more power output and higher efficiency (heat rate) that can be obtained from the cycle. Accordingly, the drive of gas turbine (GT) technology is toward higher turbine inlet

Table 4 - Simple-Cycle GT Development Trend

Model	Year	ISO Base Rating, kW	Heat Rate, Btu/kW	Turbine Inlet, °F
W501D	1980	104,400	10,290	2025
W501F	1989	167,000	9,460	2460
W501G	1996	230,000	8,860	2600

Note: ISO ratings are at International Standards Organization conditions of sea level and 59°F.

temperatures, with the focus of research on materials and coatings that can better withstand these temperatures for extended periods. This technology trend is best illustrated by the Westinghouse model 501 heavy-duty, single-shaft, simple-cycle engine evolution (Table 4).

3. Power Turbine

The power generation part of the engine cycle is represented by the turbine. The hot, pressurized gas leaving the combustor enters the turbine and expands as it passes between successive stages of fixed and moving (rotor) blades. As it moves through the stages, the gas stream gives up its energy (through decreases in both pressure and temperature), imparting kinetic and rotational movement, which in turn drives the shaft, providing power to the air compressor and electric generator.

Gas Turbine/Generator Prices

In today's competitive market, small gas turbine/generating packages below 5 MW are priced from \$400 to \$900 per kW (Table 5). The highest price is associated with the smallest output (kW) unit. Manufacturing

economies of scale (e.g., typically several GT engine models sharing a common design and equipment platform) result in a rapid drop in cost per unit of output (\$/kW) for engines above a size of roughly 2 MW. Below this size the market for standby power and generation is dominated by internal combustion (IC) engine/generator sets because of their superior unit prices, which are approximately half as much as those of GT engine/generator sets. The combination of lower sales (fewer installations) and less economy of scale at this size result in higher costs and prices for these GT engines.

The package prices in Table 5 reflect an average. Actual price quotes show a fairly wide range, depending on the vendor's and packager's competitive stance, marketing strategies, geographical area, and production capabilities. Like retail prices, actual costs depend on how badly the seller wants to do business in a particular market. The other consideration regarding the price is that it represents *equipment only*. Completely turnkeyed plant costs will conservatively add between 150% and 300% to the *equipment-package-only price*.³ The services that may be included cover land and site preparation, such as foundations and civil works; architectural and consulting engineering and EPC services; project management; equipment transportation; sales tax; installation; environmental control systems for NO_x and CO; equipment and control housing and acoustical silencing; legal and financial services; and operator training, start-up, and commissioning.

In this specific DU technology application, another potential benefit to the electric utility is the ability of the installed gas turbine facility to provide black-start capability to the area served by the substation. Black-start ability requires a storage battery system or a small (IC) motor/generator set to power the turbine equipment

(e.g., compressors and power turbine) in the event of an electrical power outage. This equipment plus associated housing and noise silencing will typically increase facility costs by another 25% to 50%. Additionally, the turbine/generator set will typically be installed in an enclosure of some type (e.g., a Butler building) to provide equipment protection, a servicing and maintenance bay, noise attenuation, and security. With limited room available, the gas turbine facility can be accommodated in a space with the approximate dimensions (l x h x w) of 30 feet by 14 feet by 10 feet. The small motor/generator set or storage battery system will also require its own enclosure, typically a dog-house-type structure.

Overall simple-cycle thermal efficiencies for the fleet of available small gas turbines are typically between 20% and 28%, with corresponding heat rates (LHV) between 12,000 Btu/kWh and 18,000 Btu/kWh. While this efficiency is lower than that of the larger industrial turbines, as previously noted, the annual operating expense for fuel becomes more of an issue as load cycle-time and/or gas prices begin to increase.

Notes to the Appendix

1. *1995 Gas Turbine World Handbook*, Vol. 16, (Connecticut: Pequot Publishing), 4:05-15.
2. Asea Brown Boveri Ltd., *Placerita Combined Cycle Goes On-Line*, Clean Energy Series, CH-KW2021 89E, 1989.
3. *1995 Gas Turbine World Handbook*, pp 1-24. Supplemental price quotations supplied to author by various vendors.

Table 5 - Prices of Representative Simple-Cycle Gas Turbine/Gen Sets
(Prices are in 1995 dollars and FOB factory)

Engine Vendor	Model	Power Output (ISO Rating), kW	Gas Turbine Engine/Gen Set, \$	Unit Price \$/kW
Pratt & Whitney	ST6L-813	780	728,000	\$933
Solar Turbines	Saturn 20	1,140	840,000	\$737
European GT	Hurricane	1,630	1,150,000	\$706
Solar Turbines	Centaur 40	3,515	1,570,000	\$447
Allison Engine	501 - KB7	4,910	1,985,000	\$408

Source: *1995 Gas Turbine World Handbook*.