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Survey of Installation and Operation Characteristics of Currently Operating Small Cogeneration Units

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A05 Microfiche A01

ORNL/TM-9428

Energy Division

SURVEY OF INSTALLATION AND OPERATION CHARACTERISTICS OF CURRENTLY OPERATING SMALL COGENERATION UNITS

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Date Published: August 1985

for the
U.S. NAVY CIVIL ENGINEERING LABORATORY
Port Hueneme, California 93043
under
Interagency Agreement No. N0003784 WR45124

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACKNOWLEDGMENTS

Many individuals provided information used in this report and gave generously of their time, making it possible for the authors to visit many small cogeneration installations. The authors wish to acknowledge these individuals, without whom this report would not have been possible: Dennis Wilson, John Young, Don Winter, and Lyle Mixon of Cogenic Energy Systems; Angelo Skalafuris, Carl Foust, and Bob Battaglini of ReEnergy Systems; Michael Feori and Jim Ring of Intellicon; Michael Gudenkauf of Martin Cogeneration; Bob Person and Cathy Mirable of Thermo Electron; Lou Winter and Fred Reaume of Waukesha Engine Servicenter, Inc. (WESI); George Thompson of Enertech; Helmut Eric Nimke and Anthony Bobelis of Brooklyn Union Gas; Ed Dickinson and Charlie Mayer of Waukesha Engine; Kayton Heavrin of Caterpillar Tractor; Darryl Franklin of On Site Energy; Roger Henneke, Manager of the Freehold, N. J. YMCA; and Bud Reeves, Manager of the Villa Del Rey Retirement Home, Escondido, California.

Ronald L. Graves, William R. Mixon, Michael A. Karnitz, and Garland Samuels reviewed this report and offered many helpful suggestions. Clara Nichols and Gil Farrell typed the manuscript. Finally, the guidance and support of Dr. T. Y. Richard Lee of the U. S. Naval Civil Engineers Laboratory who managed the study is acknowledged.

ABSTRACT

Small cogeneration systems of under 500kW electrical capacity have the potential to substantially reduce energy consumption in many commercial, institutional, and industrial applications. Whether a cogeneration user actually realizes a monetary savings will depend on several factors including installation and maintenance costs of the cogeneration equipment and the reliability of the system. This study examined these and other characteristics of commercially available small cogeneration systems.

Installed costs of small cogeneration systems were found to be in the range of $1000 to $1400 per kW of electric capacity, depending on the manufacturer's design approach. Maintenance costs, including minor and major overhauls, range between 1.0 and 1.5¢/kWh of electricity produced. Information on the installation, operation, and reliability of small cogeneration installations was collected during visits to 11 of the 35 small cogeneration systems operating in May of 1984. Control system and design problems accounted for over 60% of the major cogeneration system problems. Cogeneration system utilization ranged from 57 to 94% for the seven applications with sufficient data to calculate utilization. Consideration of the problems of the low utilization applications suggests that well designed and maintained systems should be able to achieve availabilities better than 85 or 90%.

Several recommendations were made in light of the problems identified at the 11 small cogeneration applications which were visited. Small cogeneration systems should be carefully designed with special attention to prevention of engine overheating. Untrained personnel should be prevented from modifying or adjusting the cogeneration equipment. Regular maintenance should be performed by qualified service personnel. In order to minimize down time when problems arise, the small cogeneration system should be equipped with an automatic failure notification system so that service personnel can be dispatched promptly, and service personnel should be located near the installation.

1.0 INTRODUCTION

When fossil fuel is burned in large power plants to produce electricity, typically 65% of the available energy in the fuel is lost in the form of waste heat. Much of this waste heat could be utilized for industrial process heat, space heating and cooling, or domestic hot water. However, the placement of large power plants far from population centers inhibits utilization of this waste heat. One solution to this problem is the placement of smaller natural gas or diesel power generation plants at the site where thermal energy is required. By using these smaller power generation plants to cogenerate electricity and useful heat, up to 80% of the useful energy in the fuel can be utilized.

Cogeneration, the simultaneous production of electricity and heat, was used to a limited degree in the 1960's and 70's with diesel and natural gas fuels. Widespread application of cogeneration has not come about for a number of reasons. Foremost was the reluctance on the part of electric utilities to buy excess cogenerated electricity or supply electricity when cogeneration equipment could not supply all of a user's demand. As a result, most cogeneration systems of this period were total energy plants, completely isolated from the electric utility. As a result, these systems required redundancy and oversizing to achieve reliability requirements. In addition, total energy plants were required to follow the user's electric load. This tended to reduce efficiency in two ways: heat would often be wasted since these systems tended to produce more heat than was needed; and the prime mover was not always operating at its most efficient load level. These factors tended to raise the cost of cogeneration and reduce its economic attractiveness.

This obstacle to widespread use of cogeneration was substantially removed by the Public Utilities Regulatory Policy Act (PURPA), part of the National Energy Act of 1978. As a result of this Act, utilities are required to allow cogeneration plant connection to the utility grid, provide standby and back-up electric power to cogenerator users, and are required to sell or buy electric power from cogenerators at fair and reasonable prices.

Thus, PURPA allows cogeneration units to be installed without redundancy or oversizing. Systems can now be sized to operate at the most efficient power level and to make full use of the thermal output of the system. Electric power shortfalls and excesses can be taken care of by the utility interconnection.

In the wake of PURPA, several companies began marketing pre-engineered, cogeneration units to supply the potentially large market for cogeneration units of under 500 kW electrical capacity. This market includes restaurants, athletic facilities, hotels, hospitals, some industries, and other similar commercial and institutional facilities. To reduce the cost per kW of the pre-engineered units, high-speed, lightweight engines are used in many models. A previous study showed that with the proper matching of an efficient, small, pre-engineered cogeneration unit to the thermal load, the economics of cogeneration are quite attractive.[1] However, uncertainties surround this assessment:

> "The principal uncertainties of this assessment are in the efficiencies, reliabilities, and installed costs of the small cogeneration modules. None of these cogeneration modules have been widely used... In most cases, field performance of modules has not been verified. The use of 1800 revolutions per minute engines in many of these cogeneration modules is further reason for uncertainty, since the reliability of 1800-rpm (revolutions per minute) engines in this type of application is not widely accepted."[1]

The performance, reliability, costs, and maintenance requirements of these small pre-engineered cogeneration units of under 500 kW electrical capacity are the focus of this study.

The information presented in this report was gathered by telephone inquiries and by visits to cogeneration installations. Cogeneration system suppliers, engine manufacturers, service personnel, engine users, and cogeneration system users provided much of the information presented in this report. The authors visited 13 cogeneration installations to obtain first-hand knowledge of the operation, maintenance, and performance of these systems. The 13 cogeneration installations include one test facility, one total energy cogeneration installation, and 11 small cogeneration installations. These 11 installations account for nearly one-third of the small cogeneration systems in operation at the time of the visits, May 1984.

This report is organized around four principal topics. Section 2 reports on a search for literature about the reliability and maintenance requirements of small cogeneration systems. Section 3 discusses the commercially available small cogeneration equipment and services. Section 4 describes several small cogeneration installations. Operating experience and reliabilities of small cogeneration systems are discussed in Section 5. Conclusions and recommendations are given in Section 6.

2.0 LITERATURE SEARCH

A review of the published literature on the reliability and performance of small-scale cogeneration systems and the reliability of the small, continuous duty, high-speed internal combustion engines found in these systems revealed little information. Podlasek, in a report sponsored by the Gas Research Institute (GRI), recognized a lack of information on the reliability of small cogeneration systems and their prime movers, and proposed establishing a reliability data base for natural gas cogeneration.[2] The objective of the proposal was to enhance operating performance of these systems, as well as to promote market acceptance. Work on establishing a data base is not expected to begin until 1986.

Literature does exist on large cogeneration installations, the feasibility of small-scale cogeneration, and the reliability of large industrial prime movers. This literature can be divided into four categories: (1) case studies and surveys of total energy and cogeneration installations, (2) studies on the feasibility and market potential of small-scale cogeneration, (3) reliability studies of prime movers used for standby power at nuclear power plants, and (4) reliability of large industrial prime movers. It is instructive to examine the literature for a number of reasons:

- past operating experience of large cogeneration systems can provide insights into the attributes and potential problems with smaller systems,
- projections of installation and maintenance costs of small cogeneration systems will help to put into perspective actual costs of operating systems, and
- reliability of large, slow-speed prime movers can give insights into and perspectives on the reliability and potential problems with the small, high-speed engines investigated as part of this study.

Several reports deal with case studies and surveys of total energy and cogeneration installations. The case studies reported in Refs. 3 and 4 are for installations ranging in size from 900 kW to 12,500 kW electrical capacity. Prime mover capacities range from a 400 kW diesel engine to a 6,000 kW steam turbine generator. Every system studied in these two reports had performed well and had good reliability. Reasons given for their success include: (1) competent technical management, (2) well-trained maintenance staff, (3) thorough monitoring of plant conditions, and (4) good maintenance procedures. Problems associated with unsuccessful systems included: (1) fast rising fuel costs, (2) curtailment or limitation of natural gas supplies, (3) poor system design, (4) high operating and maintenance costs, and (5) low utility buy-back rates.[1,14]

The second category of literature surveyed dealt with the feasibility, costs, and market potential of small-scale, pre-engineered cogeneration systems.[5,7,8,9,10] One study examined the technical feasibility and cost of installing a 300 kW and 450 kW Martin cogeneration unit into an existing hospital to supply electricity, hot water, and space cooling.[9] The mass production installed costs of these units were estimated to be \$1227/kW (1983\$) and \$902/kW respectively. These costs include an American Yazaki 60-ton absorption chiller and controls. Maintenance costs were calculated to be 0.8¢/kWh for the larger unit. Simple payback periods ranged from 1.3 years to 3.5 years, depending upon the unit and location. Under the sponsorship of GRI, a demonstration of the 450 kW system examined in this report was installed in a hospital in Houston, Texas during the summer of 1984.

Another GRI study examined the feasibility of installing pre-engineered cogeneration systems in fast food restaurants.[10] Four cogeneration packages using Waukesha engines rated between 70 kW and 140 kW were examined. These systems would supply hot water for heating and cooling of the restaurant, as well as electricity. Mass production installed costs, including a 30-ton Hitachi chiller, ranged from \$1828/kW (1983\$) for the 70 kW system to \$1128/kW for the 140 kW system. No projected maintenance costs were given. A demonstration of the 70 kW system is pending.

A third feasibility study calculated a payback period of 2.3 years for a non-pre-engineered 290-kW cogeneration installation supplying hot water and electricity to a winery in California.[8] A Waukesha engine was selected in this study. Installed costs were estimated to be $627/kW (1980$) with maintenance costs of 0.65¢/kWh. This system has been installed at the Paul Masson Vineyards' Winery in Saratoga, California, and, according to Waukesha Engine literature,[11] supplies approximately one-third of its electric requirements and 90% of its process heat. No published data on system reliability and economic performance are available.

The third category of literature surveyed dealt with the reliability of diesel engines used for standby power at nuclear power plants and large intermittent and continuous duty industrial prime movers.[12,13,14,15,16] One study of the failure rates of standby diesel generator sets shows that with three redundant generator sets, the probability of one not working is 50%, and the probability of two not working is 8%. The probability that all three do not function when needed is 2%.[15] Another study[14] divided the reasons for standby generator failures into three general categories: engine, electrical, and human error. Engine and related problems accounted for 55.7% of the failures. Electrical problems accounted for 26.6%, and human error accounted for 17.9% of the failures. The author points out that many of the engine-related problems are really electrical in origin since almost all of the monitoring and safety functions are performed electrically. Thus, purely mechanical problems were relatively few. Standby diesel generators at nuclear power plants range in size from about 2 MW to 7 MW. These are low-speed engines with speeds ranging between 450 rpm and 900 rpm.

Two studies[12,13] deal with the reliability of large industrial prime movers. A massive research effort was carried out in the late 1960's to determine the reliability of diesel engines ranging in sizes from about 1500 kW to 2700 kW.[12] Availability of these large engines was found to be about 96% in continuous-duty operation and 88% in intermittent operation. Mean time between failures for continuous duty was approximately 525 hours, and mean time to repair these units was 2.5 hours. Another study determined the mean time between failures for 2500-kW diesel engines to be 603 hours, and the mean time to repair to be 5.3 hours.[13]

In summary, three topics dealing with cogeneration systems were surveyed: large cogeneration installations, feasibility of small cogeneration, and the reliability of prime movers. The success some large cogeneration installations enjoyed was attributed to good management, well trained maintenance staff, and good maintenance procedures. Problems associated with unsuccessful installations included: high fuel costs, shortage of natural gas, poor system design, high operating and maintenance costs, and low utility buy-back rates. Reports on small cogeneration were limited to a few feasibility studies. Reliability studies found in the literature dealt only with large prime movers (over 1500 kW). One study calculated the availability of these large engines to be 96% in continuous duty and 88% in intermittent operation. It seems unlikely that small cogeneration systems will perform better than these large systems.

3.0 COMMERCIALLY AVAILABLE SMALL COGENERATION EQUIPMENT

A wide range of small cogeneration equipment is currently available. Small pre-engineered cogeneration systems can be purchased today to meet energy demands from as low as 15 kW electric and 110,000 Btu/hr thermal, up to and above 550 kW electric and 3.3 million Btu/hr thermal. Systems are available which can operate in parallel with the electric utility as well as in a stand-alone mode for backup and emergency power during utility outages. Small cogeneration systems typically consist of an internal combustion engine, an electric generator, heat recovery equipment, and a control system. Peripheral equipment may include a domestic hot water storage tank, a radiator, or absorption chillers. Figure 3.1 is a schematic of a small cogeneration system. Fuel is burned in the engine driving a shaft which powers an electric generator. Heat produced in the combustion process is recovered from the engine oil, engine coolant water, and from the exhaust gases.

The hot water and, in some cases, steam produced by the cogeneration system can be used for a variety of applications, including domestic hot water, space heating, absorption cooling, and industrial process heat. When more heat is produced by the engine than can be used or stored, the excess heat can be exhausted at the radiator if the system contains one. Since the heat rejected at the radiator is wasted, it is often advantageous to shut the engine off rather than produce excess heat. With this in mind, some cogeneration systems are designed without a radiator.

Eight firms that supply small cogeneration systems were identified. Table 3.1 lists these suppliers as well as the energy capacities of the units available and the prime movers used in these units. Each of these eight firms employs an internal combustion reciprocating engine with an electric generator and heat recovery equipment to simultaneously generate electricity and useful heat. However, the approach of each of these firms towards small cogeneration is often equite different.

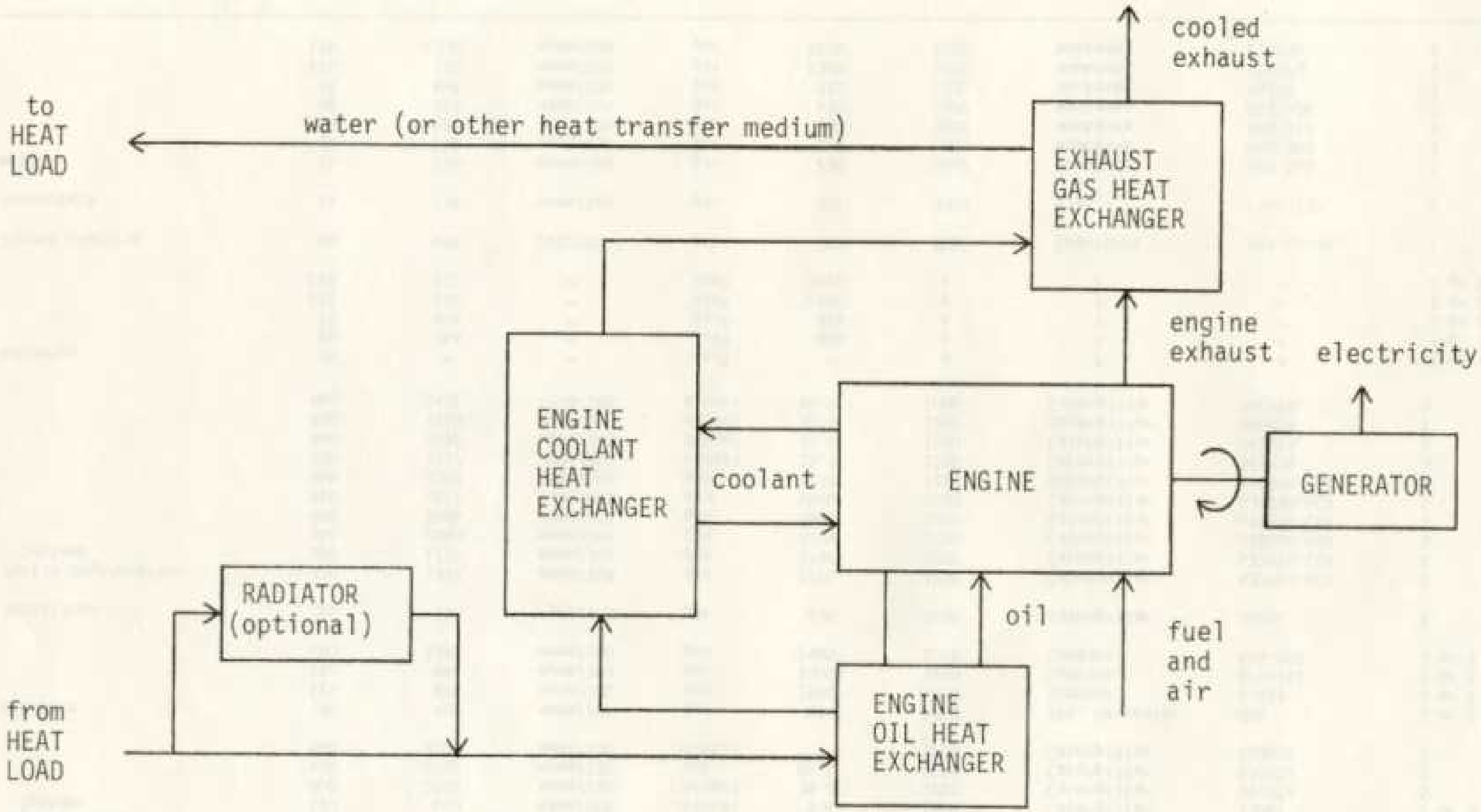

Fig. 3.1. Schematic of a Typical Small Cogeneration System.

Table 3-1. Commercially Available Small Cogeneration Units

System Supplier	Electric output kW	Thermal output 10^3 Btu/hr	Min./Max. Output Temp. (°F)	Fuel	Fuel Rate[a]	Engine RPM	Engine Manufacturer	Engine Model	Generator Type[b]
Cogenic Energy Systems	100	630	none/200	gas	1250	1800	Caterpillar	3306G	I or S
	120	660	none/200	diesel	9.6	1800	Caterpillar	3306T	I or S
	400	2200	none/230	diesel	36.0	1800	Caterpillar	3412TA	S
	450	2700	none/220	gas	5625	1200	Caterpillar	G398TA	S
	500	3100	none/230	diesel	*	1200	Caterpillar	D398TA	S
Enertech	80	460	none/200	gas	960[c]	1800	Int. Harvester	605	I or S
	125	680	none/200	gas	1500[c]	1800	Cummins	G-855	I or S
	150	840	none/200	gas	1800[c]	1800	Cummins	GTA-743	I or S
	200	1245	none/200	gas	2400[c]	1800	Cummins	GTA-855	I or S
Intellicon	65	450	none/195	gas	830	1800	Caterpillar	3304G	S
Martin Cogeneration Systems	230	1337	none/205	gas	2776	1200	Caterpillar	G379NA-HCR	S
	300	1777	none/205	gas	3797	1200	Caterpillar	G379TA-LCR	S
	350	2048	none/205	gas	4079	1200	Caterpillar	G398NA-HCR	S
	450	2545	none/205	gas	5600	1200	Caterpillar	G398TA-LCR	S
	460	2617	none/205	gas	5560	1200	Caterpillar	G399NA-HCR	S
	565	3327	none/205	gas	7233	1200	Caterpillar	G399TA-LCR	S
	330	1217	none/205	diesel	23.3	1200	Caterpillar	3412TA	S
	460	2037	none/205	diesel	33.4	1800	Caterpillar	3412TA	S
	430	1818	none/205	diesel	30.6	1200	Caterpillar	3508TA	S
	560	2431	none/205	diesel	40.5	1800	Caterpillar	3508TA	S
KeEnergy	35	*	*	gas[d]	*	e	f	*	I or S
	55	354	*	gas[d]	590	e	f	*	I or S
	75	486	*	gas[d]	810	e	f	*	I or S
	125	810	*	gas[d]	1350	e	f	*	I or S
	150	972	*	gas[d]	1620	e	f	*	I or S
Thermo Electron	60	440	210/250	gas	760	1800	Chevrolet	454 cu-in.	I
Thermotec[g]	15	134	none/165	gas	201	3000	Fiat	Fiat 127	I
WESI	15	110	none/205	gas	230	1800	Waukesha	VRG 155	I
	20	126	none/205	gas	270	1800	Waukesha	VRG 155	I
	30	192	none/205	gas	360	1800	Waukesha	VRG 220	I
	50	314	none/205	gas	630	1800	Waukesha	VRG 330	I
	75	485	none/205	gas	910	1200	Waukesha	F817G	I
	115	738	none/205	gas	1320	1200	Waukesha	F1197G	I
	175	1100	none/205	gas	2220	1200	Waukesha	F1905G	I

[a]Cubic feet per hour for natural gas, gallons per hour for diesel.
[b]I = induction, S = synchronous.
[c]Lower for turbo-charged and ebulliently cooled engines.
[d]Also offered with diesel and propane.
[e]KeEnergy uses belt drives to produce 60 Hz electric power while running engines at various speeds between 900 and 1200 rpm.
[f]KeEnergy uses Minneapolis Moline, Mack, and White-Hercules engines in their cogeneration units.
[g]This 50 Hz unit is not presently commercially available in the U.S. Brooklyn Union Gas is currently testing the unit at 3600 rpm and 60 Hz.
*Information not available.

There are five distinct areas of small cogeneration design in which different design philosophies emerge. These five areas, along with the competing design philosophies of each area, are as follows:

engine	:	industrial versus automotive
generator	:	induction versus synchronous
unit assembly	:	factory versus site
radiator	:	standard equipment versus optional
controls	:	microprocessor versus relay

Each of these differences in approach is discussed in detail in the following sections.

3.1 Equipment Description

3.1.1 Engines. Many different types of engines are used in the small cogeneration systems. Table 3.1 lists the engines used, as well as the electric and thermal output of each unit. Some of these engines were developed for industrial and standby power applications and have been applied to cogeneration systems without modification. Other engines were developed for automotive applications and have been modified for continuous operation, as is required in cogeneration.

The engines used by Cogenic, Intellicon, Enertech, ReEnergy, and WESI are all heavy duty industrial engines. Many of the engines are diesel engines which have been converted to to spark ignition natural gas engines. They all are expected to run between 24,000 and 36,000 hours between major overhauls, or 3 to 5 years of near constant operation. The cleaner running natural gas-fueled engines are expected to have longer lives than their diesel counterparts.

The Caterpiller 3306 and 3304 engines are used by Cogenic and Intellicon, respectively. These engines were developed for standby power applications and have also seen widespread use for irrigation. These engines are used in cogeneration applications unmodified. The larger Waukesha engines used by WESI have seen widespread use in gas compression applications. These engines also are used in cogeneration without modification.

ReEnergy selects from Minneapolis Moline, Mack, and White-Hercules engines to match the heat and electricity needs of each application. They report that their engines are disassembled and reassembled to exact specifications in order to give better performance for long periods of operation.

The Chevrolet engine used by Thermo Electron and the Fiat engine used by Thermotec were developed for automotive applications. They are lightweight, relatively inexpensive, and not originally designed to last for many thousands of hours of continuous operation. These engines are modified for use in cogeneration systems. Special heads and valves are installed to prolong the life of the engines. These modified engines have expected intervals between major overhauls of between 8,000 and 12,000 operating hours.

The speed of most engines used in small cogeneration units is either 1200 or 1800 RPM. These are convenient speeds for driving a generator at 60 Hz. ReEnergy runs their engines at various speeds between 900 and 1200 RPM, which they have determined to give optimum performance. By the use of belt drives, they achieve the generator speeds required to produce 60 Hz.

The Thermotec unit was developed for a European market. It is designed to produce 50 Hz electricity at a 15 kW rate with an engine speed of 3000 RPM. Brooklyn Union Gas is currently testing the unit at 3600 RPM and 60 Hz for possible commercialization in the U.S. Reliability and maintenance are among their principal concerns with the Thermotec unit.

The energy efficiencies of cogeneration systems are important characteristics when selecting a system for a particular application. There are three ways to define the efficiency of a cogeneration system: electric generating efficiency, heat production efficiency, and overall efficiency. The electric generating and heat producing efficiencies are defined as the fraction of input energy that is changed into electric and useful heat energy, respectively. The overall efficiency is the sum of the electric and heat production efficiencies. The electric generating efficiency depends mainly on the efficiency of the engine. The heat production efficiency depends on the temperature at which the engine rejects its heat and the efficiency of the heat recovery equipment. These two efficiencies are related since when the electric generating efficiency is higher, the amount of heat available to be recovered is lower. Overall efficiency is a conveniently concise parameter; however, it gives no indication of an important characteristic of the cogenerated energy, namely, the ratio of useful heat to electricity produced.

Table 3.1 lists energy output and fuel consumption rates reported by the manufacturers. Based on this information, the electric generating efficiencies of most small cogeneration systems fell in the narrow range between 26 and 28% (based on the higher heating value of the fuel). Two exceptions are the 15 kW WESI unit and ReEnergy's units which apparently have electric generating efficiencies of 22 and 31%, respectively.

The overall efficiencies at small cogeneration systems are much more variable. The Thermo Electron Unit and at least one WESI unit have overall efficiencies over 80%. The energy input and output values reported by ReEnergy imply overall efficiencies approaching 90%. At the other end of the scale, several Martin units have overall percent efficiencies in the low 70's. All of these produce heat at 190 to 210°F, so most of the variation in overall efficiency is due to variation in heat recovery efficiency.

3.1.2 <u>Generators</u>. Both induction and synchronous generators are used for small cogeneration. Induction generators rely on the utility line frequency for excitation and therefore cannot operate without utility power. Synchronous generators are self-exciting. The electric power frequency produced by synchronous generators is synchronized with line frequency to act in parallel with the utility. In the event of a utility power outage, a cogeneration unit with a synchronous generator can continue producing power for the on-site load.

Synchronous generators and the extra controls necessary for it to work in parallel with a utility are more expensive than induction generators, perhaps as much as $12,000 more for a unit of under 100 kW. For installations of under 200 kW electric, this extra cost can be a substantial fraction of the total installed cost. Therefore, on small installations, induction generators are typically used unless emergency power is necessary during utility outages. For larger installations, the extra cost of a synchronous generator will not be a major part of the total installation cost. Synchronous generators are therefore generally used for the larger (above 200 kW) installations.

3.1.3 Unit Assembly. With the exception of Intellicon, all small cogeneration suppliers are packaging their equipment at the factory into modular units. Factory assembly allows mass production and, perhaps, reduced system costs. In addition, factory assembly makes installation easier, and may reduce maintenance and repair costs due to standardization of equipment. On the other hand, site assembled systems allow more flexibility in the placement of equipment and a more flexible approach to meeting a particular installation's energy loads. Table 3.2 summarizes the characteristics of each manufacturer's modules. Figures 3.2 through 3.5 depict various installed units.

Three suppliers, Cogenic, Martin, and WESI, install radiators in all of their units. Enertech, ReEnergy, Thermo Electron, and Thermotec do not include radiators with their units. If a radiator is needed, it must be site installed. Four suppliers, Cogenic, Martin, ReEnergy, and WESI have designed their modules for outdoor installation. Enertech, Thermo Electron, and Thermotec have designed their units for indoor or shed installation, though Enertech units can be installed outside.

Intellicon prefers to assemble their systems on site. They believe that packaging the equipment at the factory reduces flexibility in siting the equipment, as well as reducing flexibility in supplying the energy load at a particular site. Many installations require the cogeneration unit's appearance to be aesthetically pleasing, and possibly might require the system housing to conform to the architecture of the building at the site. The factory-made housing of a modular unit may be an unnecessary expense in such a situation.

Table 3.2. Cogeneration suppliers' modularization stragegy

System Supplier	Modularization
Cogenic	Fully modular; engine, generator, controls, radiator, and heat recovery equipment factory assembled within metal, noise insulated rectangular enclosure. Outdoor installation.
Enertech	Factory assembled modules. Outdoor or shed installation.
Intellicon	System assembled at site, housing is site built.
Martin	Fully modular; engine, generator, controls, radiator, and heat recovery equipment housed in enclosure large enough to walk through. Outdoor installation.
ReEnergy	Some systems assembled at site; housing built around engine- generator. Other systems factory assembled in fiberglass enclosure without radiator. Outdoor installation.
Thermo Electron	Engine, generator, and controls are factory assembled in noise insulated fiberglass enclosure. Radiator, if needed, must be site installed. Enclosure intended for indoor placement.
Thermotec	Engine, generator, heat recovery equipment are factory assembled in metal enclosure. Does not include radiator or controls. Intended for indoor placement.
WESI	Engine-generator sets factory equipped with heat recovery equipment, radiator, and controls. Installed in weather protective housing at factory.

Fig. 3.2 Cogenic Energy Systems' M-100 Unit at the Freehold, YMCA, Freehold, New Jersey.

Fig. 3.3 Thermo Electron 60 kW Unit at the Hollandia Dairy, San Marcos, California.

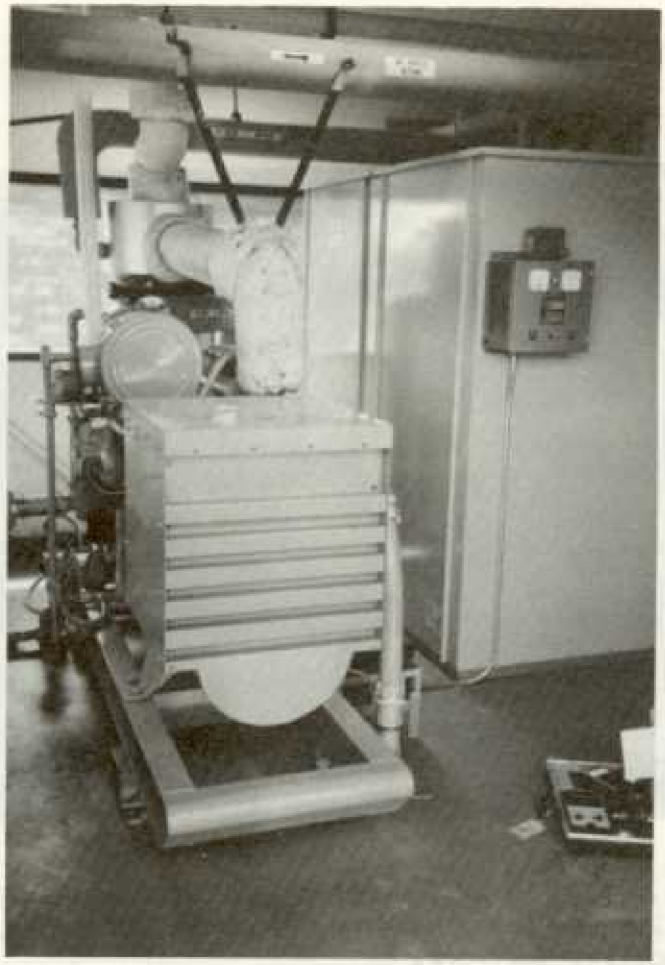

Fig. 3.4 Intellicon Installation at McDonald's Hamburger Restaurant, Chula Vista, California.

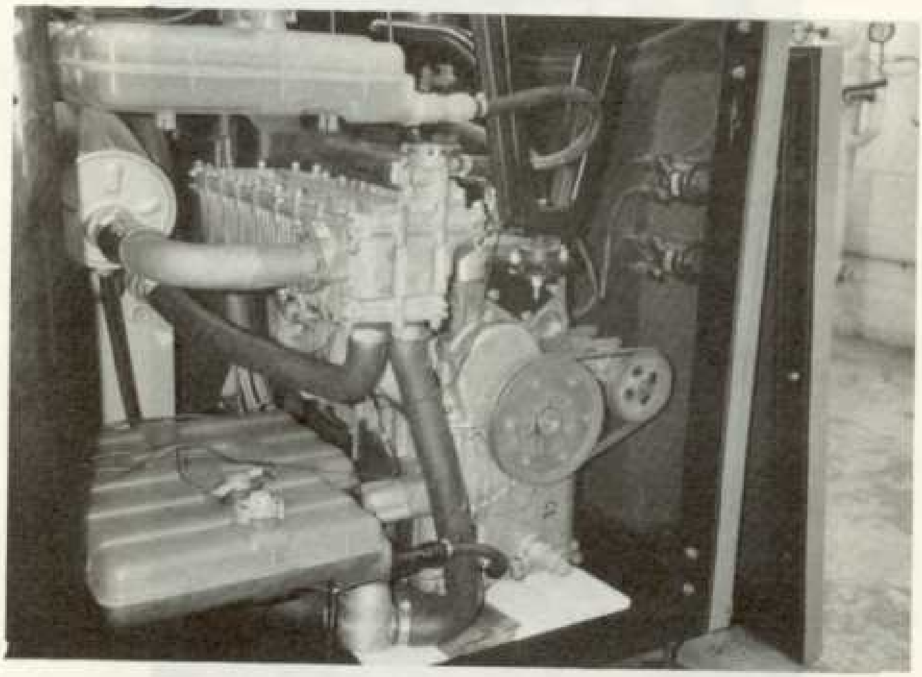

Fig. 3.5 15 kW Thermotec Unit with Sound Attenuating Enclosure Partly Removed, Brooklyn Union Gas, Brooklyn, New York.

The flexibility of site assembled systems can be illustrated with an early pre-module ReEnergy installation. This application was characterized by high peak cooling demands in the summer, which would cost the owners a great deal of money due to high demand charges. To reduce these large peak demands, a compressive chiller was installed next to the generator and attached to the engine shaft by a belt drive. During the summer months, the engine drives the compressor which produces ice 24 hours a day. At night during low cooling demand, the ice is stored to be used during the peak cooling hours of the day. This kind of flexibility in supplying the required thermal loads would be difficult with a pre-assembled modular unit.

3.1.4 Controls. All small cogeneration systems are designed to be fully automatic. An operator is not neded for these systems nor does the equipment need daily attention from site personnel. Each unit has a control system which has two, and in some cases, three functions. One function of the controls is to monitor and regulate heat and electrical energy production of the system. For instance, if more heat is being produced than can be used or stored, the controls will direct heat to the radiator or will shut the engine down if no radiator exists. When heat is needed, the controls will either redirect heat away from the radiator or start the engine.

The second function of the controls is malfunction detection. Engine parameters are continuously monitored, and when any one of these varies from a prescribed operating range, the engine is shut down. Typically, engine and utility interface parameters which are monitored, are: oil pressure, oil level, water pressure, water temperature, engine speed, and frequency and voltage variation from the utility frequency and voltage.

A few manufacturers' control systems perform a third function, economic optimization. For instance, based on electric and fuel costs in effect at the particular time of day and season, a control system can decide whether it is better to dump excess heat at a radiator or shut the engine down.

Control systems in small cogeneration are microprocessor or relay based. Microprocessor control systems are more versatile than relay control systems. Microprocessor controls can be programmed to operate the cogeneration system based on performance, economic, and safety criteria. These controls can also be easily reprogrammed to meet a new set of criteria if necessary. Microprocessors may allow for better error and malfunction diagnosis of the cogeneration system, as well as better on-site and remote monitoring of the system. In addition, microprocessor controls can more easily be adapted to operating the cogeneration system in an economically optimum manner.

Table 3.3 lists the type of control system each supplier employs. Three suppliers currently use microprocessors, although others have plans to change to microprocessors in the near future. Two of these manufacturers, Intellicon and Enertech, have capabilities for remote monitoring and economic optimization.

3.2 Operation and Maintenance

3.2.1 Failure Notification. Listed in Table 3.4 are the methods in which service personnel are notified of malfunctions of the cogeneration equipment. Cogenic and WESI install a light or bell at the site which signals a system malfunction. It is then up to the site personnel to call for service. Intellicon and ReEnergy have an automatic means of notifying service personnel of a problem. Intellicon's microprocessor system automatically dials an answering service when a problem occurs and gives a recorded message. The answering service then notifies Intellicon service personnel. ReEnergy's control system notifies a burglar alarm company when a problem occurs. The burglar alarm company then notifies ReEnergy of the problem. The remaining cogeneration firms rely on site personnel to notice that the engine is off before service personnel can be notified. However, these firms have indicated that either on-site or off-site malfunction notification could be included in an installation.

Table 3.3. System controls

System Supplier	Controls
Cogenic	relays, developing microprocessor
Enertech	microprocessor - programmable, able to perform economic optimization
Intellicon	microprocessor - programmable, able to perform economic optimization
Martin	relays
ReEnergy	relays, possibly going to microprocessor controls
Thermo Electron	microprocessor - does not perform economic optimization
Thermotec	relays
WESI	relays

Table 3.4. Malfunction notification methods

System Supplier	Notification Method
Cogenic	Site personnel are alerted to system malfunction by warning light. They then call for service.
Enertech	Can monitor system remotely or on video screen at site. May develop automatic malfunction notification.
Intellicon	Service office called automatically by system computer with message of system malfunction
Martin	Site personnel notice system not working and call for service.
ReEnergy	When system malfunctions, burglar alarm company is automatically notified. Service people are then notified by phone.
Thermo Electron	Site personnel must call for repair after noticing engine stoppage.
Thermotec	*
WESI	Light or bell at site will alert site personnel to system malfunction.

*Information not available.

Table 3.5. Maintenance Intervals

Cogeneration System	Basic Service Interval (hours)	Minor Overhaul Interval (1000 hours)	Major Overhaul Interval (1000 hours)
Cogenics	750-1000	8-12	24-36
Enertech	1000	12	35
Intellicon	1500-2000	8-12	24-36
Martin Cogeneration	1500	15	40
ReEnergy	1700	*	32
Thermo Electron	500	5-7	8-12
Thermotec	750	*	10
WESI	750	15-18	30-35

*Information not available.

3.2.2 Maintenance Schedules. Like any internal combustion engine, the prime movers used in small cogeneration systems require regular maintenance. To compare the maintenance requirements of the engines used by cogeneration suppliers, maintenance requirements have been divided into three categories: basic service interval, minor overhaul interval, major overhaul interval. Table 3.5 lists these intervals for systems of the eight cogeneration manufacturers identified in this study.

The basic service interval is the time between oil changes. When the oil is changed, other maintenance work is performed, as needed. Other maintenance might include replacing spark plugs, checking or replacing batteries, adjusting the valves, replacing the air cleaner, adjusting belts and timing, and maintaining the water treatment system. Basic service intervals range from 500 hours (about 21 days) for the Thermo Electron unit to 1700 hours (about 71 days) for the ReEnergy engines. Firms that have basic service intervals of more than 1000 hours generally use a low ash oil in their engines and use a continuous oil make-up system. Many of the firms have oil analyses done periodically. Based on the results of an analysis, they will decide when an oil change is necessary.

The second and third columns of Table 3.5 list tne minor and major overhaul intervals of the engines used by each cogeneration system supplier. A minor overhaul or "valve job" is the restoration of the cylinder heads to new condition. A major overhaul involves reboring the cylinders or replacing the cylinder liners and replacing the pistons and bearings, as well as a valve job. As Table 3.5 shows, the modified automotive engines (Thermo Electron, Thermotec) require much more frequent overhauls than most of the industrial engines.

The light duty engines used, for instance by Thermo Electron, have minor overhaul intervals of between 5000 and 7000 hours and major overhaul intervals of between 8000 and 12,000 hours. This compares with minor overhaul intervals of between 8000 and 12,000 hours and major overhaul intervals of between 24,000 and 36,000 hours for most of the heavy duty industrial engines used. Therefore, the modified automotive engines will need to be replaced or overhauled 2 to 3 times as frequently as the industrial engines. More frequent overhauls or replacements of the commercial engines need not be of concern to the users of these engines if overhauling or replacement of the engines causes little interruption of service, as suppliers of the cogeneration systems light duty engines claim. However, if extended interruptions of service occur each time the engine is overhauled or replaced, it would be preferrable to have an engine which lasts longer between overhauls.

Rather than perform a major overhaul on an engine, firms may choose to swap an old engine for a new one. Thermo Electron has indicated that they will replace (in the field) worn engines with new or rebuilt engines and have the old engine factory overhauled. ReEnergy intends to overhaul their engines at the factory, but temporarily install another engine during the overhaul to prevent an extended outage of the cogeneration system. Enertech believes that after an engine has been operating for five years it will be worthwhile to replace it with a newer technology engine, and not bother overhauling the old engine. In general, whether an engine is replaced or overhauled at the end of its useful life will be determined by the maintenance and financing agreement in effect and the relative costs of shutting the system down and rebuilding the engine compared to replacing the engine with a new one. As of the summer of 1984, no small cogeneration systems had been operating long enough to require a major overhaul.

3.3 Equipment, Installation, and Maintenance Costs

Equipment, installation, and maintenance costs for selected units are listed in Table 3.6. It is not always possible to directly compare the equipment cost or installation cost of one firm with another. This is because some equipment included in one firm's equipment cost may be part of another's installation cost. For instance, one firm may include a radiator and housing in their equipment cost, while another may include the radiator and housing in the installation cost.

3.3.1 Equipment Cost. In general, the basic equipment cost includes the engine, generator, heat recovery equipment, controls, and radiator. However, a radiator is not included in the equipment or installation cost of the Enertech,

Table 3.6. Equipment, installation, and maintenance costs of selected units

System Supplier	Unit Size kW	Basic Equipment[1] Cost $	Installation Cost $	Total Installed Cost $/kW	Maintenance Cost ¢/kWh
Cogenic	100 (I)	100,000	35-45,000	1400	1.5
Enertech	80	31,500	14,000	687	1.2
	200	84,000	33,000	585	.65
Intellicon	65	45,000[2]	37,000	1260	1.2
Martin	230	350,000	45,000	1720	*
	350	402,950	51,900	1300	
	460	446,300	57,150	1100	
ReEnergy	55	68,750[3]	25,000	1704	included in equipment cost
	75	93,750[3]	25,000	1583	
	125	145,000[3]	30,000	1400	
Thermo Electron	60	35,000[3]	25,000	1000	1.5
Thermotec	15	10,000[3]	*	*	*
WESI	20	28,720	11,500	2000	1.0 to 1.5
	50	31,670	14,000	913	
	75	51,160	21,000	962	

[1]Does not include absorption chillers.
[2]Does not include enclosure.
[3]Does not include radiator.

*Information not available.

ReEnergy, Thermo Electron, and Thermotec systems. If a radiator is installed, it will be an additional cost. In addition, the equipment cost for Intellicon does not include a housing. Intellicon considers a housing part of the installation cost. ReEnergy's equipment cost includes five years of maintenance and service.

3.3.2 Installation Cost. The installation cost will include a concrete pad for the equipment, if necessary, hot water storage tanks and associated heat exchangers, all necessary plumbing to connect the thermal output of the cogeneration system with the building, and all necessary wiring and equipment to run the cogeneration system in parallel with the electric utility. Neither the equipment nor installation costs listed in Table 3.6 include absorption chillers, which run about $1,000 per ton of cooling.

3.3.3 Total Cost. The total cost listed in Table 3.6 is the equipment cost plus installation cost per kW of electrical capacity. Total costs range from a low of $600/kW for a large Enertech unit to about $1700/kW for the smallest Martin and ReEnergy units. It should be noted at this point that the costs listed in Table 3.6 are for actual installed and operating units when such exist. As of this writing, only five firms, Cogenic, Intellicon, ReEnergy, Thermo Electron, and WESI have operating installations. The total costs of Enertech and Martin units are based on manufacturers' estimates.

3.3.4 Maintenance Cost. The maintenance costs listed in Table 3.6 include the overhaul or replacement of the engine when necessary. This cost is what the firms will charge for a service contract, or it will be the cost figured into a shared energy savings agreement. Financing plans will be discussed below. The maintenance cost of a ReEnergy unit is included in the original equipment cost. After five years, the user has the option of having a new or rebuilt engine installed at a cost of one-third the original equipment cost. The maintenance cost for Thermo Electron units includes the cost of replacing the engine, which may be necessary as often as every year. The maintenance costs on Table 3.6 are listed in ¢/kWh units, but where the module is run at less than full load, maintenance costs may be charged as though the module were running at full load.

Table 3.7. Maintenance and financing plan

System Supplier	Maintenance and Financing Plans Available
Cogenic	shared savings, service contract
Enertech	service contract, no financing
Intellicon	service contract, no financing
Martin	up to local dealer; can lease equipment through Caterpillar
ReEnergy	shared savings, leasing; 5-year full service contract included in cost of unit
Thermo Electron	shared savings, service contract
Thermotec	*
WESI	developing financing plan

*Information not available.

3.4 Financing Plans

Several maintenance and financing plans are offered by cogenerating system suppliers. These include shared savings plan, leasing, and purchase with a service contract. Table 3.7 lists the plans offered by each firm. In a shared savings agreement, the cogeneration supplier owns and installs the equipment at no charge to the user. Then each month the user pays the cogeneration firm a portion of the energy cost savings realized due to the cogeneration system. The energy cost savings is determined by a formula agreed upon by both parties. Generally, energy cost savings will be determined by the current purchased energy price and the quantities of heat and electric energy produced by the cogeneration system, and not by comparison to previous energy bills.

In a leasing agreement, the user will pay the supplier a fixed monthly amount for the use and maintenance of the equipment. In this situation, the user will pay the monthly fee regardless of whether any energy cost savings were realized that month. None of the small cogeneration installations examined as part of this study were leased.

Another way in which cogeneration systems are sold is with third party financing. In this arrangement, a third party, usually an investment firm, will buy the equipment. They then will enter into a shared savings or leasing agreement with the user and will usually maintain a service contract with the cogeneration supplier. In this way, a cash short cogeneration supplier receives cash for their unit, the third party receives tax benefits associated with their investment, and the user still makes no investment.

3.5 Service Availability

Two very important factors in the financial success of a cogeneration installation are proper service and timely repair of the equipment. A cogeneration system should not be installed without adequate service availability. The time it takes service personnel to respond to and correct a problem can significantly affect the energy savings of the cogeneration unit. To illustrate the importance of service availability, two examples are given below.

One installation that the authors visited had a problem the night before which caused the cogeneration system to shut down. Service personnel were automatically notified of the problem in the morning. Since the service personnel were located in the same city as the installation, response to the problem was quick, and the system was fixed and operating by 9:00 a.m. that morning.

Another installation visited by the authors had problems with the control system soon after startup. Each time a problem occurred, the system was idle for at least two days before service personnel arrived. This was because the nearest service personnel were located 300 miles away in the company's manufacturing plant. Clearly, if problems like this persisted, the two days per problem would add significantly to the system's down time.

The service strategy of each cogeneration firm is shown in Table 3.8. Two firms are planning to develop their own service network. Two other firms will market and service their equipment through their respective engine dealers. Two other firms plan to market and service their equipment through propane distributors. The proximity of available maintenance and repair service should play a large role in the decision to install any cogeneration system.

Table 3.8. Repair and maintenance service

System Supplier	Repair and Maintenance Service
Cogenic	will develop own service network as needed
Enertech	through Petralane, Inc.
Intellicon	developing service strategy
Martin	through Caterpillar dealers
ReEnergy	through Suburban Propane Co.
Thermo Electron	will develop own service network as needed
Thermotec	*
WESI	through Waukesha dealers

*Information not available.

4.0 SMALL COGENERATION INSTALLATIONS

As of July 1984, there were 35 small cogeneration systems in operation in the United States and Puerto Rico. The six oldest installations went on line in 1982. The majority of installations, however, had been operational for less than one year. The 35 installations break down according to cogeneration suppliers as follows:

Thermo Electron:	12
Cogenics:	11
ReEnergy:	8
WESI:	3
Intellicon:	1

All but four of these installations are of 100 kW electrical capacity or below.

Table 4.1 divides these installations into application and location. It is clear from this table that the Northeast and Southern California/Hawaii regions dominate the small cogeneration market at this time. The high cost of electricity in these regions is presumably the reason for this.

Cogeneration installations have been concentrated in those applications with high year-round thermal loads. The non-industrial applications have included hotels, athletic clubs, nursing homes and retirement homes, and schools. Industrial applications of small cogeneration include a brick factory, textile mill, meat processor, chemical manufacturer, and plastics manufacturer. Installations of small cogeneration systems have also been made at a restaurant, dairy, hospital, and two prisons.

The following sections will describe particular applications and installations of small cogeneration systems in more detail.

Table 4.1. Small cogeneration installations in the U.S., July 1984

Application	Number of Operating Installations	Number of Installations by Region			
		NE	Puerto Rico Florida	Hawaii & So. Cal.	Midwest
Hotels	8	2		6	
Athletic Clubs	5	2		3	
Nursing Homes/Retirement Homes	4	3		1	
Schools	4	1		2	1
Prisons	2	2			
Restaurants	1			1	
Dairies	1			1	
Hospitals	1	1			
Industrial	9	7	1	1	
Total	35	18	1	15	1

4.1 Hotels, Nursing/Retirement Homes

Large year-round thermal loads make many hotels, nursing homes, and retirement homes well suited for small cogeneration. The thermal loads of these applications include domestic hot water for showers, laundries, and restaurants. They also may include pool water heating and space heating and cooling. Many of the hotels, nursing homes, and retirement homes built during the last twenty years are heated and cooled by individual room units. In such cases, space heating and cooling of individual rooms using the thermal output of cogeneration systems is difficult since a central heating or cooling distribution system is not already in place. Consequently, in those installations where space heating or cooling is performed by cogenerated heat, it is usually only to heat and cool common areas such as hallways, lobbies, and conference rooms.

Table 4.2 lists the cogeneration installation characteristics for several hotels, nursing homes, and retirement homes. The largest unit is a 100 kW electric capacity system at the Summer House Inn. The Summer House Inn contains a restaurant, which uses hot water for washing dishes. This is the reason the 108-room Summer House Inn has a larger cogeneration unit than the 142-unit Fabulous Inn.

Most of the installations listed in Table 4.2 had more heat produced by the cogeneration system than the buildings could use. Both the Fabulous Inn and Summer House Inn had radiators to dump excess heat. The Villa Del Rey and Franciscan Inn installations also seemed to be producing more heat than could be used, even though neither system was recovering exhaust heat. The Harlee Manor installation was making better use of the thermal output of the cogeneration system. Part of the thermal output is used to heat and cool parts of the building, but the output of the cogeneration system is frequently (automatically) reduced when there is an insufficient heat load.

The space requirements and appearance are important considerations for hotels, nursing homes, and retirement homes. The authors observed a variety of solutions to space and aesthetic conditions. Figure 4.1 shows the rooftop installation at the Summer House Inn. A wooden barrier was constructed around the unit to reduce the noise reaching the ground.

Table 4.2. Small cogeneration installation characteristics of selected hotels, nursing homes, and retirement homes

Name, Location and Supplier	Application	Electric Capacity (kW)	Thermal Capacity 10^3 Btu/hr	Electric Use	Thermal Loads	Engine Location
Summer House Inn La Jolla, CA Cogenic	108-room hotel	100	630	buy/sell	DHW, laundry, restaurant	roof of hotel
Fabulous Inn San Diego, CA Cogenic	142-room hotel	65	*	buy/sell	DHW, laundry, pool	concrete slab next to hotel
Harlee Manor Philadelphia, PA ReEnergy	150-bed nursing home	55	354	on site	DHW, absorption A/C for dining and offices; space heating for 2/3 of building	concrete slab at rear of building
Villa Del Rey Escondido, CA WESI	retirement home	60 (rated 75)	*	buy/sell	DHW, kitchen	sunken building on back lawn
Franciscan Inn Poway, CA WESI	46-room motel	40 (rated 50)	*	buy/sell	DHW, laundry, pool, jacuzi	equipment room

*Information not available.

Fig. 4.1 Cogenic Energy Systems' M-100 Unit Inside Sound Attenuating Barrier on Top of the Summer House Inn, La Jolla, California.

Figure 4.2 shows the cogeneration unit at the Fabulous Inn installation. The unit is located at the front of the hotel. To the left of the unit are two 1000-gallon tanks for hot water storage. No attempt was made here to conceal unit or plumbing from sight. Although the noise level in front of the unit was a bit high, the noise level behind and above the unit in the hotel was minimal.

Figure 4.3 is a photo of the cogeneration installation at the Harlee Manor Nursing Home. The unit is located at the rear of the building. The noise level outside of the engine enclosure was minimal. The absorption chiller is located in the basement of the building. Figure 4.4 shows the building housing the cogeneration unit at the Villa Del Rey Retirement Home. The building is located to the side of the home and is sunk several feet into the ground. Much care was taken to produce an aesthetically pleasing installation at this site.

4.2 Athletic Facilities

Athletic facilities, with their high year-round thermal loads are another prime candidate for small cogeneration. Table 4.3 lists the characteristics of two athletic facility installations. One is a YMCA located in Freehold, NJ. The other is the Escondido Athletic Club located in Escondido, California. Both installations use the thermal output of the cogeneration units for domestic hot water, pool, and space heating. Since neither installation uses heat in the summer for absorption cooling, much cogenerated heat is wasted during the cooling season.

Figure 4.5 shows the location of the cogeneration unit at the Hidden Valley Athletic Club. A small structure was built adjacent to the club building to house the cogeneration unit. A radiator used to dump excess heat is located on the far side of this building. The noise level outside of the building housing the unit was minimal. However, the noise produced when the radiator fan came on was quite noticeable.

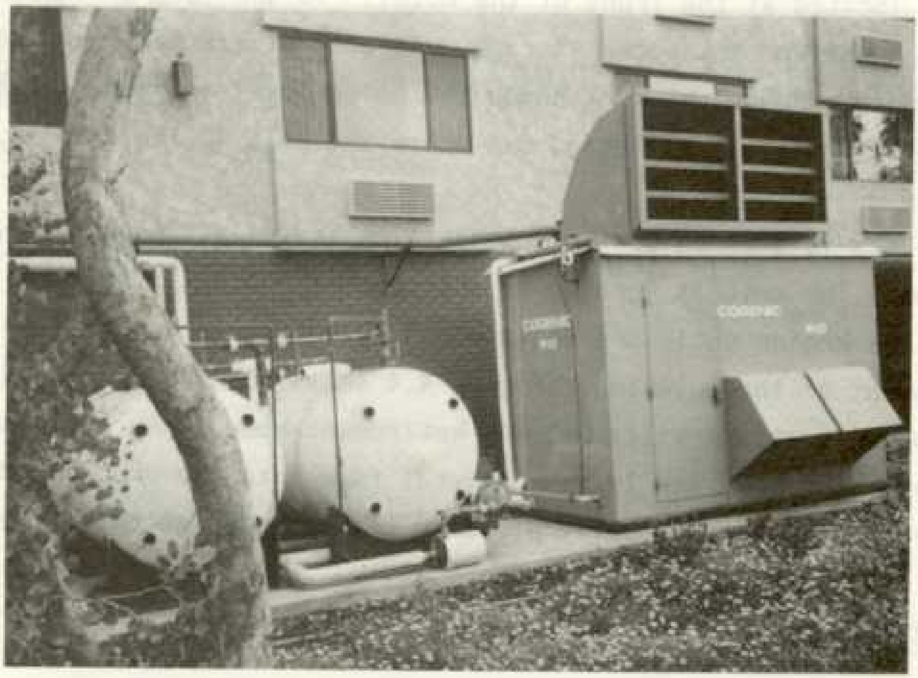

Fig. 4.2 Cogenic Energy Systems' M-65 Unit at the Fabulous Inn, San Diego, California.

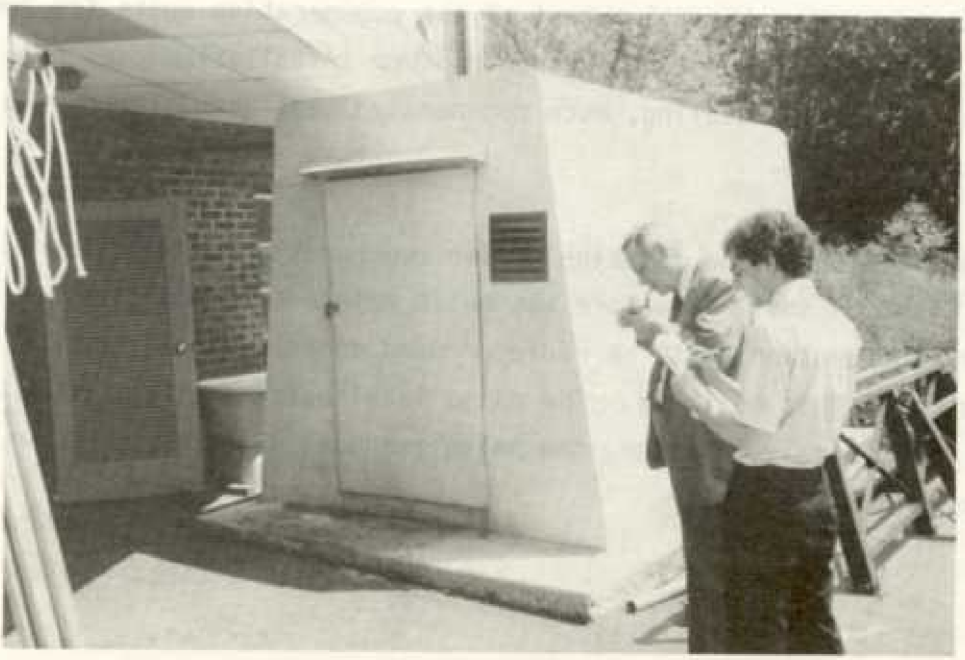

Fig. 4.3 ReEnergy's 55 kW Unit in Enclosure at Harlee Manor Nursing Home, Philadelphia, Pennsylvania

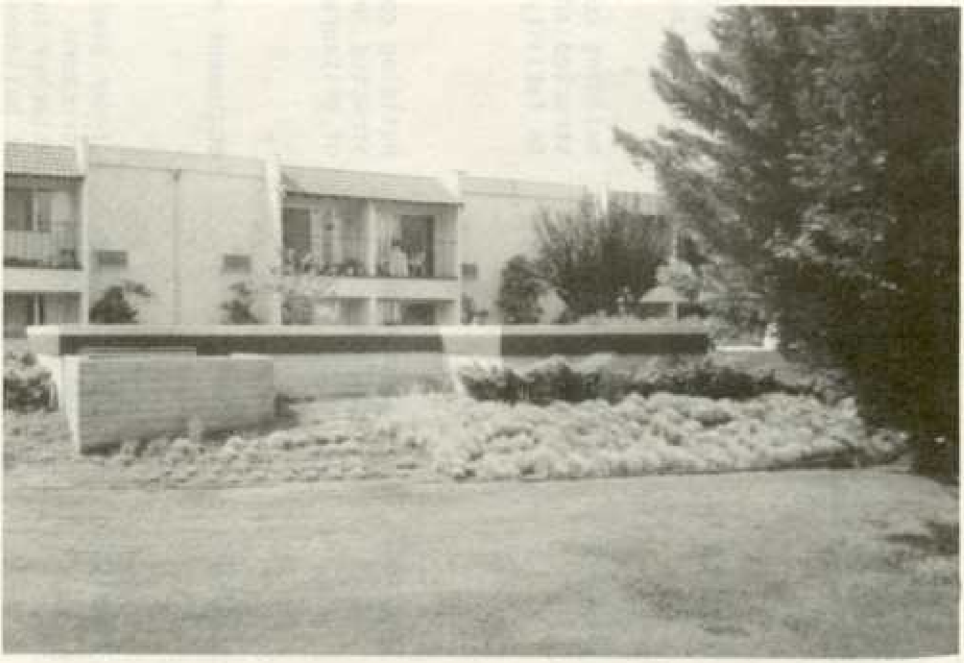

Fig. 4.4 Half Burried Building Housing the Cogeneration Unit at Villa del Rey retirement home, Escondido, California

Fig. 4.5 Building Addition Housing the 60 kW Thermo Electron Unit at the Hidden Valley Athletic Club, Escondido, California

Table 4.3. Small cogeneration installation characteristics of non-hotel applications

Name, Location and Supplier	Application	Electric Capacity (kW)	Thermal Capacity 10^3 Btu/hr	Electric Use	Thermal Loads	Engine Location
Athletic Facilities						
YMCA Freehold, NJ Cogenic	athletic facility	100	630	on site	DHW, pool, space heat	concrete slab at rear of facility
Hidden Valley Athletic Club Escondido, CA Thermo Electron	athletic club	60	440	buy/sell	DHW, pool, space heating	building constructed adjacent to facility
Restaurant						
McDonald's Chula Vista, CA Intellicon	fast food restaurant	65	450	buy/sell	absorption cooling	building constructed in rear of restaurant
Other						
Hollandia Dairy San Macus, CA Thermo Electron	dairy	60	440	buy/sell	DHW	equipment room
Sandy Mac Southern NJ ReEnergy	food processing	3-125	3-810	on site	100 psi steam and hot water	cinder block structure attached to rear of building

4.3 Restaurants

Restaurants often use large quantities of hot water to wash dishes, but the hot water used may not be enough to justify installation of any of the commercially available cogeneration systems. Some fast food restaurants have very small hot water requirements since they have virtually no dishes to wash. Many restaurants have a large cooling load; in some locations they have a year-round cooling load. Consequently, some restaurants will have more attractive applications of small cogeneration if part of the thermal output of the system is used for space cooling.

Table 4.3 lists the characteristics of a cogeneration system at a McDonald's fast food restaurant in Southern California. The entire thermal output of the 65 kW unit is used for absorption cooling. This restaurant has a year-round cooling load of 7 tons. In the summer, of course, the load is much greater. This cogeneration system was designed to meet most of the summer cooling load, so much heat is wasted during the winter months.

Figure 4.6 shows the building built to house the restaurant's cogeneration unit. It is located at the rear of the restaurant. Much care and expense was put into constructing a building that architecturally matched the restaurant. The building is soundproof and contains a window to allow the restaurant customers to view the equipment.

4.4 Other Applications

Other applications of small cogeneration include schools, prisons, dairies, and some industries. Table 4.3 lists the characteristics of an installation at a dairy and the characteristics of an installation at a food processing firm. The installation at the food processing firm located in southern New Jersey consists of three 125 kW capacity units. Thermal output is 100 psi steam and hot water and is used to process meats. The dairy is located in Southern California. The thermal output of the 60 kW cogeneration unit is used to keep milk warm as well as to clean and sanitize equipment.

Fig. 4.6 Building Housing Intellicon's 65 kW Unit at the McDonald's Hamburger Restaurant, Chula Vista, California

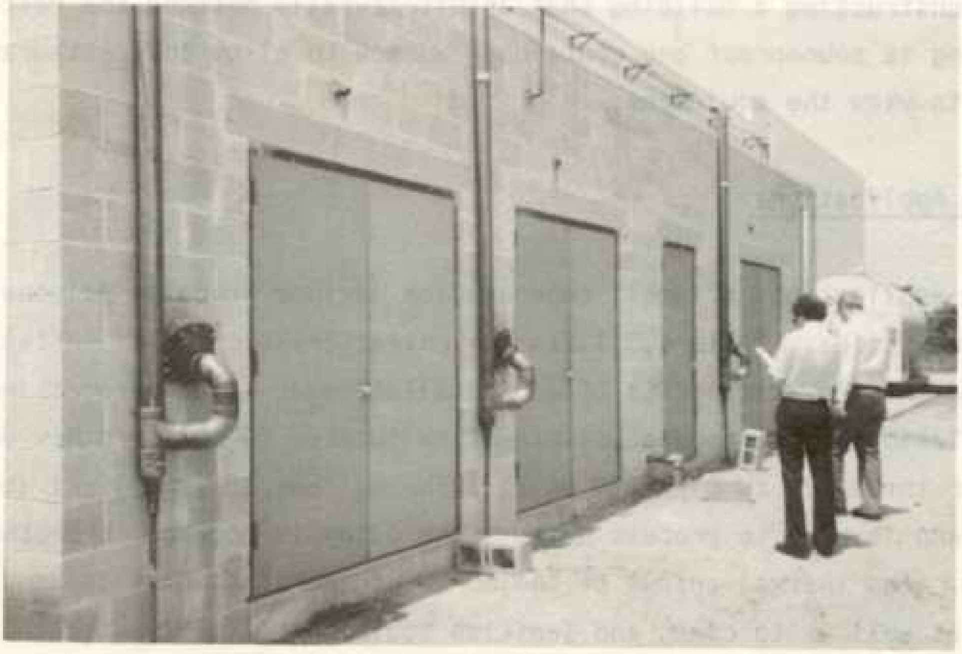

Fig. 4.7 Cinder Block Building Addition Housing Three 125 kW ReEnergy Units at Sandy Mac, New Jersey.

Figures 4.7 and 4.8 are photos of these two installations. Figure 4.7 shows the cinder block structure built to house the cogeneration equipment in the rear of the Sandy Mac food processing firm. Aesthetics were not very important at this installation. Figure 4.8 shows the Hollandia Dairy with the hot water storage tank outside. The cogeneration unit is located in an equipment room through the door shown.

4.5 Utility Interface

Every cogeneration installation listed in Tables 4.2 and 4.3 is connected in parallel with the local electric utility. This means that if a cogeneration system is shut down or not producing enough electric power to meet the load at the site, the utility will supply the needed power. Of the installations listed in Tables 4.2 and 4.3, only those in southern California sell power back to the utility when a surplus occurs. The installations in New Jersey and Philadelphia either shut their engines down, throttle them back, or use electric resistance heaters to dissipate electric energy when a surplus is being produced.

All utilities are required by law to buy surplus electricity from cogenerators. However, a utility's policy and attitude towards cogeneration will have a large impact on the economics and feasibility of actually selling power to the utility. Table 4.4 shows the electric and gas prices in three regions with cogeneration installations.

Energy prices in San Diego County are very attractive for small cogenerators. Electricity costs 10.4¢/kWh, and the utility will buy back electricity for installations below 100 kW at 10.4¢/kWh up to the quantity of electricity bought that month. Additional electricity sold to the utility will be bought at 6.57¢/kWh. In contrast, electricity prices in Philadelphia and central New Jersey are as low as 5.8¢/kWh and 6.4¢/kWh, respectively. Neither utility will pay more than 4.5¢/kWh for cogenerated electricity sold to them. In addition, cogenerators can qualify for a special reduced gas price in San Diego County. In Philadelphia and central New Jersey, cogenerators pay the same for their gas as regular customers.

Table 4.4. Energy costs in three regions with small cogeneration installations[1]

Region	Electric Costs ¢/kWh	Electric Buy-Back Rate ¢/kWh	Monthly Demand Charge $/kW	Regular Natural Gas Price ¢/therm	Cogeneration Gas Price ¢/therm
San Diego County	10.4	10.4 up to amount of kWh bought 6.57 for each kWh sold in excess of amount bought	4.00	71.5	50.5
Philadelphia	17.21 - first 65 hours of billing demand[2] 9.74 - next 80 hours (June - Sept. only) 6.77 - up to 400 hours of billing demand 5.77 - over 400 hours of billing demand	4.5	0.0	57.7	regular price
Central New Jersey	14.14 first 1000 kWh (June - Sept.) 13.14 first 1000 kWh (Oct. - May) 6.42 over 1000 kWh	4.5	10.26 (June - Sept.) 9.26 (Oct. - May)	56.1 - first 100 therms/mo. 55.3 - next 2900 therms/mo. 52.5 - over 3000 therms/mo.	regular price

[1] General service commercial rates.
[2] If the maximum demand for a month is 100 kW, then the first 6500 kWh costs 17.21¢/kWh.

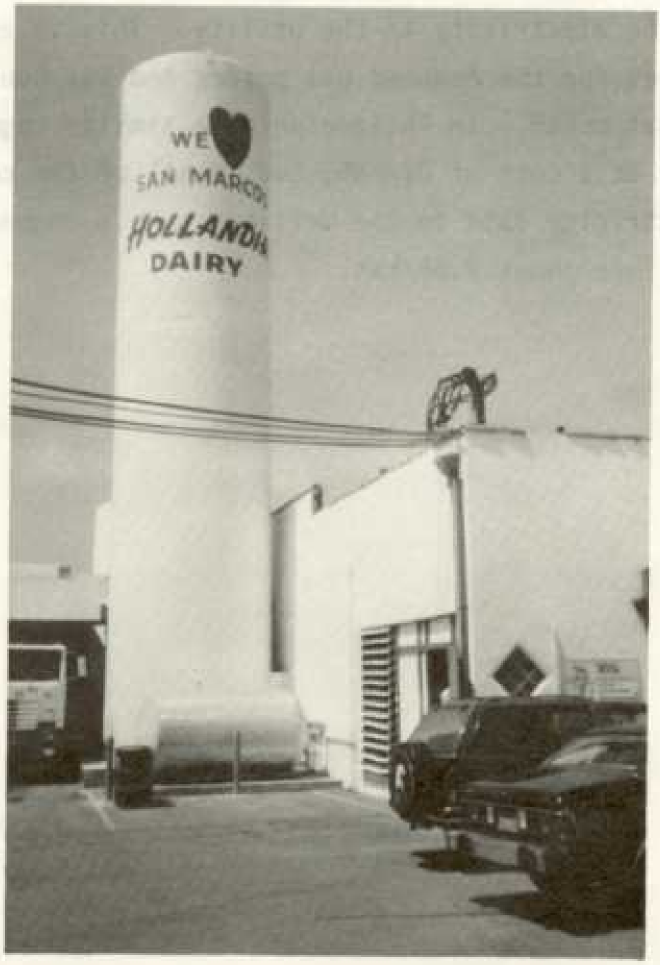

Fig. 4.8 Location of Thermo Electron's 60 kW Unit and Hot Water Storage Tank at the Hollandia Dairy, San Marcos, California.

Energy prices are so favorable to cogenerators in San Diego that, in fact, a cogenerator can produce electricity at less than 7¢/kWh (with 25% electric conversion efficiency), dump all of the cogenerated heat, and still make over 3¢/kWh by selling the electricity to the utility. This is assuming that the cogenerator qualifies for the reduced gas prices and has bought more electricity than it has sold that month. In Philadelphia, a similar cogenerator could produce electricity at a cost of 8¢/kWh, but if all of the cogenerated heat were dumped and the electricity sold to the utility, such a cogenerator in Philadelphia would lose about 3.5¢/kWh.

5.0 SMALL COGENERATION INSTALLATION, OPERATION, AND RELIABILITY EXPERIENCE

The purchase and installation of a cogeneration system is a substantial investment. For the owner to get a savings in energy and realize a return on this investment, the cogeneration system must not set idle. An idle cogeneration system does not save money or energy. It would be useful to know how reliable a cogeneration system is before it is purchased. That is, it would be helpful to know what problems can be expected from the system and what fraction of the time it will be available to operate. One can never know how well one particular cogenerator unit will operate. However, based on past experience of similar units, an estimate of future performance can be made.

To estimate future performance of small cogeneration systems and identify ways to ensure good performance, installation and operating problems that have been encountered with currently operating small cogeneration systems, visited as part of this study, are examined in this section. From these problems, the factors that most affect reliability and ways to ensure good reliability are discussed. The information presented here was obtained through visits to eleven small cogeneration installations. As part of these visits, owners, users, and service personnel were interviewed to obtain their insights on the operating performance of the cogeneration systems.

5.1 Installation

A typical small cogeneration installation will begin with the pouring of a concrete slab or the building of an enclosure for the unit outside. If the unit is factory assembled, the unit, including the engine-generator set, heat recovery equipment, and controls, can now be installed. Hot water storage tanks and necessary heat exchangers are installed and connected to the heat recovery equipment. Hot water from the storage tank is plumbed in series with the existing domestic hot water system. If the cogeneration unit is to provide space heating, a hydronic heating system may have to be installed. The electric output of the cogeneration unit is connected to the electrical system in parallel with the utility. Usually this involves installing a transformer.

There were no reports of problems with incorporating the cogeneration equipment into the existing heating or hot water systems. The most difficult part of some installations was the installation of a hydronic heating system in the existing building. In some cases, installation of a hydronic heating system was put off until after the cogeneration system was operating and producing domestic hot water. This made the initial installation much quicker. Reported installation times ranged from two weeks to three months. In no instances did the users of the cogeneration equipment complain of inconvenience or prolonged disruption of their normal operation. In fact, there was a definite concern on the part of the equipment suppliers to keep disruptions of the user's normal operation to a bare minimum.

Installation problems that were reported dealt with aesthetics. In one instance, a cogeneration unit was installed on the roof of a hotel located in a residential community. Several members of the community were concerned with the possible noise that would be produced by the unit. A wooden barrier was constructed around the unit to reduce the noise level reaching the ground. Still, there was noise from the exhaust that could be heard at ground level, so a shield was installed to deflect the noise upward. This solved the problem, and noise from the cogeneration unit is now barely audible at ground level.

At two installations, McDonald's and Villa Del Rey, great lengths were taken to disguise the cogeneration equipment. At the McDonald's installation, a building, architecturally the same as the rest of the store, including brick veneer and tile roof, was constructed to house the cogeneration unit. At the Villa Del Rey installation, a building was constructed partially underground to house the unit. The area around this building was landscaped to fit in nicely with the main building. In both cases, much extra time and money was spent to achieve the required appearance of the cogeneration equipment.

5.2 Operation

Operation of a small cogeneration system involves continuous automatic monitoring of the electric and thermal output of the system and the proper functioning of the engine and generator. In addition, the interface with the utility must be constantly monitored. If a problem is detected, such as engine overspeed or overheating or a utility outage, or if the cogeneration unit is producing more heat than can be used or dissipated, the unit will automatically shut down. Periodic maintenance, such as oil changes and water treatment, must also be done to ensure proper operation.

The operating problems that have been encountered by small cogeneration installations were divided into five categories: control, design, maintenance, engine, and human error. The number of problems observed in each category and examples of the problems are listed in Table 5.1.

Control and design problems account for most of the problems that have occurred with small cogeneration systems. Control problems have included engine water overheating, engine overspeed, utility voltage surges and voltage swings causing the cogeneration system to shut down, and shutdowns due to voltage drops caused by a large load being turned on by the user. Each of these problems was solved by adjusting or redesigning the controls in some way. Finding and correcting a control problem was, in some cases, an ordeal. For instance, at one installation a control problem plagued the cogeneration system for several months after startup and was not solved until after numerous site visits by service personnel. In this case, the equipment supplier had a shared savings agreement with the user and all startup costs were paid for by the equipment supplier.

Design problems have been almost as numerous as control problems. At one installation, the cogeneration system was greatly oversized for the thermal load at the site. This contributed to very hot water being generated, which resulted in the shortened life of the water circulation pumps. The engine was eventually throttled back to a lower power level. At another installation, engine exhaust was vented to the roof adjacent to an elevator shaft opening. This resulted in

Table 5.1. Operating problems encountered

Problems That Have Occurred	Number of Occurrences of Problems
Control	6
- engine water overheating - engine overspeed - voltage surges from utility cause fuses to melt - large voltage swings from utility shutting down unit - engine tripping due to voltage drops when large motor turned on	
Design	5
- very hot water resulting in short life of circulation pumps - exhaust vented to roof of hotel entering elevator shaft - generator failure due to overheating - exhaust pipe vibration	
Maintenance	3
- ash buildup in engine - inadequate water treatment causing fouling of radiators and heat exchangers	
Engine	2
- cracked spark plug adapter in diesel engine - rocker arm prematurely failed in engine	
Human Error	2
- user personnel turning cooling water valve off without authorization, ruining engine - exhaust heat recovery heat exchanger melting due to water flow shutoff	

fumes entering the elevator shaft. A fan was installed on the roof to direct exhaust fumes away from the shaft. At two other installations, generators failed due to overheating. New generators were installed, and cooling air was directed over the new generators to prevent this overheating. In still another installation, the engine exhaust pipe, mounted on the side of the building, vibrated, causing a loud noise both inside and outside the building. To correct this problem, a flexible length of pipe was placed between the engine and exhaust pipe to isolate the engine vibration from the exhaust pipe.

Maintenance-related problems were the next most numerous problem encountered with small cogeneration installations. Ash build-up in the engine and fouling of radiators and heat exchangers were the two problems reported. The ash build-up was corrected by switching to a low ash oil. The problem of fouling of radiators and heat exchangers had not been satisfactorily addressed at the time of the site visit. Service personnel were simply cleaning the equipment frequently. Plans were under way to institute suitable water treatment.

Reports of problems directly related to the engines used in the cogeneration systems are rare. Only two problems, both in the same engine, were mentioned. A spark plug adapter employed to convert a diesel engine to a natural gas engine cracked, and, in a separate incident, a rocker arm failed. Both problems occurred relatively soon after startup, and both were corrected by the engine manufacturer. It should be noted that no small cogeneration unit has been operating long enough to require a major overhaul, and most have operated for less than one year. It is therefore possible that engine related problems can become more common as the installations get older.

The last category of problems involved human error. In one instance, a maintenance employee of a nursing home turned off the cooling water to the engine, ruining the engine. (Apparenty the mechanism to automatically shut the engine down if overheating is detected failed to operate.) This employee was not authorized to make any adjustments to the cogeneration equipment. At another installation, service personnel attempted to lower the temperature of the hot water produced by the cogeneration unit by shutting off the flow of water to the exhaust heat exchanger. This resulted in the eventual melting of the heat exchanger. Prohibiting all unauthorized personnel from making adjustments to the cogeneration equipment, as well as making sure authorized personnel are well qualified to make adjustments, may prevent this type of problem in the future.

5.3 Reliability and Utilization

Perhaps the most concise and quantitative way to characterize how well a mechanical system has operated is to report its reliability. Reliability is expressed in terms of availability, mean time between failures (MTBF), and mean time to repair (MTTR). Availability, MTBF, and MTTR are defined as follows:

Availability = time system available for use/total elapsed time.

MTBF = average time system was available between failures.

MTTR = average time system was out of service for repairs.

To determine availability, MTBF, and MTTR of a system, it is necessary to have accurate and complete records of the operation, maintenance, and repair, including the length of time the system was out of service for maintenance or repair. Generally, records of this type are not kept for small cogeneration systems. The records that are kept usually include the time a repair or maintenance task was performed, but not the amount of time the system was idle.

Each small cogeneration system seen by the authors was equipped with a run-time meter which records the number of hours the engine ran since installation. The run-times recorded by these meters cannot be used to determine availability, since the system may have been available at times, but not running if energy from the cogeneration system was not needed. However, run-times can be used to determine the utilization of the system. Utilization is defined as:

Utilization = time system running/total elapsed time.

Utilization is useful in that it gives a lower limit to the availability. Table 5.2 lists the utilizations for those installations that have been

Table 5.2. Utilization of selected small cogeneration installations

Name and Location	Application	Commissioned Time (hours)	Operating Time (hours)	Approximate Utilization
Cogenic				
Summer House Inn La Jolla, CA	108-room hotel	15,120	12,749	.84
ReEnergy				
Harlee Manor Philadelphia, PA	150-bed nursing home	15,000	14,140	.94
Thermo Electron				
Hollandia Dairy San Macus, CA	dairy	6,480	5,510	.85
Escondido Athletic Club Escondido, CA	athletic club	3,300	1,895	.57
WESI				
Villa Del Rey Escondido, CA	retirement home	21,120	18,780	.89
Franciscan Inn Poway, CA	46-room motel	17,760	11,187	.63

operating for at least several months and had known commissioned and operating times. This list includes several of the longest running small cogeneration installations in the country.

Utilizations range from a low of 57% to a high of 94%. The two installations with the lowest utilizations both had design problems which have been corrected. It is safe to assume that the utilizations of these two installations will be much higher henceforth. Based on the utilizations of the remaining four installations, availabilities above 85% and 90% are being achieved by small cogeneration installation. Perhaps even higher availabilities can eventually be achieved.

The above discussion of problems encountered at small cogeneration installations shows that the engines are not yet the critical component in cogeneration system reliability. For the most part, the engines in the small cogeneration systems operating today have performed well. This good performance of small, high-speed engines is corroborated by the performance of these engines in other continuous-duty applications. Many hundreds of small, high-speed engines are used on a continuous basis in the gas compression industry. Availabilities of above 95% are reported by users of these engines. Through interviews with various other users of industrial engines, the general feeling was that if the engines are maintained properly, they will perform well.

5.4 Cogeneration System Repairs

The factors that will most affect the reliability of small cogeneration installations, based on the problems reported here, are the control system, system design, and maintenance, including water treatment. Since problems will inevitably occur, the factor that may determine the availability of cogeneration installations, more than any other single factor, is the time it takes system failures to be corrected.

The failure correction time can be divided into three parts: failure notification time, service personnel response time, and repair time. The failure notificaton time is a function of the notification procedure for a system failure. Figure 5.1 illustrates three possible methods of service personnel notification.

The first method of notifying service personnel of a problem starts with the engine shutting down, site personnel noticing that the engine is off, and then calling for service. This method has one obvious drawback. The engine may be idle for a long period of time before anyone notices that is is off. The second notification method improves on the first method by having an alarm ring at the installation site when a problem occurs. After hearing the alarm, site personnel call for service. If a shutdown occurs on a weekend or holiday, no one may be at the site to hear the alarm, and the engine would set idle for an extended amount of time in this case also. The third notification method is the automatic calling of an answering service, burglar alarm company, or service office directly by the control system when a problem occurs. Service personnel can then be dispatched to correct the problem. In many cases, this method is not any quicker than the second method, but it does have the advantage of not bothering the equipment users when a problem occurs. One particular installation which used the third method also had a microprocessor control system which service personnel can interrogate remotely so the repair person can know the likely problem before leaving the office.

The second factor determining failure correction time is the service personnel response time. Service personnel response time will, in general, be a function of the distance the service personnel need to travel to get to the cogeneration installation. The closer the service personnel are to the installation, the quicker the response time will be. If service personnel are located within a 20-minute drive of an installation, they may respond to a problem immediately. On the other hand, if service personnel are located more than a 3- or 4-hour drive from the installation, they may have to wait a day or two before responding to a problem.

The third factor determining failure correction time is the repair time. Repair time will be a function of both the experience of the service personnl and the diagnostic tools available to them. A microprocessor-based control system may have the ability to quickly diagnose the cause of a system failure so service personnel can immediately begin correcting the problem. In another installation without elaborate diagnosis, elaborate procedures may have to be taken to determine the cause of the failure. In addition, if a cogeneration system is equipped with off-site monitoring, service personnel may be able to diagnose the problem at their office and arrive at the installation fully prepared to correct the problem. However, no matter how sophisticated the diagnostic capabilities of the control system, there is no substitute for quality service personnel.

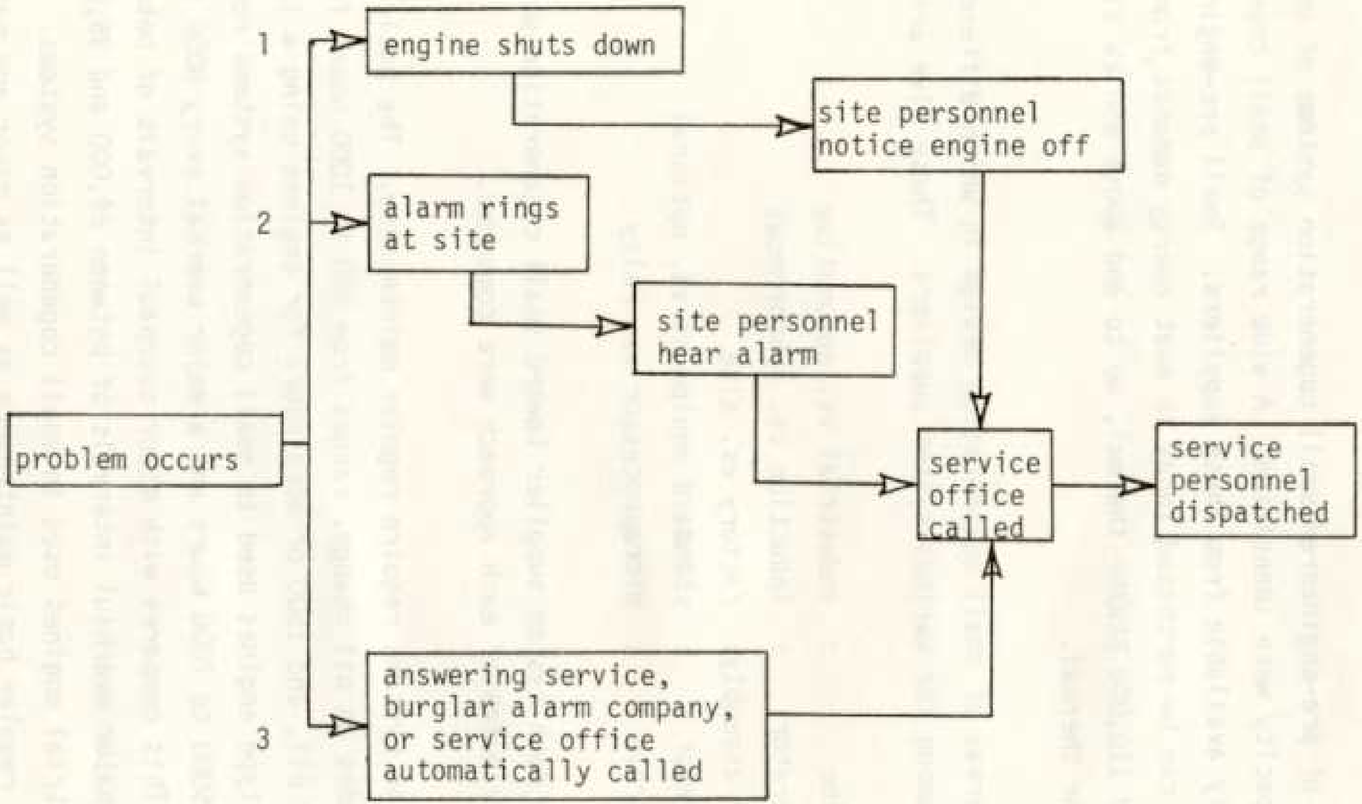

Fig. 5.1. Failure notification procedures.

6.0 SUMMARY AND CONCLUSIONS

Eight suppliers of pre-engineered small cogeneration systems of under 500 kW electrical capacity were identified. A wide range of small cogeneration equipment is currently available from these suppliers. Small pre-engineered cogeneration systems can be purchased today to meet energy demands from as low as 15 kW electric and 110,000 Btu/hr thermal, up to and above 550 kW electric and 3.5 million Btu/hr thermal.

There are five areas of small cogeneration design in which different design philosophies emerge among the various system suppliers. These five areas are as follows:

engine	:	industrial vs. automotive
generator	:	induction vs. synchronous
unit assembly	:	factory vs. site
radiator	:	standard equipment vs. optional
controls	:	microprocessor vs. relay

The approach taken by each system supplier toward small cogeneration was discussed and the attributes of each approach were compared.

Small cogeneration systems require regular maintenance. The basic service interval, which includes an oil change, ranges from 500 to 1000 hours for engines using regular oil, and 1500 or more hours for engines using a low ash oil. The automotive type engines used in small cogeneration systems require a minor overhaul every 5000 to 7000 hours and a major overhal every 8000 to 12,000 hours of operation. This compares with minor overhaul intervals of between 8000 and 12,000 hours and major overhaul intervals of between 24,000 and 36,000 hours for most of the industrial engines used in small cogeneration systems. Service contracts which cover regular basic maintenance as well as minor and major overhauls can be obtained from most of the system suppliers.

Equipment, installation, and maintenance costs were given for selected units of each supplier. The total installed cost, which is the sum of the equipment and installation cost for systems which have been installed, range between \$1000/kW for systems using automotive type engines to above \$1400/kW for systems using industrial engines. Maintenance costs which include minor and major overhauls range between 1.0 and 1.5¢/kWh.

Service for small cogeneration installations is generally performed by the system suppliers. Two firms are planning to develop their own service network. Two other firms will market and service their equipment through their respective engine dealers. Two other firms plan to market and service their equipment through propane distributors.

As of July 1984, there were 35 small cogeneration systems in operation in the United States and Puerto Rico. The six oldest installations went on line in 1982. However, at this writing, the majority of installations have been operational for less than one year. All but four of these installations are of 100 kW electrical capacity or below. Most of the small cogeneration units have been installed in the Northeast and Southern California regions of the U.S.

Cogeneration installations have been concentrated in those applications with high year-round thermal loads. Commercial applications include hotels, a restaurant, athletic clubs, nursing homes and retirement homes, and schools. Industrial applications of small cogeneration systems have been made at a meat packing plant, brick factory, textile mill, a chemical manufacturing plant, and plastics manufacturing plants. In addition, systems have been installed in a dairy, a hospital, and two prisons.

Information on the installation, operation, and reliability experience of small cogeneration installations was obtained through visits to eleven installations. As part of these visits, owners, users, and service personnel were interviewed to obtain their insights on the operating performance of the cogeneration systems.

There were no reports of problems with incorporating the cogeneration equipment into the existing heating or hot-water system. Installation problems that were reported dealt with aesthetics. In some cases, much time and money was spent to achieve the desired appearance and noise level of the cogeneration equipment.

Operating problems that have been encountered by small cogeneration installations can be divided into five categories: control, design, maintenance, engine, and human error related problems. Control and design problems account for most of the problems that have occurred. Reports of problems directly related to the engines used in small cogeneration systems were rare. No small cogeneration unit has operated long enough to require a major overhaul, so, it is possible that engine-related problems will become more common as the installations get older.

In general, the records necessary to determine availability of small cogeneration installations are not kept. Utilization, which could be determinded in seven cases, ranged from a low of 57% to a high of 94%. The low utilization of some installations was due to problems with the design of the installation and not to problems with the cogeneration equipment.

Small cogeneration is currently going through a "shake down" period. The factors that have most affected reliability at small cogenerations are the control system, system design, and maintenance, including water treatment. When the control, design, and maintenance problems are resolved, it appears likely that availability of above 85% and perhaps 90% can be consistently achieved. The engines in small cogeneration systems have performed well and are not yet the critical component in system reliability.

An important consideration in the installation of any small cogeneration system is the availability of qualified service personnel. To assure quick resolution of any problems that occur with a cogeneration system, it is best that service personnel be located within a reasonable distance from the installation and be notified automatically of any malfunction with the system.

It does not appear at this time that the cogeneration system of any one supplier is better or more reliable than that of another. For a particular installation, however, one cogeneration system may be preferred to another. The decision to install one system over another should be based on the size and type of loads to be serviced; the equipment, installation, maintenance costs; and the availability of service for that installation.

Based on the experience of currently operating small cogeneration installations, several recommendations can be made which should help to ensure higher reliability of future installations.

1. The small cogeneration system should be carefully designed with special attention to prevention of module overheating.
2. Untrained site personnel should be prohibited from making changes or adjusting equipment.
3. Regular maintenance should be performed by qualified service personnel.
4. In order to minimize down time, the small cogeneration system should be equipped with an automatic failure notification system so service personnel can be dispatched promptly.
5. In addition, service personnel should be located near the installation, preferrably less than an hour's drive away.

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