THE COGENERATION SOURCEBOOK

Compiled and Edited By F. William Payne

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FOREWORD

The *Cogeneration Sourcebook* includes the latest information on cogeneration planning, financing, and technical improvements. Each chapter is timely, topical, up-to-the minute; the authors are leading practitioners in the burgeoning cogeneration industry.

Several vital new approaches to cogeneration are covered, including the growth of prepackaged and small-scale systems. Developmental concepts such as solar cogeneration systems, fuel cell cogeneration systems, and other renewable energy cogeneration systems are reviewed by energy professionals directly responsible for the programs.

New techniques of financing cogeneration systems are discussed, as are the latest regulatory procedures required for successful implementation.

The *Cogeneration Sourcebook* is an essential reference for all energy specialists and managers who must keep up to date on the changes taking place in the multi-billion dollar cogeneration industry.

F. William Payne, Editor-in-Chief
Strategic Planning and Energy Management

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Cogeneration — An Energy Conservation and Cost Savings Update

V. Gupta

COGENERATION AND LEGISLATION

The National Energy Act, a five-piece legislative package, was signed into law by President Carter in November, 1978. This legislative package represented a strong effort on the part of the Federal Government to lay a solid foundation for a comprehensive national energy policy. Each part of NEA has a Public Law number and a title, and they are as follows:

Public Utility Regulatory Policies Act - P.L.95-617
Energy Tax Act of 1978 - P.L.95-618
National Energy Conservation Policy Act - P.L.95-619
Powerplant and Industrial Fuel Use Act - P.L.95-620
Natural Gas Policy Act - P.L.95-621.

The provisions of the NEA are expected to result in reduced oil import needs, increased use of fuels other than oil and gas, and more efficient and more equitable use of energy in the United States.

The Public Utilities Regulatory Policy Act (PURPA) in particular provides significant incentives for cogeneration technology. The main features of PURPA in relation to congeneration are as follows:[1]

- Qualified cogenerators are exempted from huge state and federal regulations that are applicable to utilities.
- Qualified cogenerators have a right to a connection to the grid of an electric utility company.

- Electric utilities must provide standby or back up electric power to the cogenerators under non-discriminatory rates and policies.
- Electric utilities are required to buy or sell power from qualified cogenerators at just and reasonable rates.
- Industries are in little peril of being publicly labeled as utilities.

The above policies present an altogether different viewpoint for the advancement of cogeneration technology as compared to the effort of 1960's. Many other state and federal initiatives also provide various incentives for cogeneration. The New York State Cogeneration Act of 1980 states: "It is in the public interest to encourage the development of cogeneration facilities in order to conserve our finite and expensive energy resources and to provide for their most efficient utilization." This important legislation which may set an example for other states, exempts "cogeneration facilities" from state and local permits, various construction requirements, and operational conditions.

In essence, the New York legislation is designed to promote cogeneration in industries and involve utilities. This state is one among many nationwide taking cognizance of what can be done and what can be gained with this off-the-shelf technology.

"Slowly, the regulatory system is adapting to the needs of conservation in general, and electricity rates are in the process of being revised so that they encourage, rather than discourage, cogeneration," wrote Yergin. "Altogether, it may be economically possible to cut industrial energy use by more than a third through cogeneration and conservation efforts."[2] As much as $40-billion in total capital investment could be saved by industry with emphasis on cogeneration and conservation compared with the capital investments necessary with conventional energy conversion approaches.

THERMODYNAMIC CONSIDERATIONS OF COGENERATION

The second law of thermodynamics tells us that quality of energy can change only in one direction and that energy loses

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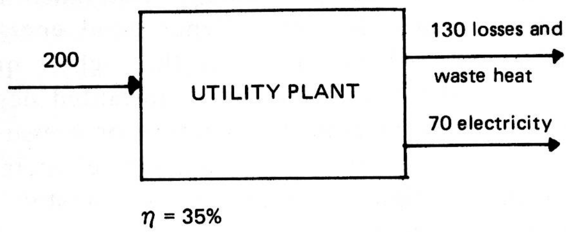
its capacity to do useful work, ultimately reaching the point of zero usefulness. Actually when energy is consumed, we do not "consume" energy, but the available work. As available work is consumed, the quality of energy is degraded; the quantity of energy remains the same. Hence good energy saving practice strives to harness energy at the highest quality or temperature possible: that is to avoid unwanted degradation due to friction, or from large temperature or pressure drops, or through mixing of different temperature energy flows.

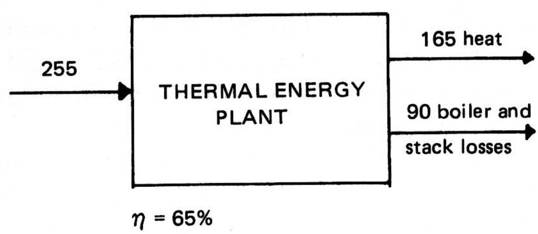
The following example illustrates that it is wasteful to burn fuels just to obtain low quality energy needed for low temperature process heat.[3] Consider for example two cases where electricity and steam or hot water or process heat are produced. In case A, electricity and heat are produced independently, and the combined efficiency of the process is 52%, and in case B where cogeneration approach is used, the efficiency is 85%. The data is shown in Figure 1-1.

From the data it appears that it is more efficient to first produce high pressure steam at a temperature of 500° C. The available work in the steam is used to drive a back pressure turbine, where it is converted to mechanical energy that drives an electric generator. The steam at the output of turbine at a temperature of 150 to 175 C is used to fulfill the thermal needs. With the scheme in case B, it is possible to convert roughly 30% of the quality energy in the fuel to electricity and 50% to useful low temperature heat. The conventional method of producing heat and electricity separately loses almost 50% of the energy content of the fuel. With cogeneration, it is possible to reduce these losses to perhaps only 20%.

In a cogeneration process, the amount of steam flowing to the condenser and the resulting heat rejected to the condenser are reduced when part of the steam is extracted for process heat. This approach provides improved cycle efficiency. As process extraction increases, cycle efficiency will continue improving to the point where all steam is extracted. This effect is shown in Figure 1-2,[4] which assumes that the extraction to process is at a point about halfway through the turbine expansion. The extraction pressure also affects the cycle efficiency.

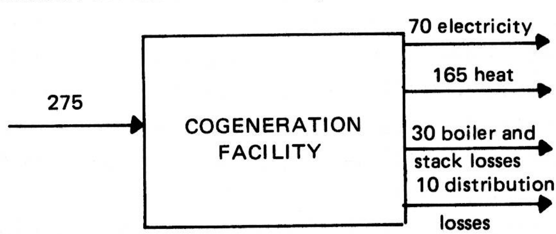
Case A: Separate production of electricity and heat
(combined first law efficiency $\eta = 52\%$)





Total fuel requirement for separate production is 455 units/h

Case B: Cogeneration of heat and electricity



Total fuel requirement for cogeneration is 275 units/h
(combined first law efficiency $\eta = 85\%$)

Rate of fuel savings is 180 units per hour, or 40% less than separate production with same useful output

FIGURE 1-1. Typical Power Balance for Separate Heat and Electricity Production Compared with Cogeneration.

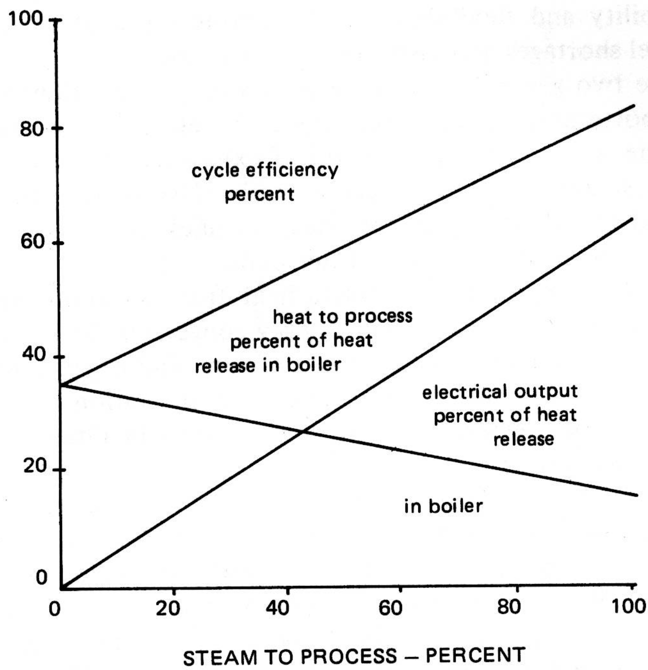


FIGURE 1-2. Cycle Efficiency as a Function of Steam to Process.

From an efficiency point of view, it is advantageous to have as low an extraction pressure as possible so that the steam produces maximum power before being extracted.

COGENERATION TECHNOLOGIES

There are various energy conversion devices[5] that can be used in cogeneration facilities. These devices include the conventional and some newly developed energy conversion devices. One major consideration in selecting an appropriate energy conversion device is the ratio of electricity and steam which it produces. The ratio should closely match the electricity and steam demand of the anticipated energy market, otherwise the benefits from cogeneration will not be fully utilized. Another consideration for a cogeneration facility is its capability and flexibility to use various types of fuels in the event of fuel shortages and disruption of fuel supply.

There are two general concepts involved in cogeneration: topping cycle and bottoming cycle. In topping cycle, electricity is generated first and the waste heat in the form of exhausted steam is utilized for process steam or thermal energy needs. The energy conversion devices used in topping cycle are: diesel engines, gas turbines, combined gas cycles, steam boilers, and fuel cells.

In the bottoming cycle, the waste heat from an industrial plant is used to produce electricity. The energy conversion devices used in the bottoming cycle are: steam waste boilers, and organic Rankine cycle engines. The main characteristics and limitations of various energy conversion devices used in cogeneration facilities are summarized in Table 1-1.

A hypothetical 26 MW coal-fired, indirect-heated gas turbine cogeneration plant has been described,[6] including the plant arrangement, mode of operation, capital cost and operating economics. Another 100 MW coal gasification combined gas cycle demonstration project is underway at the "Cool Water" site of Southern California Edison Company.[7] This project will demonstrate a large coal gasification system. It will establish the environmental performance of the concept and viability of integrated operation with gas turbines, steam turbines, and other steam heat recovery equipment. In addition, it will also provide the technical and experience base needed for subsequent commercialization to industry and utility applications.

A 4.5 MW demonstration fuel-cell plant sponsored by the Department of Energy, the Electric Power Research Institute, and Consolidated Edison of New York[5] has been implemented in New York City. A molten carbonate fuel cell[8] integrated with a coal gasifier is one of the most promising coal based technologies for electric power.

Preliminary projections indicate efficiencies exceeding 60% as compared to 35% figure of a typical utility plant. The high electrical efficiency without need of a bottoming cycle and the quality of waste heat available serve as persuasive arguments for continued support of this technology and its early adoption once demonstrated. The above figure can be further improved if combined with bottoming cycle.

TABLE 1-1. Characteristics of Various Energy Conversion Systems in Cogeneration Facilities

System	Capacity (MW)	Electicity-to-Steam Ratio	Type of Fuel	Suitability and Drawbacks
Topping Cycles				
Diesel cogeneration	0.5 - 25	400:1	premium liquid fuels	industries where steam needs are minimal
Gas Turbines	0.5 - 75	200:1	natural gas, low Btu synthetic gas, light distillate oils, ethanol and methanol	excess electricity is produced. The facility should be able to sell the excess electricity.
Combined Gas Cycles	1 - 150	150:1	gas and liquid fuels for gas turbine, steam boilers can use solid, liquid, and gaseous fuels	requires transmission of electricity in some cases where all the electricity cannot be used by the industry
Conventional Rankine Cycle Extraction Turbine	1 - 600	45 to 75:1	greatest flexibility for fuel use	utilities favoring cogeneration
Back Pressure Turbines	1 - 600	45 to 75:1	greatest flexibility for fuel use	industries where steam is required as part of process heat
Fuel Cell	1 - 150	300:1	hydrogen and oxygen or air, excess electricity can be used to generate hydrogen and oxygen	suitable for facilities with high electric and low thermal demand, ideal in isolated facilities.
Bottoming Cycles				
Steam Waste Boilers	0.5 - 10	–	high temperature heat that is wasted otherwise	brick kilns, glass furnaces, blast furnaces
Organic Rankine Engines	0.5 - 1	–	waste heat having temperature above 600 F	organic fluids are toxic and flammable thus hazardous

The concept of power plants based on coal gasification is well on its way to commercialization through the "Cool Water Project," but its industrial applications will benefit as cogeneration, trigeneration or even "polygeneration" energy facilities are possible based on clean gas from coal as shown in Figure 1-3.

CONSTRAINTS ON COGENERATION

Cogeneration is an attractive energy savings approach. Still, there are several obstacles to industrial and commercial cogeneration.[9]

- High cost of capital investment. Costs of cogeneration systems vary depending upon the size and the type of facility, but are high by any standard. 50-100 million dollars are typical costs for some types of systems. In tight economic conditions, industries do not have the necessary capital to install such facilities.
- Environmental concerns.
- Lack of restrictions on the use of oil and natural gas by utilities and power plants. In spite of the Power Plant and Industrial Fuel Use Act, there are several exemptions, where oil and natural gas are being used.
- Current low cost of electricity. Despite the rate increases of recent years, the cost of electricity still remains low for large industrial users due to the declining block rate structuring approach used by utilities.
- Restricted kwh revenue. The Federal Energy Regulatory Commission (FERC) has required utilities to purchase cogenerated industrial electricity, minimizing this obstacle, but the utilities pay a rate on an "avoided cost" basis.
- High back-up rates. Electric utilities have traditionally charged high rates to provide stand-by power. The FERC has ruled that electric utilities must apply the theory of load diversity in a non-discriminatory fashion to establish stand-by rates.

In the commercial and residential sectors, district heating is the only energy demand large enough to significantly accomodate the huge quantity of waste heat available from utilities. To some degree,

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