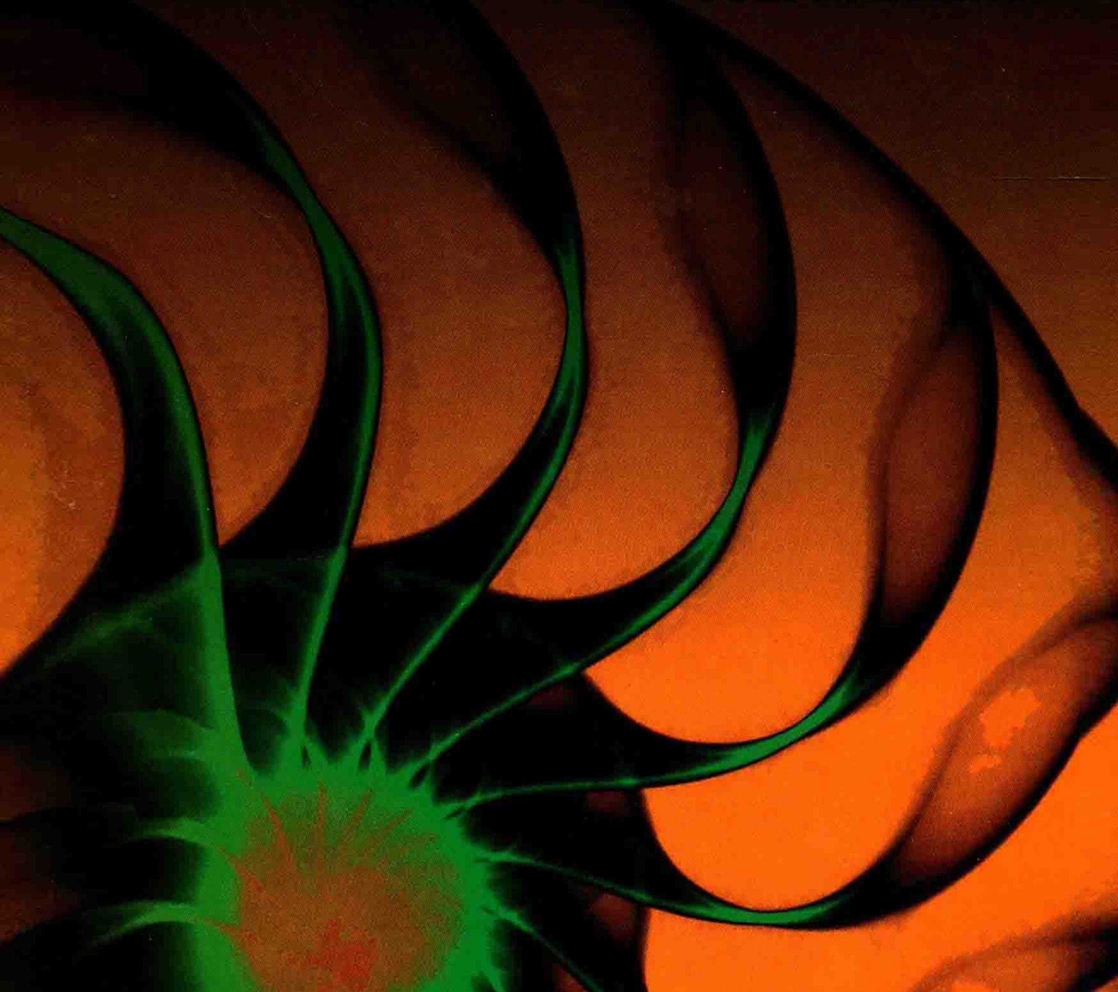
Bernard F. Kolanowski, BSME

Small-Scale Cogeneration Handbook

Fourth Edition



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Dedication

This book is dedicated to the people responsible for giving me the opportunity to get intimately involved in the field of small-scale cogeneration: Mr. Herbert Ratch (deceased), Mr. David Lumbert, and Ms. Margo (Ratch) Bennett.

and

To my loving wife, Mary Beth

Preface

Whenever you turn on the heater in your car, you are cogenerating. The heat your engine would normally dissipate through your radiator is passed through your car's heater warming the inside of the passenger compartment as you drive along. The single fuel you are using is the gasoline (or natural gas) in your tank, but it is providing both the power to drive your car and the heat to keep you warm.

And that's what cogeneration is. Using one fuel to produce two usable energy sources. In this discussion the fuel will be natural gas (although propane and diesel oil may also be used) and the usable energy will be electricity and hot water.

WHY COGENERATE?

You will use cogeneration to save money, but there are other benefits of cogeneration if you are concerned with the air you breathe and the energy used from mother earth.

Money; because cogeneration produces two usable energy sources from a single fuel, it operates more efficiently than your present sources of energy. In fact, cogeneration turns up to 90% of the fuel burned into usable energy. That compares with just 52% of the fuel burned in the local power plant and in your existing hot water heater.

That difference in efficiency saves money. Returns on investment of capital range from 25 to 50% when cogeneration is properly applied to a facility, be it a home, commercial operation or an industry. Cogeneration will throw off a positive cash flow after paying for the residual energy you buy from the utility, the debt service for the investment and the maintenance and operating costs.

Environmental, because cogeneration uses less fuel overall, less pollutants will be emitted to the atmosphere. Even in strict Air Quality Districts catalytic converters, similar to those in your automobile, will protect the atmosphere from excess pollution.

Conservational, because cogeneration will burn less fuel, the energy resources of this planet will be conserved.

WHO IS COGENERATING?

You'd be surprised at the variety of commercial and industrial businesses that are using cogeneration to cut costs and conserve energy and the environment:

- Did you visit your local fitness center this week? They are a natural for cogeneration because of the hot water they use in spas, swimming pools and showers.

- Wastewater treatment plants use cogeneration by burning a combination of biogas and natural gas to generate electricity and hot water.

- Municipalities use cogeneration to heat swimming pools and air condition associated meeting and fitness centers.

- Food processors use cogeneration to cook and pasteurize their products while generating electricity for internal consumption.

- Casinos are using cogeneration in conjunction with absorber-chillers to cool and electrify their facilities.

- Hotels are using cogeneration for guest room hot water, laundry hot water, kitchen hot water as well as heating their pools and spas while generating a percentage of their electrical needs.

- Hospitals are cogenerating for heating therapy pools to over 90 degrees, sterilizing operating instruments, and general hot water needs while making most of their electrical needs.

WHERE DO YOU COGENERATE?

On your site. The typical cogeneration system is no bigger than an executive size desk, and just about as quiet, too. Placed on site, it ties in with the existing hot water heating system and electrical distribution system to provide the facility with the first line in heating water and electrifying the facility. When more hot water or electricity is needed than the cogenerator can supply, the existing systems kick in and furnish that excess without missing a beat. When the cogenerator needs maintenance, those same existing systems that used to supply all of your utility needs are there to insure your facility keeps operating. Cogenerators can even be engineered to continue to operate during central utility power failures if that is important to you.

CAN YOU FINANCE THE COGENERATION SYSTEM?

Yes! Conventional financing through your bank or lending institution is one way. State assisted financing for energy conservation projects is available in many states. Grant money from both federal and state governments is another way. Leasing is a very popular way to do off-balance-sheet financing. Another way to attain the benefits of cogeneration and have no capital outlay is to utilize third party financing via Shared Savings Agreements.

SHOULD YOU COGENERATE?

Only if you want to save money and be a good neighbor in conserving energy and combating pollution.

This book presents the state of the art and science of the technology of cogeneration while demonstrating the practical side of implementing this art and overcoming the pitfalls while staying within the changing regulatory boundaries required to bring home a successful cogeneration project.

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Chapter 1

Introduction

Some years ago as I was moving into a new neighborhood I met some of the people I would be living around. One neighbor asked what I do for a living and I replied, "I'm in cogeneration."

He said, "What is that?" After explaining he then said, "Next time someone asks you what you do, tell them you're in real estate. Everyone knows what real estate is!"

And that's the way it's been ever since. About one in ten people will have any idea of what cogeneration is, and even that one will have a somewhat glazed look to his eyes. So, to explain to both the readers who are learning about cogeneration as well as those that have experience in this 'exotic' field I will elaborate. Cogeneration is the simultaneous production of two or more beneficial work outputs from a singular source of fuel input. In small-scale cogeneration the two work outputs are almost exclusively electricity and hot water and the single fuel input is natural gas.

An example to which most people can relate is the automobile. When automobiles were first introduced few, if any, had a heater built into the car. To enjoy both the thrill of powering yourself down the road and interior comfort during cold weather, one might have a kerosene heater inside the car to provide heating comfort. Therefore, when you stopped at the gas station you would buy gasoline for the car's engine and kerosene for the internal heater. You were getting two work outputs—motive power and interior comfort heating—but you were using two different fuels. No cogeneration here.

Then, when automobile manufacturers decided to place heaters inside the car rather than using a heater with a separate fuel source, they recognized the fact that the engine was throwing off a vast quantity of heat through its radiator. They devised a method whereby some of this heat could be channeled into the car's interior for the comfort of its driver and passengers, This was truly cogeneration: two work outputs from a single fuel input.

So in the case of small-scale cogeneration, which is the primary topic of this book, it will be shown how electricity and hot water can be created from a single fuel source and the savings that accrue from this rather simple technology. When you get a fuel to do two work efforts the savings will be in fuel costs. Electricity is generated from a prime mover, most often a reciprocating engine, driving an electric generator. The waste heat from the engine is channeled through heat exchangers to heat water that would normally have been heated by a separate hot water heater in the facility. The engine heat is captured primarily in the engine's coolant, an ethylene glycol antifreeze solution, and that coolant is pumped to a heat exchanger to transfer its heat to the water needing to be heated. The ethylene glycol loses some of its heat to the water and is circulated back to the engine block to be reheated by the engine and pumped back to the hot water heat exchanger. Since there is also heat in the engine's exhaust that heat is captured in an exhaust gas heat exchanger which transfers this waste heat to the ethylene glycol. A typical system is shown in Figure 1.

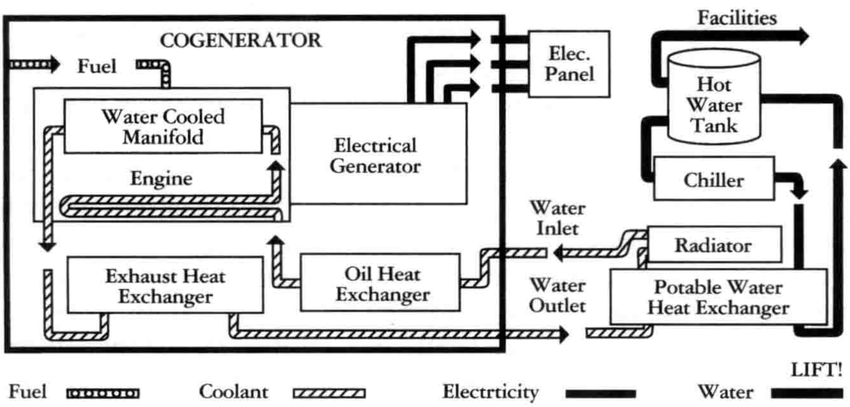

Figure 1-1

The efficiency of this system in converting the energy in the fuel to useful work is quite high. Using data from one of the manufacturers of small-scale cogenerators, it can be shown that a system designed to produce 120 kilowatts (kW) of electricity and 5.62 therms per hour of thermal energy (hot water) has a fuel-usage efficiency of more than 90%. The fuel input is 10.7 therms per hour of natural gas, or 1,070,000 Btu's per hour of energy input. One hundred twenty kW of electricity @ 3413 Btu's/kWh = 409,560 Btu's/hr of energy output, plus the 562,000 Btu's/hr of energy output in the form of hot water. Therefore, a total of 409,560 + 562,000 = 971,560 Btu's/hr of energy output vs. 1,070,000 Btu's/hr of energy input. The thermal efficiency is 971,560/1,070,000 = 90.8%.

The electricity produced at the central station has an overall efficiency of about 36% delivered to the customer's facility. That takes into account not only the fuel used to create the electricity, but also the transmission losses incurred in getting that electricity to the facility. A typical on-site hot-water heater has an efficiency of 75 to 80%. So, to deliver 120 kW of electricity, the central station utility must burn 120 kW × 3413 Btu/kWh/0.36 = 1,137,667 Btu's/hr of fuel. The hot water heater must burn 562,000 Btu's/hr/0.75 = 749,333 Btu's/hr. That's a total of 1,887, Btu's of fuel burned to create 971,560 Btu's of useful work. That's an efficiency of 971,560/1,887,000 = 51.49%.

A customer buying electricity from a central-station utility and heating water in his on-site water heaters will purchase 817,000 Btu's/hr more fuel to gain the same useful energy than if he were cogenerating on site. And that is for EVERY HOUR HE NEEDS THAT ENERGY! A facility open seven days a week for 16 hours a day will buy 47,713 more therms of energy per year than the same facility who uses on-site cogeneration. At an average street cost of $0.75 per therm that's $35,785 more dollars spent just in fuel costs alone. However, as we shall see in later chapters, that's not the only costs involved since the utility, which buys fuel at a considerably lower cost than street costs, must add much more to the cost of electricity than simply the fuel costs.

The actual costs to the user in this example to purchase 120 kW of electricity and 562,000 Btu's/hr of hot water for 7 days a week, 16 hours a day is over $80,000 per year.

Chapter 4 explores fully the economics of using cogeneration on site, but suffice it to say that the amortization of on-site cogeneration, i.e. the time to recoup the capital costs of the system, is an average of three years or less, even after accounting for operating and maintenance costs of the system.

Not only are economics involved in using cogeneration, but there are environmental and conservational issues that also benefit from getting more work with less fuel. Fifty-six percent less fuel burned will create 56% less pollutants in the atmosphere. Fifty-six percent less fuel burned will be 56% more fuel available for future generations of energy users.

Chapter 2

History of Cogeneration

The practical use of cogeneration is as old as the generation of electricity itself. When electrification of broad areas was devised to replace gas and kerosene lighting in residences and commercial facilities the concept of central station power generation plants was born. District heating systems were popular during the late 1800s and why not. District heating dates back to Roman times when warm water was circulated in open trenches to heat buildings and communal baths. District electrification dates back to Thomas Edison's plants in New York, and it didn't take long to combine the two. The prime movers that drove electric generators throw off waste heat that is normally blown to atmosphere. By capturing that heat and making low-pressure steam, that steam could be piped throughout the district for heating homes and businesses. Thus, cogeneration on a fairly large scale was born.

As electrification marched across the country, most of the generated electricity was on site in large industrial plants. With that generation, there is no doubt that much waste heat was captured and utilized in industrial processes as a natural offshoot. Probably the word cogeneration was not even used in conjunction with those efforts, but cogeneration it was. As large, central generating stations were built, it became cheaper for those industries that had been self-generating electricity to now buy from the central utility. With that change came the end to "cogeneration" in those industrial plants. Central station utility plants were now located off the beaten path, so even district heating suffered as the lines to connect to districts became too long and costly. Cheap oil and natural gas were the cause of our return to wastefulness, and little thought was given to energy efficiency when oil was selling for under a dollar a barrel.

But nothing is steady. Change is everything. With the first OPEC energy crisis in 1973 came a realization that America was no longer self-sufficient in supplying its total energy needs and that foreign countries now controlled what the price of energy would be. The oil produced in

America still only cost $4.00 per barrel, but if OPEC was going to sell its oil at $20.00 per barrel and we had to import over half our needs, then all oil was going to sell at the going rate. With expensive energy came plans to conserve energy and to seek energy supplies that were heretofore costly to get at and to seek alternative sources of energy. The famous tar sands of the Athabasca region in west central Canada were exploited when the cost of oil was predicted to go to $40 a barrel. Drilling rigs were punching holes all over the traditional oil-bearing areas of the United States opening small "stripper" wells and re-opening wells that had been abandoned due to the higher costs of production. America was in an oil boom only to see it burst when OPEC, knowing they controlled these matters, let the cost of oil slide to $10 a barrel, and we saw those efforts at exploiting domestic sources go wanting.

Conservation was now a household word. With the cost of electricity tied to the price of oil, consumers felt the pinch of rising electricity prices. An enterprising group of neighbors in the Bronx section of New York decided to put up a windmill to generate enough electricity to help cut their costs from Consolidated Edison, the major supplier of electricity in New York. They would still be tied into Con Ed's system, but when the wind blew, they could count on their costs being lowered by their wind-powered production of electricity. The system was so successful that at its peak it generated slightly more electricity than was needed at any given time, so they decided to sell this excess back to Con Ed, who, of course, was getting it free whenever an excess was generated. Con Ed balked at having to buy power from this upstart neighborhood and abjectly refused. The neighbors sued and won. From this meager beginning came the Public Utility Regulatory Policies Act of 1978 that we fondly call PURPA today.

The PURPA law paved the way for larger-scale cogeneration and independent power generation.

Very few businesses could afford to generate their own electricity exclusively. Variations in their power needs on an hour-by-hour basis; reliability and maintenance of the on-site generators; additions to their operations; all required the back up of the central station utility to make these independent power generators and cogenerators feasible. In effect, PURPA said that a central-station utility must allow interconnection of these facilities with their grid to act as standby and makeup power sources. It further said that the cost of the fuel to power these cogenerators would be similar to that which the central station utilities paid for their fuel.

Furthermore, it reinforced the law requiring the central station to purchase any excess power generated by these independent facilities at the "avoided cost" of the utility. The term "avoided cost" led to very creative accounting by the utilities to determine exactly what their "avoided cost" was. Too low, and their guaranteed return on investment would be jeopardized; too high and their payment for purchased kilowatts would be too expensive. It is doubtful that any two utilities in the country had identical policies when it came to determining their "avoided cost." The utilities that were selling kilowatt hours at 5 cents each were virtually immune to independent power producers and cogenerators, while those whose prices were 16 cents a kilowatt hour were now inundated with alternative sources of electricity. Abuses were rampant on both sides. Facilities were built in these high-priced regions, presumably as cogeneration facilities, but they were mostly power generators that wanted to capitalize on the cheap fuel costs for cogeneration systems and the other PURPA law advantages. When the utility was forced to pay 8 and 10 cents a kilowatt hour for "excess" power it became advantageous to produce "excess" power.

With these abuses came regulations. The Federal Energy Regulatory Commission, FERC, was set up by the government to put some ethics into the business of generating, buying, and selling independent power. An efficiency standard was set up requiring a cogeneration system to meet a minimum standard of thermal-energy utilization in order to derive the full benefits of PURPA.

The formula used is: (All inputs are in Btu's)

$$\text{Efficiency} = \frac{\text{Thermal Energy Produced}/2 + \text{Electrical Energy Produced}}{\text{Fuel Input}}$$

The minimum efficiency required to meet this formula is 42.5%.

Squabbles between utility and cogenerators still ensued, however, as the responsibility to prove FERC efficiency was argued. The cogenerators said that if the utilities wanted to know FERC efficiency, they could instrument and monitor the units. The utilities said it was up to the cogenerators to prove they were meeting the minimum efficiency levels. Cogenerators still wanted to generate as much electricity as possible as this was the motive force that paid for their investment. If the heat could be used, fine. But if it could not be used, it was then