# COGEN: IS IT WORTH THE CARFARE FOR YOUR OPERATION?

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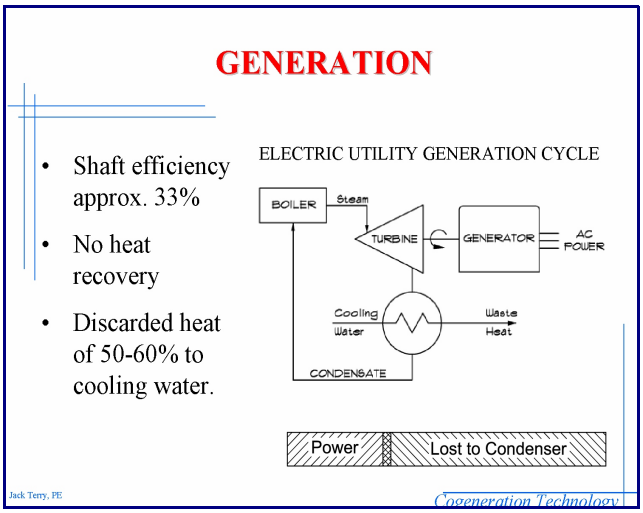
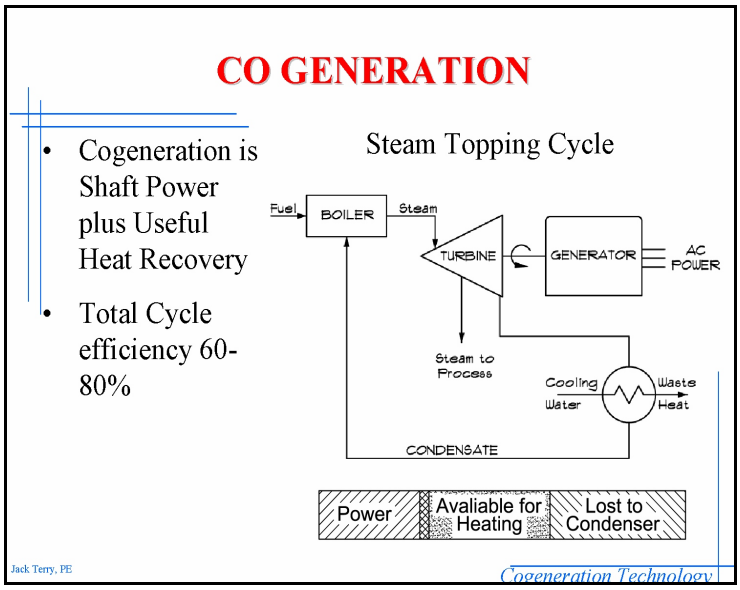
Onsite COGEN can provide improved power quality and reliability for critical process; or it may provide justification to convert the mill from more expensive thermal fuel (gas) to less expensive wood chips. Such a conversion usually involves boiler replacement for compatibility with wood firing and an increased steam pressure if COGEN is anticipated. Thus, the project can become a paradigm shift in mill operation. Consider these questions:

- Is there sufficient long term operating commitment to the site and plant?
- What is the strategic energy and business plan for long term operation of the mill?
- Does COGEN technology fit the culture of the mill?

COGENs do not work economically at every mill and when they do, there is no one size fits all. There is no easy or straight forward answer as to whether or not COGEN is worth the carfare in any given case but; this paper provides information on the technology and lays out a process leading to the answer for your particular operation. A final commitment to COGEN should not be made without a formal analysis of both financial and technical factors. At the end of the day, whether it's "worth the carfare in your operation" should be based largely on the economics.

A typical electrical generation cycle utilizing a boiler, steam and turbine generator will waste more heat than is converted to electricity in the process. A key objective of COGENeration is to improve the efficiency of this cycle by marrying it to a process whereby a greater portion of the heat produced will serve a useful purpose rather than being wasted to a body of water or a giant cooling tower, either of which is typically found next to a steam power plant.



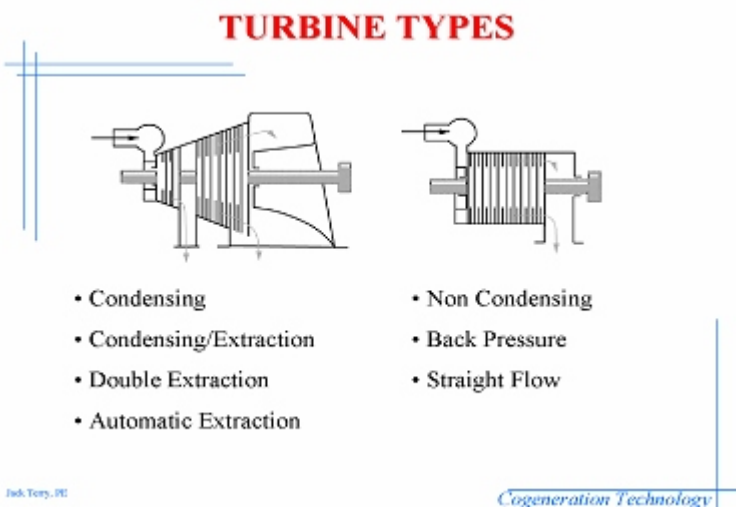



Steam turbines used in power generation are broadly classified as condensing type as steam is exhausted to a condenser at or below atmospheric pressure. Power generation utilizes the lowest exhaust pressure (vacuum) practical in order to extract the maximum heat from the steam and thus produce the greatest power output. Noncondensing turbines, on the other hand, exhaust steam at or above atmospheric pressure normally to a continuing process instead of a condenser.

What sets COGENeration apart from straight generation is the *simultaneous* and *sequential* production of two forms of useful energy from a single source. For our purposes, the two forms are heat energy (i.e. thermal, steam) and shaft power (i.e. electricity). This arrangement is also often referred to as Combined Heat and Power (CHP).

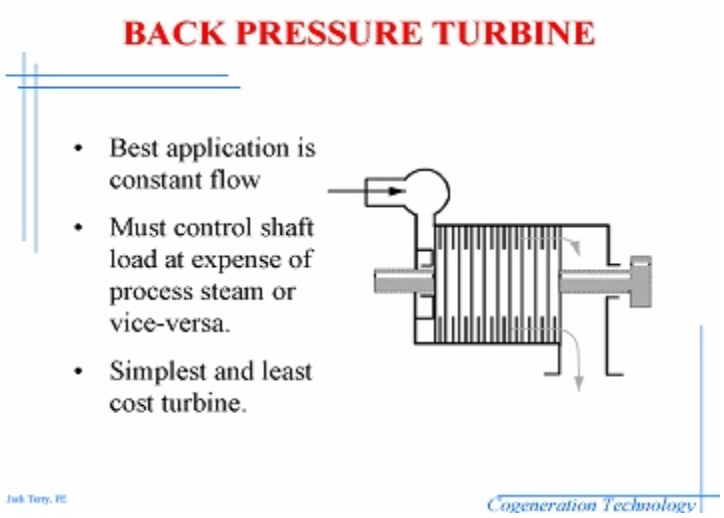
The sequence or order in which the two forms of energy are extracted further characterizes the system as either a *topping* or *bottoming* cycle. Topping cycle (depicted above) extracts shaft power first followed by thermal energy, as in the example of higher pressure steam being feed first to a turbine followed by lower pressure steam to drying kilns (thermal). A bottoming cycle, on the other hand, extracts heat first followed by shaft power. This sequence would probably be a little awkward in the case of the kiln/turbine combination. Combined cycle (power with heat recovery) is a further characterization of a COGEN system. The thing to remember is:

*heat recovery = dollar recovery*.



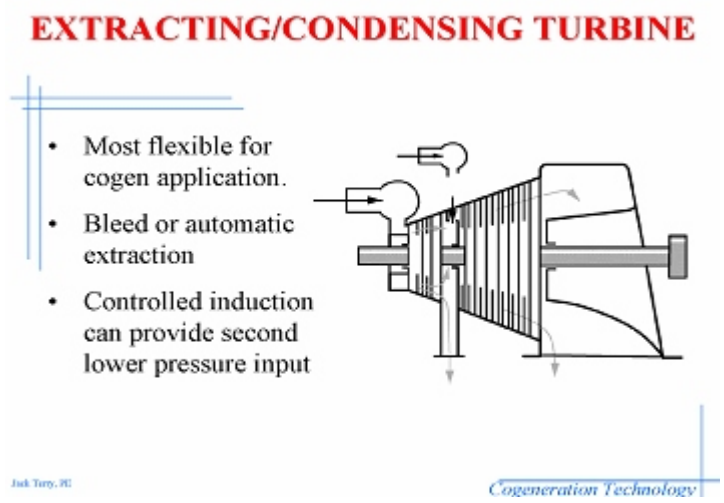

A simplified diagram illustrating the difference between a condensing and a noncondensing turbine is shown above. Condensing turbines exhaust steam to a pressure less than atmospheric and hence require an expanded casing with a large exhaust chamber to accommodate the increase in volume of the expanded steam. A pound of steam at 400 psi occupies about one cubic foot; the same pound at typical exhaust vacuum (5 psia) occupies about 70 cubic feet. The noncondensing turbine, on the other hand, exhausts steam at a higher pressure and thus, uses a simpler more straight through steam path.

Steam turbines are highly reliable devices that require a minimum of maintenance. Units, especially smaller ones, have been known to operate for 20 years with only routine maintenance. With modern control systems they run almost automatically and generally do not require a dedicated operator over and above that required for boiler operation. Water quality and steam water rate (i.e. quality or super heat) are extremely important for prolonged trouble free turbine operation. Erosion of the turbine blades and premature wear can result from poor steam or water quality.



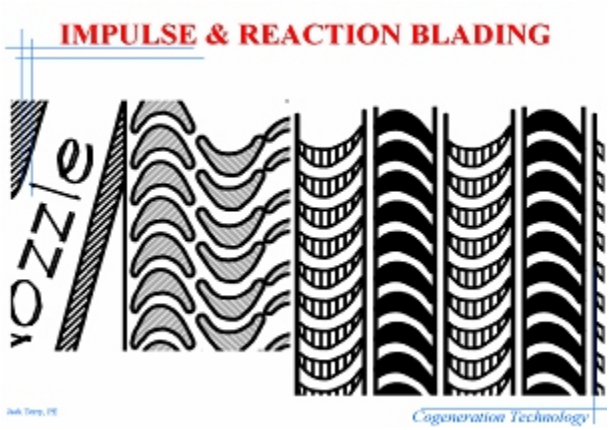
The back-pressure turbine develops only about half the power as that of a condensing turbine on the same amount of steam. All turbines produce power from the steam pressure drop that occurs as the steam expands from input to output. Without this “delta p” there is little or no shaft power. A 4:1 pressure drop is typical for a backpressure turbine producing power for COGENeration.

Back pressure units are the simplest and least expensive turbines but, also the least flexible. Their best application is one of constant flow where the steam rate and hence the pressure drop and shaft speed are relative constant. These units can be controlled on speed (frequency in a generator) or output pressure; but not both. Where used for generation, if the control is based on speed, a supplemental steam source may be required to keep an adequate steam supply feeding the kilns.

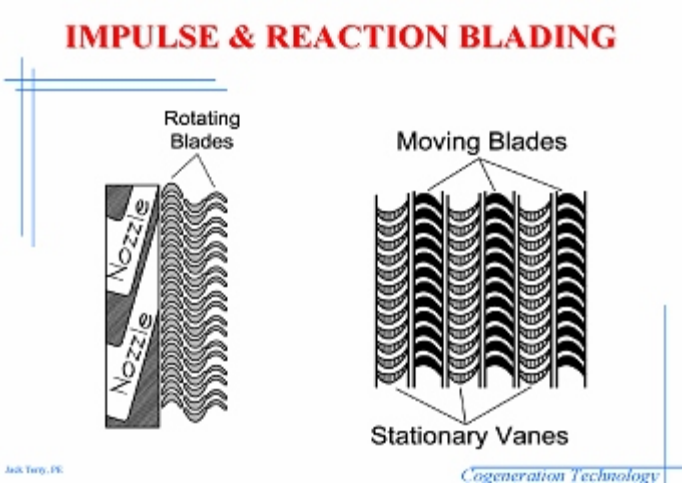



Operating flexibility and efficient use of steam dictate the use of extraction turbines in many cases. A combined extraction/condensing turbine offers the greater flexibility as it provides a dual path for steam exhaust. A small amount of steam (20%) must always be exhausted to the condenser in order to cool the last stages of the turbine but, aside from this requirement, steam can be balanced between the kiln (extraction) and power production.

Extraction turbines may be either uncontrolled (bleed) or automatic extraction type. Bleed is simply an open port in the case located at a point corresponding to the desired extraction pressure. Since the extraction pressure is related to steam flow, bleed port pressure will vary with steam rate to the turbine. Automatic extraction adds a pressure control valve at the extraction port in order to maintain a more constant pressure. Some turbines are fitted with a second induction port to utilize available steam at a lower pressure. This additional inlet is known as admission port but it is essentially the same port as an extraction port. There are also compound turbines – two separate units on a common shaft. For example, a back pressure unit compounded (in series) with an extraction turbine. A cross compound configuration utilizes a similar configuration but with separate shafts. There are many options.



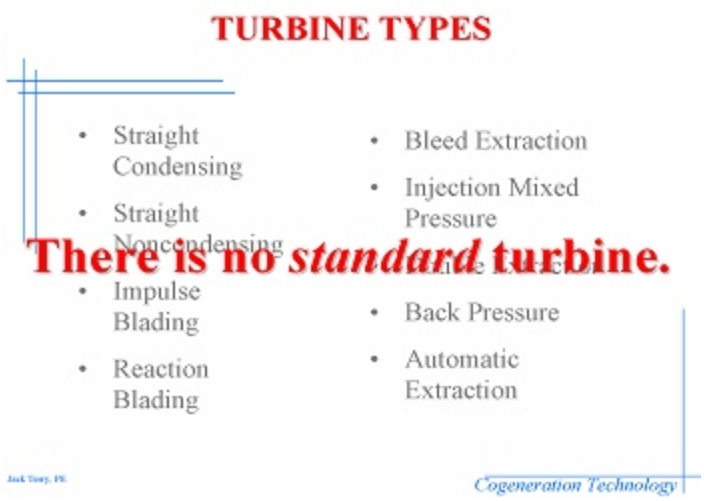

Similar to the two broad classes of turbines (condensing and noncondensing) there are two types of internal blades that create shaft power from the steam. Blading, as it is known, is either *Impulse* or *Reaction*. The impulse stage is somewhat analogous to the water wheel as the moving blades are cup shaped and catch the steam directed at them by fixed nozzles which accelerate the steam across their pressure drop. In velocity staging (shown) two moving blades are separated by a stationary blade that redirects steam off the first to the second. Pressure staging uses a single movable blade. Almost all the pressure drop for the stage is in the fixed nozzles after which pressure is relatively constant through the blades. Impulse stages are rugged and typically used in the first stages of a multi staged unit. Reaction blading, on the other hand, utilizes blades shaped more like an airfoil and work on a reaction principal. Pressure continues to drop as the steam progresses through the series of reaction blades. Reaction blade stages are more complicated to build and more fragile than impulse units due to their tighter tolerances but have a slight edge in efficiency. In practice, most large turbines are a combination of the two types.

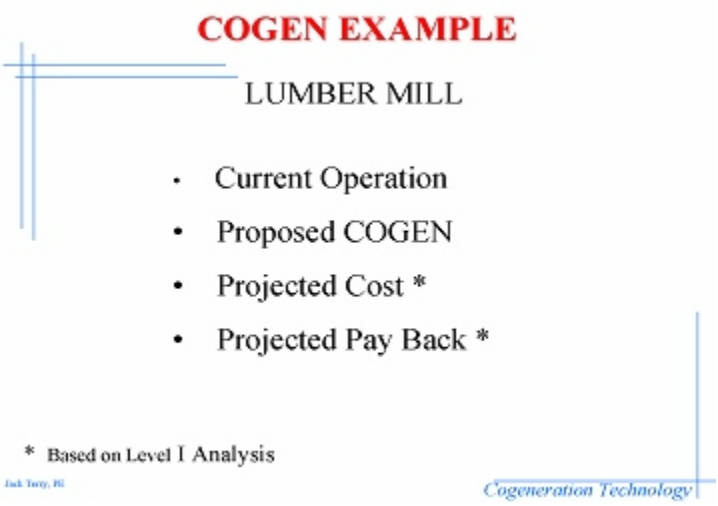


The key factor affecting economic viability (pay back) of a COGEN project is the *thermal* to *electric* ratio. The turbine is the heart of the system in this regard because it establishes this ratio.

Too little power production results in unacceptable incremental payback for generation. Over doing power production tilts the operation too much towards a generation station – a business you probably don't want to be in. And this balance must be reached while satisfying the steam requirements of the thermal process (kilns); the business you do want to be in.

With so many combinations of types and turbine characteristics, there are hundreds of combinations from which to select. The type, size and characteristics must be balanced to optimize the operational and economic equations. Without proper and optimal selection of the turbine, payback on an otherwise well designed COGEN project may not be adequate.



The example chosen here is a typical sawmill and drying operation with existing low pressure boilers operating at 100 psi supplying steam to conventional kilns. Boilers are presently gas fired and rates have nearly doubled in the last year. We will examine the current operation and go through the proposed COGEN solution. The financial aspect of the proposed project will be examined on the basis of an initial Level I analysis.

## EXAMPLE – CURRENT OPERATION

### SAW MILL – LUMBER DRYING

***STEAM:***

| | |
|---|---|
| Pressure: | 100 psi (saturated) |
| Volume: | 10,000 Lb/Hr Avg (Drying Kilns) |
| Fuel: | Gas @ $0.80/Therm (Avg 2005) |
| | Projected 2006 @ $1.00/Therm |

***ELECTRIC:***

| | |
|---|---|
| Average Demand: | 0.9 MW |
| Peak Demand: | 1.6 MW |
| Effective Rate | $0.065/KWH |
| Demand Charge: | $7.00/KW |

Utility Cost (2005 – Gas & Electric): $1.2M

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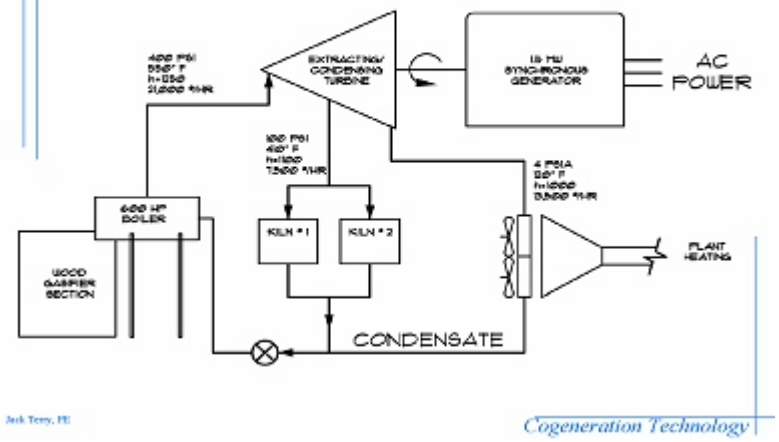
Recap of current operations (2005) thermal and electric rates. This information was gathered principally from monthly utility billing records for the period, a typical starting point for Level I analysis.

## PROPOSED COGEN SYSTEM

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## PROJECTED COST

COGEN EXAMPLE

| | |
|---|---|
| 600 HP Wood Fired Boiler, Super Heat, 450 psi Design | $1,100k |
| Bag House | 300k |
| Electro Static Precipitator | 400k |
| Steam Turbine/Generator | 1,100k |
| Automated Control System | 150k |
| Air Exchange Condenser | 100k |
| Total: | **$3,150k** |

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First cut engineering estimates of capital costs for the proposed system.

## PROJECTED PAY BACK

COGEN EXAMPLE

| | |
|---|---|
| Avoided Gas Costs @ $1.00/Therm | $800k |
| Avoided Electric Costs @ $0.065/KWH | 350k |
| Wood Fuel Cost (Green) | (110k) |
| Electricity Sales @ $0.04/KWH | 100k |
| | **$1,140k** Annually |

Simple Pay Back: $\frac{\$3,150,000}{\$1,140,000}$ = **2.8 Years**

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The proposed COGEN System replaces the current gas fired boilers with a 600 HP 400 psi wood fired unit. A condensing-extracting turbine provides 100 psi steam to the two drying kilns while the remaining steam exhausts to the condenser producing about 1 MW of electric power representing about two thirds of the mills' 1.6 MW peak demand. There are usually 5 or 6 days per month when the kiln's do not operate during which time the system can run entirely in the condensing mode producing approximately 1.5 MW of electricity. An air exchange condenser was chosen over a water cooled surface condenser to provide plant heating.

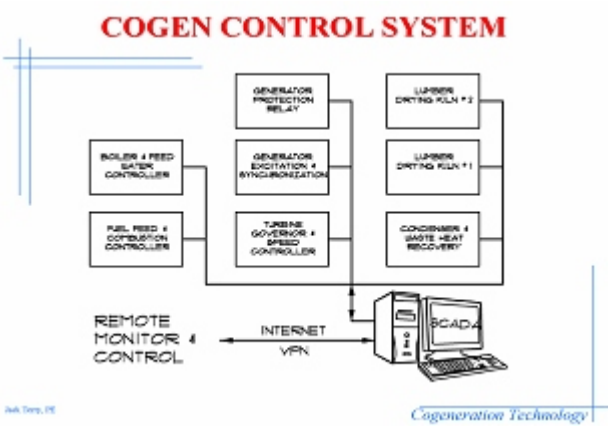
Electrical generation economy of scale must always be considered to find a "sweet spot" where COGEN becomes worth the carfare. Turbines, generators and Qualified Facility (QF) grid connections are costly and without sufficient up side can not be justified.

For example, had the pressure on the existing boilers simply been raised to their limit of 150 psi and a turbine added to reduce steam pressure to 100 psi for the kilns, power generation would be just over 100 KW (0.1 MW). Another option discarded was the use of a backpressure turbine feeding the kilns from the new higher pressure boiler. This configuration would have produced about 400 KW (0.4 MW) of electric power when the kilns were running and zero when the kilns were not operating.

Projected payback for system as proposed; note the buyback rate for electricity sold typically less than purchase. Actually, the buyback rate in this case is somewhat reasonable, although there is more to the story.

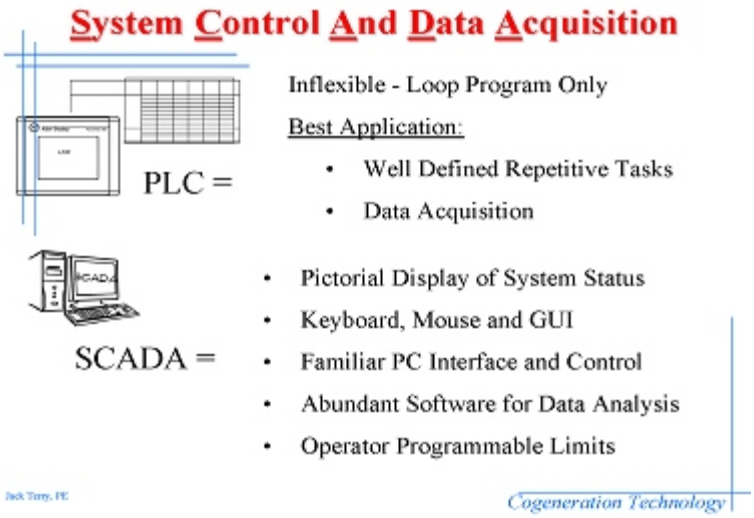
When a 1.5 MW electric utility customer sheds load while at the same time, wishes to have the larger supply available for backup to cover generation outage, the utility typically sees an opportunity to impose standby charges. The Public Utility Regulatory Policy Act (PURPA) requires utilities to supply standby power to qualified COGEN sites at non-discriminatory pricing but the rate is not defined. In extreme cases this can lead to a "catch 22". Utility negotiations need to be started early in the COGEN planning process to establish the buyback rate and ensure standby charges are not a deal breaker The other option for a determined mill owner is to cut the utility cord altogether!

The best economic scenario is usually to displace power consumed because it returns 100 cents on the dollar compared to selling power at pennies on the dollar. Selling power to a utility is a difficult option because of the bureaucracy, regulations, utility resistance and changing government policies. Couple this with the fact that the business of power generation is not an attractive one due to the fact that returns on investment can typically be 15 to 20 years.




In a COGEN system, overall system operation, monitoring and control can be challenging given the number of sub-systems. A method of orchestrating these systems together with an operator friendly environment is to overlay these individual pieces with a SCADA system. COGEN systems, by their nature, require a number of sub-systems. Taken individually, these components are monitored and controlled by their respective PLC's or controllers provided and optimized by the supplying vendor for the functionality required in their area of expertise.

Control strategy should be considered early in the design in order to develop an operator friendly system that fits the mill operation without burden. A properly designed system runs automatically for the most part but, intelligent technology should be employed to assist management and control of the system.




The Programmable Logic Controller (PLC) has been and continues to be the work horse of automation. These highly reliable devices operate on a programmed sequential loop cycle providing data collection and control. This makes them ideal for control of repetitive tasks but limits their ability to run application software and provide a flexible Graphical User Interface (GUI) so familiar on today's Personal Computers (PC).

A SCADA System can be broadly characterized as PLC subsystems coupled together with the flexibility of a PC to create a powerful operator friendly control and monitoring strategy for a COGEN system. Not only is the interface familiar to most people, it has the ability under normal operation to convey complete system status at a glance. Combined with an off site remote via the internet, those having proper authentication can securely check into the system from anywhere in the world.


Typical operator SCADA Display for a COGEN system.

**Level I Analysis**

Estimate everything; measure nothing.

- Usually requires a single plant visit
- Takes about 30 days to complete
- Work from existing T/E records
- Budgetary estimates; Concept design
- Memo report; go-no go decision
- Accuracy ± 25%

To answer the question poised at the outset, "is COGEN worth the carfare in your operation"; we start with a Level I analysis of your site as outlined above.

Level I COGEN analysis is a screening study to determine if there is sufficient justification to look deeper. Monthly thermal and electric utility bills establish a broad plant wide energy consumption profile that when properly analyzed can provide sufficient data for screening purposes. The example mill presented herein is an advanced Level I at this point but, it provides a reasonable instance of the depth. Keep in mind Level I is an estimate and, as such, the accuracy of a Level I analysis is ± 25%.

**Level II Analysis**

Measure everything; estimate nothing.

- Requires multiple site visits
- Takes 60 to 120 days to complete
- Comprehensive evaluation of site thermal and electric data on hourly basis with energy balance
- System configuration; general layout; one line diagrams; optimum unit sizing
- Development of control and operator strategy
- Accuracy ± 10%

Assuming there is a "go" following Level I, Level II analysis is a more detailed study of the plants' thermal and electrical profiles necessary to ensure peak as well as average demands identified in Level I are, in fact adequately met. Load duration profiles with heat and power balances for utilizing equipment help to identify critical parameters. Load leveling strategies are explored in order to optimize equipment size for the application.

A Level II Analysis will identify major equipment items and provide vendor quotes to establish more accurate costs. Equipment placement, layout and space requirements are considered. Control and operator strategies are defined. Negotiations are opened with the local electric utility to establish the economic environment and requirements for grid connection. Permitting and code authority requirements are explored to ensure that there are no technical or financial road blocks to construction. At the conclusion of Level II the project is ready for final (detailed) design, permitting and construction. Level II accuracy ± 10%.

**Conclusion**

- COGEN is the Simultaneous production of thermal and electric energy
- Selling power to utilities is a difficult option, design system to displace power consumed
- Choose the right thermal/electric ratio (i.e. turbine)
- Design system that does not allow steam to be wasted and minimizes electricity sold to the utility
- Examine incremental payback of every proposed refinement considered for addition to the system
- Integrate control and monitoring into an operator friendly comprehensive SCADA system

There is little doubt gas and electric rates will continue to escalate. A strategic plan to control these future energy costs for your mill operation is your best assurance of long term survivability.