Engineering and Economics: Cogeneration Edition

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1. Abstract

Since December 1995, the Rutgers Cogeneration plant has provided heat and electricity for certain campuses in the New Brunswick areas, such as the Rutgers Busch and Livingston campuses, as well as UMDNJ. Our objective was to evaluate the efficiency of the plant using the data from January 2006 to October 2007 to determine when it would be more efficient to buy electricity from the power grid versus producing our own. To do this, we compared the cost of buying electricity from the grid and the cost of producing it using the cogeneration plant by finding the spark spread. The spark spread is found by subtracting the cost of the plant's electricity from the cost of the grid's. The conclusion our project group came to is significant for the reason that, after calculating the efficiency of the plant, we found that the numbers show that it is actually more economical to buy electricity from the grid.

2. Introduction

2.1 The Rutgers Cogeneration Plant

The Rutgers Cogeneration plant was originally designed to be both cost efficient and environmentally friendly. However, after studying recent data from the cogeneration plant at Rutgers University, we found that the cogeneration plant was not a good economic choice for Rutgers. With today's economy, spending money wisely is an important aspect for everyone, including large universities such as Rutgers.

Figure 2.1
The Rutgers Cogeneration Plant located on the Busch Campus. (NJ-CHP)

2.2 What We Learned

This research project was more than just numbers, figures, and data. Our research extended to the process cogeneration plants use to have their outputs combined as heat and energy. It also included learning about the machinery behind the process, such as the gas turbines used and how they run, as well as the absorption chillers that were added to the plant after it had been constructed and built.

Our team visited the Busch Campus Cogeneration plant, where we observed the turbines, absorption chillers, and other parts of the process at work. Certain machinery was computer controlled, and there were computers that alerted the workers if any of the values of the machinery dropped beneath standards set by law. One example is that daily emissions from the turbine are monitored to insure that the plant complies with federal emissions guidelines.

Figure 2.2
These are the computers that supervise the emissions of the plant. If the values do not meet the standards set by the federal government, the computers will alert the staff at the plant.

2.3 Previous Reports

A previous report on the cogeneration plant found it to be very cost efficient; however, the numbers used in those findings were from the beginning of the plant's life in 1995. The electricity, heating, and cooling loads now vary greatly from when the plant was designed for, due to Rutgers being a growing university. The report states that the plant should have been able to repay for its building costs in five years, but our data shows that it does quite the opposite ("Final CA-CP Case Study").

3. Background

3.1 Cogeneration

Cogeneration is the process of using normally wasted heat energy produced by a plant and using it to heat and cool surrounding buildings. It is also known as Combined Heat and Power, or CHP; these terms will be used interchangeably throughout the paper. CHP is fueled with natural gas that is about 95% methane. The fuel is turned into energy and power through the use of gas turbines. The cogeneration cycle consists of the Rankine cycle and heat exchangers. Cogeneration plants generate heat and electricity, and they are a thermodynamically efficient use of fuel, due to the fact that they don't waste the extra heat that escapes like other plants do.

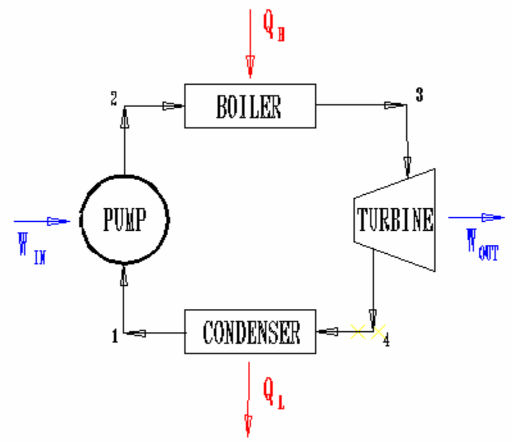

Figure 3.1a (Penn State Erie)

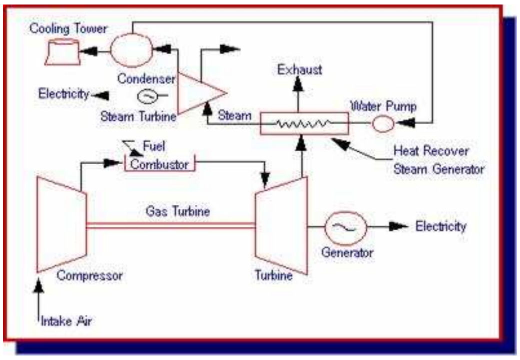

Figure 3.1b (Cruise Power)
Figure 3.1a is a schematic of the Rankine cycle, while Figure 3.1b is the Cogeneration cycle. Note that the Rankine cycle can be found within the Cogeneration cycle.

3.2 Machinery

The Taurus 60, as seen in Figure 3.2a, is a gas turbine generator set that was designed to meet the needs of industrial power generation applications. Its frequency is 50 hertz and it also has a capacity of 6000 kilovolt-amperes (kVAs). The Taurus 60 can use more than one type of fuel, such as naphtha or light fuel oil. The alternator's output is 6300 V and its total plant hours of operation are 59264 hours. It also comes with a built in heat recovery steam generator, as well as an economizer. This is the type of turbine that the Rutgers Cogeneration plant is currently using.

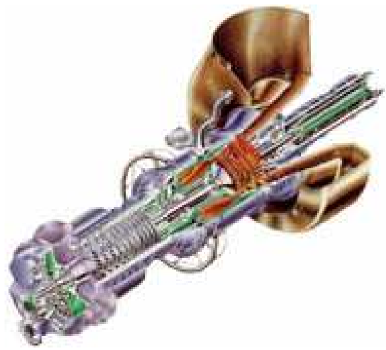

Figure 3.2a [5]
This is the gas turbine known as the Taurus 60, made by Solar. It is currently the type of turbine used in the Rutgers Cogeneration Plant.

Figure 3.2b [6]
This picture represents an absorption chiller, much like the ones used by the cogeneration plant.

An absorption chiller is a refrigerator that provides energy to the cooling system and it is powered by heat from the combustion of liquefied petroleum gas, which has a very low boiling point. When the refrigerant evaporates, it takes heat away with it making the cooling effect. It is then changed back from gas to liquid so the cycle can continuously repeat itself.

The heat exchanger is a device that is used to transfer heat from one fluid to another fluid on two sides of a barrier without bringing the fluids into direct contact with each other.

3.3 Process

CHP is an integrated energy system that can be modified. At the Busch Campus cogeneration plant, work enters into the compressor. Fuel is put into the combustion chamber. Part of the energy goes into the generator where torque is applied to create electricity. More fuel is then put into the afterburner. It later transfers into the heat exchanger. The exhaust passes through a heat exchanger to heat water, which contributes to the heat and cooling load for the buildings and facility. During the winter, the Rutgers cogeneration plant uses waste heat for high temperature water, while in the summer; an absorption chiller is used for cooling during the summer.

3.4 History

The Rutgers Cogeneration plant was constructed in December of 1995, and its potential lifespan is anywhere from 20 to 25 years. At the time the plant was built, Rutgers was smaller than today, which means the plant was satisfactory in meeting the electrical, heating, and cooling loads for that size of Busch campus.

4. Method/Calculations

4.1 Spark Spread

While researching, we were provided with a spread sheet for the current cogeneration plant in Rutgers University for the months of January 2006 through October 2007 [A]. This data helped us calculate the sparks spread which is the difference between the wholesale price of electricity and the cost of the fuel used to generate it. If the spark spread gives a negative value, this means that buying electricity from the grid is a better option and when positive, it indicates that the cogeneration plant was the better choice. The spread sheet (found in Appendix A) gave the outputs and inputs in various units, which we had to convert into one single unit, kilowatt-hours (kWh).

4.2 Efficiency

The efficiency is determined by dividing the outputs of the plant by the inputs used. The outputs of the plant are the electricity production, the chiller, and the heat load. The inputs are the fuel added to the duct burners and the turbines. Efficiencies are calculated with the following formulas:

$$\text{Electrical Efficiency} = \frac{\text{Electricity Production (kWh)}}{\text{Turbine Inputs (kWh)}}$$

$$\text{Heat Efficiency} = \frac{\text{Outputs (CHP Plant + Absorption Chiller)}}{\text{Inputs (Duct Burners + Turbines)}}$$

$$\text{Overall Efficiency} = \frac{\text{Electricity Prod'n + CHP Output + Chiller Output}}{\text{Duct Burner + Turbine Inputs}}$$

5. Results

5.1 Efficiency

After analyzing the data on the spreadsheet, we determined the efficiency of the plant in three different ways: electrical, heat, and overall. The overall efficiency electricity-wise was just 24.74%, the heat efficiency was even less with it being just 7.02%. The overall efficiency comes out to be 29.4%.

5.2 Spark Spread

Along with the plant having a low efficiency, it also has a negative spark spread for several months of the year. This indicates that producing its own power and heat was a bad business move on Rutgers' part. To get the most bang out of their buck, they should have bought electricity from the grid. As much as 14 cents per kWh could have been saved, which may not sound like much, but it adds up when millions of kWh are used each month by the Busch campus dorms. Using the average spark spread, we determined that Rutgers could have saved $10,763,894.93 in the time period between January 2006 and October 2007 had they bought their electricity from the grid. We also found that the only two months that were efficient were June and July of 2007. An explanation for these anomalies could be explained by the facts that "June 2007 was the 23rd warmest June on record… The warmer than average June temperature helped increase residential energy needs for the nation… the nation's residential energy demand was approximately 1.5 percent higher than what would have occurred under average climate conditions for the month" [NCDC] and "For the … United States, July 2007 was the 15th warmest July since records began in 1895" [NCDC]. But even in those months, less than a penny was saved per kWh, making it just a mere difference between the cost of buying from the grid and producing electricity with the cogeneration plant.

	spark spread
Jan-06	($0.14343)
Feb-06	($0.12219)
Mar-06	($0.09889)
Apr-06	($0.03905)
May-06	($0.03361)
Jun-06	($0.03957)
Jul-06	($0.03905)
Aug-06	($0.04242)
Sep-06	($0.04925)
Oct-06	($0.05177)
Nov-06	($0.07085)
Dec-06	($0.09937)
Jan-07	($0.07768)
Feb-07	($0.07922)
Mar-07	($0.07653)
Apr-07	($0.04966)
May-07	($0.04103)
Jun-07	$0.00298
Jul-07	$0.00315
Aug-07	($0.00952)
Sep-07	($0.01196)
Oct-07	($0.01616)

Figure 5
Sparks Spread Excerpt of [B]. The red represents the negative values, or the values where buying from the plant would be more inefficient. It's clearly shown that the grid is a better choice.

6. Conclusion

All of our research and calculations led us to one conclusion: the Rutgers Cogeneration plant is not saving Rutgers money. The only way to fix this issue is to create a totally new plant to meet efficiency standards needed by today. Currently, Rutgers employees are working on a proposal for a new cogeneration plant for Rutgers.

Another solution would be to change the heating and cooling loads of the cogeneration plant. However, this would not be a realistic solution because the university is growing. The original system had been built for a smaller school, with smaller heating and cooling loads.

The more realistic approach would be to add new turbines or to replace the entire plant. In the proposal, the new cogeneration plant would use 2-10 megawatt turbines. The new system, even with additional output, would still reduce CO_2, SO_x, and NO_x emissions and have an efficiency of about 64%.

In conclusion, our research project gave us an opportunity to look at not only at the mechanics behind cogeneration, but also allowed to evaluate the economical side. We found the Rutgers Cogeneration plant to be inefficient, but our research may bring Rutgers one step closer to getting a more efficient plant.

7. Acknowledgements

We would like to thank our counselor, Wanda Duran, for keeping us on track and ahead of the game. We would also like to thank our project advisor, Charles Manolio, and his student advisors, David Boyea and Arjun Wadnerkar. They really helped us by getting us data for the plant and walking us through the process of cogeneration, and their help was invaluable whenever we had questions. Our gratitude also extends to Chris Langley, the Plant Chief Engineer, Kevin Holman, the Plant Manager, Michael Muller, a Director or Center for Advance Energy Systems and Mechanical Engineering Professor. We would also like to show our gratitude appreciation to Rutgers University, the Rutgers University School of Engineering, the Motorola Foundation, Morgan Stanley, PSEG, Silver Line Building Products, and the families of 2001-2008 program alumni.

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Appendix

A. Data for the Cogeneration Plant, January 2006 to October 2007, with calculation.

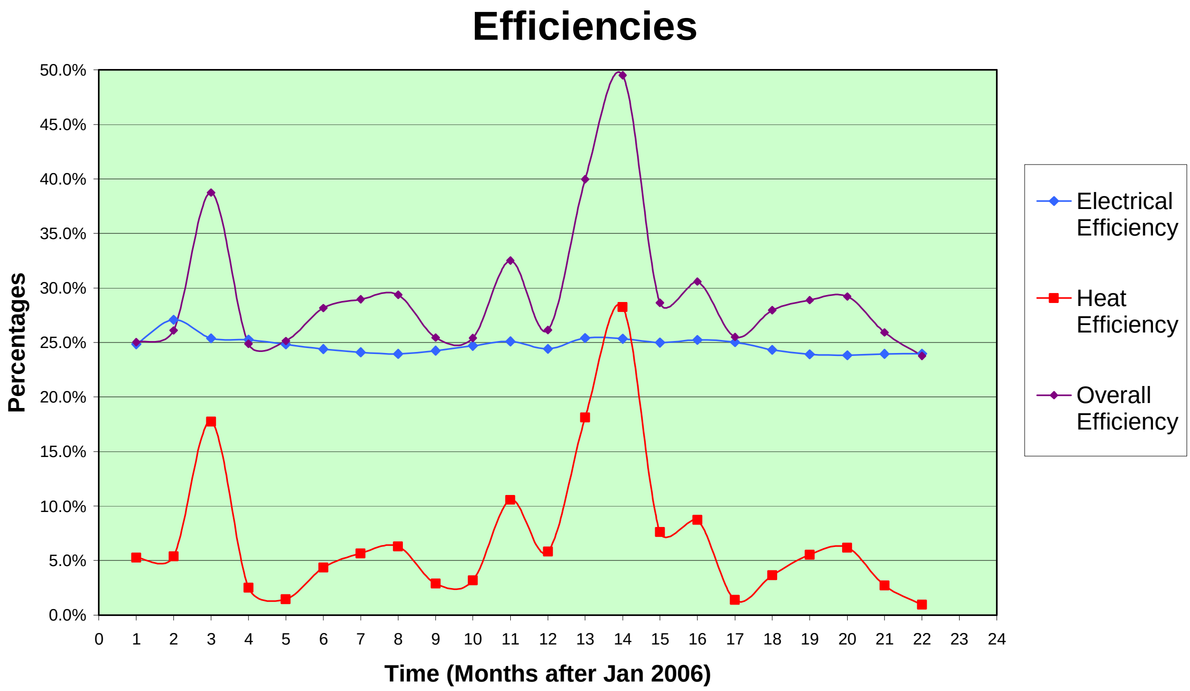
Busch Cogeneration and Central Heating Plant Data

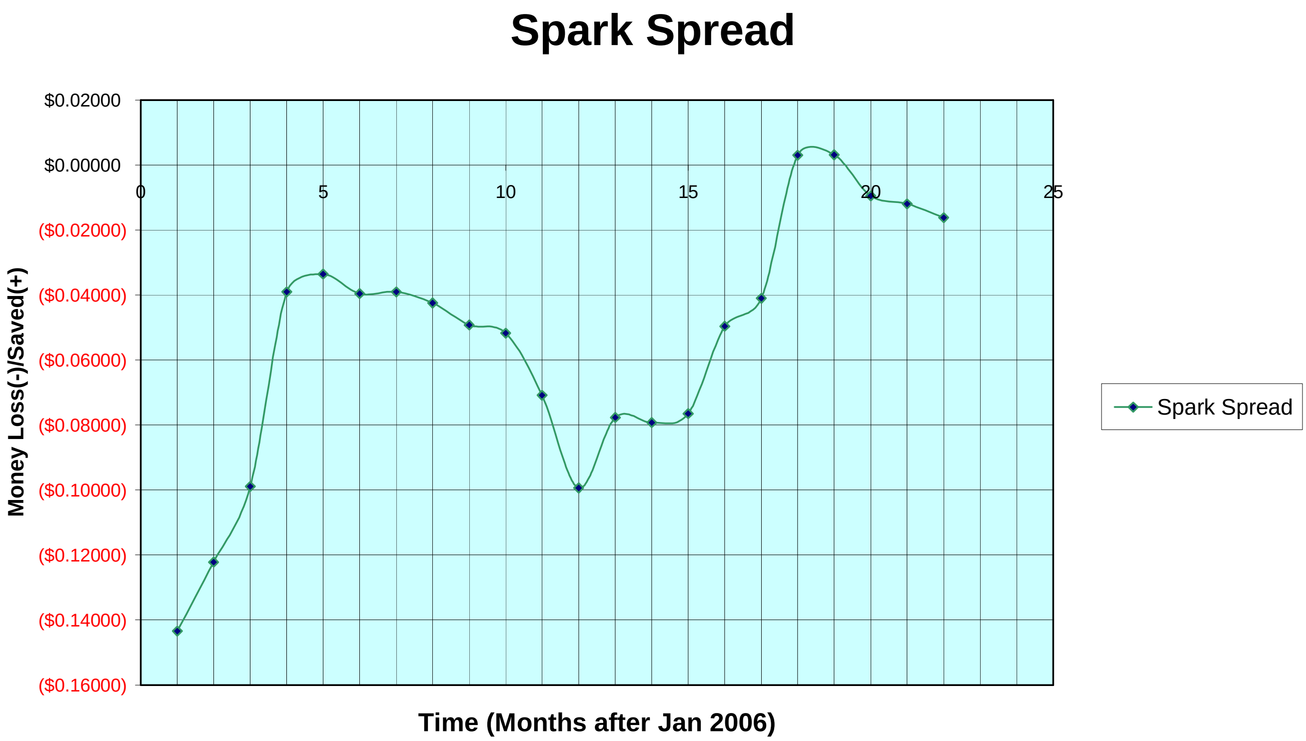
	Cogeneration Plant								
	Elect prod'n kWh out	Turbines therms in	Turbines kWh	Duct Burners therms in	Duct Burners kWh	Chiller therms out	Busch CHP therms out	total busch and chiller	busch chp kWh
Jan-06	9,975,000	1,370,470.265	40,154,417.375	352,863.616	10,338,810.900	0.000	90,872.244	90,872.244	2662532.79
Feb-06	9,208,600	1,160,674.123	34,007,445.737	357,864.154	10,485,325.344	0.000	82,031.499	82,031.499	2403501.29
Mar-06	8,026,300	1,079,410.053	31,626,429.915	224,873.869	6,588,745.063	0.000	231,361.976	231,361.976	6778844.89
Apr-06	9,044,300	1,222,620.391	35,822,455.054	158,280.522	4,637,577.556	4,662.000	30,214.229	34,876.229	1021864.31
May-06	9,143,300	1,256,880.603	36,826,270.231	61,946.514	1,815,016.525	18,900.000	468.779	19,368.779	567500.12
Jun-06	8,646,900	1,209,503.942	35,438,146.557	30,599.640	896,561.383	43,360.000	10,703.101	54,063.101	1584034.60
Jul-06	8,683,000	1,229,603.040	36,027,044.829	42,456.983	1,243,978.406	71,694.000	322.945	72,016.945	2110077.50
Aug-06	8,719,300	1,242,344.258	36,400,359.156	47,219.539	1,383,520.041	80,892.000	311.888	81,203.888	2379252.51
Sep-06	8,703,200	1,224,495.381	35,877,391.767	92,437.065	2,708,381.629	34,902.000	3,162.947	38,064.947	1115292.91
Oct-06	9,352,800	1,292,941.047	37,882,831.732	142,227.297	4,167,222.297	11,970.000	33,729.948	45,699.948	1338996.43
Nov-06	7,950,000	1,080,897.159	31,670,001.729	154,774.516	4,534,852.505	0.000	130,524.641	130,524.641	3824337.56
Dec-06	9,499,100	1,327,562.513	38,897,231.556	267,199.823	7,828,884.354	0.000	92,698.720	92,698.720	2716048.05
Jan-07	10,122,200	1,358,933.704	39,816,399.180	222,826.550	6,528,759.156	0.000	286,904.612	286,904.612	8406229.48
Feb-07	9,244,700	1,245,118.384	36,481,640.316	240,746.591	7,053,811.632	0.000	419,912.354	419,912.354	12303321.24
Mar-07	10,249,000	1,399,976.141	41,018,931.761	263,251.118	7,713,188.339	0.000	126,728.050	126,728.050	3713098.45
Apr-07	8,979,100	1,214,172.414	35,574,931.556	187,958.274	5,507,127.864	4,662.000	117,663.862	122,325.862	3584115.50
May-07	9,713,000	1,324,165.399	38,797,697.011	50,453.344	1,478,269.675	18,900.000	285.756	19,185.756	562137.59
Jun-07	8,905,800	1,249,857.671	36,620,500.176	1,269.037	37,182.449	43,360.000	2,405.542	45,765.542	1340918.31
Jul-07	8,892,800	1,269,589.829	37,198,647.215	31,165.976	913,154.865	71,694.000	483.602	72,177.602	2114784.71
Aug-07	8,824,300	1,263,974.249	37,034,112.186	44,058.860	1,290,912.983	80,892.000	202.427	81,094.427	2376045.33
Sep-07	8,749,100	1,246,361.690	36,518,068.843	40,749.393	1,193,946.481	34,902.000	0.000	34,902.000	1022619.40
Oct-07	9,187,000	1,308,419.462	38,336,345.212	65,697.191	1,924,910.369	11,970.000	1,108.022	13,078.022	383182.60

Purchased Cost

electric cost/kWh	cogen gas cost/therm	chp gas cost/therm	cogen cost/kwh	spark spread	kWh to therm	electrical efficiency	heat efficiency	overall efficiency
$0.08815	$1.68557	$1.84882	$0.23158	($0.14343)	340446.75	24.8%	5.3%	25.0%
$0.08797	$1.66738	$1.54520	$0.21016	($0.12219)	314289.518	27.1%	5.4%	26.1%
$0.08816	$1.39088	$1.54643	$0.18705	($0.09889)	273937.619	25.4%	17.7%	38.7%
$0.08776	$0.93808	$1.07376	$0.12681	($0.03905)	308681.959	25.2%	2.5%	24.9%
$0.09659	$0.94713	$1.97236	$0.13020	($0.03361)	312060.829	24.8%	1.5%	25.1%
$0.09488	$0.96123	$1.11646	$0.13445	($0.03957)	295118.697	24.4%	4.4%	28.2%
$0.09502	$0.94677	$1.06160	$0.13407	($0.03905)	296350.79	24.1%	5.7%	29.0%
$0.09605	$0.97187	$1.09276	$0.13847	($0.04242)	297589.709	24.0%	6.3%	29.4%
$0.08902	$0.98275	$1.10435	$0.13827	($0.04925)	297040.216	24.3%	2.9%	25.4%
$0.08901	$1.01840	$1.16083	$0.14078	($0.05177)	319211.064	24.7%	3.2%	25.4%
$0.08984	$1.18187	$1.34113	$0.16069	($0.07085)	271333.5	25.1%	10.6%	32.5%
$0.08995	$1.35466	$1.52797	$0.18932	($0.09937)	324204.283	24.4%	5.8%	26.1%
$0.09000	$1.24902	$1.41158	$0.16768	($0.07768)	345470.686	25.4%	18.1%	40.0%
$0.08987	$1.25544	$1.46720	$0.16909	($0.07922)	315521.611	25.3%	28.3%	49.5%
$0.09020	$1.22058	$1.38626	$0.16673	($0.07653)	349798.37	25.0%	7.6%	28.7%
$0.09028	$1.03488	$1.18881	$0.13994	($0.04966)	306456.683	25.2%	8.7%	30.6%
$0.09786	$1.01882	$1.16234	$0.13889	($0.04103)	331504.69	25.0%	1.4%	25.5%
$0.14147	$0.98682	$1.12822	$0.13849	$0.00298	303954.954	24.3%	3.7%	28.0%
$0.14371	$0.98457	$1.12579	$0.14056	$0.00315	303511.264	23.9%	5.5%	28.9%
$0.13143	$0.98400	$1.12522	$0.14095	($0.00952)	301173.359	23.8%	6.2%	29.2%
$0.12822	$0.98404	$1.12522	$0.14018	($0.01196)	298606.783	24.0%	2.7%	25.9%
$0.12877	$1.01761	$1.15564	$0.14493	($0.01616)	313552.31	24.0%	1.0%	23.8%
			avg s.s.:	($0.05)		24.7%	7.0%	29.4%
			savings:	10763894.93		AVERAGES		

Graph Form of the Efficiencies and Spark Spread





B. Inside the Cogeneration Plant


Control box for one of the three turbines


Air Compressors


Side of the turbines


Control room