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August 1, 2014

Texas Commission on Environmental Quality
Office of the Chief Clerk - MC 105
Tax Relief - Appeal
PO Box 13087
Austin, TX. 78711-3087

Re: **Docket Numbers**
2008-0832-MIS-U (Borger Energy Associates, L.P. – Hutchinson County)

Dear Agenda Docket Clerk;

Enclosed is the brief filed by Pritchard & Abbott, Inc., on behalf of nine appraisal districts.

We respectfully support the Executive Director's Negative Use Determination for Heat Recovery Steam Generators in co-generation power plants. Thank you for your consideration of our brief and request that your Executive Director's Negative Use Determination be upheld.

Sincerely,

C. Wayne Frazell

C. Wayne Frazell, P.E., RPA
Engineer/Appraiser
Pritchard & Abbott, Inc.

CWF/

copy to: see Mailing List Enclosed

Mailing List
TCEQ Docket Number
2008-0832-MIS-U (Borger Energy Associates, LP. - Hutchinson County)

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IN SUPPORT OF THE EXECUTIVE DIRECTOR'S NEGATIVE USE DETERMINATION ISSUED TO	§ § § §	**BEFORE THE**
		TEXAS COMMISSION ON
BORGER ENERGY ASSOCIATES, L.P.	§	**ENVIRONMENTAL QUALITY**

PRITCHARD & ABBOTT, INC. (P&A)
FOR HUTCHINSON COUNTY APPRAISAL DISTRICT
BRIEF IN SUPPORT OF NEGATIVE USE DETERMINATION

TCEQ Docket Number

2008-0832-MIS-U (UD 07-11971/Borger Energy Associates, L.P. – Hutchinson County)

I. Property Description

The Borger Energy Associates, L.P. facility is a co-generation plant. This plant has two (2) generators powered by industrial size jet engines fueled by natural gas. The hot exhaust from these engines is passed through a heat recovery steam generator (HRSG). At Borger Energy the steam is sold directly to the adjacent oil refinery. Please note that this plant was designed to produce two (2) products, Electricity and Steam for sale.

II. History of Co-generation Power Plants

The first co-generation power plants were built in the late 1950's (See ASME Article Appendix A) at chemical plants that needed both steam and electric power very similar to the arrangement at Borger. These installations were made before there were any environmental rules like nonattainment zones. Before 2007, there were no environmental tax exemptions granted for the HRSG in any power plant. The original reason for installing a HRSG in the Borger Energy power plant was to create income by selling both electricity and steam.

III. Compliance

The TCEQ rules were changed in response to the 2007 Texas Legislature HB 3732. The bill states in Sec. 382.5067(k) "The Texas Commission on Environmental Quality shall adopt rules establishing a nonexclusive list of facilities, devices, or methods for the control of air, water, or land pollution which must include: ..." The following list has Heat Recovery Steam Generators as the eighth item. This does not say that HRSGs are exempt but only puts them on the list for consideration. Various items following the list clearly leave the determination of pollution control to the TCEQ.

To some it will appear that the boiler that recovers the exhaust heat from the turbine engines qualifies as a pollution control item. This of course ignores the fact that this boiler is a major component of production. It was installed to produce steam to sell and not to reduce pollution. If the jet engines were not ducted to the boiler and burners were added, the HRSG side of the plant would operate as a conventional steam boiler. It is not the boiler that reduces the pollution. Ducting the hot gases from the jet engine(s) reduces the pollution by reducing the need for an additional heat source (burners).

As a general rule when a component for pollution control is removed, there is little or no loss in production. For example, when a catalytic converter is removed from an engine it still produces the same horsepower. If electronic precipitators are removed from the exhaust of a coal-burning power plant, it still produces the same amount of electricity.

If the HRSG (boiler) is removed from a co-generation power plant, one of its products, steam, is no longer produced. Therefore, this HRSG is production equipment and is not a pollution control device. Also, one must look at the fact that the only thing a HRSG removes from the gas turbine exhaust is heat. Please note that ALL gaseous pollution that enters a HRSG is still released into the atmosphere. A HRSG is a heat transfer device and is not a pollution control device.

On September 28, 2005 the Texas Commission on Environmental Quality heard the case docket number 2005-1008-AIR-U Appeal of Use Determination No. 04-8353. This case was between XTO Energy and Freestone County Appraisal District concerning a plant that removes sulfur and CO_2 from natural gas. In this case the TCEQ ruled that those components used directly in production were not pollution control equipment. Since these HRSGs are in the production path, they should be considered production equipment and should be treated in the same way as this previous ruling.

The federal government recognizes that these types of plants are more efficient and produce less pollution than conventional power plants. In fact, the federal government has done much to encourage their development and construction. It is our understanding however that the federal government does not mandate this type of plant nor do they specifically specify that a HRSG is a pollution control device.

In 1992 the people of Texas voted and approved Proposition 2 creating the current environmental tax exemption. The ballot read "The constitutional amendment to promote the reduction and encourage the preservation of jobs by authorizing the exemption from ad valorem taxation of real and personal property **used for the control of air, water, or land pollution**." These HRSGs are used for production and not to control pollution. We believe the majority of the people would have voted **"NO"** on this proposition, if they thought it would include production equipment that produces INCOME and is not MANDATED by law!

IV. Tier III Calculation

Because of the economics that dictated the use of a HRSG, we believe that using the TCEQ's Tier III equation is the most appropriate method to determine if HRSGs should be exempt. In the Tier III section of the TCEQ Rules, there are equations for calculating a Partial Use Determination (PUD). The Tier III calculations reduce the amount of exemption based on the sale of any product sold setting the precedent that the economic benefit of any device can influence the amount of exemption.

A Tier III calculation in this case should be done comparing the first cost and operating income difference between the co-generation facility and a combustion turbine generator combined with an industrial boiler sized to produce the same electricity and steam as the co-generation facility. Based on actual steam income the HRSGs have already paid for themselves several times over.

V. Other Considerations

If these HRSGs are found to be exempted, then a detailed description of what will be exempted needs to be provided to all parties. For example, do we also include the deaerator, the condenser, the pumps, all of the steam piping, and other equipment installed to produce INCOME? If any exemption is granted in this case, then the TCEQ should provide direction to the applicants and the appraisal districts as to what does and does not qualify.

Just to point out how ridiculous an applicant request can become - if common sense is not exercised - please consider the following example. A case can be made to exempt plant lighting since this yields fewer emissions than gas lamps. Although there are safety and convenience reasons for electric lighting, the primary reason for this type installation is economics - not pollution control. If you say this is not a valid argument because electric lighting is the accepted technology, then we submit that HRSGs in these plants are also the accepted technology used for many years.

The TCEQ grants property tax exemptions for pollution control and not energy efficiency. If energy efficiency becomes the basis for exemption the TCEQ needs to be prepared for the consequences. Energy efficiency is a slippery slope. A considerable amount of most chemical plants and oil refineries are heat exchangers installed for greater efficiency. There are arguments of energy efficiency for many other processes as well. Exempting all energy efficiency devices will entail billions in market value which will be many millions of Property tax dollars shifted from corporations to small businesses and home owners.

The primary reason for building combined cycle and cogeneration power plants is economics and not pollution control. Again, if the gas turbine(s) is removed, then all you need is a set of burners and an intake fan to have the same production on the steam side. Since this type of boiler is a major component of production, it is not pollution control equipment.

VI. Conclusions

The 2007 Texas Legislature HB 3732 required the creation of a non-exclusive list that included HRSGs that the TCEQ must consider but does not specify that they are pollution control equipment. The bill clearly leaves the determination of pollution control devices to the TCEQ. HB 3732 does not mention including equipment that is in place for producing a product.

The HRSGs in these power plants are installed to produce steam and to generate electricity for sale rather than to reduce pollution; and therefore should not qualify for a tax exemption. Any device that has become a standard part of co-generation power plants for over 40 years for economic/production reasons, prior to the property tax exemption program, does not magically become a pollution control device in 2007. **Therefore, we respectfully request that the Negative Use Determination be upheld for the HRSG of any co-generation power plant.** Thank you for your favorable consideration.

Appendix A

Based on my observations of this committee in the last three years, I know that we can count on the support of every member of the committee. It takes the efforts of all of us to continue the growth of this committee; we have come very far in a short period of time. We are past the birth of this committee and now I believe we need to chart our future and explore what we can do with the committee. I look forward to meeting each of you at the next meeting in Orlando. I also ask you again for suggestions and comments on how we can move this committee forward.

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Forty Years of Combined Cycle Power Plants

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Heinz Termuehlen, Consultant
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Introduction

Even though the first installations of combined cycle power plants with heat recovery steam generators (HRSG's) are only about forty years old, the first attempt to build gas turbines for power generation was made more than 100 years ago. It took however about 40 years before gas turbines were installed to supply peaking power.

When the first gas turbines were installed in the US, they were mostly used as mechanical drives or as peaking units. At the same time it was also realized that the thermal performance of a gas turbine installation can be enhanced by utilizing the gas turbine's sensible heat of the exhaust gases in a heat recovery system. Such system can provide heat in the form of hot water or steam for either a combined cycle power plant and/or cogeneration.

The first Westinghouse gas turbine rated at 1340 kW went into operation in 1949. [3] This W 21 unit, illustrated in Figure 1, was installed at the River Fuel Corporation in Mississippi. Also in 1949, General Electric installed its first gas turbine for power generation at the Belle Isle Station of the Oklahoma Gas and Electric Company, which provided already sensible exhaust heat for feedwater heating of a steam turbine unit.

The development of combined cycle power plants was mainly influenced by the available gas turbine technology. Initially, relatively small gas turbines were available to build power plants at which the exhaust heat of the gas turbines was utilized for heating feedwater or to use the gas turbine's discharge as preheated air for the boiler of a steam turbine unit. In the late 1960s the gas turbine unit sizes became large enough to start building combined cycle power plants with heat recovery steam generators supplying main

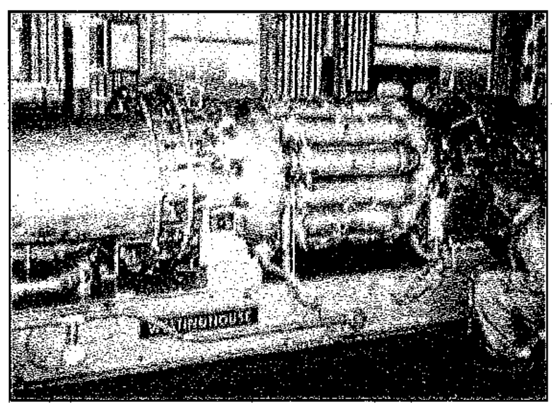
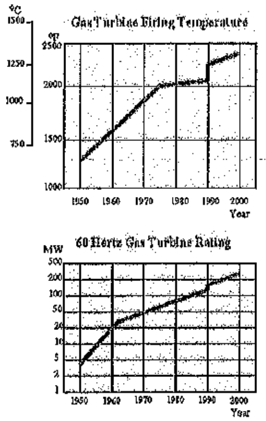


Figure 1: First Gas Turbine Installed for Commercial Operation in 1949

Figure 2: Gas Turbine Development Trend



steam for a bottoming steam turbine cycle.

The evolutionary development of the large heavy-duty gas turbines is best revealed by their increasing firing temperatures and unit ratings. Figure 2 illustrates the trends of both of these values over the past 50 years.

The firing temperature in the early 1950s was increased from roughly 1300°F (705°C) to 1500°F (815°C) in the late 1950s and reached 2000°F (1090°C) at about 1975. From there it increased slowly until 1990, when the first advanced gas turbines were introduced resulting in a step change in the firing temperature from initially roughly 2300°F (1260°C) to approximately 2400°F (1315°C) at the turn of the century. This advancement was possible by adopting already proven design features from aero-engines for heavy-duty gas turbines, such as directionally solidified or even single-crystal blading, improved blade coatings and advanced film cooling.

The second diagram in Figure 2 shows the unit rating of gas turbines for 60 Hertz applications. In the early 1950s the gas turbine unit rating was relatively small, less than 1/100 of the unit rating of steam turbines which reached already the 500 MW mark. However the development toward large units went fast and in the early 1960s 20 MW gas turbines became available. In the mid 1980s the highest gas turbine rating was already 100 MW. A small step change was made in 1990 with the introduction of the first advanced gas turbines. In the late1990s advanced gas turbines with a rating over 200 MW for 60 Hertz were already being built.

The trend of the two design parameters, firing or rotor inlet temperature and output of gas turbines, were the main influential factors for the potential application and economics of combined cycle power plant concepts.

Combined Cycle Plant Concepts

When building a combined cycle power plant on a greenfield or as a repowered steam plant, four basic plant concepts can be applied, namely:

- Feedwater heating
- Parallel steam supply
- Fully-fired boiler (Hot wind box)
- Heat recovery steam generator (HRSG).

All four concepts are best utilized at a certain gas turbine output to steam turbine output ratio, namely for 100 % steam turbine output:

- Feedwater heating 10% - 30 % gas turbine output

Figure 3: Combined Cycle Power Plant History

First Combined Cycle Power Plant Applying Feedwater Heating	1949
First Heat Recovery Steam Generator for a Gas Turbine	1957
First Fully-Fired Boiler Combined Cycle Power Plant	1965
First Combined Cycle Power Plant with Heat Recovery Steam Generator	1968
First Coal-Gasification Combined Cycle Power Plant	1972
First Combined Cycle Power Plant with an Advanced Gas Turbine	1990
First Combined Cycle Power Plant with Fuel Cell	2000

- Parallel steam supply 20 % - 60% gas turbine output
- Fully- fired boiler (Hot wind box) 15 - 35 % gas turbine output
- Heat recovery steam generator ~ 200 % gas turbine output

These relationships of gas turbine to steam turbine outputs for different plant concepts and the development trend of gas turbines shown in Figure 2 clearly reveal why the first combined cycle power plants were either feedwater heating or hot wind box applications.

In the late 1940s and early 1950s the firing temperature of gas turbines was around 1300°F (705°C). At this low firing temperature level the gas turbine exhaust temperature level was with roughly 700°F (370°C), too low to generate main or reheat steam for steam turbines, which at that time were designed for main steam temperatures in the 950°F (510°C) to 1000°F (540°C) range. Pilot power plants with even 1100°F (590°C) main steam temperatures were already being built.

However, these low gas turbine exhaust temperature levels were well suited for feedwater heating, co-generation and also, together with a high oxygen content in the 13 to16% range due to the high gas turbine excess air, for hot wind box applications. The parallel steam supply concept as an advancement of the feedwater heating concept was introduced much later as a more efficient way to utilize the gas turbine exhaust heat for not only preheating feedwater, but also to generate some secondary steam for the steam turbine as either reheat steam or even main steam.

With these three combined cycle concepts most of the fuel is burned in the steam generator, which can be fueled with coal or any other fuel, and the first two concepts can even be applied to nuclear plants. [4] Only the relatively small gas turbine fuel potion requires natural gas or distillate oil.

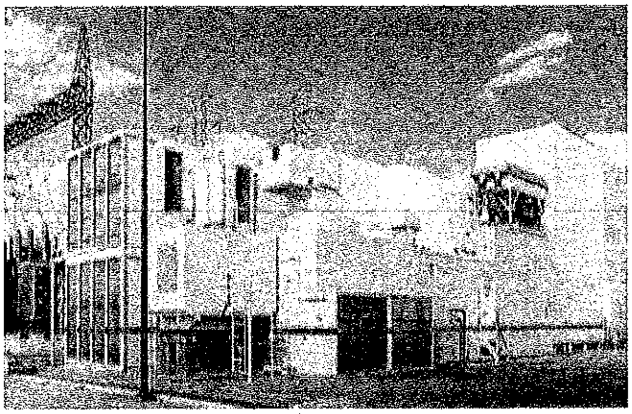


Figure 4: 39 MW Gas Turbine Package of the 1970's (Model W251 Econopac™)

As revealed in Figure 3, more than forty years ago in 1957, the first heat recovery steam generator (HRSG) for a gas turbine was built. Early gas turbine/ HRSG units were mostly used in the chemical industry.

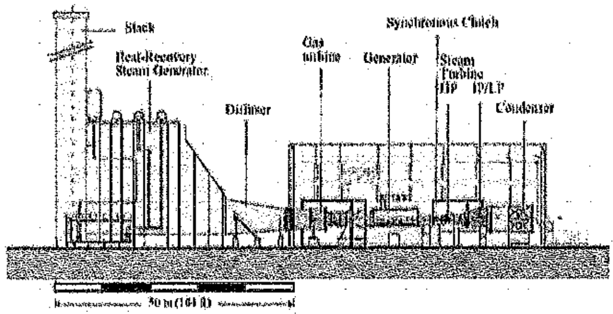
In the late 1950s heat recovery steam generators (HRSGs) with continuous spiral fin-tubing become available for building more efficient gas turbine/HRSG units. Initially, they provided steam for co-generation applications, since the gas turbine temperature level was still relatively low. It took another decade before, in the 1960s, this technology was generally utilized for combined cycle power plants with gas turbines of 20 MW to 50 MW output.

Co-generation, also today referred to as CHP (Combined Heat and Power), which provides electric power and process steam with extremely high fuel utilization, became an additional incentive in 1978, when the Public Utilities Regularly Policy (PURPA) was introduced to promote the selling of co-generation power to the utilities.

From there on, the development of combined cycle power plants with HRSGs went fast and in the early 1970s gas turbines with ratings above 50 MW and firing-temperatures around 20000F (1090°C) became available. The next major step in building highly efficient combined cycle power plants was done in 1990 when the advanced gas turbine technology was introduced to eventually reach the goal of the Department of Energy (DOE) to develop combined cycle power plants with a 60 % power plant net efficiency.

Pre-Designed Combined Cycle Plants

In the late 1960s and early 1970s the gas turbine suppliers started to develop pre-designed or standard combined cycle power plants, like GE developed the STAGTM (Steam and Gas) system, Westinghouse the PACETM (Power at Combined Efficiency) system and Siemens the GUDTM (Gas und Dampf meaning gas and steam) system. The goal was to build standard power plants around the different gas turbine and steam turbine models to supply an optimal combined cycle power plant package. The early predesigned packages featured a gas turbine and heat recovery steam generator (HRSG) only to provide steam for co-



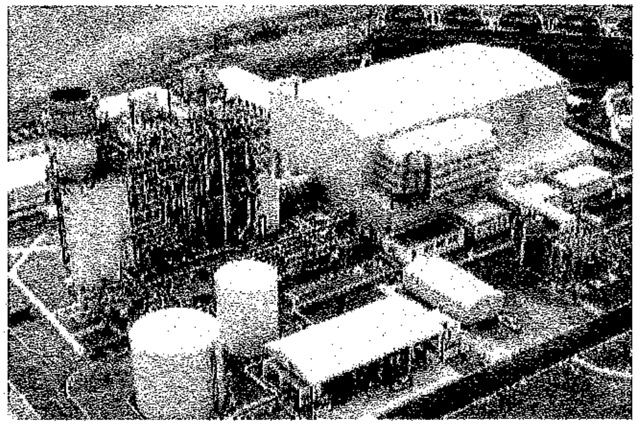


Figure 5: Otahuhu Installation of Single-Shaft CCIS.V94.3A Reference Plant

generation. But also packages for just the gas turbines used for any kind of application were offered by the gas turbine suppliers. Such an example of a Westinghouse model W251 EconopacTM gas turbine unit is illustrated in Figure 4 [5]. In the late 1960s the first gas turbine/HRSG units with sufficiently high steam conditions became available to generate main steam for steam turbines of initially only 750°F (400°C).

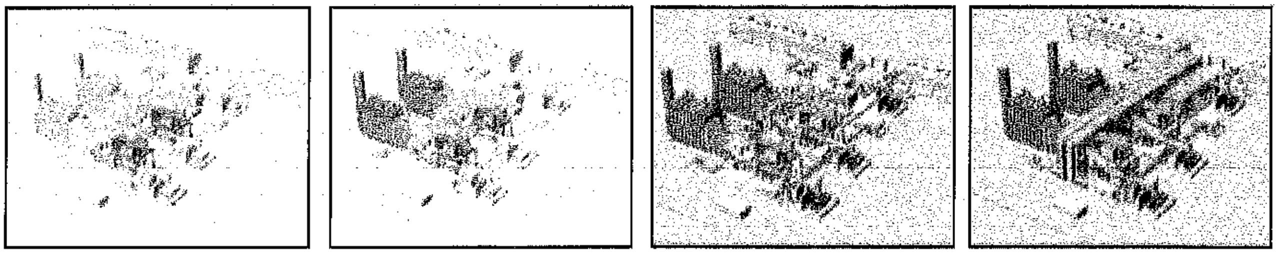
The pre-designed combined cycle power plants included a variety of plant arrangements. For example, options like the number of gas turbine/ HRSG units feeding into one steam turbine as well as different plant arrangements like single shaft gas turbine/ generator/ steam turbine units or multiple shaft units with separate generators for each gas turbine and steam turbine can be selected.

Combined Cycle Plant Arrangements

Two examples of pre-designed reference power plants (RPP) featuring advanced gas turbines in a single and a multiple-shaft arrangement are given.[6]

The first example is single-shaft arrangement of a 50 Hertz CC1S.V94.3A combined cycle power plant arrangement as shown in Figure 5. This predesigned RPP unit features a 265 MW advanced V94.3A gas turbine and a 130 MW reheat steam turbine. The HRSG is of a horizontally arranged triple-pressure reheat design. The gas turbine is directly coupled to a hydrogen-cooled generator. The two casing steam turbine consists of an HP casing and a combined IP/LP casing with axial exhaust into the axially arranged condenser. The steam turbine is coupled to the other end of the generator by a synchronous clutch for best operating flexibility. The

Figure 6: Multiple-Shaft CC2.W501F Reference Power Plant Installation Options



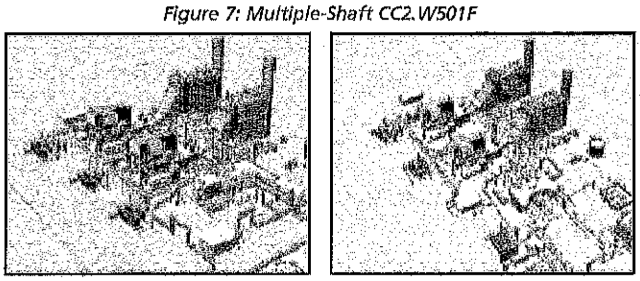
Two W501F Econopacs™ | 2.W501F Power Island | 2.W501F Turnkey Plant (outdoor design) | 2.W501F Turnkey Plant (indoor design)

start-up of such combined cycle power plant after a nightly shutdown takes only 1/2 hour.

The photograph in figure 5 shows the 380MW/50 Hertz Otahuhu CC1S.V94.3A power plant in New Zealand. This power plant was placed into operation only 20 months after receipt of order, which was possible because a pre-designed reference power plant (RPP) was installed. The major advantage of such RPP concepts is the short delivery time. Power plant components can be pre-fabricated and materials such as large forgings pre-ordered.

The second example is a multiple-shaft arrangement of advanced gas turbines for 60 Hertz applications [7]. Two 185 MW W501F gas turbines can be arrange with one steam turbine as 550 MW reference power plants for combined cycle application with different scopes of supply and site-dependent options. Figure 6 illustrates four major steps of the scope of supply growth for a RPP, starting with two EconopacTM providing the gas turbine-generators with all, associated auxiliaries, electrical and I&C equipment. The EconopacsTM include the gas turbines' air intake systems and the exhaust gas ducts. The remaining combined cycle power plant equipment is not within the scope of supply from the gas turbine supplier. The next step is the 2.W501F power island which includes all components of the EconopacsTM, the HRSGs and the steam turbinegenerator with all their auxiliaries, electrical and I&C equipment, the condenser and major pumps. The power island scope puts the thermodynamic plant design into the hands of the gas turbine supplier and consequently he can warrant the plant's overall performance. The third step would be a turnkey outdoor plant, including all remaining balance of plant equipment. The final step would be an indoors turnkey power plant by adding the machine house structure.

Figure 7: Multiple-Shaft CC2.W501F



CC2.W501F with Single-Flow LP Turbine | CC2.W501F with Double-Flow LP Turbine

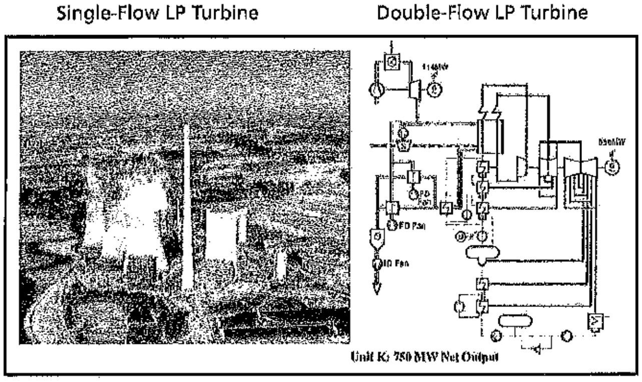


Figure 8: 2300 MW Combined Cycle Power Station Gersteinwerk

The steam turbine design of the 2.W501F RPP is highly influenced by the site-dependent backpressure. As shown in Figure 7, the RPP design concept provides the option of applying either a single-flow or a double-flow LP turbine design. The single-flow axial exhaust steam turbine features a HP turbine and a combined IP/LP turbine section, whereas the doubleflow side exhaust unit features a combined HP/IP turbine section and a double-flow LP turbine section.

Combined Cycle Plant Performance

The early feedwater heating and fully-fired plants were combined cycle plants in which the gas turbine installations enhanced the performance of the steam plants. The major portion of the fuel is still burned in the steam generator. Figure 8 shows, as an example, the fifth unit of the 2300MW Gersteinwerk combined cycle power plant in Germany.

This 750 MW unit features a coal-fired steam generator, only the 114 MW gas turbine is natural gas-fired. The unit achieves a power plant net efficiency of 41 %, an improvement of about 7 % points over a conventional coal-fired unit, both featuring desulfurization systems.

The performance improvement for such combined cycle power plants over conventional steam turbine plants depends greatly on the steam turbine to gas turbine output ratio. The following power plant efficiency improvements can be typically achieved:

- Feedwater heating 10% - 30% gas turbine output improvement: 1.5% - 4% points
- Parallel steam supply 20% - 60% gas turbine output improvement: 3% - 7% points
- Fully-fired boiler (Hot wind box) 15 - 35% gas turbine output improvement: 3% - 6% points

Figure 9: Bottoming Steam Cycles of Combined Cycle Power Plants

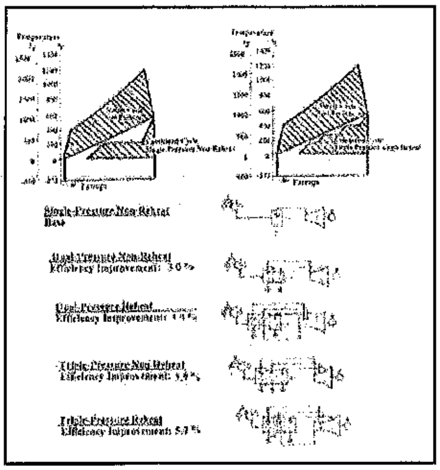
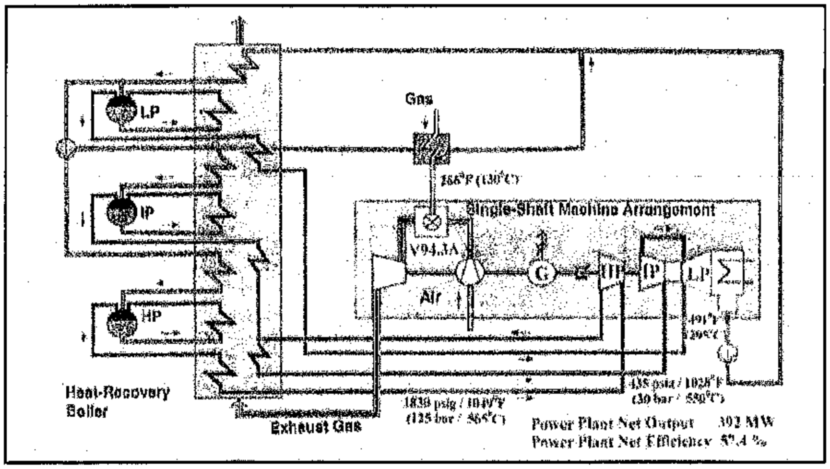


Figure 11: Combines Cycle Power Plant CCIS.V94.3A Performance



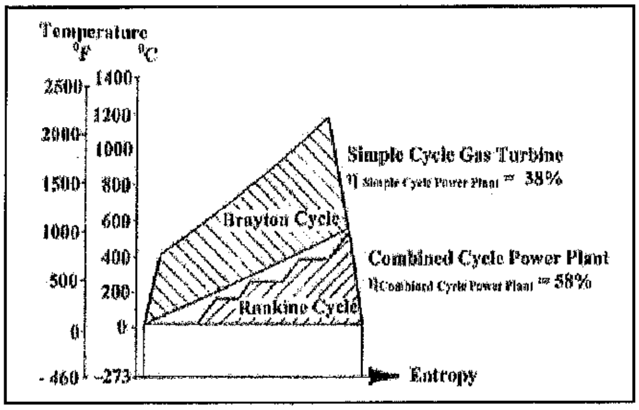


Figure 10: Combined Cycle Power Plant with Advanced Gas Turbine and Triple Pressure Single-Reheat Steam Cycle

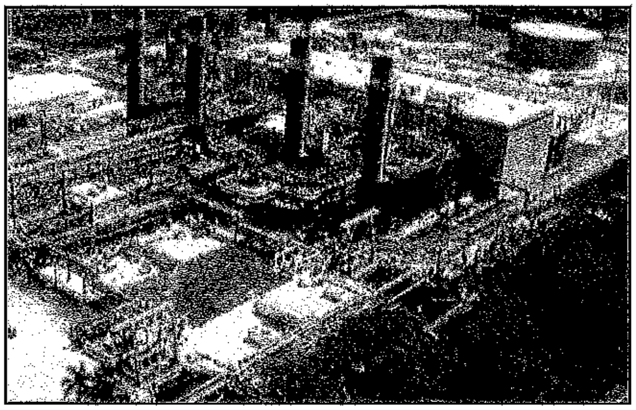


Figure 12: Repowered Lauderdale Power Station

The performance improvements seem to be small when compared to as much as 20% points performance improvement of combined cycle power plants with HRSGs, but one must realize that roughly 200% gas turbine output is required for these applications. The evolutionary development of combined cycle power plants with HRSGs and steam turbines for pure power generation started in the 1960s at an efficiency level below 40%. Gas turbine efficiency levels were around 25% and the gas turbine firing temperatures reached about 1600°F (870°C), providing an exhaust temperature level high enough to generate 750°F (400°C) main steam for a bottoming steam turbine.

The rating, firing temperature and efficiency of gas turbines were rapidly increased, leading to larger and more efficient combined cycle plants. The combination of the gas turbine Brayton cycle and the steam turbine Rankine cycle was improved by building more efficient bottoming steam cycles. Figure 9 illustrates how the changes in bottoming cycles affect the plant heat rate. The single-pressure non-reheat cycle as shown in the Entropy/Temperature diagram, can be improved by bringing the Rankine cycle closer to the Brayton cycle to raise the overall combined cycle performance. With the most effective triple-pressure single-reheat cycle a heat rate improvement of 5.2% can be achieved.

Presently, advanced gas turbines, triple-pressure single-reheat HRSGs and specifically designed steam turbines for combined cycle applications achieve about 58% combined cycle efficiency level as illustrated in Figure 10.

Further combined cycle performance improvement can be expected to reach the 60% plant net efficiency level within this decade. The importance of the increase in firing temperature for combined cycle power plants is best revealed by the fact that the combined cycle efficiency increase from 58% to 60% can be achieved by only raising the firing temperature by about 120°F (67°C). Also the bottoming steam cycle can further be improved by utilizing a once-through boiler design with advanced main steam pressure and temperature. Increasing the main steam pressure from 1600 psig (110 bar) to 2600 psig (180 bar) and the main steam temperature from 1020°F (550°C) to 1110°F (600°C) would improve the combined cycle power plant net efficiency by 3/4 of a % point.

The performance of an advanced combined cycle power plant is shown in Figure 11 for a singleshaft gas turbine/generator/steam turbine arrangement. The diagram is based on the present performance of a V94.3A 50 Hertz gas turbine with a nominal rating of 265MW. The triplepressure single-reheat HRSG provides main steam of 1830 psig (125 bar) and 1049°F (565°C).

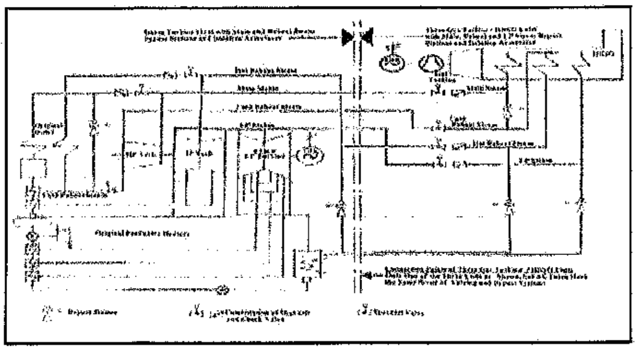


Figure 13: Repowering Concept of Peterhead Power Station

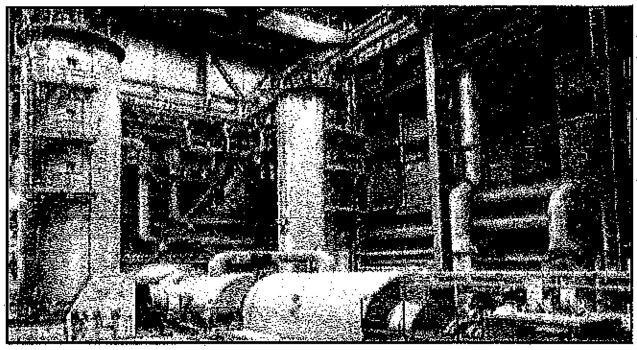


Figure 14: Integrated Coal Gasfication Combined Cycle Power Station Luenen

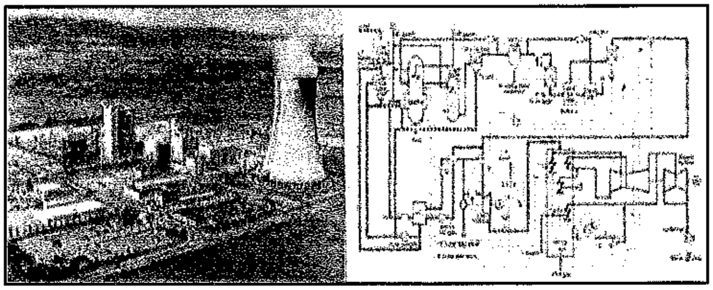
Reheat steam is provided at a temperature of 1028°F (550°C) and LP steam at a temperature of 491°F (295°C). The reheat steam turbine features an HP turbine section and an IP/LP turbine with axial single-flow exhaust and is rated at about 130MW. With this combined cycle power plant arrangement which also includes natural gas preheating to 266°F (130°C) the net power plant output of 390 MW can be generated at a net power plant efficiency of 57.3%. This data can be considered a conservative performance level, since the performance of such combined cycle power plant was last year tested to achieve 398 MW net output at a net power plant efficiency of 58.4 % under ISO conditions.

Repowering

At the Lauderdale power plant site in Florida the first steam turbine was installed in 1926 and the first peaking power gas turbine in 1970 [8]. In the early 1990s all but the last two steam turbines were retired. The last two 125 MW reheat steam turbines, built in the late 1950s, were modified for combined cycle operation. Four advanced 501F gas turbines were installed to build two identical combined cycle units with two gas turbine/HRSG units feeding steam to one steam turbine. These two triple-pressure reheat combined cycle power plant units generate 425 MW each. The 32% net power plant efficiency of the original reheat steam turbine plant was improved to an nearly 50% efficiency of the repowered combined cycle units illustrated in Figure 12.

Continued on page 26

Figure 15: IGCC Power Plant Puertollano



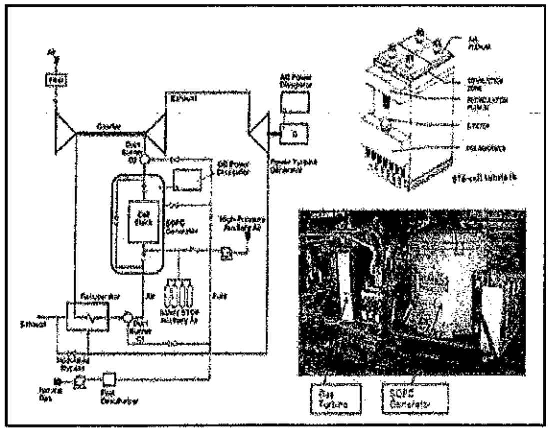


Figure 16: 217 kW Combined Cycle Pilot Power Plant with Solid Oxide Fuel Cell and Gas Turbine

The next example is a repowering project of the late 1990s, for the repowering of the 660 MW Peterhead power station in Scotland with three advanced V94.3A/ 50 Hertz gas turbines [9,10]. The goal was to achieve close to green-field combined cycle power plant performance when operation with the gas turbines and still keep all the equipment to allow also operation with the existing boiler burning a different fuel. The existing reheat steam turbine was designed for a main steam pressure of 2300 psig (160 bar) and a main and reheat steam temperature of 1000°F (538°C). The existing 660 MW power plant provides a plant net efficiency of about 39 %. When operating the existing steam turbine with the three 270 MW gas turbines, a total output of 1210 MW can be generated with a 57 % plant net efficiency. Figure 13 illustrates how the two different power plant cycles are connected to each other and how they can be separated.

A combination of shut-off valves and bypass systems allows independent start-up of the boiler as well as each gas turbine/HRSG unit. This repowering concept also has the capability to operate in a hybrid mode with both the boiler and the HRSGs supplying steam to the steam turbine for up to it's original 660 MW output. This operating flexibility also provides fuel flexibility because electric power can be generated by burning the original fuel in the boiler or by burning natural gas or #2 fuel oil in the gas turbine combustion system.

Coal-Gasification, Fuel Cell and Solar Energy Combined Cycle Power Plants

Integrated coal-gasification combined cycle (IGCC) power plants became available in the mid 1970s and fuel cell combined cycle (FCCC) power plants as well as solar energy combined cycle power plants (SECC) are presently in their pilot plant stage [11]. In 1972 the first integrated coal gasification combined cycle (IGCC) power plant went into operation at the Luenen power station in Germany, featuring five air-blown fixed bed gasifiers, a 74 MW gas turbine and a 96 MW non-reheat steam turbine. A unique feature of this pilot plant is two pressurized steam generators directly mounted to the gas turbine, replacing the two silo-type combustion chambers of the 1960 vintage gas turbine as illustrated in Figure 14. The pressurized steam generators operated at about 150 psia (10 bar) pressure. The plant net efficiency was 37% based on the lower heating value (LHV) of the coal. The next IGCC pilot plant was the Cool Water project in California featuring an oxygen-blown gasifier and an 80 MW gas turbine. The net plant output was about 120 MW. Presently, about 30 large IGCC plants are in operation world-wide. However some of these plants are burning either refinery residues or orimulsion instead of coal.

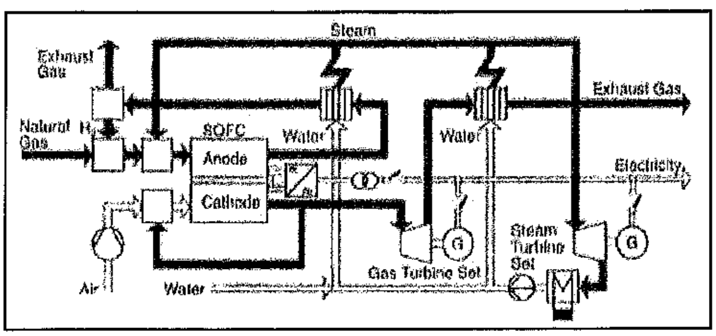


Figure 18: Solar Energy Combined Cycle (SECC) Power Plant

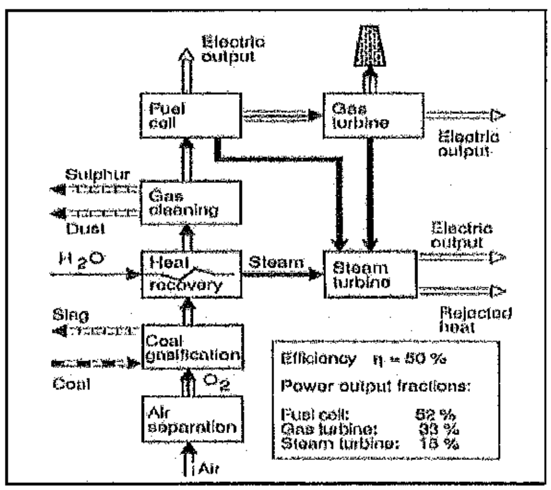


Figure 17: Solid Oxide Fuel Cell and Integrated Coal Gasification Power Plant

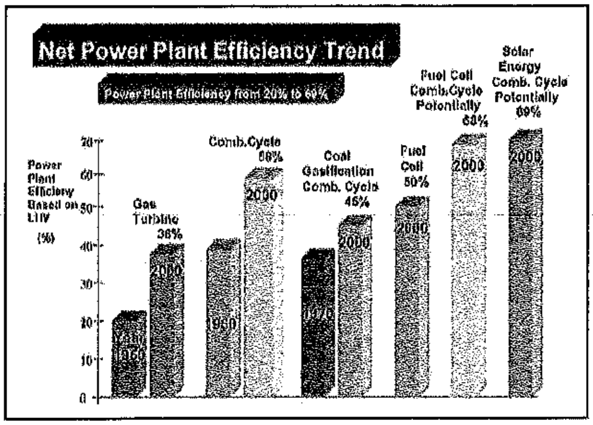


Figure 19: Historic Development of Combined Cycle Power Plant Performance

An IGCC power plant provides fuel for solid oxide fuel cells and the heat from the SOFC is recovered in the gas turbine/ steam turbine combined cycle power plant. The fuel cells generate about 52 % of the plant's output and the gas and steam turbines together the remaining 48%. A combined fuel cell/ coal gasification (FCCC/IGCC) power plant concept could raise the 45% efficiency of present IGCC power plant concepts to a 50 % and higher net power plant efficiency level.

The latest technology already in operation with syngas since 1998 has been applied for the largest (300 MW) single-train coal-fired IGCC plant in Puertollano, Spain [12]. As illustrated in Figure 15, this plant is equipped with an oxygen-blown entrained-flow gasification system. It features an advanced V94.3/50 Hertz gas turbine operating at a firing temperature of about 2280°F (1250°C).

This IGCC power plant concept can achieve a power plant net efficiency of 45 %. However, the Puertollano plant under site conditions burning with a fuel mixture (1:1) of high-ash coal and high-sulfur petroleum coke has achieved a tested net power plant efficiency slightly below 45 %. The first hybrid SOFC+GT plant for 217 kW output with a 187 kW (SOFC) assembly and a 47 kW micro gas turbine was put into operation in California. This pilot plant concept with its pressurized SOFC is illustrated in Figure 16. The SOFC and gas turbine are skid mounted with the following approximate dimensions: 7.4 m (24.3 ft) length, 2.8 m (9.2 ft) width and 3.9 m (12.8 ft) height.

The electrical net efficiency of this first pilot plant has been estimated to be already 57%, plus cogeneration of heat or hot water supplied by a heat recovery system. Such co-generation facilities would be ideally suited for distributed power generation.

With the future availability of coal gasification and fuel cell technologies, power plants can be built which combine both. Such potential coal-fired fuel cell combined cycle power plant concept is illustrated in Figure 17.

Another potential of combined cycle power plants is to add solar energy to the steam cycle of a combined cycle unit. Figure 18 illustrates how such plants could generate electric power especially for air conditioning at a time of the day when it is most needed. The example shows how the output of a combined cycle 80 MW plant with a mid size V64.3 gas turbine can be raised from 88 MW to 115 MW by an LP steam supply from a solar field at noon at a potential power plant net efficiency of 69%. Such solar energy combined cycle (SECC) power plants are presently in their development phase.

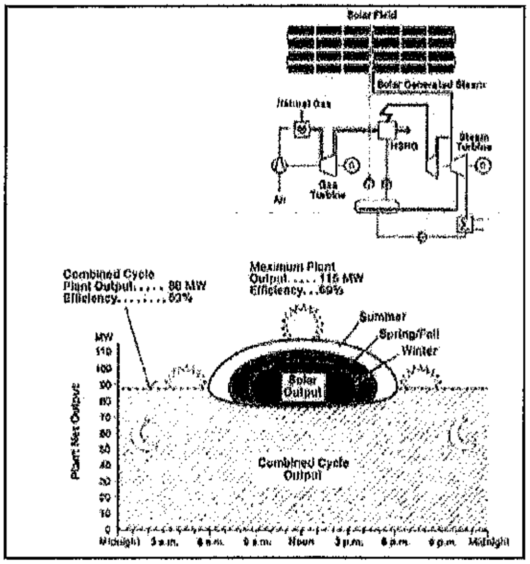


Figure 20: Fuel Cell Combined Cycle (FCCC) Power Plant

Conclusion

In the last forty years combined cycle power plants have greatly influenced the power generation industry. Presently, about 90% of the newly constructed power plants are either combined cycle power plant or to a less smaller portion gas turbine peaking units. Figure 19 illustrates the combined cycle power plant development with gas turbines as prime movers over the last forty years. The history reveals that there is a potential improvement of the net power plant efficiency from about 20% for the early gas turbine plants to 68% for future fuel cell combined cycle power plants in sight. The combined cycle power plant efficiency has risen in the last 40 years from less than 40% to 58% and still in this decade the goal of 60% can be reached.

Integrated coal gasification combined cycle (IGCC) plants have reached a 45% efficiency level and also here future improvement is possible. Fuel cell combined cycle (FCCC) power plants and solar energy combined cycle (SECC) are the newest technologies in power generation and have just been introduced by building the first pilot plants. With the FCCC technology a power plant featuring a gas turbine/steam turbine bottoming cycle as illustrated in Figure 20 can reach already, with present technology available, a 68% net power plant efficiency level. The SECC technology could enhance a combined cycle power plant net efficiency from 53% to 69% as shown in figure 18.

For such combined cycle power plants the proper judgment of the plant's performance is of most importance. Power generation from a SECC plant can reach easily 100% if the relative portion of solar energy is increased and only the fuel for the gas turbine is accounted for as used energy. All the combined cycle power plants can also ideally be applied for co-generation to further enhance their fuel utilization. Here it is important to properly judge the efficiency to generate power as well as the fuel utilization for providing electric power and heat. Combined cycle power plant concepts can also be designed to provide by-products, e.g. an oil shale fueled combined cycle power plant can produce oil.

The history of combined cycle power plants has been relatively short compared to the more than 100 years of electric power generation by coalfired steam turbine plants. However, combined cycles power plants provide excellent performance especially when burning natural gas. But even if natural gas would become scarce, gasification combined cycle power plants can be utilized to burn lower quality fuels, e.g. nearly any grade of coal, refinery residues, biomass, waste or oil shale.

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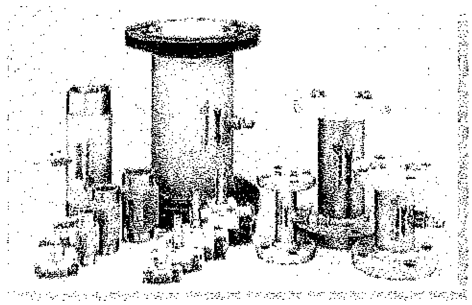

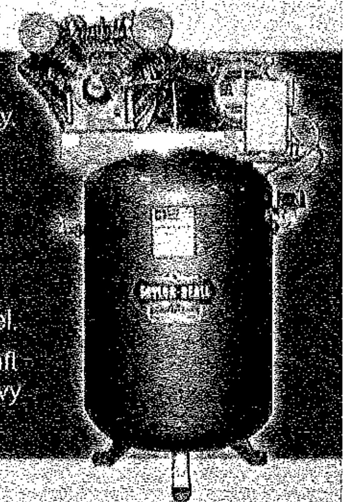

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