INTRODUCTION

Coal fired power plants have been producing a significant amount of power in the United States since the late 19th Century when they surpassed wood as the main fuel source in homes. Currently coal is used to generate roughly half the power in the U.S., but as environmental regulations become more stringent, the cost to maintain and modernize the coal plants to meet these regulations become problematic.

Three options are commonly considered for conventional coal plants to continue to produce power. First, modifications and upgrades to the existing plant can be made utilizing post-combustion cleanup technologies, but these are capital-intensive and may not generate any new revenues. Even with the best post-combustion cleanup, plant emissions are not as low as with other technologies. Another option is to repower the site as a natural gas combined cycle facility. Although the emissions using this technology are low, fuel costs are relatively high.

The third option is repowering with an Integrated Gasification Combined Cycle (IGCC) plant, using clean syngas (hydrogen and carbon monoxide) as fuel to a combustion turbine/steam turbine combination. Use of this combination, or “combined cycle”, reduces the emissions of the coal plant to near natural gas levels, while utilizing existing infrastructure and maintaining a relatively low coal-based fuel cost.

For this analysis, Texaco Gasification Power Systems (TGPS) has been selected. TGPS incorporates the commercially-proven Texaco Gasification Process with a gas turbine using Texaco’s experience and know-how to optimize the IGCC’s economics, environmental performance and overall efficiency. Details of the TGPS can be found on our website at www.texaco.com.

Repowering conventional coal burning power plants with TGPS is an alternative to the expensive upgrades facing these plants, especially those near the end of their useful lives. The life cycle cost of TGPS may be less costly than that of upgrading the existing plant. This is because TGPS has the capability to:

- process inexpensive, high sulfur coal and petroleum coke;
- eliminate post combustion environmental controls; and
- can utilize existing infrastructure.

TGPS can also be readily configured to produce other coproducts such as hydrogen, steam, ammonia, methanol, and oxochemicals, increasing profitability due to economies of scale and synergies between power generation and production of other saleable commodities.
TGPS SYNERGIES

Infrastructure from the existing power plant can be utilized in the TGPS to minimize capital costs and reduce construction and permitting time. Some of the benefits that are realized when repowering with TGPS are the reduced costs for common infrastructure such as water systems, solids handling facilities, electrical transmission, and offsites.

Water systems existing in the coal power plant that can be reused by the TGPS include demineralized, makeup, and cooling water systems. Slight modifications to these systems may be necessary to apply them to the TGPS but there is still a net capital cost reduction. It is common for the TGPS plant to utilize the cooling water system to maximum capacity. This results in greater power output from the TGPS plant, because the TGPS uses a combustion turbine in addition to the condensing steam turbine.

TGPS yields increased efficiency over a conventional coal plant. Existing infrastructure, including the solid feed handling system, is capable of handling the increased load. The coal unloading facilities can also be debottlenecked, upgraded or operated additional hours per day to accommodate the load. This is only a small capital cost compared to installing new facilities, leaving the TGPS with a net capital cost savings. TGPS reduces the onsite coal storage requirements because there is backup fuel, distillate or natural gas, for the combustion turbines in the event that syngas is not available for any given period.

TGPS produces a relatively small amount of by-product solids for sales. Thus, the existing ash handling systems and ash ponds are typically not required. Direct truck loading facilities are included within the TGPS for transportation of the by-product solids.

Electrical transmission studies and possible upgrades for new production can be very costly and even prohibitive to new facilities. By repowering the existing coal plant, the transmission system is already available and minimal capital expenditure is needed to connect the new facilities into the grid. Other offsites infrastructure that can be utilized by the TGPS are buildings for offices and administration, shops for repairs and maintenance, warehouses for storage of spare parts, and roads. The existence and utilization of these peripheral facilities also reduces the capital cost of the TGPS.

Reducing the capital cost of TGPS will in turn reduce the cost of the syngas produced from the facility. By utilizing the existing infrastructure above, the capital cost of the TGPS facility is reduced by about twenty percent. With a lower cost fuel to the combustion turbines, the power plant will be producing the lower cost power.

EMISSIONS REDUCTIONS

Another benefit of repowering conventional coal fired power plants using TGPS is lower solids and gaseous emissions. The TGPS achieves these lower emissions through commercially proven pollution prevention methods. One method is precombustion sulfur capture, which typically converts more than 98% of the sulfur present in the coal feedstock to elemental sulfur, which is
then sold as a coproduct from the process. Another pollution prevention method is the low BTU gas implemented in the combustion turbines which produces a fuel gas inherently low in NOx, CO, and particulate emissions, when burned in an appropriately designed combustion turbine.

**Solids Emissions**

TGPS minimizes solids production. The ash in the coal feed does not react in the gasifier and because of the reducing conditions in the gasifier, these solids are glassy, low-permeability materials suitable for use as road or cement aggregates. The unconverted carbon from the coal feed is readily separated from the slag. Most or all of this material is recycled, but some may be sold as solid fuel blending stock for coal and coke.

The sulfur in the coal is converted to gaseous hydrogen sulfide (H$_2$S) in the gasifier. A conventional solvent is then used to remove essentially all the sulfides from the syngas in the acid gas removal section of the synthesis gas cleanup. This stream is converted to marketable elemental sulfur or sulfuric acid. The chloride salts found in most coals can be converted to ammonium chloride salts and sold as a fertilizer or removed in a relatively small effluent water stream that is compatible with a standard biopond. In this way, the TGPS produces very small amounts of solid waste. Figure 1 below compares conventional coal plant solid emissions to TGPS.

![Solids Emissions Comparison for Conventional Coal Plants and the TGPS](image)

**Gaseous Emissions**

As with conventional coal plants, there are also gaseous emissions from TGPS, but TGPS provides a significant reduction in those emissions. As shown in Figure 2, both SOx and NOx emissions are reduced by 70%-80% each through the repowering with TGPS. The reduction of
air emissions by TGPS will bring the plant into compliance with the more stringent regulations currently proposed in many areas that would otherwise require significant and expensive modifications.

An emerging potential issue is carbon dioxide (CO₂) emissions reduction. The TGPS reduces CO₂ emissions due to its higher efficiency. It also offers the plant owner an opportunity to recover CO₂ at relatively low cost for sequestration or other uses. Thus TGPS provides a natural hedge for future CO₂ emissions controls.

![Figure 2. Gaseous Emissions Comparison for Conventional Coal Plants and the TGPS](image)

Many conventional coal power plants have been in operation for at least 50 years and most are near the end of their useful lives. Conventional coal plant owners are being pressured by the EPA to meet stricter New Source Performance Standard (NSPS) limits for NOx and SOx emissions. To remain exempt from the NSPS, existing plants are normally restricted to only minor throughput, reliability, and efficiency upgrades.

In order to meet the SOx and NOx emission limits required by the NSPS, conventional coal plants may be forced to reduce emissions. Operators normally install stack gas scrubbers and selective catalytic reduction (SCR) technology. These methods reduce the air emissions but are costly and produce potentially harmful waste products. For example, the solid waste from SCR may be leachable and therefore difficult to dispose of in an environmentally acceptable manner. Also, due to the high volume and low pressure of the stack gas in the scrubbers, NOx and SOx removal efficiencies are limited.
The factor that sets TGPS apart from typical power plants, whether natural gas or coal based, is that the TGPS has a multi-stage, high-pressure cleanup of the syngas prior to combustion. TGPS does not require coal-based post combustion cleanup since the removal of precursors to NOx and SOx emissions is done in the gasification block. The power block owner receives clean syngas, which produce very low NOx and Sox when combusted in the gas turbine. Below is a table summarizing the comparison of air emissions from a natural gas combined cycle facility, TGPS, and a conventional coal plant.

Table 1. Gaseous Emissions Comparison

<table>
<thead>
<tr>
<th></th>
<th>Natural Gas Combined Cycle</th>
<th>Coal TGPS</th>
<th>Conventional Coal Plant</th>
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<tbody>
<tr>
<td>NOx</td>
<td>3 ppm</td>
<td>&lt;9 ppm</td>
<td>150 ppm</td>
</tr>
<tr>
<td>Sulfur Recovery</td>
<td>95%</td>
<td>&gt;98%</td>
<td>95%</td>
</tr>
<tr>
<td>CO₂ (lb/kWh)</td>
<td>0.81</td>
<td>1.95</td>
<td>2.26</td>
</tr>
<tr>
<td>SCR</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Stack Gas Scrubber</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Clean syngas not only reduces emissions from a power plant but also minimizes maintenance. Without extensive backend cleanup that a typical power plant needs to meet the increasingly stringent emissions regulations, the TGPS has less solid waste, and less spent catalyst for these add-on processes.

**Carbon Dioxide Control**

Regulations to control carbon dioxide emissions are currently being considered.

In TGPS, when the CO₂ is combined with syngas to the combustion turbines, there are two benefits realized by the power plant. First, the CO₂ lowers the flame temperature reducing NOx generation. Second, the CO₂ adds more mass per unit volume to the syngas, which increases the power output of the combustion turbine. If the CO₂ is removed then steam injection or syngas saturation would replace CO₂ for NOx suppression and power augmentation.

Another option is to remove the CO₂ from the process entirely and use it elsewhere. TGPS has the capability to sequester the CO₂ from the syngas before sending the gas to the combustion turbines, because the sulfur removal process used in the TGPS can produce a by-product CO₂ stream. Conventional coal plants do not have the capability to extract the CO₂ without extremely costly measures, but the TGPS gas cleanup configuration produces a high pressure, high quality CO₂ stream. For example, this CO₂ can be injected into oil wells for tertiary oil recovery or injected into aquifers where it will dissolve naturally.
OWNERSHIP OF THE PLANT

Texaco’s approach to repowering conventional coal plants allows the current power producer to remain an integral part of the new plant. This structure is detailed in the diagram in Figure 3, below where ownership of the TGPS facility may be split into two discrete plants - a gasification plant (which may also include an air separation unit), and a power plant. The gasification plant may be fully owned by Texaco, and operate as a fuel supplier to the power plant. The power plant may be owned by some combination of the current power producer, Texaco, or another party.

Figure 3. Business Structure of the new TGPS facilities

This ownership structure allows both Texaco and the power producer to exploit their expertise. The power producer will use the clean synthesis gas provided by the gasification section together with nitrogen from the air separation plant. In turn, the power producer may supply the gasification section with extraction air from the combustion turbines, and a small amount of high-pressure steam.

In addition to the ownership structure in Figure 3, there is significant ownership flexibility. Texaco may own the entire facility (gasification section and power block) and sell the power output, or Texaco may partner with the power offtaker in the ownership of the power block.

Within each of these ownership structures, TGPS offers the power producer many benefits that a stand-alone combined cycle facility is unable to provide. TGPS can process low value, high sulfur coal or petroleum coke which yields a low fuel cost to the power producer for the syngas product. This low fuel cost (compared to natural gas) makes the power producer who receives fuel from the TGPS a low variable cost power producer. Thus TGPS will be dispatched more frequently than a natural gas fed combined cycle facility.
**THE GASIFICATION/POWER BLOCK INTERFACE**

Syngas contains hydrogen, which allows stable combustion at low fuel heating values. Thus significant amounts of inert gases (nitrogen and/or carbon dioxide) can be blended with the syngas to suppress NOx formation. The nitrogen is available with TGPS because the air separation unit that supplies the gasifier with oxygen produces a significant amount of by-product nitrogen, that would otherwise be vented to the atmosphere.

The inert gas addition increases the mass flow through the combustion turbine, increasing power output. The inert gas mixed with the syngas also reduces the effective oxygen concentration in the combustors thus minimizing NOx formation during combustion. Air is extracted from the turbine preventing compressor surge and allowing maximum diluent addition.

The extraction air from the combustion turbines may also be cooled and used to supplement the compressed air in the air separation unit. The extraction air benefits the TGPS in two ways. First, the extraction air exits the combustion turbine at high temperature (750°F – 850°F) and pressure (200psig). The heat from the extraction air can be used to preheat boiler feed water and superheat steam produced in the gasification heat recovery section. Secondly, following the heat recovery, the extraction air can be fed to the air separation unit, thus reducing the supplemental air compression needed within that unit.

Syngas nitrogen and carbon dioxide are supplied to the power plant facilities preheated above the dew point allowing them to be directly fed to the combustion turbines. Optionally, the power block owner may elect to perform additional preheating using steam from the HRSG. This decreases syngas consumption requirements, increasing the efficiency of the power block.

**PERFORMANCE**

The power plant will look the same as a typical combined cycle plant with steam and power sales to third parties. Using the synthesis gas from TGPS will allow this power plant to achieve nearly constant output over ambient temperatures up to 95 degrees F, which provides an additional 20% total power output over natural gas. The table below shows a summary of a single GE 7FA turbine, and a combined cycle power plant fueled with natural gas and syngas at both 59 (standard conditions) and 95 degree F.

Using steam drives in the air separation unit has minimized the power consumption for the gasification section. All of the excess steam produced in the gasification heat recovery section is consumed by the steam drives. No steam is exported from the gasification section to the power block.
Table 2. Power Output Comparison: Syngas vs. Natural Gas

<table>
<thead>
<tr>
<th></th>
<th>Syngas</th>
<th>Natural Gas</th>
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<tbody>
<tr>
<td>Ambient (°F)</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>Exhaust Gas Flow (kpph)</td>
<td>3850</td>
<td>3500</td>
</tr>
<tr>
<td>CT Power Output (MW)</td>
<td>197</td>
<td>170</td>
</tr>
<tr>
<td>ST Power Output (MW)</td>
<td>90</td>
<td>91</td>
</tr>
<tr>
<td>Power Block Consumption (MW)</td>
<td>(4)</td>
<td>(4)</td>
</tr>
<tr>
<td>Net Power Block Output (MW)</td>
<td>283</td>
<td>257</td>
</tr>
</tbody>
</table>

Combustion turbines fired on synthesis gas from TGPS produce 10% more exhaust flow compared to natural gas at approximately the same temperature. This allows the HRSG to produce additional steam. The extra steam produced from the HRSG is approximately the amount that is consumed by the gasification plant during normal operation. During the peaks of power pricing the steam can be backed out of the gasification plant and routed to the steam turbine to make approximately 4 MW of additional steam turbine power over the value shown in Table 2. This extra capacity during the periods of the highest demand allows the power producer to maximize profits.

The power block owner will have the option of operating the power block on natural gas or syngas. Due to the limited integration with the gasification block, operation of the power block steam cycle will not be significantly different during syngas and natural gas operation. The main difference between syngas and natural gas operation is the increased combustion turbine output during syngas operation.

Another option is to co-fire natural gas and syngas in the combustion turbines simultaneously. In this configuration, the power block has the ease of turn down and flexibility to reduce the natural gas going to the turbine during periods of low power demand, while maintaining the additional power output associated with syngas alone.

COMPETITIVE FUEL PRICING

Pricing of the syngas fuel to the turbines will determine the viability of the project. It is therefore important to have a mechanism for comparison to a published commodity price as well as a comparison with the competitors such as natural gas combined cycle facilities.

For a natural gas combined cycle facility, the power price can be directly linked to the published price of natural gas for any given day. However, the syngas produced by the TGPS is not a
commodity that is tracked nor is there an established index market from which a price can be directly quoted. But one can readily determine the equivalent natural gas volume for syngas.

Syngas has a lower calorific value than natural gas and, when fully diluted for NOx control, increases power plant electrical output compared to the maximum natural gas power plant electrical output.

To compare syngas to natural gas, the quantity of natural gas that would have been needed to produce the actual power output from the syngas plant is calculated. Now the pricing for the fuel to the power plant can be compared to a published commodity to determine if the pricing structure is fair and can compete with other power plants for dispatch.

In Table 3 below, total power is calculated for both syngas and natural gas for one GE 7FA combustion turbine rated for a nominal 170 MW at ISO conditions on natural gas. Natural gas fueled power output is significantly less during high ambient temperatures, while syngas fueled power output remains constant. In addition to the net power production, steam is sold to the syngas plant. This represents an additional equivalent power output of 4 MW.

### Table 3. Equivalent Natural Gas Calculation

<table>
<thead>
<tr>
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<th>Syngas</th>
<th>Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient (°F)</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>Net Power Output (MW)</td>
<td>283</td>
<td>277</td>
</tr>
<tr>
<td>Equivalent Power from Steam Sales (MW)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total Power Output (MW)</td>
<td>287</td>
<td>281</td>
</tr>
<tr>
<td>Equivalent NG (MMBTU/h) (Based on 7000 BTU/kWh HHV)</td>
<td>2,009</td>
<td>1,967</td>
</tr>
<tr>
<td>Capacity Increase at 95F</td>
<td></td>
<td>48 MW</td>
</tr>
</tbody>
</table>

The natural gas needed to produce the total output for each case is calculated. For the natural gas cases, this is the amount of natural gas needed for a natural gas combined cycle plant to produce 257 MW at 59°F. For the syngas case, this is the amount of natural gas that would have been needed if syngas were unavailable, to produce the 287 MW, based on a 7000 BTU/kWh heat rate. This is the equivalent natural gas. The power block owner realizes a savings of natural gas purchase of 209MMBTU/h.

By fueling the power plant with syngas from the TGPS, the owner of the power plant is not only benefiting from a reduced fuel cost, but also from increased capacity. With syngas feeding the combustion turbines, the power output from a single turbine will increase by 20% over a natural
gas fed turbine. For the case above, the capacity increase is 48 MW at high ambient temperature. Although modifications are required to the combustion turbine and HRSG, the additional output is more than the cost of the modifications, resulting in a lower installed cost per kilowatt.

Syngas is capable of producing maximum power output throughout the year, (at ambient temperatures less than 95°F,) unlike natural gas. Natural gas fired turbines have reduced output at high ambients, when power is the most valuable. Syngas nearly eliminates that output swing and brings in the additional revenue during peak power periods.

As demonstrated above, syngas alone will not perform in the combustion turbines as natural gas does. Because of the reliance of syngas performance on the addition of nitrogen and the extraction of air from the combustion turbines, the equivalent natural gas price is all inclusive of these streams, as in Figure 2 above.

This structure is often appealing to power plant owners who are comfortable with the configuration of natural gas combined cycle plants and all of the economic parameters associated with that plant. With the structure above, the power plant is structured similar to that of a natural gas combined cycle facility and can be efficiently fueled using partial or full natural gas firing if syngas is unavailable.
CONCLUSION

Many conventional coal power plants have limited options to continue operation. As the regulations on emissions become more stringent, the costs to upgrade the existing facilities will force conventional coal plants to higher power production costs and many will not be able to compete in the market place. The best solution for these plants is to repower using Texaco’s gasification technology.

TGPS allows continued use of coal to produce power, but provides savings by processing low value, high sulfur coal while reducing the air emissions from the level of the existing plant. Also, the TGPS produces no solid waste; all solid by-products are sold because of their characteristics based on the conditions in the gasifier.

Repowering conventional coal plants with TGPS allows continued utilization of the existing infrastructure available at the site. Using these facilities provides a net capital cost reduction for the TGPS over a greenfield site, and reduces the site preparation and cleanup costs for the existing coal plant.

TGPS is competitive with natural gas combined cycle facilities. The syngas is provided to the power block at an equivalent natural gas price that is below projected natural gas prices. Once the syngas and natural gas facilities are levelized, it is easy to see that the TGPS allows a lower fuel price, and therefore a lower power price.