Gas Turbine Improvements Enhance IGCC Viability

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Abstract

Gas turbine technology development has greatly contributed to increased use of IGCC power plants worldwide. Along with environmental factors and gasification processes, this development will continue to lead the way toward improving performance and lowering costs. Several specific areas of development have resulted in 24 IGCC plants currently on line or in construction:

- Combustion/environmental testing
- System/operability design and controls
- Improved ratings and performance
- Reliability/availability and maintenance (RAM).

New records have been set yearly in each of these areas to extend the viability of IGCC technology (Figure 1). This report summarizes the current capabilities and discusses plans for future development.

Introduction

Some important IGCC milestones for GE in Year 2000 include startups, new projects and technology improvements. Three breakthrough startups are shown in Figure 2:

- The Motiva-Delaware 9 ppmvd NOx, 240 MW plant on Pet Coke first used syngas in September. This 6FA GT has operated at a rating 30% higher than natural gas.
- The Sarlux 540 MW vis breaker tar plant first used syngas on August 13th. It had already achieved 7050 hours of operation on distillate oil.
- The Exxon Singapore 180 MW steam cracker bottoms plant is planned for startup later this year. It has already operated 3000 hours on distillate oil, which is one of 42 different fuel combinations it is designed to handle on the fly.

Figure 1. Gas Turbine Improvements
Total accumulated operation for GE IGCC technology is now more than 322,000 hours. Four new projects have been awarded that total 1995 MW, as shown in Figure 3. These plants will be put into operation in 2003, 2004 and 2005. The Gonfreville plant is a tri-fuel/dual gas design operating at a rating 24% above natural gas operation. PIEMSA will operate at a rating 14% higher than natural gas while simultaneously providing partial air integration with the air separation unit (ASU). NTW uses blast furnace gas and distillate fuel. Three Confidential

**Figure 2.** Year 2000 IGCC Startups

**Figure 3.** New Syngas Plant Awards
7FA units will use the next generation design based on Motiva-Delaware at a rating 8% higher than natural gas with partial air extraction. The technology for each of these plants has been developed step by step in cooperation with other industry suppliers. This illustrates how IGCC is a technology partnership rather than a simple grouping of GT, ASU, and gasifier equipment.

**Combustion/Environmental Testing**

The core of an IGCC design is based on combustion development through laboratory testing. As the critical orifice in the plant, the combustor must be designed for a wide range of operating conditions with backup and co-firing fuels. It also has to meet ever tightening environmental requirements. Experimenting with these parameters in the field can be very costly because they can affect all the related technologies, as shown in Figure 4. This data was created in 1990 at the request of Shell and EPRI and shows that typical gasifier syngas outlet constituents are not suitable for meeting today’s NO\(_x\) requirements. It also shows that dilution of the syngas with nitrogen, water, CO\(_2\) or combinations can meet the desired operating conditions. Note that the diluent quantities needed are equal or greater than the quantities of syngas. This means the resultant flow in the combustor may be eight times that of a natural gas machine.

*Figure 5 shows the typical can annular combustor. Current production has evolved to an increased diameter standard that allows a wider range of fuel constituents and co-firing capability. An individual combustor can be tested at full flow, temperature, and pressure for any syngas expected by the gasification system. In many cases there is also a field test at startup to tune the multiple cans and confirm the results of laboratory testing. These machines require a startup fuel because of the dangers of starting on hydrogen based fuels. This allows many plants to operate on backup fuel earlier, which considerably reduces interest costs on construction. The dual fuel capability has been developed into a co-firing feature so users can design

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**Figure 4.** GE “F” Combustor Testing
plants for larger power output than can be obtained with syngas alone.

The numerous projects shown on Figure 6 indicate the wide flexibility developed to date for plants using syngas. Hydrogen varies from 8.6% to 61% while other constituents vary widely with air-blown versus oxygen-blown syngas. The top half of the chart shows the constituents from the gasifier while the bottom half shows the diluents needed to meet emission or power augmentation requirements. By combining this combustion technology with output enhancement capability, plants can determine the most optimum and economic mix of diluents. The ability to use nitrogen economically is derived from elevated pressure ASU improvements and can be very

<table>
<thead>
<tr>
<th>Syngas</th>
<th>PIS</th>
<th>Temp</th>
<th>El Dorado</th>
<th>Pomeu</th>
<th>Skira</th>
<th>Pacific</th>
<th>ILVA</th>
<th>Schwarze</th>
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<td>210</td>
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<td>143</td>
<td>317</td>
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<td>319</td>
<td>241</td>
<td>248</td>
<td>230.4</td>
<td>10.655</td>
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</tbody>
</table>

* Always co-fired with 50% natural gas

**Figure 6.** Syngas Comparison
important in obtaining flat ratings at high ambi-
ents. Many of these plants produce co-products
from the syngas and the GT must be able to
accommodate the resultant tail gas.

We have completed testing for hydrogen-only
and CO-only fuel to complete the combustion
map. The H2-only case is based on removal of
CO as CO2 for Enhanced Oil Recovery (EOR)
or sequestration and allows CO2-free power
plants. Figure 7 indicates that ratios of 50/50

![Video Capture of Flame Structure - 85-90% H2](GT30052A.ppt)

**Figure 7. NOx vs. Equivalent Calorific Value for Several Fuel Compositions**

hydrogen/nitrogen can have very low NOx
capability as well as enhanced output in a
modern IGCC. With this new combustion
technology it may be possible to use IGCC for
CO2-free plants at about 15% extra cost.

Typical NOx emissions are shown in Figure 8.
It is unfortunate that not all regulatory agen-
cies give credit for IGCC plants’ excellent
emission characteristics for heavy/solid fuels,
preferring to treat them as GT plants.
Fortunately, individual localities can make
that distinction. We must become sophistica-
ted in resolving this issue so that Best Available
Control Technology (BACT) can be
addressed for the type of feedstock rather
than as a generic GT plant. For instance, NOx
emissions from Motiva-Delaware using Pet
Coke should have a lower BACT than a heavy
oil plant due to the extra effect of higher CO2
illustrated in the original 1990 data.

Figure 9 summarizes recent combustion devel-
opments that are contributing to the success-
ful startups and improved viability of IGCC.

**System/Operability Design and Controls**

System design of an IGCC has become a team
effort in order to optimize the whole plant
rather than an individual component. Various
teams of suppliers and EPCs have contributed
significantly to the continued improvements.
GE has worked on both air-blown and oxygen-
blown systems, as shown in Figure 10. Most of
the recent efforts have concentrated on oxy-
gen due to the large size of plants and particu-
larly the co-production of chemical products.
To achieve optimal results for each system shown in Figure 10 we can design a different type of air integration. Tampa Polk is designed for air side integration at 0%, which means no air extraction to the ASU but full nitrogen return to the GT. PIEMSA is designed for partial integration where some air is extracted for the ASU. Sierra Pacific is designed for full integration where all air for the ASU is extracted. Various gasifiers require from 11% to 20% of the GT air flow for full air integration. The IGCC combustor is designed to extract up to 20% on Model F machines without affecting the cooling air. For systems such as GTL that...
require more air, a medium air extraction (MAE) system at 37% is available. For E level machines a high air extraction (HAE) system at 50% is being designed. Overall IGCC optimization for a specific site depends upon the operating requirements and the fuel type to determine the kind of air side integration to be used, if any. In the larger plants we are finding that operability can be enhanced with partial air integration by reducing the size of ASU compressors.

Mixed fuel operation or co-firing has become an important operating mode to enhance economics. It was first used at the Texaco El Dorado IGCC plant in Kansas where the gasifier was only a third of the size of the plant electrical load. Since starting in 1996 the El Dorado GT has performed at better than 97% power availability. Many later plants such as Exxon Singapore, Gonfreville and PIEMSA also have this feature. For a dual gas design the operability standard is in the 70/30% range. However,
there is a new system used for Exxon Singapore capable of operating in the 90/10% range, as shown in Figure 11. Mixed fuel operation can generally be accommodated down to 20% load. For a dual fuel syngas/distillate machine the distillate can be controlled down to 10% while the syngas is generally used in the 70% range. A tri-fuel dual gas system is being used for the Gonfreville plant. This 90/10 system incorporates a single fuel nozzle for natural gas operation and splits the fuel flow into all six nozzles in each combustor on the syngas side of the bumpless transfer zone. Figure 12 shows the fuel system, inert and main air purge systems for this plant. Both nitrogen and air from the compressor discharge (CPD) are used to purge during various operating modes. This system also has the 90/10 capability. In keeping with the GT packaging concept the complete system is modularized as shown on Figure 13. This particular module was shipped to Exxon Singapore. Many studies have determined that NOX benefits as well as power augmentation benefits can be realized by using diluents to lower the heating value of the syngas. GE has chosen to inject nitrogen in the combustor in the same manner used for steam injection rather than mix it with the fuel. In this manner the nitrogen pressure can be lower than the syngas pressure and the fuel control valves can be reduced to half size since they are controlling only the fuel. Combinations of N2 and moisture are frequently the most cost effective, considering the aero limitations in a standard GT for additional flow. Figure 14 compares several methods of moisturization. The amount of water saturation is generally limited by the low-level heat available and varies widely by gasifier type. Several recent systems have chosen to moisturize the nitrogen. Another area of concern to the operator is the method of overall plant control. IGCCs can be
designed to follow the gasifier and use only the syngas fuel that is made. They also can be designed to meet electrical load demand either by forcing the gasifier to follow the demand or by co-firing the backup fuel. The latter is more frequently used. A part of the design normally incorporates a GT simulation for the benefit of the team. This study of startup and shutdown modes and ambient effects at the beginning of the plant design is crucial. Many components need to be designed for conditions other than the “Guarantee Point” to provide flexibility and economics. Cost of Electricity (COE) or the combined products on an annual kW/hrs basis is helpful in producing the best proforma results.
**Improved Ratings and Performance**

For natural gas machines, normal GT full load operation over the ambient range follows air density and falls off considerably at high ambient temperatures. We can counteract this with IGCC designs and frequently design the system to utilize the full winter capability, even at 90°F / 32°C. The most illustrative example is the 9EC machine which produces 150 MW at high ambient on natural gas and 215 MW at the same high ambient in an IGCC design. This ratio of 43% extra power in the GT is partially diminished by plant auxiliaries but can be a major influence on the IGCC viability. *Figure 15* demonstrates the physics of this benefit.

Natural gas fuel provides 2% of the flow through the turbine as compared to syngas at 16% flow due to the lower heating value. This allows the turbine to make more power, generally an increase of 20%, when fired to the same temperature. The mechanical capability of a specific turbine and its surge margin requirement limit this capability differently for each machine setting a specific maximum output.

For GE units this is usually the torque limit which was originally designed for some very low ambient. If the syngas flow raises the GT above its maximum capability at an average ambient, inlet guide vanes are closed to restrict air and therefore output. As ambient increases, these guide vanes are opened to hold maximum output until the guide vanes are fully open. That ambient point is called the break point in the curve. Above that the output falls off. For Tampa Polk, the break point is 90°F / 32°C. We are constantly endeavoring to remove limits and expect to make even more improvements in the next generation IGCCs.

An important new system developed over the past year incorporates the latest GT improvements for a High Efficiency Quench (HEQ) design. This plant incorporates all of the features developed from previous plants and includes an additional output enhancement of an expander turbine in the fuel system. It produces an additional 4% output. GE now has the ability to supply this expander and incorporate it into the plant guarantees.

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**Figure 15. IGCC Output Enhancement with Gas Turbine Advances**

*Gasification Technologies Conference, October 8-11, 2000*
When added together, these output enhancements have been the major contributor to the significant plant cost reductions we are seeing in recent bids.

**Reliability/Availability/Maintenance (RAM)**

Cost of Electricity is affected by RAM performance in a manner similar to plant cost and fuel efficiency. Generally, RAM performance is improved during the design stage by incorporating lessons learned in previous plants. GT suppliers can do some of this based on their experience in other fields but it is very important to have IGCC experience. Figure 16 shows over 322,000 hours of modern experience, including some machines that have accumulated over 24,000 hours of syngas experience. The lessons learned have been reported before and incorporated in all current designs. The Tampa plant has reported that power availability is running at 96%. The fleet leader is El Dorado, which has a power availability average of 97% for the last 4 years.

From this experience GE has concluded, “A Syngas CC can have the same performance as a Natural Gas CC,” as shown in Figure 17. To realize this same performance, several specific conditions need to be met by the supplier. Experience has shown that higher hydrogen content, which produces more water, and the increased flow of syngas tend to increase metal temperatures in the hot gas path. GE has developed a control system to mitigate this effect by lowering firing temperature to maintain metal temperatures consistent with natural gas machines. On this basis we have been willing to provide Long Term Service Agreements (LTSA) at a cost basis similar to natural gas machines along with availability guarantees. Many current IGCC plants have found this to be a cost effective way to make IGCC viable.

<table>
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<tr>
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<th>Type</th>
<th>MW</th>
<th>Customer</th>
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<td></td>
<td></td>
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<td>Cool Water</td>
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<td>5/84</td>
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<td>PSI</td>
<td>7FA 262 11/95</td>
<td>21,000 - 4,000</td>
<td>21,000</td>
<td>262</td>
<td>11/95</td>
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<td>107FA 250 9/96</td>
<td>22,000 - 4,570</td>
<td>22,000</td>
<td>250</td>
<td>9/96</td>
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<tr>
<td>Texaco El Dorado</td>
<td>6B 40 9/96</td>
<td>22,100 17,100 -</td>
<td>22,100</td>
<td>40</td>
<td>9/96</td>
</tr>
<tr>
<td>Sierra Pacific</td>
<td>106FA 100 -</td>
<td>0 25,000 -</td>
<td>0</td>
<td>100</td>
<td>-</td>
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<td>SUV Vresova</td>
<td>209E 350 12/96</td>
<td>63,000 1,500 -</td>
<td>63,000</td>
<td>350</td>
<td>12/96</td>
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<td>Schwarze Pumpe</td>
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<td>40</td>
<td>9/96</td>
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<td>120</td>
<td>11/97</td>
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<td>ISE / ILVA</td>
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<td>0 3,000 -</td>
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<td>180</td>
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**Totals** 322,900

**Figure 16.** GE Syngas Hours of Operation
Conclusion

In summary, current production gas turbines can be used for IGCC applications but some modifications are desirable to enhance the IGCC economics.

*Figure 18* lists the types of modifications normally considered up front.

Gas turbine improvements have come from operation in many applications and from industry competition. In addition, specific attention to IGCC needs in an emerging market has generated a host of new technology needed for IGCC viability. When combined with the same type of efforts by ASU, cleanup, and gasification technologies, we can see an exciting trend. *Figure 19* quantifies one version of these technologies since 1994. Heat rate improvements of 15% and plant cost improvements of 26% have been achieved. More important, however, is an 18% reduction in COE with room for further reductions. This trend of improvements and cost reductions can be applied to the industry as a whole.

As shown in *Figure 20*, we now count 24 plants and 6752 MW capacity. Our fast growing experience base, along with at least 10 more plants in the bidding stage, demonstrate that IGCC power plants are a viable and welcome development in the field.

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*Figure 17. Syngas – Reliability/Availability/Maintenance*

*Figure 18. Gas Turbine Modifications for IGCC*
Gas Turbine Improvements Enhance IGCC Viability

Figure 19. Economic Impact of HEQ IGCC Design Study Improvements

<table>
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<tr>
<th>Customer</th>
<th>C.O. Date</th>
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<th>Application</th>
<th>Gasifier</th>
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<td>120</td>
<td>Power/Coal</td>
<td>Texaco - O₂</td>
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<td>250</td>
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<td>Shell - O₂</td>
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<td>260</td>
<td>Repower/Coal</td>
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<td>260</td>
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<td>Texaco - O₂</td>
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<td>Lurgi - Air</td>
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<td>180</td>
<td>Power/Pet Coke</td>
<td>Shell - O₂</td>
</tr>
<tr>
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<td>750</td>
<td>Power/Pet Coke</td>
<td>Texaco - O₂</td>
</tr>
<tr>
<td>PIEMSA</td>
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<td>800</td>
<td>Power/H₂/Oil</td>
<td>Texaco - O₂</td>
</tr>
</tbody>
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