



GE Power Systems

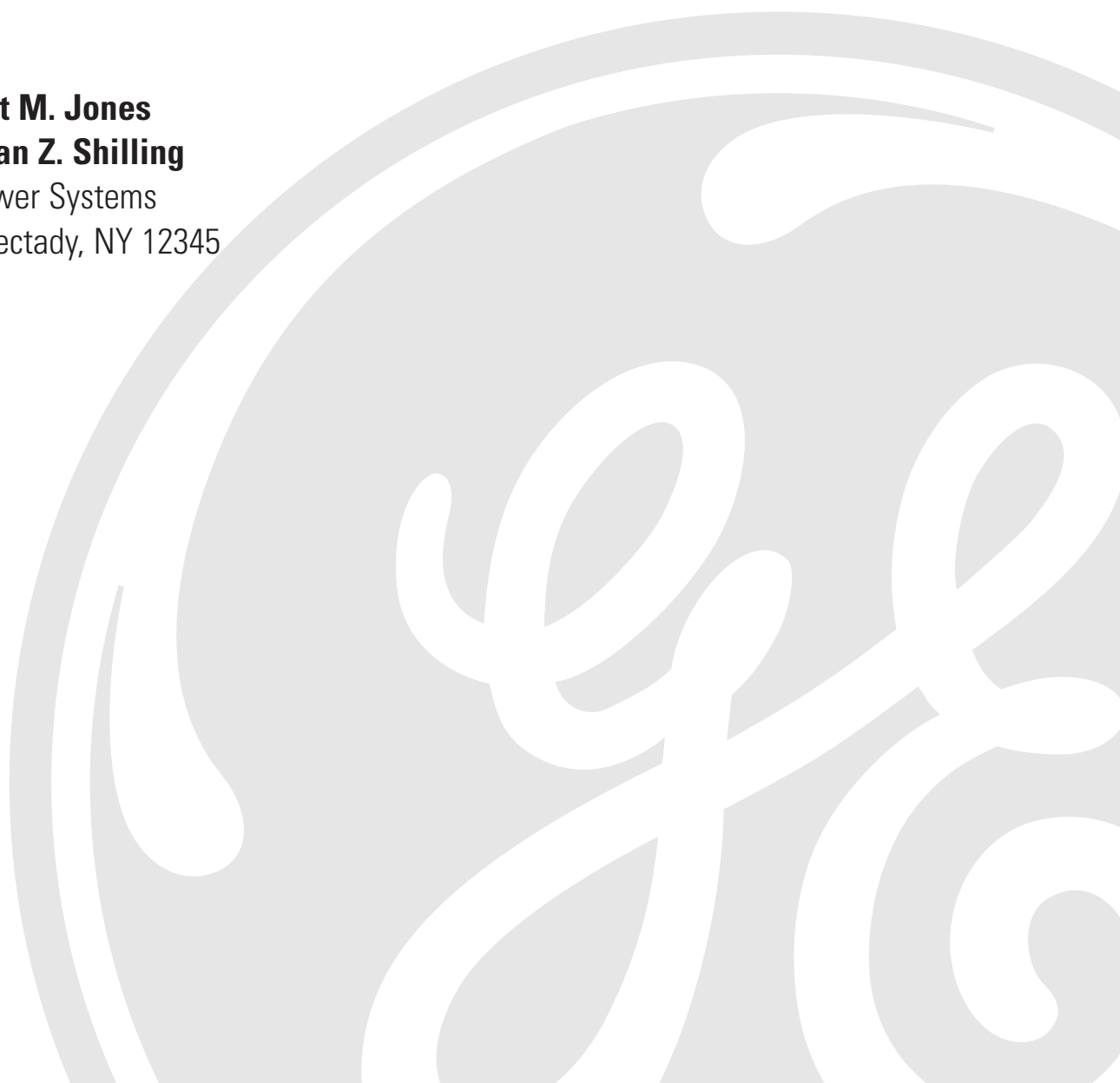
IGCC Gas Turbines for Refinery Applications

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Contents

Abstract	1
Introduction	1
IGCC Refinery Experience	3
Gas Turbine Advancements	6
<i>Fuel Flexibility</i>	7
<i>Environmental Performance</i>	11
GE IGCC Gas Turbine Product Line	13
<i>Economic Considerations</i>	15
Conclusion	15
List of Figures	16

Abstract

Integrated Gasification Combined Cycle (IGCC) plant designs are successfully operating and meeting challenging service requirements at several world-class refinery locations around the globe. Advancements in gasification, air separation, syngas cleanup, and gas turbine combined cycle equipment designs have contributed to continuous improvements in system performance and operating characteristics. These improvements enhance the prospect for continued growth in the IGCC refinery segment. Today's challenge for IGCC systems is to meet market requirements (which demand lower capital costs, improved operating reliability, and increased fuel flexibility) in combination with increasing efficiency and environmental performance standards.

This paper focuses on improvements in gas turbine technology that contributed to the commercialization and leadership of IGCC systems for the clean conversion of refinery residues and solid wastes to economical “poly-generation” of power and other high valued by-products used by the refiner.

Environmental performance is a key benchmark for contemporary IGCC plant design. IGCC's high marks in environmental performance stem from both the fundamental characteristics of the process and advances in gas turbine technology. The early breed of commercial IGCC refinery projects (at Texaco El Dorado and Shell Pernis) still achieve performance in criteria pollutants that are better than that of many direct-combustion technologies. IGCC's viability is ensured by its capability to meet tighter emissions standards for criteria pollutants including NO_x, SO_x, and particulates.

Fuel flexibility provides a hedge against potential excursions in both fuel cost and availability. The robustness of gasification technology to

deal with a wide range of solid and liquid fuels has been demonstrated in refinery applications fueled by heavy oil and petroleum coke residues—integrated with systems providing both power generation and chemical co-production. Current gas turbine combustion control systems provide for full or combined “co-firing” of synthesis gas with natural gas or distillate back-up fuels.

To date, GE gas turbines have accumulated more than 499,000 fired hours on synthesis fuel gas (of which 132,000 hours were fired on syngas derived from refinery feedstocks). This broad experience—enabled in large part by developments in gas turbine technology—serves as a superb entitlement for environmentally superior value generation from poor quality, low cost opportunity fuels.

Improvements in gas turbine performance on low heating value syngas fuels have enhanced the economics of IGCC systems to where it is a clear choice for new power generation at refineries. GE has a total of ten IGCC projects that have gone into syngas operations, with five more plants either beginning or planned for operation within the next four to five years. Nine of these fifteen plants are associated with refinery operations. GE continues to invest in turbine product development efforts allowing for increased performance benefits with liquid and solid fuel IGCC projects.

Introduction

Integrated Gasification Combined Cycle (IGCC) systems are receiving increased recognition as flexible, environmentally superior solutions for the conversion of solid and heavy liquid feedstock to power, co-generation steam, and other chemical production purposes. The capability of IGCC systems to use opportunity fuels to produce high value co-products along

IGCC Gas Turbines for Refinery Applications

with power generation enhances the economic viability of new projects. The co-production of chemicals and other utility products required by refineries is a key advantage afforded by IGCC technology. By fully utilizing the capabilities of modern combined cycle designs, IGCC systems are able to achieve exceptional levels of environmental performance, availability, and efficiency at a competitive cost of electricity.

With the production of conventional syngas fuel components, the opportunity exists to further separate carbon elements prior to combustion and sequester CO₂ when necessary. Improvements in advanced gas turbine technologies—allowing for increased power densities, improved cycle efficiencies, and lower installed costs—will continue to enhance IGCC systems to provide increased benefits and capabilities to refineries for the foreseeable future.

The environmental legislation proposed in the U.S. to reduce sulfur content in transportation fuels from >250 ppm to <15 ppm by the year 2006 has many refiners facing costly process design changes. The crude slate available to

U.S. refiners continues to reflect increasing sulfur content and decreasing quality as more diversified supplies come to market. (See Figure 1.) At the same time there is an increasing demand for middle distillates. The incremental capital cost to refiners to meet these requirements is projected to be more than \$8 billion, which figures to add \$0.06 per gallon to current fuel pump prices nationwide. Similarly, the hydro-treatment needed to increase light petroleum production requires hydrogen from the expansion of coking facilities. The net effect is an increase in petroleum coke production coming from U.S. refining, which is either stockpiled or marketed for export. Given increased worldwide environmental awareness, combined with a general acceptance of the Kyoto agreements, there is a shrinking global market available for petroleum coke.

The logical solution for refiners is to utilize pet coke on site as a ready fuel source for the beneficial production of power and/or steam products. The qualifying technologies suitable for providing this energy conversion are quickly

Refinery Segment

Higher Sulfur Residuals Favor IGCC

- Transportation fuel Sulfur will change from >250 ppm to <15 ppm by '06

Increased Petroleum Coke Production

- Increasing demand for middle distillates
- Hydrogen from expansion of coking facilities and IRCC

Kyoto & Enviro Shrinking Market for Pet Coke

- Pet coke stockpiled or handled by middlemen for blending to saleable fuel
- Several countries are restricting new coking capacity or import pending environmental solutions

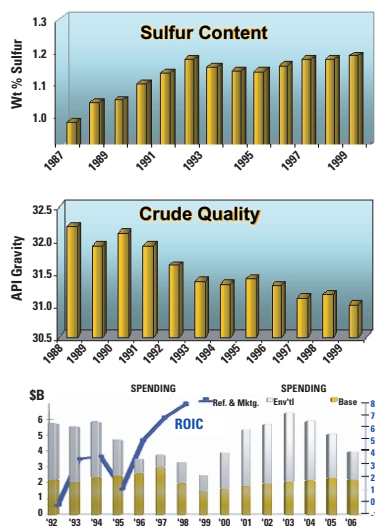


Figure 1. Refinery drivers

IGCC Gas Turbines for Refinery Applications

reduced to IGCC and CFBC (Circulating Fluidized Bed Combustion), owing to strict environmental emissions standards. A technology assessment illustrating comparative source volume reduction, air emissions, and annual disposal costs is shown in *Figure 2*. IGCC technology clearly provides significant environmental advantages for air emissions and lower disposal costs albeit at higher initial capital investment. When operating costs, flexibility for co-production, and collateral environmental costs are factored into the financial analysis, IGCC can provide improved project net present value.

This paper discusses the features, capabilities, and experience of gas turbines applied to IGCC systems designed for efficient conversion of refinery waste liquid and solid petroleum residues to useful energy products.

IGCC Refinery Experience

An IGCC plant is the product of collaboration between major subsystem providers and the

owner to form an optimized design that meets demanding process and environmental requirements. *Figure 3* shows the five major technologies contributing to this design:

- Gasification island
- Gas treatment
- Air separation
- Combined-cycle power block
- Integration

Typically for existing refinery applications, IGCC plants provide a number of useful by-products which contribute to the economic viability of the overall integrated facility. These products can include power, steam, and hydrogen—depending upon project specific needs.

There have been five refinery-based IGCC projects using GE-designed gas turbines that have gone into commercial operation during the past six years. (See *Figure 4*.) Included among these are two petroleum coke refineries (Texaco El Dorado and Motiva Enterprises) and

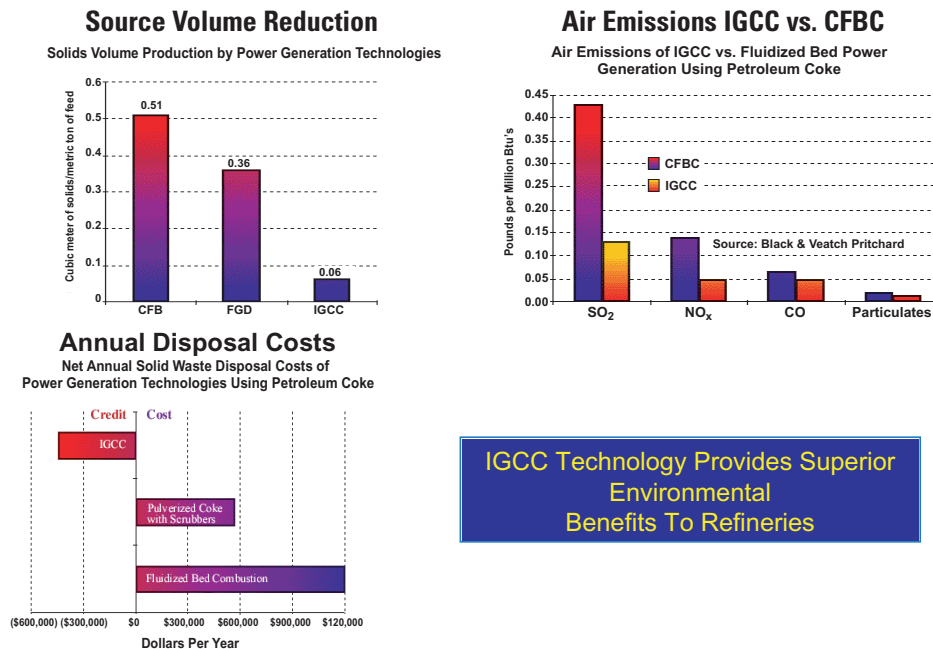


Figure 2. Refinery competitive assessment

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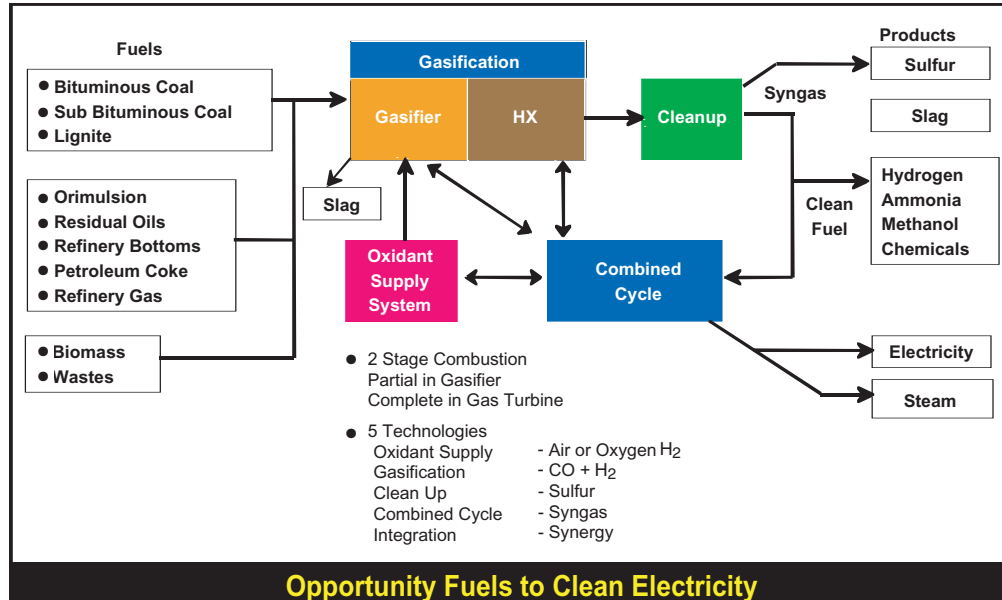


Figure 3. IGCC process

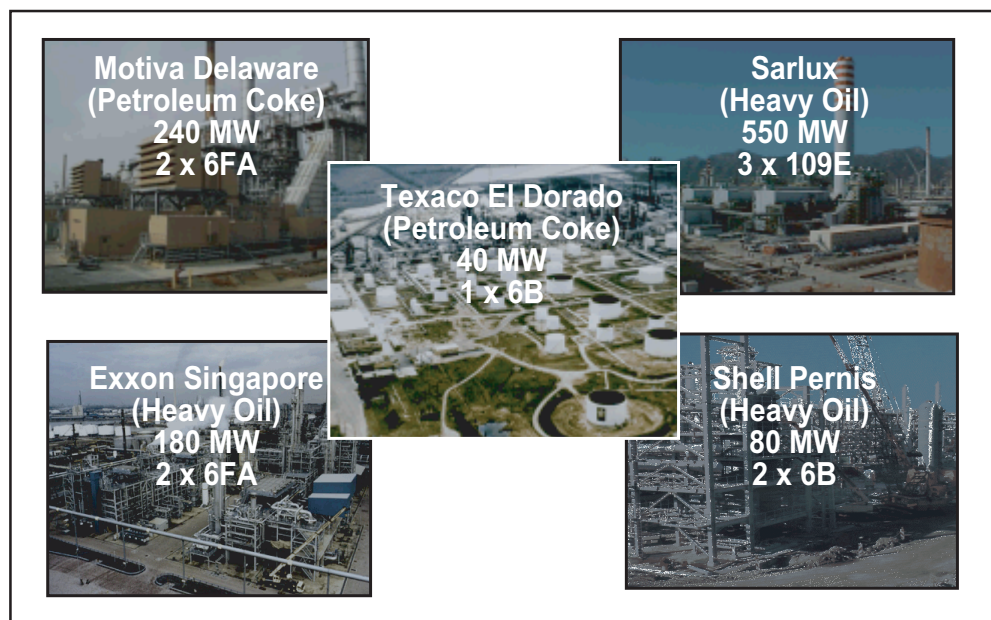


Figure 4. GE gas turbines in refinery IGCCs

three heavy oil refineries (Shell Pernis, Sarlux, and Exxon Singapore). The gas turbines used in these projects included both E class (6B, 9E) units and more recently advanced F class (6FA) gas turbine technologies.

Power production ranges from a single 6B 40 MW gas turbine (the first refinery IGCC GE

unit) at the Frontier Oil refinery in El Dorado, Kansas—to the world’s largest IGCC cogeneration plant (serving the Saras refinery in Sarroch, Italy), which produces more than 550 MW and 185 tons of steam from three single-shaft combined cycle units (3x109E). Another significant IGCC co-production facility at Shell’s

IGCC Gas Turbines for Refinery Applications

Pernis refinery in Rotterdam, Netherlands includes two 6B units that co-generate to produce power and steam from syngas and other available refinery gases.

More recently, two 6FA advanced gas turbines units with heat recovery steam generators are in commercial operation at Exxon Chemical's facility on Jurong Island, Singapore. Similarly, another two 6FA units at the Motiva Enterprises refinery in Delaware City are beginning to fire on syngas with improved gasification operations.

Taken as a whole, these five plants have accumulated in excess of 132,000 fired hours on syngas fuels, and represent ~26% of the total GE experience base (now expected to top 500,000 fired hours before year end) for gas turbines burning low heating value fuels. (See Figure 5.)

Low calorific value (LCV) fuel applications—including refinery IGCCs and steel mills—encompass a wide variety of operational demands and time-varying fuel gas compositional requirements. For example, the 6FAs at

Exxon's Singapore refinery are expected to operate over a range of syngas fuel compositions, including co-firing with start-up fuels. Other units such as the 9Es at Sarlux IGCC are designed to operate at baseload conditions, operating on fairly consistent syngas once the unit has achieved start-up. The composition of the syngas consumed in these operating units also varies considerably from project to project. (See Figure 6.)

A measure of this project-to-project variability is the hydrogen content of the fuel. As shown in Figure 6, the hydrogen content for these applications varies widely from a low of 8.6% at ILVA to a high of 61.9% at Schwarze Pumpe—with heating values of 193 and 318 Btu/SCF respectively. These diverse conditions and operating demands emphasize the importance of sound combustion system design. For most projects a diluent is introduced at the combustor to reduce NO_x emissions and consequently increase output through turbine expansion. Air extraction from the gas turbine can also be

GE Syngas Hours of Operation						
September 2002						
Customer	Type	MW	Syngas Start Date	Hours of Operation		
				Syngas	N.G.	Dist
Cool Water	107E	120	5/84	27,000	-	1,000
PSI	7FA	262	11/95	24,500	1,800	4,100
Tampa	107FA	250	9/96	33,500	-	7,101
Texaco El Dorado	6B	40	9/96	30,660	56,372	-
Sierra Pacific	106FA	100	-	0	48,438	-
SUV Vresova	209E	350	12/96	90,040	1,715	-
Schwarze Pumpe	6B	40	9/96	37,600	-	3,800
Shell Pernis	2x6B	80	11/97	58,250	22,687	-
ISE / ILVA	3x109E	540	11/96	141,000	4,732	-
Fife Energy	6FA	80	-	0	26,220	-
Motiva Delaware	2x6FA	240	8/00	450	-	5,290
Sarlux	3x109E	550	10/00	33,100	-	10,500
Piombino	109E	150	10/00	12,400	2,930	-
Exxon Singapore	2x6FA	180	3/01	9,700	12,776	921
			Totals	499,100		
■ Refinery Applications						
IGCC Product Technology — Proven Through Operating Experience						

Figure 5. GE gas turbine syngas experience

IGCC Gas Turbines for Refinery Applications

Syngas	PSI	Tampa	<i>El Dorado</i>	<i>Pernis</i>	Sierra Pacific	ILVA	Schwarze Pumpe	<i>Sarlux</i>	Fife	<i>Exxon Singapore</i>	<i>Motiva Delaware</i>	<i>PIEMSA</i>	Tonghua
H ₂	24.8	37.2	35.4	34.4	14.5	8.6	61.9	22.7	34.4	44.5	32.0	42.3	10.3
CO	39.5	46.6	45.0	35.1	23.6	26.2	26.2	30.6	55.4	35.4	49.5	47.77	22.3
CH ₄	1.5	0.1	0.0	0.3	1.3	8.2	6.9	0.2	5.1	0.5	0.1	0.08	3.8
CO ₂	9.3	13.3	17.1	30.0	5.6	14.0	2.8	5.6	1.6	17.9	15.8	8.01	14.5
N ₂ + AR	2.3	2.5	2.1	0.2	49.3	42.5	1.8	1.1	3.1	1.4	2.15	2.05	48.2
H ₂ O	22.7	0.3	0.4	--	5.7	--	--	39.8	--	0.1	0.44	0.15	0.9
LHV _v - Btu/ft ³	209	253	242	210	128	183	317	163	319	241	248	270.4	134.6
- kJ/m ³	8224	9962	9528	8274	5024	7191	12,492	6403	12,568	9,477	9,768	10,655	5304
T _{fuel} F/C	570/300	700/371	250/121	200/98	1000/538	400/204	100/38	392/200	100/38	350/177	570/299	338/170	-
H ₂ /CO Ratio	.63	.80	.79	.98	.61	.33	2.36	.74	.62	1.26	.65	.89	.46
Diluent	Steam	N ₂	N ₂ /Steam	Steam	Steam	--	Steam	Moisture	H ₂ O	Steam	H ₂ O/N	N ₂	n/a
Equivalent LHV													
- Btu/ft ³	150	118	113*	198	110	--	200	--	*	116	150	129	134.6
- kJ/m ³	5910	4649	4452	7801	4334	--	7880	--	--	4600	5910	5083	5304

* Always co-fired with 50% natural gas

Refinery Projects

Demonstrated: Syngas Fuel Flexibility

Figure 6. GE gas turbine syngas capabilities

used to supply all or a portion of compressed air for the air separation plant. This reduces the capital for compressors, while providing gas turbine compressor margin to contend with higher resistance from increased fuel mass flow and nitrogen injection in the gas turbine.

Refinery-based IGCC projects can also be phased in over time to meet changing operational requirements. The Total refinery in Gonfreville, France for example, will first install a natural gas fired combined-cycle cogeneration plant to produce steam and power for initial operations. It is planned to add the IGCC process later to produce valuable chemical products needed by the refinery at that time—and also provide a LCV fuel feed for the existing cogeneration facility.

By combining the combustion technology with output enhancement capability, IGCC plants can be designed with an optimum and eco-

nomix of fuel and diluents. For example, CO₂ streams generated from hydrogen production may be effectively used in the gas turbine as a diluent for NO_x reduction. The multi-generation capability afforded by the IGCC process design provides significant operating flexibility to meet changing refinery needs over time.

Gas Turbine Advancements

Gas turbine technology development has greatly contributed to increased use of IGCC power plants worldwide. Several specific areas of development have resulted in 21 IGCC plants currently on line, in construction or development. (See Figure 7.) Fuel flexibility and environmental performance are proving to be critically important to contemporary IGCC plants designed for integrated operations with refineries. Significant advancements have been made in each of these areas to extend the viability of IGCC technology.

IGCC Gas Turbines for Refinery Applications

Customer	C.O. Date	MW	Application	Gasifier
SCE Cool Water - USA	1984	120	Power/Coal	Texaco - O ₂
LGTI - USA	1987	160	Cogen/Coal	Destec - O ₂
Demkolec - Netherlands	1994	250	Power/Coal	Shell - O ₂
PSI/Global - USA	1995	260	Repower/Coal	Destec - O ₂
Tampa Electric - USA	1996	260	Power/Coal	Texaco - O ₂
Texaco El Dorado - USA	1996	40	Cogen/Pet Coke	Texaco - O ₂
SUV - Czech.	1996	350	Cogen/Coal	ZUV - O ₂
Schwarze Pumpe - Germany	1996	40	Power/Methanol/Lignite	Noell - O ₂
Shell Pernis - Netherlands	1997	120	Cogen/H ₂ /Oil	Shell - O ₂
Puertollano - Spain	1998	320	Power/Coal/Pet Coke	Prenflow - O ₂
Sierra Pacific - USA	1998	100	Power/Coal	KRW - Air
ISAB - Italy	1999	500	Power/H ₂ /Oil	Texaco - O ₂
API - Italy	2000	250	Power/H ₂ /Oil	Texaco - O ₂
MOTIVA - Delaware	2000	240	Repower/Pet Coke	Texaco - O ₂
Sarlux/Enron - Italy	2000	550	Cogen/H ₂ /Oil	Texaco - O ₂
EXXON - Singapore	2000	180	Cogen/H ₂ /Oil	Texaco - O ₂
<hr/>				
FIFE - Scotland	2001	120	Power/Sludge	BGL - O ₂
EDF/ Total - Gonfreville	2003	400	Power/H ₂ /Cogen/Oil	Texaco - O ₂
FIFE Electric - Scotland	2003	400	Power/Coal/RDF	BGL - O ₂
Nihon Sekiyu - Japan	2004	350	Power/Oil	Texaco - O ₂
PIEMSA	2006	800	Power/H ₂ /Oil	Texaco - O ₂
<hr/>				
■ GE GTs		5,810		

21 Global IGCC Plants

Figure 7. Current IGCC plants

Fuel Flexibility

Gas turbine fuel flexibility is measured by four key characteristics:

- Capability to deal with low heating value fuel containing varying hydrogen content
- Operability on a wide range of fuels, including startup, transfers and system upsets
- Capability to co-fire synthesis gas with natural gas over a wide total heat input
- Low emissions

The key component in meeting these requirements is the gas turbine combustor.

Combustor Design: The gas turbine combustor is the principal process orifice for an entire IGCC plant. The standard IGCC combustor for GE gas turbines is derived from the Multi-Nozzle Quiet Combustor (MNQC). (See Figure 8.) Since hydrogen is a typical constituent of synthesis gases, Dry Low NO_x (DLN) combustors are not appropriate for synthesis gas due to hydrogen's high flame speed, which can initiate flashback

and combustor failure. GE's contemporary IGCC combustor has evolved to an increased diameter standard that allows a wider range of fuel constituents and co-firing capability.

The lower specific calorific content of synthesis gas requires that the combustor be able to process more than five times the fuel flow relative to a natural gas combustor. Also, combustion of 100% syngas results in NO_x emissions that exceed regulatory requirements, so dilution of the syngas with nitrogen, water, CO₂ or combinations is needed to achieve desired performance. Note that the quantity of diluent needed to achieve acceptable NO_x concentrations typically is equal or greater than the quantity of synthesis gas. This means the flow of diluent plus fuel in the combustor may be eight times or more than that of a natural gas machine. The combustion engineer's challenge is to deliver stable, low-noise combustion, acceptable liner temperatures and full fuel burnout despite relatively high fuel injection velocities. The key to achieving this is full-scale testing.

IGCC Gas Turbines for Refinery Applications

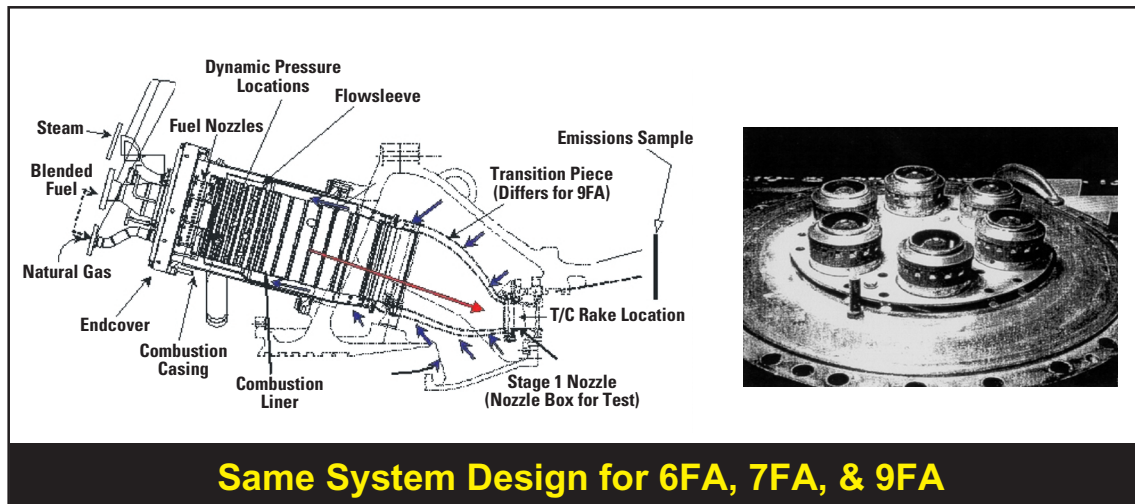


Figure 8. GE multi-nozzle combustor

Owing to the can-annular design of GE turbines, a single can may be fully tested and proven at full airflow and pressure for many machines over the entire range of cycle conditions before releasing it to the field. The performance of new designs is subsequently verified in the field. In 2002, GE successfully commissioned its new IGCC combustion laboratory in Greenville, S.C. (See Figure 9.) This state-of-the-art facility includes two test stands dedicated solely to IGCC combustion development. Each single burner test stand is designed to simulate the internal flow patterns of a particular machine. Fuel blending tank farms and gas conditioning skids allow for simulation of fuel characteristics representative of all anticipated fuel and gasifier types. Compressor capability is capable of simulation of up to H-turbine combustor conditions.

IGCC machines require a start-up fuel because of the dangers of starting on fuels containing hydrogen. This allows many plants to begin operation on backup fuel with introduction of IGCC and synthesis gas capability phased-in at a later date. The dual fuel capability has been

developed into a standard co-firing feature so users can design plants for higher power output if syngas production is restricted, or if a plant is contemplating parallel or staged co-production for utilization of syngas.

Fuel Flexibility: The application of IGCC technology to refinery plants presents another interesting synergistic opportunity to incorporate a water shift reactor for hydrogen production to feed both the refinery and power island. (See Figure 10.) GE has completed feasibility testing for 100% H₂ and 100% CO fuel to define the entire combustion map. The H₂-only case is representative of pre-combustion removal of CO as CO₂ for Enhanced Oil Recovery (EOR) or sequestration, and allows for CO₂-free power plants. Figure 11 indicates that ratios of 50/50 hydrogen/nitrogen can produce very low NO_x as well as provide enhanced output in a modern IGCC gas turbine. With this new combustion technology it may be possible to use IGCC for CO₂-free plants at about 15% extra cost with approximately 3 points of reduction in net plant efficiency.

IGCC Gas Turbines for Refinery Applications

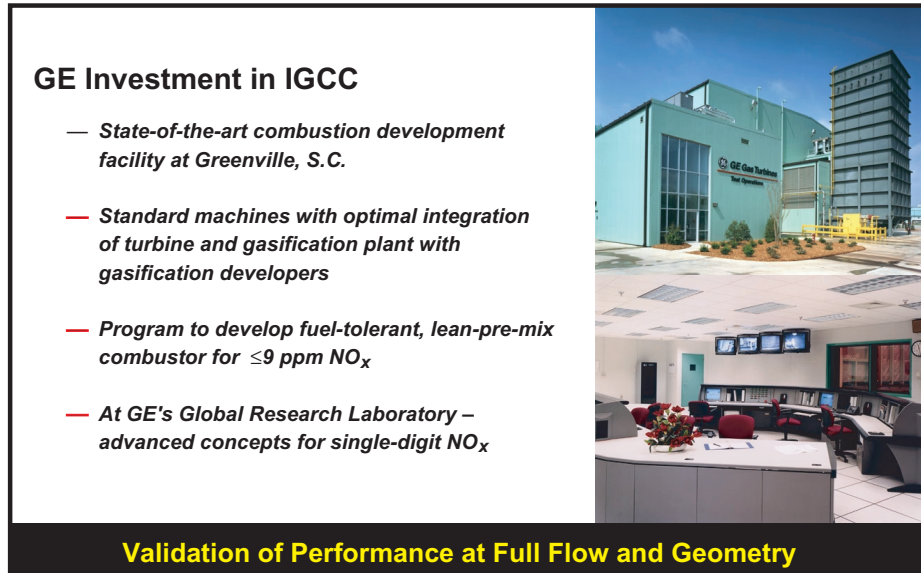
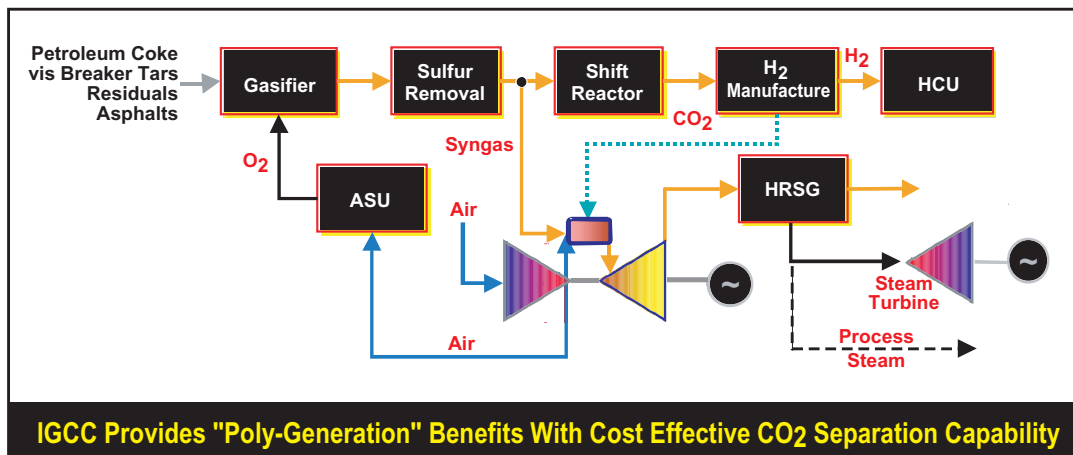


Figure 9. GE combustion test facility



IGCC Provides "Poly-Generation" Benefits With Cost Effective CO_2 Separation Capability

Figure 10. Refinery IGCC flow sheet

Operability: Mixed fuel operation or co-firing has become an important operating mode to enhance project economics. Co-firing was first used at the Texaco El Dorado IGCC plant in Kansas where the gasifier provides about one-third (1/3) of the gas turbine thermal input requirements. Since starting in 1996 the El Dorado GT has performed at better than 97% power availability. More recently, Exxon Singapore also has this feature. The standard types of fuel systems and operating characteristics are provided in *Figure 12*. For a dual gas

design the co-firing operability standard is in the 70/30% range. This range is dictated by combustion system controllability requirements at low fuel flow rates. However, a new system now operating at Exxon Singapore is capable of operating over the 90/10% range. Mixed fuel operation can generally be accommodated down to ~30% load. For a dual fuel—syngas/distillate application, the distillate can be controlled down to 10% while the syngas is generally regulated over the 30%–70% range.

IGCC Gas Turbines for Refinery Applications

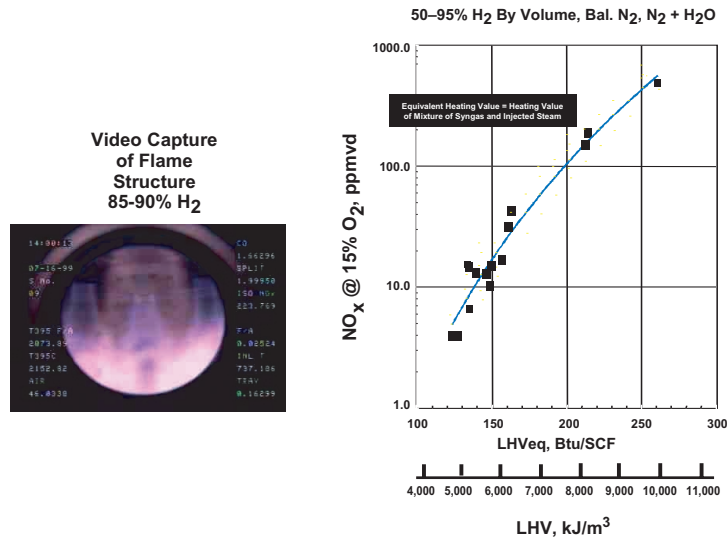


Figure 11. GT hydrogen combustion capability for CO₂ removal

Type	Operational capabilities for IGCC systems*	Fuel Operability Range
1	Baseline Distillate/SG system - Similar to other dual fuel standard combustor machine except inert purge on SG side. - Cofiring capability provided for Singapore (ADO/Syngas)	100% SG 100% DIST 90% SG/ 10% dist 30% SG/ 70% dist
2	Baseline NG/SG system - NG and syngas travel down separate paths - Simplest, least expensive	100% SG 100% NG 65% SG/ 35% NG 35% SG/ 65% NG
3	Extended Turndown system - Verified at Exxon-Singapore - Manifolds interconnect via transfer valves - Exclusion zone 10% wide from 15% to 30% NG	100% SG 100% NG 90% SG/ 10% NG 10% SG/ 90% NG
4	Simplified Extended Turndown System - Same as #3 except 35% min SG - Eliminates exclusion zone - Simplifies control logic	100% SG 100% NG 85% SG/ 15% NG 35% SG/ 65% NG

* All assumed to provide for maintaining load set point using NG modulation.

Figure 12. Syngas control configurations

A tri-fuel dual gas system design concept was developed for the Gonfreville refinery IGCC project. This dual manifold system incorporates fuel nozzles and piping sized for natural gas and refinery gas, with a separate syngas manifold and nozzle assembly to handle syngas. A transfer valve arrangement is utilized to interconnect the two systems during fuel transfers and co-fir-

ing operations. A simplified fuel system schematic illustrates the fuel module configuration, including inert and main air purge systems for this design. (See Figure 13.) Both nitrogen and air from the compressor discharge (CPD) are used for line purge during various operating modes.

IGCC Gas Turbines for Refinery Applications

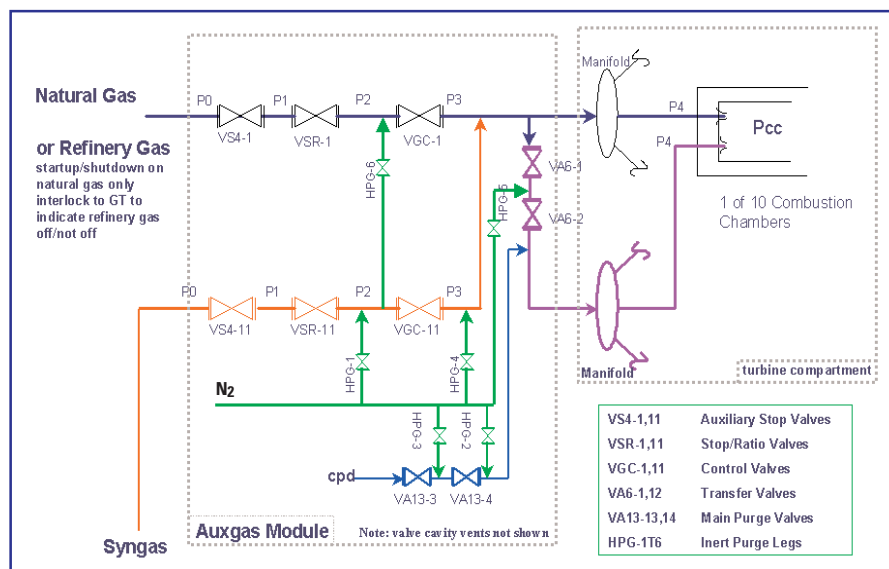


Figure 13. 90/10 Tri-fuel dual gas system

Environmental Performance

Emissions: As already discussed, NO_x reduction as well as power augmentation 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.

In general, IGCC NO_x emissions will depend upon the specific fuel characteristics and the type, quality and quantity of available diluent. Figure 15 lists NO_x emission level experience achieved to date with GE gas turbine units oper-

ating at several IGCC plant facilities over the past eighteen years, in addition to predicted levels for other IGCC sites currently under development. Figure 16 summarizes the U.S. permitted NO_x levels for IGCC plants past and present. The TECO Polk IGCC plant was originally permitted at 25 ppm NO_x but recently underwent a BACT re-determination to 15 ppm—equivalent to 0.065 lb/MMBtu—which is well below recently permitted new pulverized coal plants. The 6FA gas turbines at the Motiva refinery have demonstrated single digit NO_x at 85 MW approaching full load.

Process Integration: Most recent IGCC efforts for refineries have concentrated on high-to-medium pressure oxygen-blown systems due to the large size of plants and particularly the co-production of chemical products. The IGCC plant design for PIEMSA has included partial integration where ~1/3 of the ASU air requirement is extracted from the gas turbines. On Model F machines the IGCC combustor allows for air extraction up to 20% (full integration), without affecting turbine cooling air. Overall IGCC

IGCC Gas Turbines for Refinery Applications

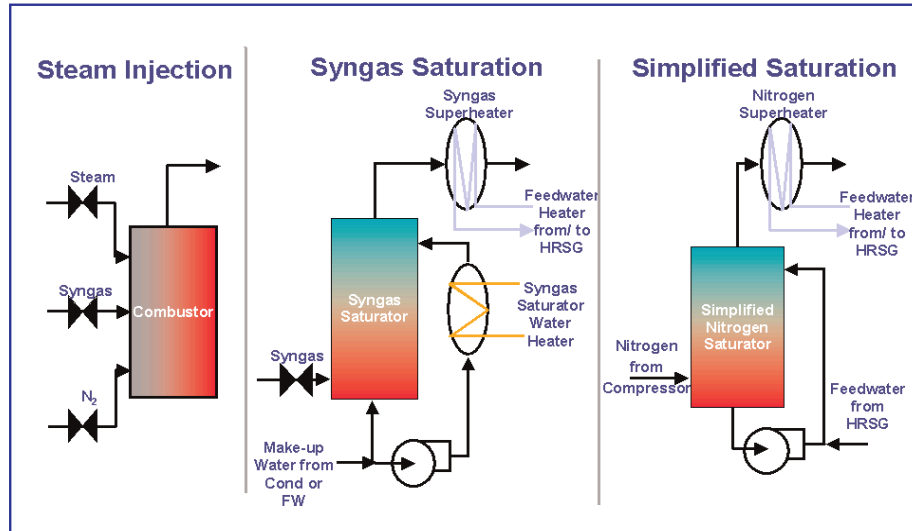


Figure 14. Moisturization alternatives

Operating	NO _x PPMVD @15%O ₂
Cool Water	25
PSI - Wabash	<25
Tampa - Polk	<25
<i>Texaco - El Dorado</i>	<25
<i>Motiva - Delaware</i>	9 - 15
<i>Sarlux - Italy</i>	<30
<i>Exxon - Singapore</i>	42
Predicted	
Sierra Pacific - Pinon	<42 (<9 Thermal)
<i>Gonfreville</i>	35
<i>PIEMSA</i>	30

Figure 15. Typical NO_x emissions

optimization for a specific project depends upon site operating requirements and fuel type to determine the kind of airside integration to be used, if any. In larger plants, IGCC operability can be enhanced with partial air integration allowing for reduced ASU MAC size by utilizing the excess air available from the gas turbine compressor.

Controls: An important consideration for IGCC

operations is the method of overall plant control. IGCC plants can be designed to follow the gasifier syngas production. They can also be designed to meet electrical load demand either by regulating the gasifier to follow the demand, or by co-firing with backup fuel. The latter is more frequently used as it provides a higher degree of control and faster response than gasifier follow. The design validation process nor-

IGCC Gas Turbines for Refinery Applications

Representative USA IGCC NO_x Levels and Permits			
Plant	Date	Fuel	NO_x (ppmbv@15% O ₂)
Cool Water	1984	Coal	25
Wabash River	1995	Coal/Pet Coke	< 25
Polk	1996	Coal/Pet Coke	< 25
Texaco El Dorado	1996	Pet Coke/ Refinery Wastes	< 25
Motiva Delaware	2000	Pet Coke	15
Polk BACT Redetermination	2002	Coal/Pet Coke	15
Kentucky Pioneer*	2001	Coal	15**
* Permit issued 6/17/2001 ** Subject to re-evaluation			

Figure 16. NO_x emissions for recently permitted IGCC plants

mally incorporates a GT control simulation. The system study of startup and shutdown modes and ambient effects at the beginning of the power plant design effort is crucial and a significant design aid to establish an integrated control strategy.

GE IGCC Gas Turbine Product Line

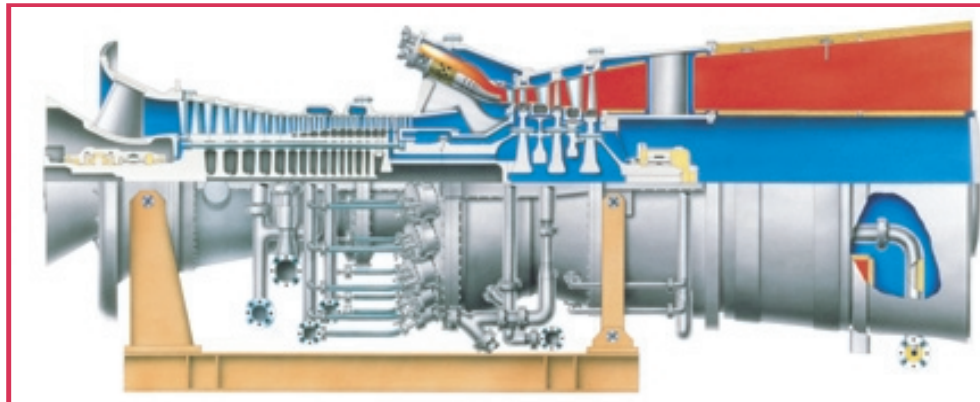
GE pioneered IGCC nearly three decades ago and has developed a broad dedicated IGCC product line of gas turbines and matching steam turbines ranging from 10 to 300 MW. (See *Figure 17.*) GE gas turbines having LCV fuel capabilities are proven products with a total of 22 units sold, and collectively accumulated over 340,000 hours of operation on synthesis gas from gasification.

Gas turbines for IGCC applications have basic technical and functional requirements that are different from those of a gas turbine operating on natural gas. Therefore, IGCC gas turbines must be modified with features that allow for efficient and reliable syngas service. The IGCC-

specific features relate primarily to the combustion and fuel system components but also include special fire protection, packaging, and controls modifications.

GE has developed the technology to provide power producers with a complete range of gas turbines that can be efficiently integrated with IGCC plants and refineries to generate least cost electricity and co-generation steam while meeting strict environmental regulatory requirements. With new product introduction programs (NPI), GE continues to improve its IGCC gas turbine product line technology and competitiveness. As an example, *Figure 18* shows the evolution of the advanced 7FA gas turbine power output from the initial 150 MW natural gas rating to the present 197 MW on syngas (more than a 30% increase) over a five-year period—with expectations for an additional 7% increase by the year 2006 for applications. Similar advancement programs are in the planning stages for the 6FA and 9FA IGCC products.

IGCC Gas Turbines for Refinery Applications



IGCC 7FA

GAS TURBINES		IGCC	
Model	Syngas Power Rating	Model	Net Plant Power Rating
GE10	10 MW (50/60 Hz)	106B	60 MW (50/60 Hz)
6B	40 MW (50/60 Hz)	107EA	130 MW (60 Hz)
7EA	90 MW (60 Hz)	109E	210 MW (50 Hz)
9E	150 MW (50 Hz)	106FA	130 MW (50/60 Hz)
6FA	90 MW (50/60 Hz)	107FA	280 MW (60 Hz)
7FA	197 MW (60 Hz)	109FA	420 MW (50 Hz)
9FA	286 MW (50 Hz)		

Figure 17. GE IGCC GT/CC product line

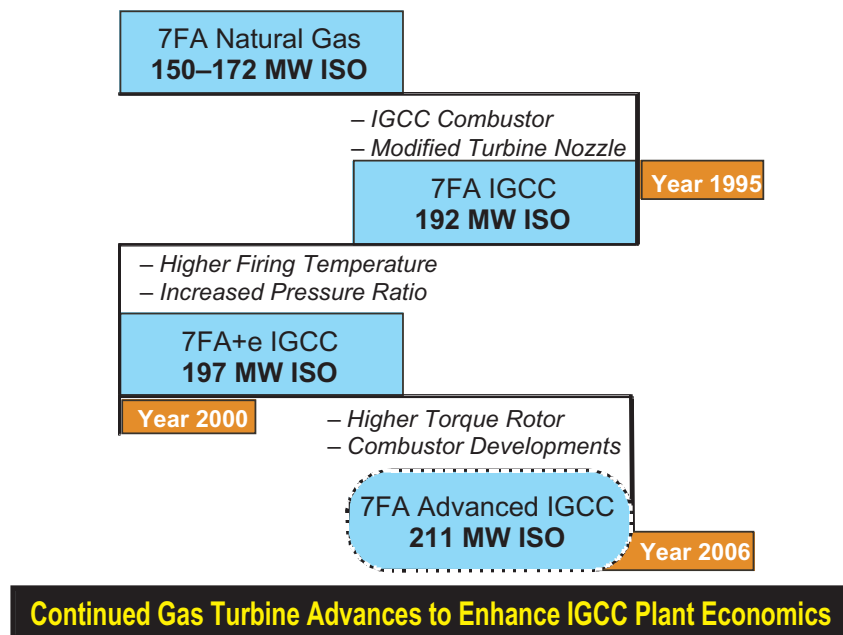


Figure 18. 7FA IGCC gas turbine product development

IGCC Gas Turbines for Refinery Applications

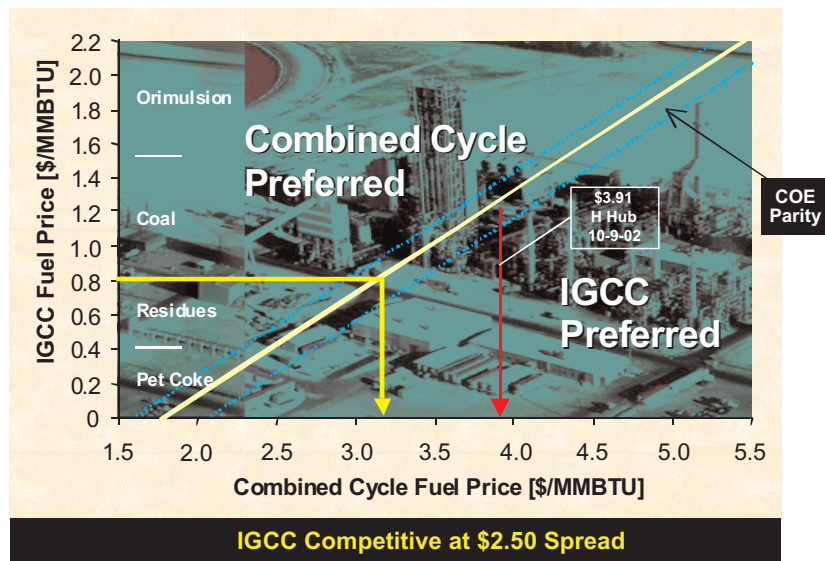


Figure 19. Breakeven fuel price comparison

The core of an IGCC gas turbine design is based on combustion system development and adaptation through full scale laboratory testing. Advanced programs to develop fuel-tolerant lean pre-mix syngas combustors for ≤ 9 ppmvd NO_x capability are being planned as the next logical extension of dry low NO_x combustion technology. At GE's Global Research Laboratory, advanced combustion concepts for single-digit NO_x are in the conceptual planning stage with promise for additional application to syngas and long term emissions reduction.

Economic Considerations

Figure 19 shows a COE breakeven curve developed for IGCC plants using various opportunity feedstocks versus natural gas combined cycle (NGCC). Namely, the graph directly compares cost competitiveness of IGCC and NGCC as a function of the respective fuel costs. This curve is based on 20-year averaged cost of electricity calculations for generic domestic 500 MW IGCC and NGCC plants. The conclusion: At

natural gas prices of \$2.5 per MMBtu higher than IGCC fuel prices, IGCC provides a cost of electricity equivalent to NGCC. Current natural gas pricing (e.g., Henry Hub-\$3.91/MMBtu-HHV, 10/9/02) would suggest that COE from refinery-based IGCC plants fueled by low cost opportunity fuels (e.g., residuals or pet coke) should be significantly lower than NGCC plants with spot-market fuel pricing.

Conclusion

Gas turbine improvements have come from operating experience 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. Current market drivers are favorable for refinery-based IGCC projects driven in part by high investment costs for environmental compliance. Contemporary IGCC plant designs are commercially viable with refinery operations owing to their broad capability to

IGCC Gas Turbines for Refinery Applications

use opportunity and low value waste fuels. IGCC technology enjoys compelling environmental advantages for waste fuel conversion to economical “poly-generation” products, with growth potential to meet future regulatory challenges. Furthermore IGCC economics are at parity or better than conventional solid fuel technologies using opportunity fuels. GE’s gas

turbine IGCC product line is experienced and well matched for refinery syngas applications, which favor the advanced F class turbine high output and efficiency performance attributes. Finally, the fuel flexibility and high system reliability afforded by today’s gas turbines are critically important to the economic success of refinery based IGCC projects.

List of Figures

Figure 1. Refinery drivers

Figure 2. Refinery competitive assessment

Figure 3. IGCC process

Figure 4. GE gas turbines in refinery IGCCs

Figure 5. GE gas turbine syngas experience

Figure 6. GE gas turbine syngas capabilities

Figure 7. Current IGCC plants

Figure 8. GE multi-nozzle combustor

Figure 9. GE combustion test facility

Figure 10. Refinery IGCC flow sheet

Figure 11. GT hydrogen combustion capability for CO₂ removal

Figure 12. Syngas control configurations

Figure 13. 90/10 Tri-fuel dual gas system

Figure 14. Moisturization alternatives

Figure 15. Typical NO_x emissions

Figure 16. NO_x emissions for recently permitted IGCC plants

Figure 17. GE IGCC GT/CC product line

Figure 18. 7FA IGCC gas turbine product development

Figure 19. Breakeven fuel price comparison