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PROJECT ENGINEERING – MECHANICAL
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TECHNOLOGY SCAN ON INTEGRATED GASIFICATION COMBINED CYCLE (IGCC)

1.0 COAL GASIFICATION & IGCC

1.1 Coal Gasification

Coal gasification is a process that converts coal from a solid to a gaseous fuel through partial oxidation. Once the fuel is in the gaseous state, undesirable substances, such as sulfur compounds and coal ash, may be removed from the gas by established techniques. The net result is a clean, transportable gaseous energy source.

In contrast to combustion process which works with excess air, gasification process works on partial combustion of coal with the oxygen supply controlled (generally 20 to 70% of the amount of O_2 theoretically required for complete combustion) such that both heat and a new gaseous fuel are produced as the coal is consumed.

$$C + {}^{1}/_{2}\, O_2 \xrightarrow{\text{gasification}} CO$$

$$C + H_2O \xrightarrow{\text{gasification}} CO + H_2$$

1.2 IGCC (Integrated Gasification Combined Cycle)

The IGCC process is a two-stage combustion with cleanup between the stages. The first stage employs the gasifier where partial oxidation of the solid/liquid fuel occurs by limiting the oxidant supply. The second stage utilizes the gas turbine combustor to complete the combustion thus optimizing the gas turbine/combined cycle (GT/CC) technology with various gasification systems. The SynGas produced by the Gasifiers however, needs to be cleaned to remove the particulate, as well as wash away sulfur compounds and NOx compounds before it is used in the Gas Turbine. ***It is the Integration of the entire system components which is extremely important in an IGCC Plant.***
Various sub-systems of an IGCC Plant thus are:

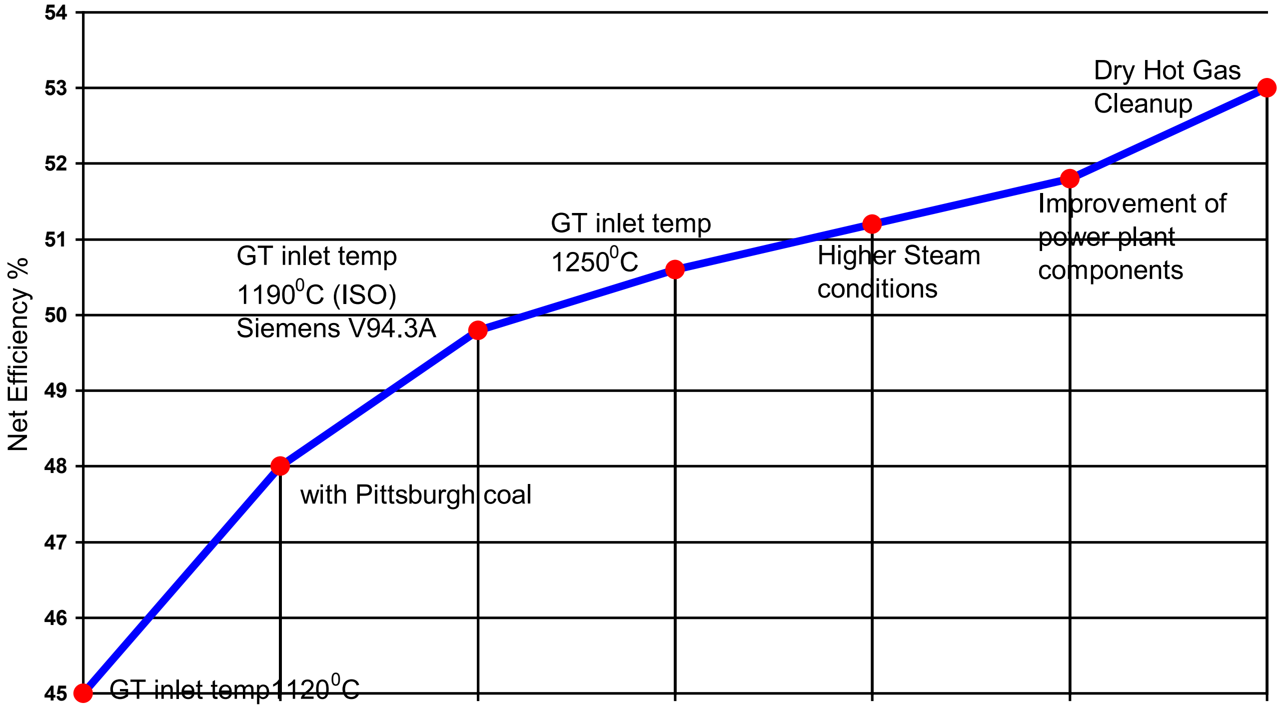
i) Gasification Plant
ii) Power Block
iii) Gas Clean-up System

2.0 Relative Merits of IGCC over Conventional PC Fired Technology

- **Potential for higher efficiencies**

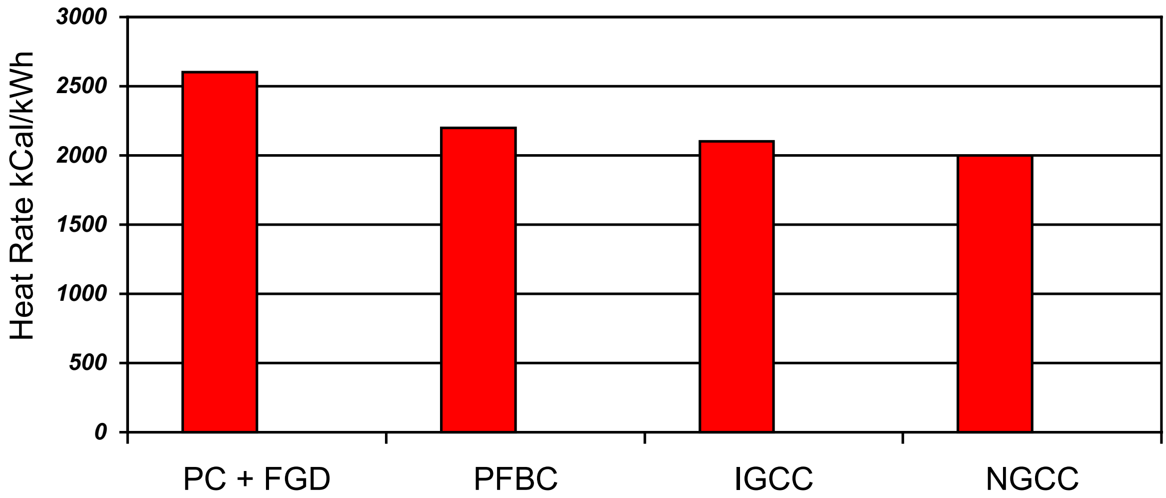
Recent advances in the Gas Turbine technologies have presented great potential towards much higher gas turbine efficiencies. Increasing the firing temperatures and utilizing materials that withstand higher temperatures can increase the efficiency of gas turbine. Continuous developments have been taking place in the newer materials of construction thus consequent higher gas turbine performance. At present the efficiency of gas turbines is in the range of 45-50% which is projected to go upto 60% with the development of H-technology by GE. The advances in gas turbines would improve the overall efficiency of IGCC plant.

EXPECTED IMPROVEMENTS OF IGCC POWER PLANT EFFICIENCY



- **Lower Heat Rates & Increased Output**

  The heat rates of the plants based on IGCC technology are projected to be around 2100 kCal/kWh compared to the heat rates values of around 2500 kCal/kWh for the conventional PC fired plants.



- **Flexibility to accept a wide range of fuels**

  IGCC technology has been proven for a variety of fuels, particularly heavy oils, heavy oil residues, petcokes, and bituminous coals in different parts of the globe. In fact the same gasifiers can handle different types of fuels.

- **Environment Friendly Technology**

  IGCC is an environmentally benign technology. The emission levels in terms of NOx, SOx and particulate from an IGCC plant have been demonstrated to be much lower when compared to the emission levels from a conventional PC fired steam plant. **In fact, no additional equipment is required to meet the environment standards.**

3.0 Type of Gasifiers

The Coal Gasification requires the presence of an oxidant in the process. Air or Oxygen may be used as an oxidant and the gasifiers are accordingly known as either Air-Blown or Oxygen-Blown Gasifiers.

- Moving-bed
- Fluidized-bed
- Entrained-flow

Typical operating characteristics of the gasifiers are as follows:

	Moving Bed	**Fluidised Bed**	**Entrained Bed**
Exit Gas Temp. ^{0}C	420 - 650	920 - 1050	1200
Coal Feed size	< 50 mm	< 6 mm	< 100 mesh
Ash Conditions	Dry / Slagging	Dry / Agglomerating	Slagging

4.0 Technology Suppliers:

Different technology suppliers worldwide have developed the gasifiers which are either air-blown or oxygen-blown and are either of the moving bed, entrained bed or fluidised bed. The choice of the type of the gasifier is purely a factor of the coal/fuel characteristics. Various technology suppliers for the gasification process are as below:

Technology Supplier	**Coal Feed Type**	**Oxidant**	**Gasifier Type**
Texaco, USA /	Water Slurry	O_2	Entrained Flow
Shell, USA	N_2 carrier/Dry	O_2	Entrained Flow
KRW, USA	Dry	Air	Fluidised Bed
Lurgi, Germany	Dry	Air	Fluidised Bed
British Gas/ Lurgi	Dry	O_2	Moving Bed
Prenflo, USA / Krupp Uhde , Germany; Deutsche-Babcock, Germany	Dry	O_2	Entrained Flow
Destec Energy, USA	Water Slurry	O_2	Entrained Flow
IGT U-Gas, USA / Carbona, Finland; IBIL, India	Dry	Air	Fluidised Bed
Rheinbraun HTW, Germany RWE Energie, Germany	Dry	Air	Fluidised Bed
MHI, Japan / IGC, Japan	Dry	Air/O_2	Entrained Flow
ABB-CE, USA	Dry	O_2	Entrained Flow

VEW/Steinmuller, Germany		O_2	Entrained Flow
Hitachi	Dry	O_2	Entrained Flow
Noell/GSP	Dry	O_2	Entrained Flow
Ahlstrom, Sweden	Dry	Air	Fluidised Bed

5.0 SynGas Characteristics

Composition of the syngas depends on the fuel as well as on the gasification process. The typical characteristics of the SynGas as generated from different fuels at some of the IGCC projects are presented below.

	Project						
	PSI Wabash	**Tampa Polk**	**El Dorado**	**Shell Pernis**	**Sierra Pacific**	**IBIL**	**Schwarze Pumpe**
Fuel	Coal	Coal	Pet Coke/ Waste Oil	Vacuum Residue	Coal	Lignite	*
H	24.8	27.0	35.4	34.4	14.5	12.7	61.9
CO	39.5	35.6	45.0	35.1	23.5	15.3	26.2
CH_4	1.5	0.1	0.0	0.3	1.3	3.4	6.9
CO_2	9.3	12.6	17.1	30.0	5.6	11.1	2.8
N_2+Air	2.3	6.8	2.1	0.2	49.3	46.0	1.8
H_2O	22.7	18.7	0.4	--	5.7	11.5	--
LHV, KJ/M^3	8350	7960	9535	8235	5000	4530	12500
T_{fuel}, ^oC	300	371	121	98	538	549	38
Oxidant	O_2	O_2	O_2	O_2	Air	Air	O_2

* Lignite/Oil Slurry with Waste Plastic & Waste Oil

6.0 Gas Clean-up System

The typical steps for Gas Clean-up System aim at particulate removal, sulfur removal and NOx removal. This is achieved as follows:

- Particulate Removal: Combination of Cyclone Filters & Ceramic candle Filters
- SOx & NOx removal: Combination of steam/water washing and removing the sulfur compounds for recovery of sulfur as a salable product.

Hot Gas Clean-Up technology is currently under demonstration phase and various demonstrations have not been successful so far. Wet scrubbing technology, though with a lower efficiency, still remains the preferred option for gas clean-up systems in IGCC.

6.1 Technology Suppliers for Particulate Removal

S. No	Manufacturer	Gas Temp. (Max.)	Particle collection efficiency	Remarks
1.	Westinghouse Ceramic Candle Filter	1000^0C	99.99% for 0.1 mm size	Hanging Type Candles
2.	LLB Lurgi Lentjes Babcock Ceramic Candles Filter	1000^0C	99.99%	Supported both sides
3.	Pall Process Filtration Ceramic Candle Filter	1000^0C (max.)	99.99%	Supported both sides; Clay bonded silicon carbide filter
4.	Schumacher Ceramic Candle Filter	1000^0C	99.9%	Hanging type candles; Clay bonded silicon carbide filter
5.	Mott Metal Candle Filter	950^0C	99.99%	Hanging type candles; Sintered Hastelloy

6.2 Sulfur Removal

Sulfur from the hot fuel gas is captured by reducing it to H_2S, COS, CS_2 etc. The current sulfur removal systems employ zinc based regenerative sorbents (zinc ferrite, zinc titanate etc.) Such zinc based sorbents have been demonstrated at temperatures upto 650 ^0C.

Sulfur is also removed by addition of limestone in the gasifier. This is commonly adopted in air-blown fluidised bed gasifiers.

In fact, in the case of Air Blown Gasifiers, sulfur is captured in the gasifier bed itself (above 90%) because of addition of limestone. The sulfur captured in the bed is removed with ash.

7.0 Power Block

The Power Block in the IGCC Plant is essentially a Gas Turbine Unit that operates on SynGas. This Gas Turbine Unit is basically the same as used for Natural Gas with certain modifications. The areas that are modified and also which need to be critically evaluated for use with SynGas are:

- Modification of Fuel Supply System
- Modification in the Burners -- Special burners are required when using SynGas because of its higher flame propagation velocity.
- Checking for Surge Conditions and suitability of Gas Turbine Units because of excess flow in case of SynGas on account of it being a lean gas.

The gas turbine combined cycle technology has been proven for use with natural gas as well as with syngas.

<u>Modifications in Gas Turbines for IGCC:</u>

ABB-syngas combustor

Main features:

1) sequential combustion by second combustion chamber

2) annular combustion chambers.

This sequential combustion option is not offered yet for low calorific value syngases as this should first be demonstrated with natural gas. Proven GT 13 (50Hz) and GT11 (60Hz) gasturbines can be used instead.

MBTU-gas (6-12 MJ/kg) can also be fired in annular chambers with EV-burners. An 189 MWe GT13E2-MBTU GT (with EV burners) is expected to be in commercial operation in the API-project in Italy by the end of 1998.

For LBTU-gas (2-4 MJ/kg) a silo-combustor with a single burner should be selected. The size of the combustor will be considerably larger than for natural gas and the burner must be adapted to the low heat content. A 144 MWe GT11N-LBTU gasturbine will for example come in operation for blast furnace gas in the Baoshan Steel Plant, Beijing China, as early as 1997.

General Electric

GE has introduced an advanced GT design for 50 Hz and 60 Hz applications that will significantly increase IGCC market penetration for large size coal plants. The H-technology product line increases IGCC single train ratings by 60% with only a 10% larger footprint. The first H technology machine will be factory tested in 1997. Initial operation in IGCC applications is anticipated by the year 2000. This means that gasification and ASU suppliers will need matching programs aimed at technology readiness in a similar time frame.

Westinghouse

State of the art Westinghouse Gas Turbine is the "F Class" with a rotor inlet temperature of 1350^0C. Westinghouse F technology includes increases in air flow and firing temperature, improved component efficiencies and advances in materials, turbine cooling, and dry low NOx systems.

In 1987 two Westinghouse 501D5 units were converted to operate on 2248 kCal/Nm^3 syngas of the Destec gasifier in Plaquemine, Louisiana, USA. Natural gas is mixed with syngas for produce maximum power output. These units have operated over 100,000 hours with an availability factor greater than 95%.

8.0 Status of IGCC Technology

The technology level for each individual system component of IGCC i.e. gasification block, gas clean-up system and power block have already been established and proven in practice at commercial level. Integrating these individual technologies for the electricity generation is the concept of IGCC. To demonstrate IGCC technology at the commercial level, a number of projects have been in demonstration/operation stage. The fact that the IGCC technology has reached maturity stage, can be seen from the following table which gives status of various IGCC projects.

Major (Coal based) IGCC Projects Worldwide -- under operation

Project	Capacity	Operation	Fuel	Remarks
Luenen, STEAG, Germany	170 MW	Operated 1972-77	Oil	First Commercial Scale Gasifier (5 Lurgi dry ash gasifiers, Siemens KWU combined cycle)
Coolwater Plant, Barstow, California, USA	125 MW	Operated 1984-88	Coal	Texaco Gasifier (1000TPD)
Plaquemine Plant, Louisiana,USA	160 MW	In operation since April,1987	Coal	Dow (Destec)Gasifier(2200TPD), Westinghouse 501D5 GT
Demkolec	253 MW	Started operation in	Coal	Shell Gasifier / Siemens V94.2 GT

Buggenum Plant, Netherlands		1993, commercial w.e.f. 1.1.98		– Initial problems encountered in Gas Clean-up System. Now operating with good availability.
PSI Energy, Wabash River Plant, USA	262 MW	Commissioned November,1995	Coal	Destec Gasifier, Repowering plant, GE 7FA GT
Tampa Electric Polk Power Plant, USA	260 MW	Commissioned Sep. 1996	Coal	Texaco Gasifier, GE GT, HGCU
Sierra Pacific Pinon Pine Plant, USA	100 MW	Commissioned 1998	Coal	KRW Gasifier, GE 6FA GT, Hot Gas Cleanup
ELCOGAS, Puertollano, Spain	335 MW	Prenflo, Krupp Uhde	Coal	Prenflo gasifier / Siemens V94.3 GT, commissioned in 1998
Schwarze Pumpe, Germany	40 MW	Noell KRC (7 fixed bed gasifiers)	Coal/ Wastes	commissioned on syngas September,1996 Power/methanol

Major (Refinery Residue based) IGCC Projects World-wide --- Under Operation

Project	Capacity	Gasifier	Fuel	Status
Texaco El Dorado, USA	40 MW + Steam	Texaco	Waste/ Pet Coke	Commissioned September, 1996
ILVA, Taronto, Italy	500 MW	--------	mill recovery gases	Commissioned January,1997
Shell PER+, Pernis, Netherlands (IGCC retrofit)	127 MW + H_2	Shell SGHP process	Heavy residues	Commissioned on NG in June,1997 & on syngas at November,1997
ISAB, Sicily, Italy	520 MW	Texaco	Asphalt	Commd. late 1999 (2 Siemens V94.2)
Sarlux, Sardinia, Italy	551 MW	Texaco	Visbreaker Residue	Commd. August 2000 (3 GE MS9001E GTs)
API-Energia, Falconara, Italy	280 MW	Texaco	Visbreaker Residue	2000 (ABB GT13E2 GT)
Motova Delaware, USA Saudi Aramco-Texaco JV	240 MW	Texaco	Pet Coke	Commd. September 2000 , Cogen (120MWe + steam), Repowering, 2 X GE 6FA GTs
Exxon, Singapore	180MW			Commd. 2001

Status of IGCC Projects World-wide --- Under Construction

Project	Capacity	Gasifier	Fuel	Commissioning
KoBra, Kraftwerk Goldenberg, Hurth, Germany	312 MW	HTW/ Rheinbraun AG	Coal	2001
Fife Energy, Scotland	109 MW	British Gas/Lurgi	Wastes/pet coke/ coal	2001 Global Energy, $117m
EXXON,	40 MW	Texaco	Pet Coke	1999 Power/ H_2/ CO

Baytown, USA				
General Seikyu K.K., Kawasaki, Japan	540 MW	Texaco	Heavy oil	2001
Vresova, Czech Republic	400 MW	HTW	Coal	---
IBIL,Gujarat, India	53 MW	Carbona/ Enviropower	Lignite	Environment approval pending

Gasification Technology Demonstration/Pilot Scale Plants

SCGP-1, Shell Oil Deer Park Complex, Texas, USA.	250 TPD demonstration unit	Operated between 1987-1991	Coal/lignite/pet coke	Shell Gasifier - 80% coal to clean gas efficiency, 99% sulfur removal achieved. Gas used for synthesis.
Rheinische Braunkohlenwerke, Berrenrath, Germany	720 TPD		Dry Lignite	HTW Gasifier; gas used for methanol production
American Natural Gas Co. Beaulah, North Dakota, USA	1000 TPD	In operation since 1984	Lignite	14 Lurgi dry ash gasifiers of 1000 TPD each for syngas production
British Gas Lurgi Westfield, Scotland	600 TPD/ 30MWe	Commissioned in 1984		Demonstration unit; pressurised dry feed moving bed slagging BGL Gasifier
IGT U-Gas Shanghai, China	800 TPD (8 trains)	Commissioned in Dec,1994	Coal	1st IGT U-Gas commercial plant Industrial fuel gas
Krupp-Koppers Saarbrucken, Germany	48 TPD		Coal	
IGT RENUGAS Maui, Hawaii, USA		Commissioned in October,1996	Bagasse	IGT Biomass gasification technology demonstration plant
Sydkraft, Varnamo, Sweden	6 MWe + 9MWth	in operation since June,1996	biofuel	Pilot Plant; Ahlstrom CFB Gasifier, Sydkraft & Foster Wheeler JV

From the above, it can be seen that IGCC technology has now reached commercialization stage in the USA & Europe with a number of plants already in demonstration/operation phase. *It may be noted that a number of IGCC based plants have been set up in USA with financial participation of USDOE with the objective of promoting the Clean Fuel Technology as well as part funding of the high cost of such plants.*

A Japanese R&D team at the Tokyo Institute of Technology has claimed to have developed a new hot air-blown gasification system suitable for all kinds of solid fuel ranging from coal to waste. A demonstration plant of 4tpd capacity using this technology is scheduled for completion by 2000. The process named MEET (Multi-stage Enthalpy Extraction Technology) system, using air at 1000 ^{0}C is being developed to suit Indian fuels.

9.0 Operational feedback

Typical problems that have been encountered in various projects relate to the following areas:

- Gas Turbine Combustors : GT combustor design has been altered to handle low BTU gas with high mass flow due to problems encountered in gas turbines. High vibrations in the Siemens turbine led to long-term shutdown of the Demkolec's Buggenum IGCC Plant in the Netherlands.
- Hot Gas Clean-up System: Breakage of ceramic candle filters & stress corrosion cracking in heat exchangers has also been reported.

10.0 Investment Costs

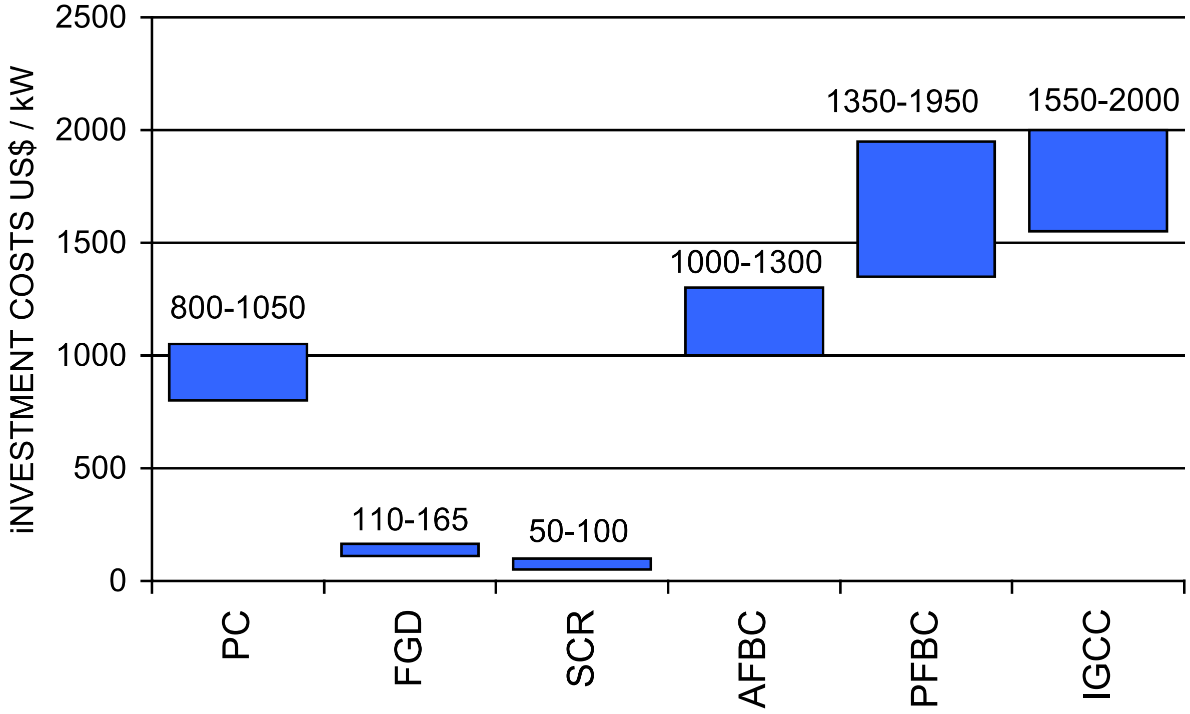
The costs for the IGCC based plants as reported are noted to be somewhat variable, depending on economy of scale, local labor costs, and applicable engineering standards. Further, gasification costs usually are estimated in combination with the downstream processing equipment necessary for delivery of a syngas suitable for conversion to the designed end product. Accordingly, gasification investment costs are best addressed on a project specific basis. The typical project costs as reported for different demonstration/commercial projects are as below:

S. No	Project	Capacity	Fuel	Gasifier Type	Gasifier Supplier	CapitalCost $/kW
1.	Buggenum, Demkolec, Netherlands	253 MW	Coal	O_2 blown	Shell	2400
2.	Polk, Tampa Electric, USA	260 MW	Coal	O_2 blown	Texaco	2000
3.	Wabash, PSI Energy Inc. USA (Repowering)	262 MW	Coal	O_2 blown	Destec / Dow	1600
	Texaco El Dorado, USA	35 MW	Residue	O_2 blown	Texaco	2150
4.	Pinon Pine, USA	100 MW	Coal	Air Blown	KRW	2320
5.	Puertollano, Spain	335 MW	Coal	O_2 blown	Prenflo	2900
6.	API-Energie, Italy	280 MW	Residue	O_2 blown	Texaco	2850
7.	SARAS - Sarlux, Italy	550 MW	Residue	O_2 blown	Texaco	2100
8.	ISAB Energy, Italy	512 MW	Residue	O_2 blown	Texaco	2400

Source: Data published in journals

An IGCC plant operating on heavy oil is somewhat less complex than a coal-based IGCC and costs are marginally less. The following graph compares current investment costs of IGCC with other new technologies.

Comparison of IGCC investment costs with other new technologies



Source: World Bank Website, Data published in journals

Source:

1. Technical papers of Gasification Technologies Conference 1998-2000. (http://www.gasification.org).
2. Technical papers of Ist International Conference on Green Power - The need for the 21st century (12-14 Februray,1997 New Delhi)
3. Technical papers of Indo European Seminar on Clean Coal Technologies (1997 New Delhi)
4. Proceedings of the Seminar on Texaco Gasification For Refining in the 21st Century (New Delhi April,1998)
5. Various international journals such as Power Engineering International, Power, Modern Power System, Gas Turbine World etc.

IGCC PROCESS DIAGRAM (POLK POWER STATION, TAMPA, FLORIDA)