

IGCC Plants : a Practical Pathway for Combined Production of Hydrogen and Power from Fossil Fuels

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ABSTRACT

Integrated Gasification Combined Cycle (IGCC) represents a commercially-proven technology available for the combined production of hydrogen and electric power from fossil fuels, i.e. coal, coke and heavy residue oils. In this paper asphalt has been considered as feedstock with the intent to represent one of the most exhausted and unvalued refinery products.

The IGCC plant gives an answer to important and strategic targets like:

- A clean and environmentally compatible use of high sulphur and heavy metal contents fuels and more when associated to CO₂ removal and sequestration.
- Large size plants for competitive electric power and hydrogen production.
- A flexible design to meet different capacity requests.

The paper describes an IGCC plant based on oxygen blown entrained bed gasification unit sized to produce a large amount of hydrogen and to feed an F technology gas turbine. Various different production quantities of hydrogen have been considered in order to perform a sensitivity analysis.

The overall performances and investment costs are estimated and used to evaluate the cost of electricity assuming a selling price for hydrogen.

HYDROGEN PRODUCTION: THE IGCC OPTION

Gasification is the conversion of either a solid (coal, coke, biomass, solid waste) or a liquid fuel (oil, tar, pitch) into a gas, often identified as syngas, in which the major components are hydrogen (H₂) and carbon monoxide (CO).

In the early part of the last century the first major application of gasification was to convert coal into fuel gas for domestic heating and lighting. In the last few decades of the past century, the main application of gasification was in the petrochemical industry to convert different hydrocarbon streams into synthesis gas, for the manufacture of ammonia, methanol and hydrogen, which is used in hydrodesulphurization and hydrocracking of oil stocks. There is therefore a long experience of hydrogen production through gasification.

Today gasification is integrated with power production, acting as a bridge between coal or heavy fuel oils and the gas turbines. Gasification of such fuels generates a fuel gas which, after cleaning, can be used in a gas turbine combined cycle power plant. The resulting process configuration (Integrated Gasification Combined Cycle – IGCC) is the only power technology that, even burning coal or high sulphur residues, can approach the environmental performance of natural gas fired systems. In fact the syngas, before firing in the gas turbine, can be cleaned to reduce to very low levels contaminants such as sulphur compounds and particulates. Furthermore, the syngas can be mixed with nitrogen and/or saturated with water to reduce similarly the nitrogen compounds originated in the combustion.

In addition IGCC represents the most promising technology for the CO₂ capture.

This paper describes one possible IGCC plant configurations that represent a realistic and practical route to combine production of hydrogen and power from a fossil fuel, i.e. asphalt from a refinery solvent deasphalting unit.

BASES OF DESIGN

The IGCC plant is designed considering three alternatives to produce either 150,000 or 100,000 or 50,000 Nm³/h (99.8 % purity) of hydrogen at 30 barg, and approx 350 MWe electric power, processing, in an environmentally acceptable manner, the following feed:

- Asphalt produced by a deasphalting unit fed with Visbroken Vacuum Residue (LHV equal to 38,124 kJ/kg and 7.58 % wt sulphur content)

The site conditions assumed for the IGCC plant are nearby a refinery located in a russian area with an average air temperature of 9°C and an average sea water temperature of 12°C. Table 1 shows the three cases which were evaluated.

Table 1 – Description of the process alternatives

CASE	FUEL	Gasification pressure Bar g	CO ₂ capture	Hydrogen production Nm ³ /h
A	Asphalt	42	No	150,000
B	Asphalt	42	No	100,000
C	Asphalt	42	No	50,000

The gasification is based on an oxygen-blown entrained bed gasification, operating at a pressure at least suitable to feed the gas turbine.

For each alternative the IGCC plant design capacity is fixed to fulfill both the required production of hydrogen and the appetite of one gas turbine General Electric Frame 9FA. This gas turbine is representative of the current state-of-the-art of large commercial gas turbines suitable to be fed with syngas.

The IGCC Complex by-products are:

- Sulphur (liquid or solid).
- Solid by-products: metal cake

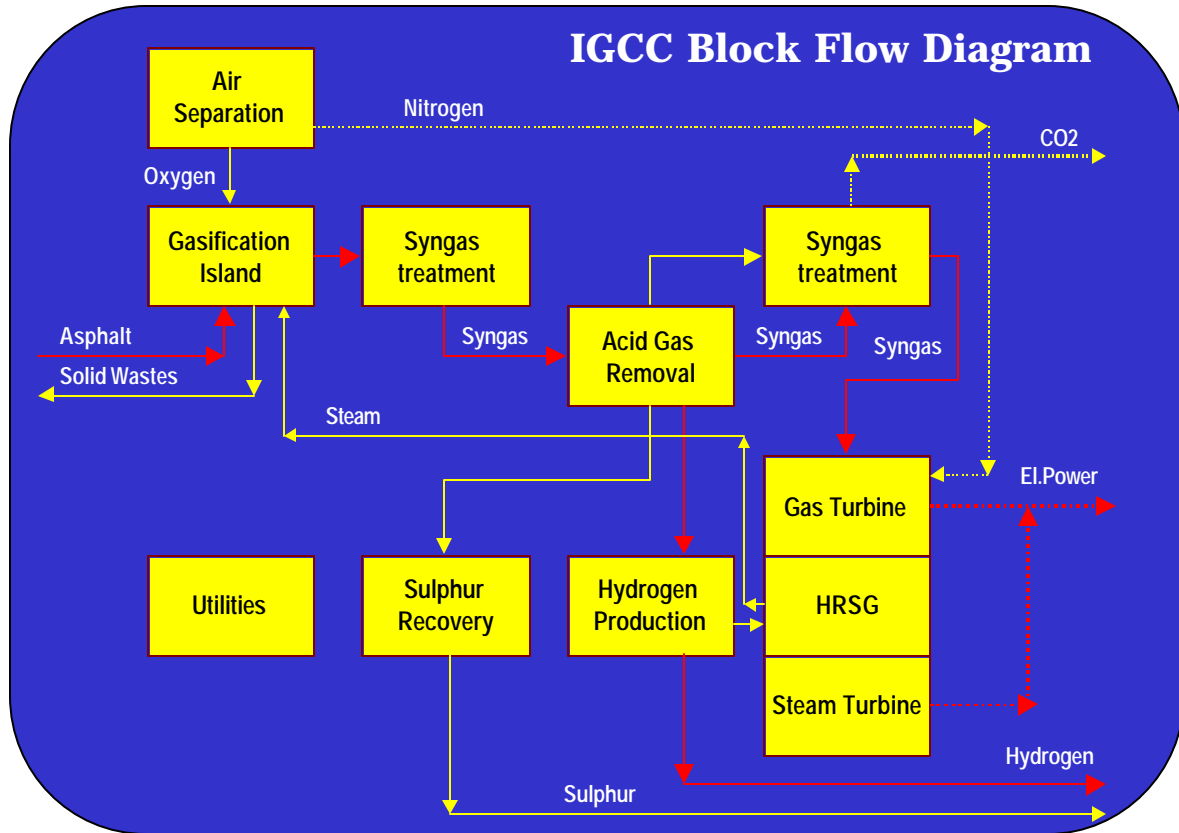
The overall gaseous emissions from the IGCC Complex referred to dry flue gas with 15% volume O₂ shall not exceed the following limits:

- NO_x (as NO₂): ≤ 80 mg/Nm³
- SO_x (as SO₂): ≤ 10 mg/Nm³
- CO: ≤ 50 mg/Nm³
- Particulate: ≤ 10 mg/Nm³

These limits are lower than those defined by the applicable European Directive and are set in order to reduce the emissions without penalizing the plant efficiency and investment cost.

PROCESS DESCRIPTION

The IGCC Plant is a multi unit complex (process and utility units) which is called to operate simultaneously in an integrated way. Its design can be optimised to meet the desired hydrogen and electric power production.



The above Figure shows the IGCC block flow diagram and the main process streams. The main process blocks of the complex are:

- Feedstock storage and preparation;
- Air separation (cryogenic technology);
- Gasification including black water/grey water treatment;
- Syngas treatment and conditioning, including acid gas removal;
- Hydrogen production;
- Combined cycle power generation

These basic blocks are supported by other ancillary units, such as sulphur recovery, tail gas treatment, and a number of utility and offsite units, such as cooling water, flare, plant/instrument air, machinery cooling water, demineralized water, auxiliary fuels, etc.. Each process unit of the complex may be a single train for the total capacity or split in two or more parallel trains, depending on the maximum capacity of the equipment involved or on the necessity to assure, through the use of multiple parallel trains, a superior degree of reliability.

The key and first process step is the entrained flow gasification. In this type of gasifier the feed, atomized oil, flows co-currently with the gasification agents (O_2 and steam). Residence time is

very short, between 0.5 and 5 seconds; the temperature inside the gasifier is uniform and very high, from 1,300° to over 1,500°C, well above the ash fusion temperature.

Entrained flow gasifiers are suited to process both solid and liquid feed, provided that they can be atomized to very small particles, less than 200-300 micron. They are not suited to process solid wastes, which cannot be readily pulverized. Gasification reactions are extremely fast due to the high temperature and great surface of the atomized feed.

Ash in the feed is melted and extracted, together with the unconverted carbon, part from the gasifier bottom and part with the gas to be captured in the gas clean-up facilities downstream of the gasifier.

Recovery of gasifier sensible heat can be made in a waste heat boiler, downstream of the gasifier, generating high pressure steam, or through a water quench inside the gasifier and subsequent recovery of the degraded heat in external waste heat boilers, producing medium and low pressure steam.

The waste heat boiler system improves energy efficiency, but the quench system permits to remove efficiently solids from the raw gas before entering the downstream facilities. In addition water quench is attractive when syngas requires CO shifting, to increase the H₂/CO ratio. In fact CO shift requires the addition of large amounts of water in the gas, which can be done conveniently in the quench. For this reason a quench gasifier has been adopted.

After quench the raw syngas is routed to a venturi scrubber, followed by a scrubbing tower, adequately sized to remove solid particles.

Syngas main components are H₂, CO, CO₂, H₂O and, additionally, H₂S and COS that need to be removed, and inerts.

Downstream scrubbing the shift reaction occurs on a catalyst suitable to process H₂S containing syngas (sour shift) to convert CO and water to H₂ and CO₂. The shift catalyst promotes also the COS hydrolysis with its conversion to H₂S and CO₂.

Raw syngas is then treated in the syngas treatment and conditioning unit to remove all the contaminants and prepare the syngas at the proper conditions of temperature, pressure and water content in order to produce both hydrogen and electric energy.

The removal of acid gases, H₂S and CO₂ is made by a chemical or physical solvent washing. In the acid gas removal (AGR) two clean syngas streams are produced: the first one taken from the H₂S absorber outlet is ready to be fed to the power island. The second one is further washed to remove CO₂ and then sent to a pressure swing adsorption unit for hydrogen purification. The hydrogen produced with a purity of 99.8% is sent to the plant battery limits at 30 barg to be delivered to users by means of a dedicated pipeline. The CO₂ rich stream is compressed and mixed to the clean syngas upstream of the gas turbine.

For the CO₂ capture option the system can be modified. CO₂ removed by the entire syngas stream entering AGR, is dried and compressed to 110 bar in order to be delivered to geological storage reservoirs. The cost of CO₂ storage depends on local factors, such as transport distance, pipeline diameter and type of reservoir. At some locations CO₂ could have a positive value for enhanced oil recovery but at other locations transport and storage result in additional substantial costs.

In the sulfur recovery unit, the H₂S rich stream coming from the AGR regenerator is burned in the presence of oxygen in a muffle furnace followed by two reactors in series where the Claus reaction takes place to produce liquid sulfur.

The tail gas from Claus unit is processed in a tail gas treatment unit where the SO₂ present is completely converted to H₂S by catalytic hydrogenation. The treated tail gas is compressed and sent to the AGR.

The oxygen required both for the gasification reaction and the Claus reaction is produced in the air separation unit (ASU) where air is fractionated by cryogenic distillation. The ASU is partially integrated with the power island. In fact, a portion of the compressed air required by the oxygen plant is delivered directly from the gas turbine compressor, while nitrogen is injected into the gas turbine for power augmentation and NO_x reduction.

PERFORMANCE DATA

The performance data of the three alternatives are summarised in Table 2.

Table 2 – Performance data.

Case	Fuel t/h	Gross Power Output MWe	Hydrogen production		Aux. Cons. MWe	Net Power Output MWe	Thermal Efficiency %	Net Electrical Efficiency %	Total Efficiency %
			Nm ³ /h	MWth					
A	165.90	466.0	150,000	449.1	124.9	340.1	25.6	19.4	45.0
B	142.46	451.0	100,000	300.1	104.4	345.5	19.9	22.9	42.8
C	118.70	436.0	50,000	150.0	84.7	350.2	11.9	27.9	39.8

Both electrical and thermal efficiency of the plant are referred to the feedstock Low Heating Value. The IGCC thermal efficiency is related to the hydrogen production.

The total efficiency is the sum of thermal and net electrical efficiency.

The feedstock flow rate shown in Table 2 is different for each alternative whose target is to produce sufficient syngas to fulfil both the required hydrogen production and the appetite of one GE 9FA gas turbine.

INVESTMENT COST DATA

The investment cost data of the three IGCC plants are reported in the attached Table 3, showing the total investment cost split into the main sections of the IGCC Complex. These figures represent the total investment cost including the EPC contract cost and the Owner's cost.

Table 3 – Total Investment cost data.

Case	Air Sep.		Process Units		Power Islands		Utilities & Offsites		Total
	10 ⁶ €	%	10 ⁶ €	%	10 ⁶ €	%	10 ⁶ €	%	
A	95	14.8	269	41.9	167	26.0	112	17.3	643
B	86	14.3	245	40.8	164	27.4	105	17.5	600
C	69	13.0	207	38.6	162	30.1	98	18.3	536

PRODUCTION COSTS

The following Table 4 provides the cost of electricity (C.O.E.)

The cost of electricity has been evaluated on the basis of the following assumptions:

- Cost of Asphalt: 20 Euro/t (Asphalt value can be below 0)
- Price of hydrogen: 0.095 Euro/Nm³
- 7,446 equivalent syngas operating hours of the (100% capacity).
- Total investment cost as given in Table 3.
- 10% discount rate on the investment cost over 25 operating years.
- Maintenance cost equivalent to approx 3.5% of the total capital costs.
- Direct Labour: 100 people at an average yearly cost equal to 50,000 Euro.
- Administration and General Overheads: 30% of the direct labour costs.

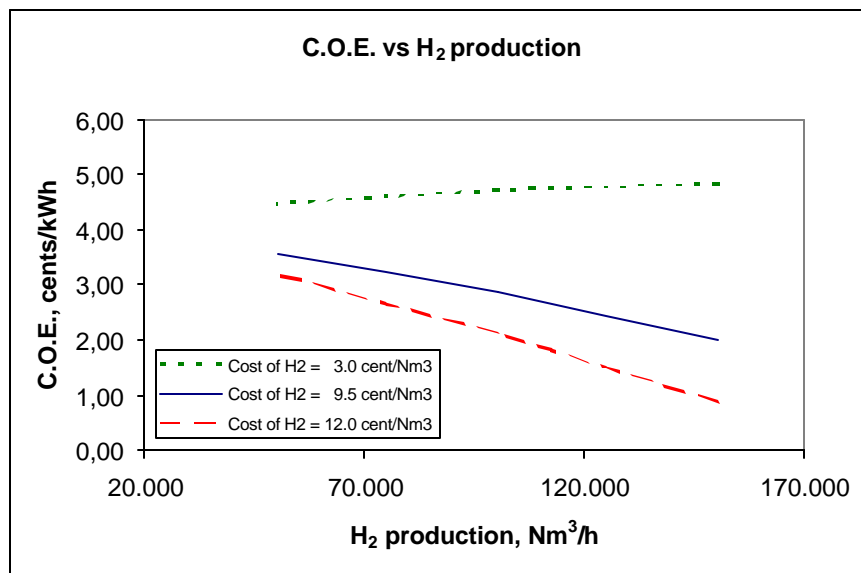
Table 4 – Cost of electric power production.

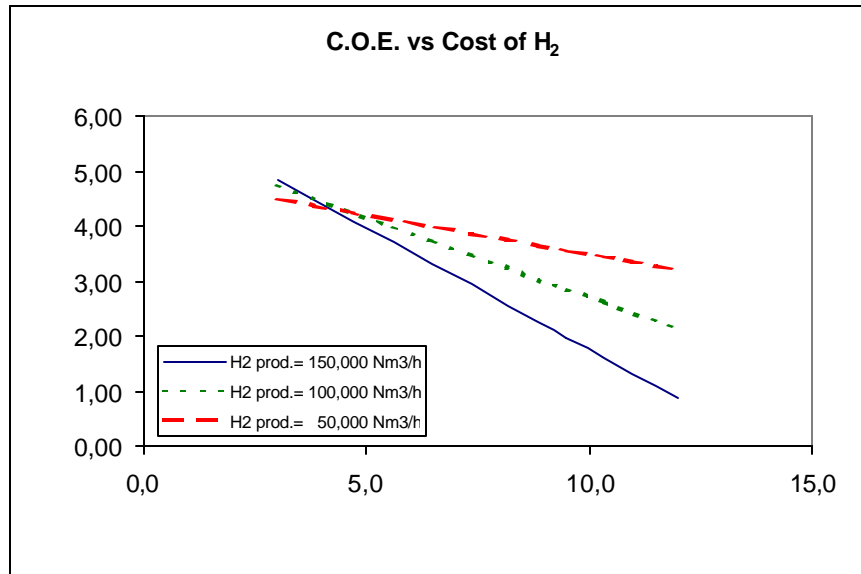
CASE	FUEL	C.O.E. Cent/kWh	Cost of H ₂ Cent/Nm ³
A	Asphalt	1.97	9.5
B	Asphalt	2.86	9.5
C	Asphalt	3.56	9.5

SENSITIVITY ANALYSIS

To complete the evaluation two drawings are here below attached:

- Cost of Electricity versus Hydrogen production
- Cost of Electricity versus cost of Hydrogen





ANALYSIS AND CONCLUSIONS

IGCC is a complex combination of different technologies that can be designed to meet different requirements, optimising capital cost, efficiency and simultaneously reducing the emissions to the atmosphere.

The most important conclusions of the study are:

- Hydrogen and electric power are produced with an acceptable efficiency, taking into account the feedstock quality and the environmental performances.
- The cost of electricity, obtained assuming a hydrogen price of 9.5 cents/Nm³, is very attractive, demonstrating the advantage of their combined production. This demonstrates, that in competitive electric power market, the IGCC will always be able to dispatch power still maintaining hydrogen cost compatible with market value.
- The convenience is demonstrated through a wide range of Hydrogen values as can be deduced from the sensitivity analysis drawings reported; it should be considered that asphalt has been given a value, but everybody knows that more than a value is a burden.
- Environmental performances of the IGCC technology is far superior to that of any other power producing technology known today based on solid or liquid fossil fuels. In addition, the impact on the environment of IGCC is independent of the quality feedstock, which makes it possible to process in IGCC the worst coals or residues and still meet the most severe emission limits.
- The IGCC plant configuration and size can be easily adjusted to fulfil different requirements of electric power and hydrogen production. Further the plant operation is flexible, allowing the variations of these productions.
- Improvements of IGCC efficiency and investment cost are expected in next years from the technology evolution in the areas of gas turbines, gasifiers, Air Separation Unit. This will make the combined production of hydrogen and electric power from IGCC plants more and more attractive.

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