

Production of Electric Power and Chemicals in a Carbon Constrained Environment

Guido Collodi, Luca Mancuso, Federico Fazi
Foster Wheeler Italiana SpA
Via Caboto 1, 20094 Corsico – Milan - Italy

The Chemical Industry is confronted with a difficult challenge: how to deal with natural gas supply security and price volatility while ensuring, at the same time, an efficient reduction of CO₂ emissions. Gasification of solids (e.g. coal or petcoke) is a promising answer to these needs: it is a commercially proven technology available for the combined production of electric power and chemicals. IGCC (Gasification integrated with a Combined Cycle) is also the technology that facilitates the retrofit to CO₂ capture with a moderate capital pre-investment in the base configuration. Two case studies are developed in the paper:

- Co-production of ammonia/urea and electric power from petcoke gasification;
- Co-production of methanol and electric power from coal gasification.

The alternatives, based on oxygen blown entrained bed gasification, are CO₂ capture-ready plants, sized to produce different amounts of electric power and chemicals. Overall performances and investment costs are evaluated and discussed through a sensitivity analysis on Cost of Electricity and Cost of Chemicals. Loss of performances and additional costs due to the CO₂ capture retrofit are also evaluated.

1. Basis of design

The study is based on commercially available technologies and evaluates costs and plant performance of plants that can be presently engineered and built.

Two alternative plant configurations for the combined production of chemicals and power are investigated:

- Bituminous coal-based IGCC (LHV=25,870 kJ/kg; Sulphur=1.1% wt dry, ash free), designed to produce 5,000 t/d of methanol and to satisfy the appetite of one 250 MWe F class gas turbine (IGCC-MeOH).
- Petcoke-based IGCC (LHV=32,450 kJ/kg; Sulphur=6.7% wt dry, ash free) designed to produce 3,400 t/d of urea and to satisfy the appetite of one 120 MWe E class gas turbine (IGCC-Urea). The gas turbine frame is selected in order to produce electric power as required by a modern refinery, with an overall petcoke consumption (derived from urea plus electric power production) meeting the delayed coker capacity (approx. 100,000 BPSD).

The plants are designed by considering a moderate capital pre-investment to facilitate the subsequent retrofit to CO₂ capture. Both cases separate the CO₂ from the synthesis gas in the base configuration, so the CO₂ capture retrofit mainly consists in the installation of the CO₂ drying and compression avoiding a prolonged plant shutdown to complete the conversion. These two retrofit alternatives are also investigated in the study (IGCC-MeOH with CCS and IGCC-Urea with CCS).

Location for cost estimate is a generic European coastal site. The reference ambient conditions for performance evaluation are 15°C, ambient relative humidity of 60% and an average seawater temperature of 15°C.

Depending on the alternative, the plants produce the following main products and by-products:

- Electric Power an HV substation for connection to the National Grid.
- Methanol at 99.85% wt purity (AA Grade).
- Granulated Urea at 99.8% wt purity.
- Carbon Dioxide at 150 barg, 30 °C, Moisture: < 0.1 ppmv.
- Liquid Sulphur at 99.9 wt.%, H₂S content: 10 ppmwt (max).
- Slag and filter cake by-products.

2. Description of IGCC complex

The following description makes reference to Figure 1 and Figure 2, showing the IGCC block flow diagram and the main process streams of the two study alternatives (IGCC-MeOH and IGCC-Urea). The main process blocks of the complex, common to the two alternatives, are the following:

- Feedstock storage and preparation: milling, slurry preparation, etc;
- Air separation: O₂ for the gasification, N₂ for NO_x control;
- Gasification, including black water/grey water treatment: the key process step is the entrained flow gasification, which is suitable both for solid and liquid feed. In this type of gasifier the feed (petcoke slurry or coal slurry) flows co-currently with the gasification agents (O₂ 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°C to over 1,500°C, well above the ash fusion temperature;
- Syngas treatment and conditioning: shift reaction, heat recovery, etc;
- Acid Gas Removal (AGR): physical solvent, H₂S removal, partial CO₂ removal;
- 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. The resulting syngas is free of any contaminant and prepared to produce both chemicals and electric energy (in the combined cycle power generation).

For the alternative with retrofitted CO₂ capture, after removal in the AGR unit, CO₂ is dried/compressed to 150 barg in order to be delivered to geological storage reservoirs. The cost of CO₂ storage depends on local factors, such as storage

distance, pipeline diameter and type of reservoir. At some locations CO₂ could have a positive value for enhanced oil recovery (EOR), or embedded coal methane recovery (CBM), but at other locations transport and storage result in additional costs. An additional average cost for transport and storage equal to 10€/t of CO₂ has been assumed to discuss the alternatives with CCS.

3. Electric power and methanol co-production plant (IGCC-MeOH)

The target of this alternative is to produce 5000 t/d and to satisfy the appetite of a nominal 250 MWe F-class gas turbine.

Downstream the shift reactor and the heat recovery, shifted syngas is cleaned in the AGR (see Fig.1). The composition of the Clean Syngas at the AGR outlet shall meet the following specification, in order to be suitable for the methanol production:

$$(H_2-CO_2)/(CO+CO_2) \approx 2.0$$

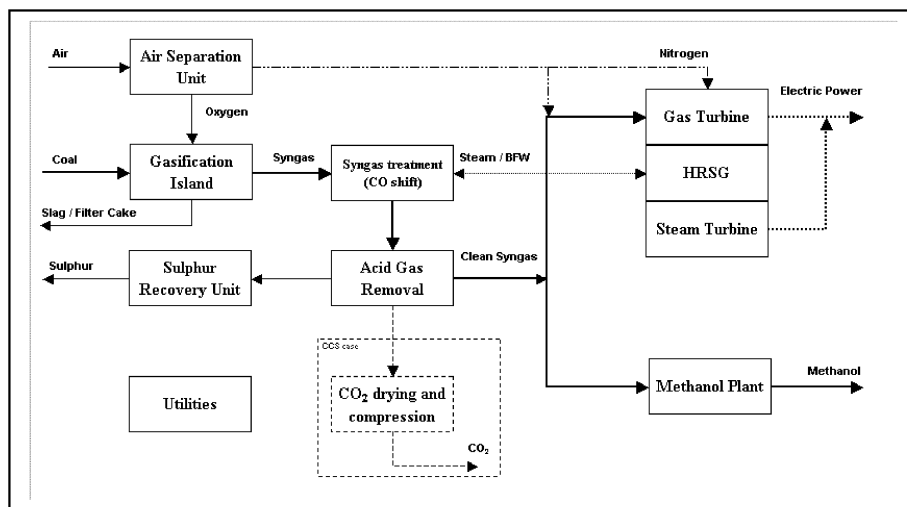
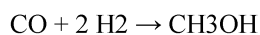


Fig. 1 – IGCC Block flow diagram for Methanol and Electric Power Co-Production.

This specification is met with a CO₂ capture rate equal to approx. 80%.

The captured CO₂ is vented to atmosphere in the base configuration (IGCC-MeOH) or sent to geological storage (IGCC-MeOH with CCS).

At AGR outlet, a portion of the syngas goes to the methanol plant and the remaining part flows to the GT combustor. In the methanol plant syngas is compressed in order to enter the methanol synthesis reaction. The main reaction involved in this catalytic process is:



The liquid mixture of methanol and water is finally distilled in different columns to achieve the desired methanol purity.

4. Electric power and urea co-production plant (IGCC-Urea)

The configuration of the gasification section is the same of the previous case, but the feedstock is petcoke. The gasifier produces enough syngas to feed a 120 MWe E-class gas turbine and the amount of hydrogen necessary for a 3,400 t/d urea plant. The syngas exiting the gasification island is almost totally shifted in two shift reactors in series in order to maximize the hydrogen production. Downstream the heat recovery, the syngas is cleaned by H₂S and CO₂ in the AGR unit (approx. 90% CO₂ removal rate). At the outlet of the AGR part of the hydrogen rich fuel is sent directly to the gas turbine, while the remainder flows to the hydrogen purification achieved through a pressure swing adsorption (PSA). The PSA offgas is fed to the HRSG postfiring system (see Fig.2).

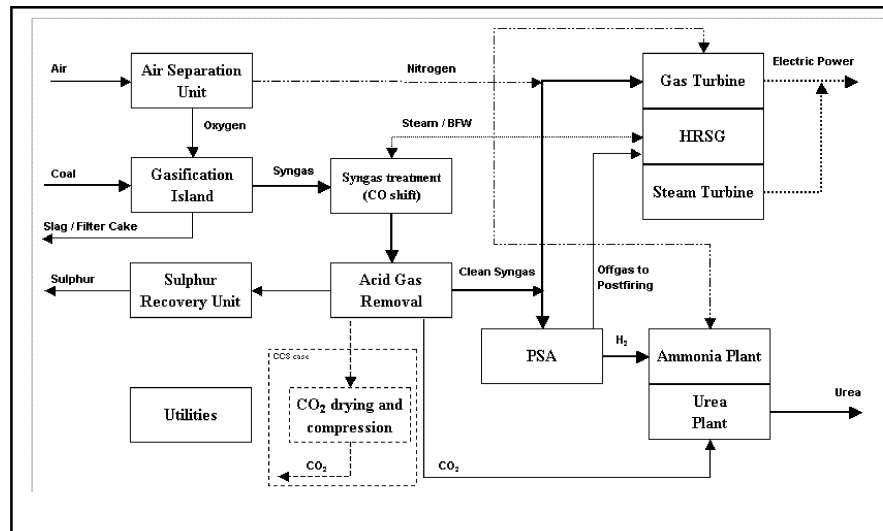
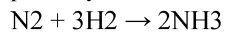


Fig. 2 – IGCC Block flow diagram for Urea and Electric Power Co-Production.

Almost pure hydrogen from PSA is mixed with nitrogen, compressed, heated and partially converted to ammonia according to the following catalytic reaction:



Pure CO₂ from AGR is compressed and then mixed with the produced ammonia before entering the urea synthesis reactor. The urea synthesis is based on the decomposition of ammonium carbamate as shown in the following reactions:



The produced urea is purified and finally granulated.

As mentioned before, the adopted plant scheme is a “carbon capture ready” plant to minimize the CCS retrofit modifications cost. For this reason gas turbine and AGR do not need any changes when the plant shifts to the CCS configuration.

5. Performance data

The performance data of the two alternatives are summarised in Table 1.

Table 1 – Performance data.

Case	Fuel	Methanol / Urea production	GT Power Output	Gross Power Output	Aux. Cons.	Net Power Output	CO ₂ emission	Overall carbon removal efficiency *
	t/h	t/d	MWe	MWe	MWe	MWe	t/h	%
IGCC-MeOH	474.5 coal	5,000	305.0	563.3	309.1	253.7	782.8	26.8
IGCC-MeOH with CCS	474.5 coal	5,000	305.0	563.3	350.5	212.4	183.5	82.8
IGCC-Urea	174.8 petcoke	3,400	150.6	303.5	170.6	132.6	414.6	20.0
IGCC-Urea with CCS	174.8 petcoke	3,400	150.6	303.5	192.5	110.8	70.6	86.4

* Including carbon present in the chemicals (methanol or urea) produced.

6. Investment cost estimate and production cost

The investment cost estimate for the four alternatives is reported in Table 2. Figures represent the total investment cost, including EPC and owner's costs of the base case and the delta required to make the capture of the CO₂.

The same table provides also the cost of electricity (COE) for the different alternatives. The cost of electricity has been evaluated on the basis of the following main assumptions:

- No selling price is attributed to the sequestered CO₂.
- 7,621 equivalent operating hours (reference: 100% capacity) corresponding to 87% equivalent availability.
- 10% discount rate on the investment cost over 25 operating years.
- Maintenance cost equivalent to approx 3.0% of the total capital costs.

Table 2 – Cost of electric power production

CASE	MeOH/Urea prod., t/d	Total Inv. Cost 10 ⁶ €	Cost of Coal/Petcoke €/t	Cost of MeOH/Urea €/t	COE cent€/kWh
IGCC-MeOH	5,000	2,051	75	380	1.8
IGCC-MeOH with CCS	5,000	+36	75	380	2.5
IGCC-Urea	3,400	1,558	30	270	1.1
IGCC-Urea with CCS	3,400	+26	30	270	1.8

7. Sensitivity Analysis

The following sensitivity analyses have been performed for both alternatives:

- Cost of Electricity versus Cost of Chemicals (COE):
 - Because of the continuous and significant fluctuation of methanol and urea prices, a sensitivity analysis is performed:
 - Methanol: 250 to 450 €/t, without and with CCS (Figure 3);
 - Urea: 230 to 300 €/t, without and with CCS (Figure 4);

Figure 3 and 4 show the COE vs the chemical product price (methanol and urea respectively). It may be noticed that, over a certain price of methanol and urea, the investment returns from chemicals sales give power production “free of charge”. This means that chemicals sale is sufficient to repay the whole plant complex, or viceversa, by applying a certain COE, the IRR is more than 10%.

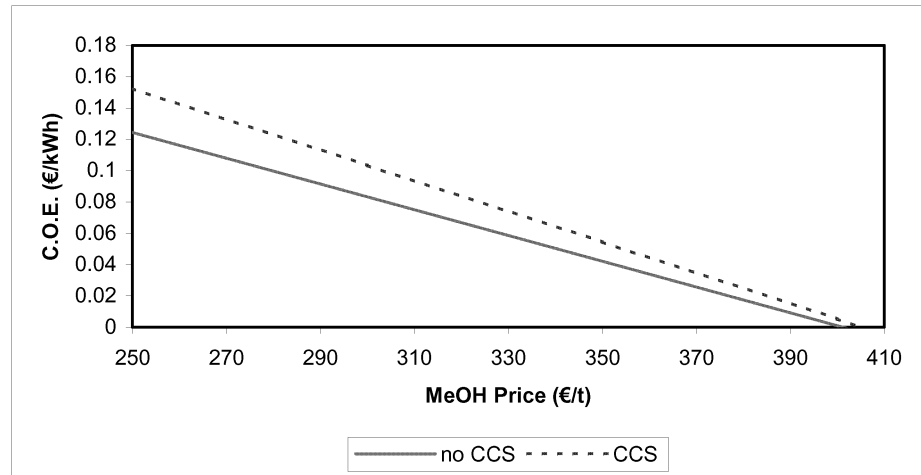


Fig.3 – IGCC-MeOH case - COE vs. MeOH price

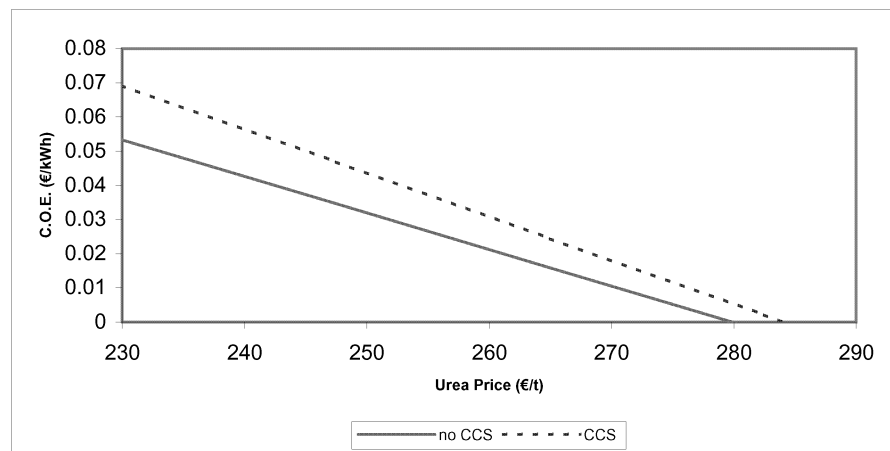


Fig.4 – IGCC-Urea case - COE vs. Urea price

The previous simulations do not take into account the CO₂ emission penalty.

8. Conclusions

The analyses performed in this study lead to the following conclusions:

- IGCC with electric power and chemicals co-production shows an attractive COE, especially for a low value feedstock like petcoke.
- The price of chemicals heavily affects the economical evaluation of the plants. A low chemicals price (approx. < 330 €/t of methanol or approx. < 220 €/t of urea for plant without CCS lead to a COE higher than 6.0 cents €/kWh, which is the current average European value.
- CO₂ capture leads to a higher investment cost and to a loss of efficiency with respect to the alternative without CO₂ capture. However an IGCC plant with CO₂ capture is economically viable even at a very low level of carbon tax (> 16.5 €/t for IGCC-MeOH and > 15.5 €/t for IGCC-Urea). If transport and storage costs are offset by revenues from EOR or CBM applications, the values decrease respectively to 3.5 and 3 €/t.
- Improvements in the main areas like the gas turbines, gasifiers and ASU are expected in the next years, thus making the IGCC alternative more and more attractive.
- COE for the IGCC-Urea alternative seems to be less affected by the cost of feedstock and price of chemical with respect to the IGCC-MeOH alternative.

References

- Arienti, S., Cotone P. and Davison J., 2007, Hydrogen and Electricity Co-production with CO₂ Capture, IChemE, 8th European Gasification Conference, Antwerp.
- Davison J., Bressan L. and Domenichini R., 2003, Coal Power Plants with CO₂ Capture: the IGCC Option, GTC 2003, San Francisco.
- Domenichini R., Mancuso L., Bressan L. and Fazi F., 2008, Gasification for Combined Production of Electric Power and Chemicals, GTC 2008, Washington.
- Domenichini R. and Mancuso L., 2008, Cost of Electricity Generation of Power Plants Technologies with and without CO₂ Capture, PowerGen Europe, Milan.
- Domenichini R., Mancuso L. and Davison J., 2007, CO₂ Capture from Low Rank Coal Power Plants, 20th World Energy Congress, Rome.

