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Assessing the Economic Feasibility of Flexible Integrated Gasification Co-Generation Facilities

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Abstract

This paper evaluated the economic effects of introducing flexibility to state-of-the-art integrated gasification co-generation (IG-CG) facilities equipped with CO_2 capture. In a previous paper the technical and energetic performances of these flexible IG-CG facilities were evaluated. This paper investigated how market conditions affect the economics of flexible IG-CG facilities by analyzing several case studies. The IG-CG facilities used Eucalyptus wood pellets, torrefied wood pellets and Illinois #6 coal as feedstock and produced electricity, FT-liquids, methanol and urea. Results indicated that currently biomass is, compared to coal, too expansive. Therefore, feedstock flexibility is not attractive. Production flexibility between chemical and electricity production under current economic conditions reduces the profitability of the IG-CG facility. Therefore, with state-of-the-art technology and the current economic climate, introducing flexibility to IG-CG facilities is not economically profitable.

Keywords: Flexibility; Co-generation; Gasification; Economics; Biomass; Synthetic fuels

1. Introduction

A significant reduction of global CO_2 emissions will require the decarbonisation of both the transportation and power sectors. Flexible integrated gasification poly-generation (IG-CG) facilities equipped with CO_2 capture can potentially decarbonise both sectors. They can produce CO_2 neutral transportation fuels and, at the same time, act as back-up power plants. Furthermore, flexible IG-CG facilities can improve their economics by responding to fluctuating feedstock, CO_2 and product prices. IG-CG facilities could also improve profitability by taking advantage of economics of scale. These characteristics could make flexible IG-CG facilities very valuable in the development of a sustainable energy infrastructure.

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Most literature studies that evaluate the economics of IG-CG facilities only consider static operation without any variation in feedstock or production. Only a few literature studies have been found that evaluate the economics of flexible facilities.[1,2] In a previous study we have investigated the technical performance and limitations of state-of-the-art (SOTA) flexible IG-CG facilities.[3] The overall efficiencies found are displayed in Table 1. The results indicated that, from a technical point of view, both feedstock and product flexibility are possible, although within certain constraints (for instance, the volume of the syngas exiting the gasifier remains constant, regardless of the used feedstock; minimal load for important processes - reactors, distillation columns and gas turbine - is 40%; and co-feeding of biomass is maximised at 50% on an energy basis[2]). The results also indicate that substituting coal by biomass will lower the thermal input, and thus the net output and that substitution of feedstock would hardly affects overall efficiency of the facility.

Table 1 Overall energy efficiencies of XtY[3] facilities. [3]

Energy Efficiency		Coal	TOPS (1)	EP
Electricity (XtP)	**Power**	**40%**	**39% (35%)**	**38%**
FT-Liquids (XtL)	FT	49%	47% (42%)	43%
	Power	10%	11% (10%)	12%
	Total	**60%**	**58% (53%)**	**55%**
Methanol (XtM)	MeOH	33%	31% (28%)	29%
	Power	21%	21% (19%)	21%
	Total	**53%**	**52% (47%)**	**49%**
Urea (XtU)	Urea	29%	28% (25%)	25%
	Power	22%	22% (20%)	22%
	Total	**51%**	**50% (45%)**	**47%**

(1) During torrefaction roughly 10% of the biomass energy is lost. The values in bracket include this penalty.

The results of the aforementioned study indicate that flexible IG-CG facilities are technically feasible. However, the question remains whether they make sense from an economic point of view. A main advantage of flexible facility is that market conditions can be exploited, resulting in lower feedstock costs and higher product sales compared to static facilities. However, a flexible facility has higher capital and O&M costs. The goal of this study is to determine if flexibility can improve the economics of SOTA IG-CG facilities. In this paper a selection of the results are given. A more detailed analysis of the economics of flexible IF-CG facilities will be given in Meerman et al. (in progress).[4]

2. Methodology

In this study it was assumed that IG-PG facilities use SOTA technology and operate between 2015-2035. By comparing the production costs of static IG-CG facilities with those of flexible IG-CG facilities, insights can be generated into whether overall facility economics can be improved under the current economic conditions by introducing flexibility. For this purpose production costs of 3 different case studies were assessed taking into account capital costs data and historic commodity prices. A schematic overview of the used methodology is displayed in Figure 1. In the rest of this section an overview of each step is presented. In this study all units are in SI-units, heating values in higher heating value (HHV) and costs in $€_{2008}$, unless stated otherwise.

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[2] This limitation results from the different ash and alkali composition and quantity of biomass compared to coal.
[3] Facilities or systems where feedstocks are gasified and converted to products are referred to as XtY systems. The X is often substituted if a specific feedstock is used; biomass (BtY), torrefied biomass (TtY) or coal (CtY). The Y is often substituted if a specific output is produced; electricity (XtP), FT-liquids (XtL), methanol (XtM) or urea (XtU).

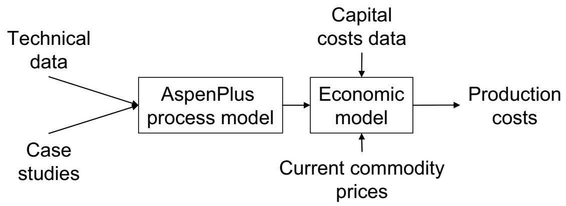

Figure 1 Schematic overview methodology.

2.1. Technical data and AspenPlus process model

The analysis departs from an Aspen process model (Figure 2) and detailed technical data developed in [3]. Here only the most important characteristics of the modelled facility are given:

- A gasifier scale of 2000 MWth coal input-equivalent;
- Three different types of feedstock: Illinois #6 coal, Eucalyptus wood pellets (EP) and torrefied wood pellets (TOPS);
- Three different feedstock ratios: 100% coal, 50/50% biomass/coal on an energy basis and 100% biomass; both for TOPS and EP;
- Four different outputs as main product: electricity, FT-liquids, methanol or urea. When producing chemicals as main product, electricity is produced as by-product. A maximum of one type of chemical is produced at any one time. When considering production flexibility, minimal load of chemical production is 40%[3];
- As all IG-CG facilities already separate CO_2 after gas cleaning. The only additional step for CO_2 capture is compression. In this study all investigated IG-CG configurations are assumed to operate with carbon capture and storage (CCS).

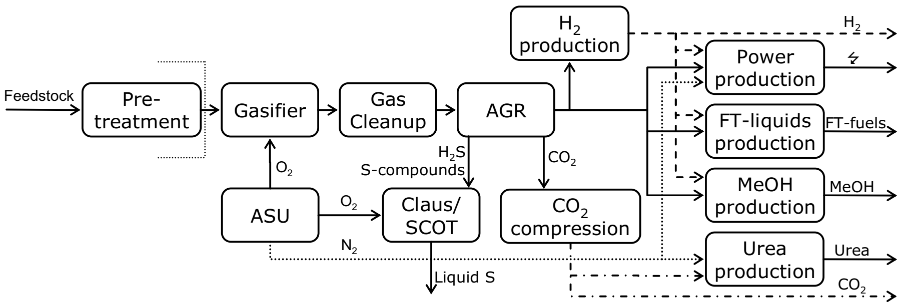

Figure 2 Simplified layout of a flexible IG-CG facility process. Waste and heat streams are not displayed.

2.2. Case studies

In this study, 3 case studies have been assessed. The combination of these cases allows generating insights into the economics of introducing flexibility to IG-CG facilities.

Case 1. **Static IG-CG facilities. U**sed as reference case. The static IG-CG facilities have specific feedstock and production mixtures. All equipment is optimised to these characteristics. As a result the facilities are almost non-flexible.

Case 2. **Feedstock variation.** Used to investigate whether and when feedstock flexibility pays-off. It considers the trade-off between lower feedstock costs and higher equipment costs combined with lower efficiencies. It is assumed that for half the time period biomass prices are reduced, while coal prices are unaltered. During the other half, coal prices are reduced, while biomass prices are unaltered. The investigated price reductions are 15% and 30%.

Case 3. **Production variation: Producing mainly chemicals/fuels during off-peak hours and mainly electricity during peak hours.** Used to investigate whether and when being operated as a chemical/mid-load[4] power plant pays-off. It considers the extent at which the ability to adjust production can counterbalance the higher capital and O&M cost and lower overall efficiencies. It is assumed that the IG-CG facilities operate with a specific feedstock mixture. During peak hours electricity production is maximised and during off-peak hours chemical/fuel production is maximised. For both extremes a 40% minimal load restriction is enforced.[3] When operating an IG-CG facility in such a way the gasifier, syngas cleaning and AGR remain at nominal load, but the chemical/fuel and power sections vary in load depending on the output. Production is switched from chemical/fuel to electricity when the electricity market price increases above the chemical-electricity equivalent price (PEP), see section 2.5. The additional electricity is sold conform to spot market prices.

2.3. Commodity prices

The commodity prices are based on their prices beginning 2010 (see Figures 3-6). The used prices are given in Table 2.

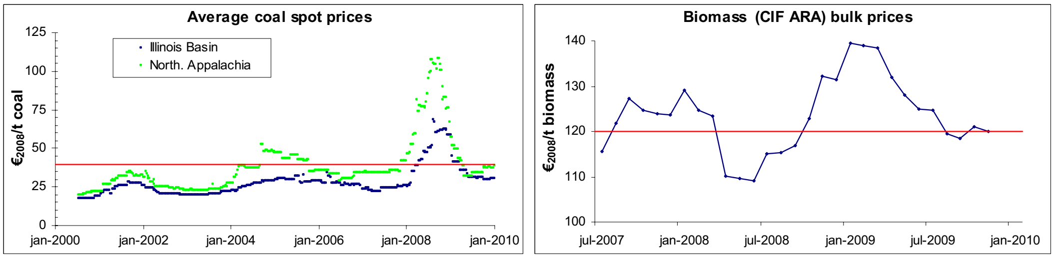

Figure 3 Historical coal[5] (left) and bulk biomass[6] (right) prices. The horizontal line indicates the current price.

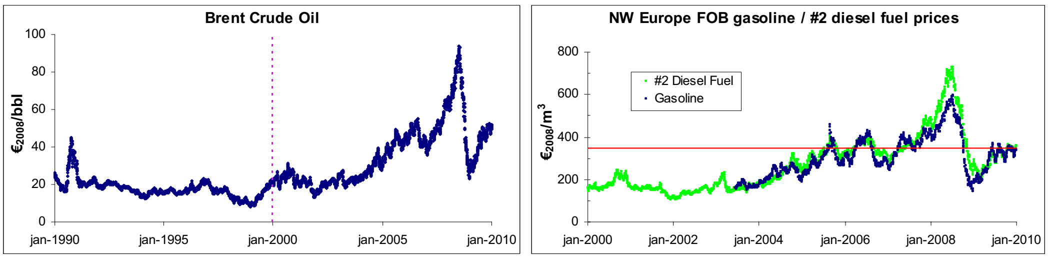

Figure 4 Historical crude oil (left) and oil products (right) prices.[7] The horizontal line indicates the current price.

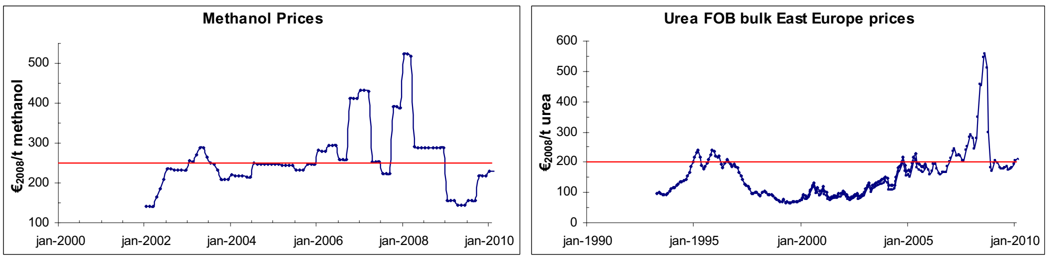

Figure 5 Historical methanol[8] (left) and urea[9] (right) prices. The horizontal line indicates the current price.

[4] Mid-load power are operated after the main base (nuclear and coal) power plants and renewable (wind and solar) generators, but before the peak (gas) power plants. This roughly means that during working days mid-load power plants are operated at full capacity between 08:00u-20:00u. Outside this time-window the power plants are shutdown.

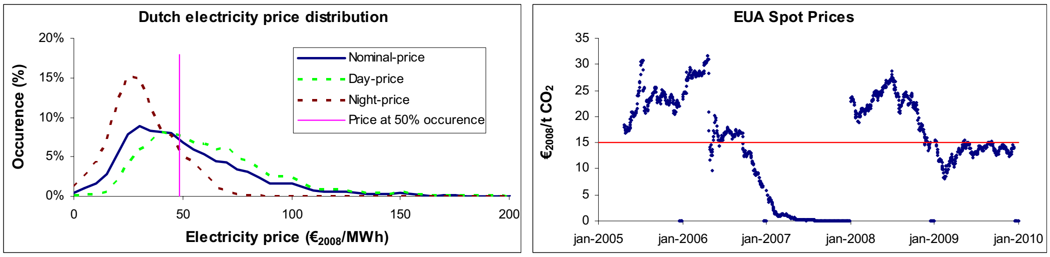

Figure 6 Historical electricity price distribution[10] (left) and European Union Allowance[11] (CO_2 emission rights) spot prices (right). The vertical line in the electricity graph marks half of the occurrences. The horizontal line in EUA graph indicates the current price.

Table 2 Commodity prices.

	Parameter	Unit	
Feedstock Prices	EP	€/GJ	6.7 (1)
	TOPS	€/GJ	6.7 (1)
	Coal	€/GJ	1.5 (2)
CO_2	CO_2 credits	€/t CO_2	15 (3)
	CO_2 transport & storage costs	€/t CO_2	10 (4)
Product prices	FT-fuel	€/GJ	10.1 (5)
	Methanol	€/GJ	11.0 (6)
	Urea	€/GJ	19.0 (7)
	Electricity	Aver. €/GJe	15.7 (8)
	Slag	€/t	0
	Sulphur	€/t	100

(1) Biomass prices are 120 €/t ARA. Assuming an energy density of 18 GJ/t, this results in 6.7 €/GJ. For TOPS no reliable cost data is available. Although torrefaction results in additional costs, it is assumed that the reduction in transportation costs compensates this.[12] Therefore, it is assumed that the price for TOPS is also 6.7 €/GJ.
(2) Coal prices are 40 €/t. Assuming an energy density of 27 €/GJ, this results in 1.5 €/GJ.
(3) CO_2 prices are currently fluctuating around 15 €/t CO_2.
(4) It is assumed that CO_2 transport and storage can currently be realised at 10 €/t CO_2 using niche storage fields.[13]
(5) Gasoline and diesel prices were 350 €/m^3. Assuming an energy density of 45 GJ/t and a mass density of 770 kg/m^3, this results in 10.1 €/GJ.
(6) Methanol prices are fluctuating around 250 €/t. Assuming an energy density of 22.7 GJ/t, this results in 11.0 €/GJ.
(7) Urea prices are 200 €/t. Assuming an energy density of 10.5 GJ/t, this results in 19 €/GJ.
(8) Electricity prices are based on the average Dutch day-hourly prices between 2004-2008. During that period the electricity price varied between 0-1050 €/MWh (0-290 €/GJ), with an average price of 57 €/MWh (15.7 €/GJ).[10]

2.4. Total Capital Investment

Total capital investment (TCI) was calculated using the factored estimation method. The inherent uncertainty of this method is approximately 30%.[14] In this method the component costs of each major component was estimated using data from open literature sources and from expert interviews. The summation of each individual component costs results in the TCI.

To adjust for differences in scale in the modelled component and the literature data, the scaling function (equation (1)) was used. In case multiple identical components were used, the multiplication function (equation (2)) was used.

$$y_s = y_0 * \left(\frac{x_s}{x_0}\right)^S \quad (1)$$

$$y = y_s * n^m \quad (2)$$

where y, y_s and y_0 = actual, scaled and initial costs respectively; x_s and x_0 are the actual and initial scale respectively; S is the scaling exponent; n the desired number of units and m the multiplication exponent.

2.4.1. Capital costs data

Capital costs have varied significantly in the last years, increasing rapidly from 2005 and peaking in 2008.[15], [15] Since that peak, capital costs dropped by 12% (EU) and 7% (U.S.).[16] Early 2010, prices are back at mid 2006 (EU) or mid 2007 (U.S.) level. For the current research, the average cost data as published in by the IEA GHG[17] have been used as point of departure since the prices at the time of that study are in line with the latest developments observed in the market. The used component capital cost data are described in more detail by Meerman et al.[4]

2.5. Economic model

The economics of the different case studies were evaluated by calculating the production costs of the main product by using the Net Present Value (NPV) method[18], see equation (3). By setting the NPV to zero the production cost of the main product was calculated.

$$NPV=-I+\sum_{i=o}^{L}\frac{B_i-C_i}{(1+r)^i} \quad (3)$$

where B stands for the annual revenues (benefits), C for the annual costs, r is the discount factor, L stands for the plant lifetime, I for the total capital investment cost and I for the year.

General parameters used in all case studies are displayed in
Table 3. It is assumed that construction will take four years and that the capital costs are evenly divided over these years.

Table 3 Economic assumptions IG-CG facilities.

Parameter	Unit	
Location	-	NW-Europe
Construction time	Year	4
Plant economic lifetime	Year	20
Discount rate	%	10
Availability	%	90
O&M costs	% of cap. cost	4

In case study 3 a production equivalent price (PEP) was calculated to determine the switch point in production and feedstock respectively. PEP is the electricity price at which production should be switched from chemical to electricity and is calculated according to:

$$PEP=\frac{\Delta E_{Chemical}*P_{Chemical}}{-\Delta E_{Electricity}} \quad (4)$$

where PEP = chemical-electricity equivalent price (€/GJ); ΔE_i is the difference in input or output of commodity i (energy flow (GJ/yr) for feedstock, main product and electricity or mass flow (kt/yr) for by-products and CO_2) and P_i is the price of commodity i (€/GJ for feedstock, main product and electricity or €/kt for by-products and CO_2).

3. Results

3.1. Case 1. Static IG-CG facilities

The production costs for static IG-CG facilities vary between 9-40 €/GJ, depending on used feedstock and desired production (see Figure 7). The pure coal cases have significant lower production costs than the biomass cases (24-65% lower). This is mainly due to higher feedstocks costs of biomass and, to a lesser extend, reduced output when using biomass, resulting in relative larger capital costs. In all cases, using TOPS results in lower production costs compared to using EP, especially when producing chemicals. Only for the Coal to Methanol case the production costs are lower than the market price of the products.

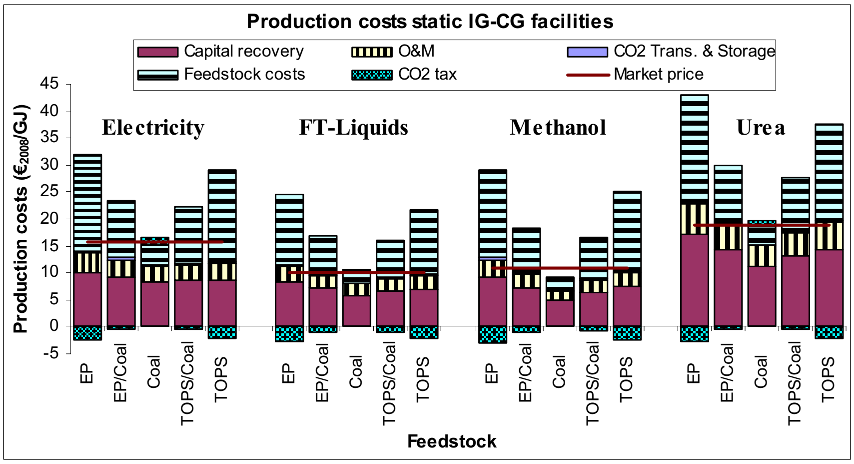

Figure 7 Breakdown annual costs and production cost of static IG-CG facilities with following conditions: 1.5 €/GJ coal; 6.7 €/GJ biomass; 10 €/t CO_2 for transport and storage; 15 €/t CO_2 credit; 15.7 €/GJ co-produced electricity; 2000MW_{th} coal eq. input; 4% O&M; 10% discount rate; 20 year lifetime.

3.2. Case 2. Feedstock variation

Here results are provided on t the impact of using that flexibility with reduced feedstock prices. Results indicate Feedstock costs are between 20% (for coal) and 60% (for biomass) of total production costs. Being able to reduce these costs by exploited short term price variation might be an interesting option. If pure coal is used for half the time and for the other half biomass or a 50/50 biomass/coal mixture is used, then each 10% reduction in feedstock price would reduce production costs by 0.6 €/GJ for FT-liquids production to 1.4 €/GJ for urea production. The production costs are much lower than those of the static IG-CG facilities using the biomass or biomass/coal mixture as feedstock. The main reason for this is that in the feedstock flexible cases, half the time coal is used. The impact of coal's higher energetic value appears much larger than the reduction in feedstock price assumed in this case study.

3.3. Case 3. Production variation

When the IG-CG facility can switch between chemical production and electricity production, it can exploit the daily price variation of electricity. However, it also means higher capital costs and lower efficiencies as equipment is over-dimensioned. The effect of production flexibility on annual profit is given in Table 4. The produced chemicals were sold conform market prices. Results indicate that production flexibility further decreases the economic profitability of the IG-CG facilities.

Table 4 Impact production flexibility on annual profit (M€/yr). (1)

		Feedstock				
		E	EC	C	TC	T
X to FT-liquids	Static	-212	-129	-12	-122	-208
	Prod. variable	-218	-135	-18	-126	-215
	Power mode (2)			35%		
X to Methanol	Static	-182	-94	31	-81	-173
	Prod. variable	-195	-109	12	-97	-189
	Power mode (2)			28%		
X to Urea	Static	-224	-138	-12	-125	-217
	Prod. variable	-234	-151	-32	-141	-231
	Power mode (2)			6%		

(1) Used conditions: 1.5 €/GJ coal; 6.7 €/GJ biomass; 10 €/t CO_2 for transport and storage; 15 €/t CO_2 credit; 15.7 €/GJ co-generated electricity; 10.1 €/GJ FT-liquids; 11.0 €/GJ methanol; 19.0 €/GJ urea; 2000MW_{th} coal eq. input; 4% O&M; 10% discount rate; 20 year lifetime.
(2) The power mode percentage is the fraction the facility maximised electricity production instead of chemical production.

4. Conclusion

This study investigated whether flexibility can improve the economics of IG-CG facilities under current economic conditions. To answer this question the flexibility was divided into feedstock and production flexibility.

The results indicate that feedstock flexibility does not improve the economics of this facilities. The main reason is the current high feedstock price for biomass compared to coal. Without a substantial CO_2 credit price it is not attractive to use biomass, therefore there is no need for feedstock flexibility. Furthermore, under the current market conditions production flexibility between chemical and electricity production reduces the economics of the IG-CG facility. However, the reduction is small and, considering the uncertainties is the used methodology, it is not clear difference is small.

Currently, IG-CG processes are being improved or replaced by superior innovative processes. Further research is required to determine if this is sufficient to turn the table in favour of flexible IG-CG facilities.

5. Acknowledgement

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