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Perspectives on Investment Cost Estimates for Gasification-Based Biofuel Production Systems

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This study presents investment cost estimates for three different gasification based biofuel production systems producing synthetic natural gas (SNG), methanol and Fischer-Tropsch (FT) fuels. A comparison of cost estimates for similar systems presented in the scientific literature and technical reports was also made. The comparison is made on a common basis for a gasifier capacity of 480 $MW_{th\ LHV}$ biomass input. Results show that for all three fuels most of the compared estimates fall within the ±30 % uncertainty range of a study estimate. The Chemical Plant Cost Index (CEPCI) was used for updating cost estimates to the money value in 2012. An analysis of the impact of using alternative cost escalating indices showed that two of the most commonly used cost escalating indices, the CEPCI and CERA DCCI (downstream capital cost index), gave differences in total plant investment of as much as 30 % for long or specific updating periods. For short updating periods the difference was small. These results underline the importance of sensitivity analysis for investment costs in the analysis of profitability for 2nd generation biofuel plants.

1. Introduction

The aim of this study is to point out some important sources of uncertainty in the wide range of investment cost estimates given for gasification based second generation biofuel production systems. Investment costs for three different biofuel production systems are presented, i.e. synthetic natural gas (SNG), Fischer-Tropsch (FT) and methanol (MeOH) production systems.

Haarlemmer et al. (2014) concluded that differences in the raw material costs, the technology choices, the conversion efficiencies (yields) as well as the economic source data, mainly the costs of units are important sources of uncertainties for the investment and production costs of FT fuel systems. Previous studies have also observed the difference in development for some cost escalating indices for a shorter time period (e.g. Kreutz et al. (2008)). In the present study, a comparison of investment costs presented in the scientific literature and technical reports for each of the three biofuel production systems is made. The comparison is made for systems with a similar gasifier capacity and of similar technical setup. Further, this study compares the Chemical Plant Cost Index (CEPCI), the CERA Downstream Capital Cost Index (DCCI) and the Marshall and Swift construction indices during 2000-2012 and, analyses their impact on investment cost estimations. A comparison of investment cost estimates based on literature sources and estimates by industry is also made.

2. Methodology

2.1 Investment cost estimation

The definition of total plant investment, TPI, was based on the expression given by Kreutz et al. (2008), see Eq(1). The interest during construction, IDC, is set to 5 % of the total plant cost, TPC, based on Hannula and Kurkela (2013).

$$\mathrm{TPI} = \mathrm{TPC} * (1 + \mathrm{IDC}) \tag{1}$$

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The TPCs are estimated by dividing each plant into major process areas and sub-components. The capital cost of each component, C, is estimated and summarised to obtain the TPC. In general cost estimate, C_0, for a given component size (capacity), S_0, is given in literature. Scaling is done according to Eq(2):

$$C = C_0 * \left(\frac{S}{S_0}\right)^f \tag{2}$$

Where f is the scaling factor typically ranging between 0.6 and 0.8. Sometimes an upper limit for the size is given and multiple trains could be necessary. In cases where multiple trains are needed, equal size for each train are applied and the installed cost of each additional train is estimated to be somewhat less than the cost of the first train. The trained cost, C_m, of a unit is determined by Eq(3) based on Liu et al. (2011).

$$\mathrm{C}_m = \mathrm{C} * \mathrm{n}^m \tag{3}$$

Where m is the scaling exponent for multiple trains, with a value of 0.9.
In general the scaled component cost estimate needs to be complemented by adding balance of plant costs (BOP) and indirect costs. The BOP is direct costs and includes equipment erection, piping, instrumentation and controls, electrical, utilities, off-sites, buildings (including services) and site preparation. Indirect costs include engineering, head office, start-up and contingencies. In most cases the required addition for BOP and indirect costs are given along with the C_0 cost estimates in literature.
All values and comparisons in this study are based on costs and performances of Nth plants.

2.2 Common value basis

To be comparable, cost estimates need to have a common cost basis, i.e. currency and year. In this study, conversion between currencies is based on annual average currency rates published by the Swedish central bank, (Sveriges Riksbank, 2014) whereas the updating between years is done by using the Chemical Engineering Plant cost index (CEPCI) according to Eq(4).

$$Cost_{\$Year\,Y} = Cost_{\$Year\,X} \times \frac{CEPCI_{Year\,Y}}{CEPCI_{Year\,X}} \tag{4}$$

The same principle could be used with another cost escalating index. The present study compares the results of using the CEPCI and the CERA DCCI index for estimating the investment cost of FT syncrude upgrading equipment. The FT syncrude upgrading equipment was chosen as an illustrative example for which we had access to explicit data from several sources including estimates from industry.

2.3 Process setup and energy balances

As a basis for the investment cost estimation, where product mix and input requirements are needed as scaling parameters for different equipment items, a process scheme and an energy balance need to be defined. In this study data from previous work was used, see section 3.1, but scaled to a common size of 430 $MW_{th,LHV}$ of biomass input at 50 % moisture content.

3. The biofuel production systems and data

Simplified process schemes for the biofuel production system and detailed data on equipment cost data for the cases of this study are given in the supplementary report (Holmgren, 2015). Holmgren (2015) also give additional details on the technical setup for the systems included in the investment cost comparison.

3.1 The biofuel production systems

The technical setup of the SNG case is based on data from Heyne et al. (2010) and employs an atmospheric indirect gasifier and an adiabatic methanation. The technical setup for the methanol and the FT cases are based on Isaksson et al. (2012). Both systems use a direct oxygen blown pressurised CFB gasifier. The employed liquid phase methanol synthesis does not require CO_2 separation but a case with MEA technology for CO_2 separation was included in order to reduce the amount of recycled gas. For the FT case, updated modelling including also the FT syncrude upgrading process was based on Johansson et al. (2014) and for the sizing of the upgrading on Johansson et al. (2013). The biomass air dryer used in all three systems of this study has a heat demand of 2,600 MJ kg^{-1} of evaporated H_2O.
Stream data from Aspen simulations were used in order to construct Grand Composite Curves (GCCs) for the systems and split GCCs were used for determining the potential power production in a heat recovery steam cycle utilising the excess heat from the gasification process as described in e.g. Holmgren et al. (2014). All three gasification systems have a biomass input of 430 MW_{LHV} wet (50 % MC) which corresponds to ~480 MWth of dried biomass. The moisture content of the biomass input is 20 % for the indirect gasifier (SNG case) and 15 % for the CFB gasifier (MeOH and FT cases).

3.2 Cost indices

The CEPCI and CERA indices tracks the costs of equipment, facilities, materials and personnel used in the construction of industrial plants. The CEPCI is based on statistics on producer price indices published by the US department of Labor´s Bureau of Labor statistics (Vatavuk, 2002). The CERA DCCI index is based on a set of refining and petrochemical construction projects which enables the comparison of costs around the world (CERA, 2013). The CEPCI is based on the development in the USA (Remer, 2008). In this study the CEPCI and the CERA DCCI are compared since these are the most commonly used indices. The comparison of using different cost escalating indices was made for FT syncrude upgrading equipment. The estimates for the upgrading equipment made in the present study, indicated by Holmgren in Table 2, are based on the estimates in Liu et al. (2011), (base year 2007), except for the distillation unit which was based on Bechtel (1998). The estimates for refinery sized equipment are based on insurance values for current equipment and the empirical rule that new equipment cost twice as much as the value of existing equipment given by B Karlsson (2014, pers. comm., 12 December).

3.3 Estimating investment costs and comparing to other studies

In order to reflect the wide spread in cost estimates for the indirect gasifier (SNG case) that was found in literature, two cases are included in the cost estimates of the present study. The low estimate is based on NREL (2011) (min) and Tock et al. (2010) (max) whereas the high estimate it is based on Heyne and Harvey (2014). For FT there is one case including costs for the upgrading equipment for the FT syncrude and one without. Upgrading of the syncrude can be made in existing refinery equipment without significant modification (Johansson et al., 2014) and could therefore be left out from the investment cost estimation.
In order to compare investment cost estimates from different literature sources the capacity of the plants were scaled to a common size, i.e. 480 MWth based on the LHV of the biomass input to the gasifier. The scaling was done using Eq(2) with the scaling factor f set to 0.7. The compared systems were selected for having comparable technical setups and sizes that could be scaled reasonably. All methanol and FT cases except Haarlemmer et al. (2012) and van Vliet et al. (2009) are based on CFB gasifiers. Haarlemmer et al. (2012) use an entrained flow gasifier and pretreats the biomass by torrefaction and van Vliet et al. (2009) use a two-stage gasifier. All compared FT plants include syncrude upgrading equipment. For SNG, the current study and the studies by Gassner and Marechal (2012), Heyne and Harvey (2014) and Tunå and Hulteberg (2014) employ indirect gasifiers whereas the rest of the studies have pressurised direct oxygen blown gasifiers. Significant differences in characteristics of these gasification technologies include; the limited scaling of the indirect gasification, requiring multiple trains (three trains in the current study) which increases costs; and the pressurised direct gasifiers requiring equipment for oxygen production and more expensive biomass feeding. The Bio2gas study (Möller et al. 2013b) is a 200 MW_{SNG} plant planned in Sweden using a direct oxygen blown gasifier and an adiabatic methanation. Möller et al. (2013b) give estimates both for a first of its kind plant and for and N^{th} plant. This study uses the N^{th} plant estimate.

4. Results

4.1 Estimated investment costs and comparison to commercial projects

The investment costs for the biofuel systems analysed in this study are given in Table 1. Figure 1 displays the result of the comparison of costs in terms of plain investment cost and investment cost per output. The output is the sum of the fuel production and the net power production. All estimates have been updated to $M€_{2012}$ and a capacity of 480 MW_{LHV} biomass input to gasifier. The Holmgren points refer to values from the current study. SNG and methanol cases are put in the same diagram due to space limitations. All of the compared FT plants except the Haarlemmer et al. (2014) fall within the ± 30 % uncertainty range that is standard to this type of cost estimates. Also all of the compared methanol and SNG cases except the Norrtorp (Möller et al., 2013a) and “SNG low estimate” fall within the ± 30 % uncertainty range. The study by Möller et al. (2013a) is a site specific estimate and does not include full potential for heat recovery etc.

Table 1: Total capital investment cost for stand-alone biomass gasification systems, 430 $MW_{th, LHV}$ biomass input (at 50 % moisture content), $M€_{2012}$.

Total capital investment	SNG, low estimate gasifier	SNG, high estimate gasifier	MeOH no CO_2 sep.	MeOH, MEA CO_2 sep.	FT excl. upgrading	FT incl. upgrading
Min [$M€_{2012}$]	350	510	420	490	450	500
Max [$M€_{2012}$]	360	520	450	510	470	530

Technical choices and conversion efficiencies differ between the systems in this study and the ones in Möller et al. (2013a), but both studies show that the difference in investment costs for SNG and methanol systems is small.

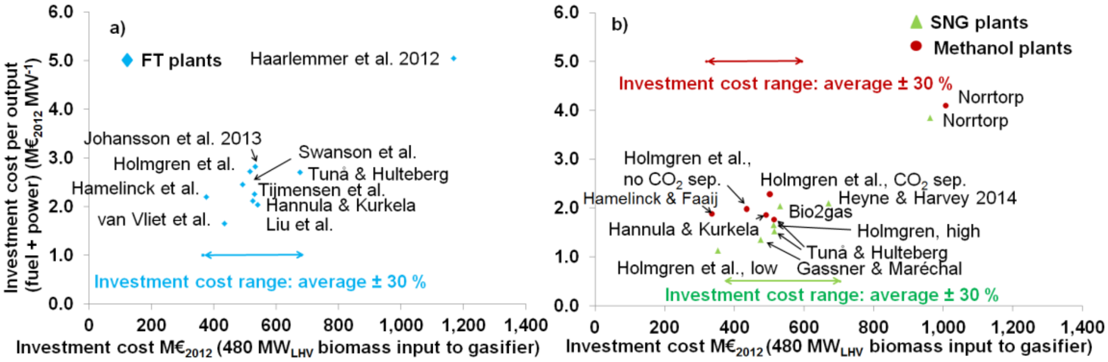

Figure 1: Comparison of total plant investment cost estimates for FT systems (a) and SNG and methanol systems (b).

4.2 The development of different cost escalating indices

Figure 2 shows the development of the CEPCI, the CERA DCCI and the Marshall and Swift cost escalating indices. The CEPCI and the Marshall and Swift indices have had quite similar developments during the past decade whereas the development of the CERA DCCI is different.

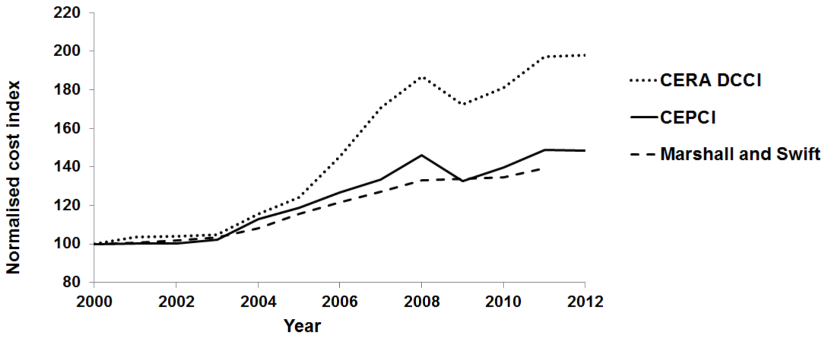

Figure 2: Display of CEPCI, CERA DCCI and Marshall & Swift indices development during 2000-2012. The data has been normalised with year 2000 as 100.

4.3 Investment costs for FT syncrude upgrading using different cost index and base cost sources

Table 2 presents the estimated investment costs for the equipment needed for upgrading the FT syncrude at the size in the current study (indicated by Holmgren) and the size and investment cost of corresponding equipment at a conventional refinery. Results show that the refinery estimates are significantly higher, and that using the CERA index or the CEPCI index result in similar cost estimates for the updating period 2007-2012. If the cost estimates would have been updated over another period or longer time period, the difference between using the two indices could have been significant. For example, for the period 2002-2012 the difference is 30 %.

Table 2. Equipment capacities and investment costs for FT syncrude upgrading equipment.

Equipment process	Refinery size	Refinery cost	Holmgren size	Holmgren cost (CEPCI)	Holmgren cost (CERA)	Cost, refinery down-scaled
	$m^3\ h^{-1}$	$M€_{2012}$	$m^3\ h^{-1}$	$M€_{2012}$	$M€_{2012}$	$M€_{2012}$
Distillation	1,450	340	23	16.0	-[a]	18.8
Naphtha hydrotreater	240	80	3.3	2.0	2.1	5.0
Naphtha reformer	220	290	2.9	8.9	9.5	22.0
C5/C6 Isomerisation	105	60	1.2	1.8	1.9	3.6
Wax hydrocracking	340	460	7.2	16.9	18.0	55.5
Distillate hydrotreater	270	190	10.9	11.4	12.1	27.4

[a] The cost estimate for the distillation was not recalculated since the original cost estimate was older than the CERA index timeline.

5. Discussion

The comparison of investment cost estimates has been done on a basis of similar gasifier capacity. This required re-calculations from HHV to LHV and sometimes also from undried to dried biomass since this was stated differently by different authors. A common basis is important for a fair comparison.

The comparison shows no general trend on which gasifier technology that has the highest investment costs, although the statistical basis is too small to draw general conclusion. Possible explanations to the significantly higher cost found for the FT system by Haarlemmer et al. (2012) are their use of the CERA index for updating costs and possibly the more expensive biomass pretreatment.

The comparison between down-scaled cost estimates for standard refinery equipment and general cost estimates for syncrude upgrading equipment in Table 2 might contain significant uncertainty since the scaling is larger than normally recommended (>10 times), but still indicate that sites specific estimates might deviate significantly from general estimates. The cost estimates given by the refinery expert are valid for site specific conditions whereas the estimates made for the syncrude upgrading based on literature sources are general and the indices are based on costs from a wide range of geographical locations.

Updating cost estimates that are older than five years should be avoided (Vatavuk, 2002). However, the latter is commonly done since many cost estimates are reused in studies and if tracked, the original source is often older than five years. The compared cost estimates are for some studies and equipment items based on the same original source but overall they can be considered to be at least partially independent.

6. Conclusions

Investment cost estimates for gasification based production of SNG, methanol and Fischer-Tropsch fuels, are presented. The group of compared investment costs for each biofuel system turned out to fit, with only a few exceptions, within the ± 30 % uncertainty range of a study estimate although the systems include different gasification and synthesis technologies and some technologies are not commercially available.

The updating of costs between years and currencies is a significant source of uncertainty for the cost estimates. Cost estimates calculated by updating with the CEPCI and the CERA indexes differed only slightly for the updating period 2007-2012. However, for other or longer updating periods the difference can be significant, for 2002-2012 it was 30 %. This result emphasizes the importance of sensitivity analysis with respect to the investment cost when analysing the profitability of gasification based 2^{nd} generation biofuel plants. Updating should be limited to only a few years.

The comparison between the general cost estimates for upgrading equipment and the site specific estimates for standard refinery equipment indicates that site specific cost estimates might deviate significantly from general estimates.

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