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Economy of Biomass-to-Liquids (BTL) plants

An engineering assessment

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Justification

The work described in this report was performed within the scope of an in-house project of the ECN Unit Biomass, Coal & Environmental Research. Applicable ECN project number was 7.5310. Preliminary results of this study have been presented at workshops of the Transportation Fuels Task of the Altener EU project ThermalNET.

Abstract

To meet the ambitious 15% biofuel targets of the European Commission a total installed BTL production capacity of 785 PJ is required by 2020. From the implementation perspective, BTL plants of 1,000 to 5,000 MW_{th} are optimal, i.e. or ten to fifty plants in the whole EU-25. Reference for all TCI (Total Capital Investment) calculations is the 34,000 bbld ORYX-1 GTL plant of Sasol-QP in Qatar with a TCI of 1,100 million US$. The TCI costs for different scales were calculated using a simple constant scale factor of 0.7. For scales below 20,000 bbld the specific TCI increases more rapidly. TCI costs of BTL plants are typically 60% higher than for corresponding GTL plants. The TCI of a 34,000 bbld BTL plant is 1,760 million US$ or 51,800 $/bbld. The heart of a BTL plant is a pressurised oxygen-blown slagging entrained flow gasifier; this technology was identified as optimum technology for biosyngas production. Torrefaction is the optimum biomass pre-treatment technology for entrained flow gasification. Commercial available technologies can be applied for biosyngas cleaning and conditioning, as well as for Fischer-Tropsch synthesis. The economy of BTL fuel production is very dependent on the production scale and large-scale facilities are required to benefit from the economy of scale. The decrease in investments costs is much more significant than the increase in transport costs. Large-scale plants in the gigawatt range yield the lowest fuel production costs, i.e. approximately 15 €/GJ or 55 €ct/L. That means that at an oil price of ~60 $/bbl the biomass-based BTL Fischer-Tropsch fuels are competitive with fossil diesel. The scope of this study was to answer the question: “what is the (economic) optimum scale for BTL fuel production”, according the author the answer to this question is: “The optimum scale of a BTL plant lies in the range of 2,000 to 4,000 MW_{th} (or 16,000 to 32,000 bbld)”.

Keywords

Biomass, gasification, Fischer-Tropsch, economic assessment, entrained flow gasification, pre-treatment, torrefaction, gas cleaning, large-scale, Biomass-to-Liquids (BTL), investment costs.

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Summary

The European Commission has defined very ambitious proposals for the substitution of fossil transportation fuels by alternative fuels and biofuels. The 2020 target proposal equals 15% biofuel substitution or 2,330 PJ. The first 5-6% substitution can be realised with the so-called first-generation biofuels, *i.e.* mainly biodiesel and conventional bio-ethanol. Higher biofuel shares can only be realised with the second-generation biofuels like Fischer-Tropsch (FT) diesel and ligno-cellulose bio-ethanol. FT diesel is a high-quality 'designer fuel' and this so-called biomass-to-liquids (BTL) fuel has a much higher environmental efficiency and superior fuel properties compared to the first-generation fuel biodiesel. To meet the targets, the required 2020 production capacity for Fischer-Tropsch diesel is 785 PJ.

From the implementation perspective, BTL plants of 1,000 to 5,000 MW_{th} are optimal, *i.e.* ten to fifty plants in the whole EU-25. Considering the fact that in Europe there are approximately one hundred oil refineries, it implies that a BTL plant has to be build on every third refinery. The advantages of the existing infrastructure and site conditions are evident. However, the economy of the BTL fuel production is the most important consideration to determine the optimum scale of each individual BTL project. Fuel synthesis is associated with high investment costs. Therefore, large-scale is required to benefit from economy-of-scale due to high investment cost. However, small-scale plants may use cheap local biomass and the transport costs are lower, which may compensate for the higher investment costs.

The scope of the study in this report is to answer the question: "what is the (economic) optimum scale for BTL fuel production". For this purpose the production costs of Fischer-Tropsch diesel was calculated as a function of the plant scale. In this study a simple engineering approach was followed to determine the investment costs.

Note: at time of publication of the report (May 2006) the EPC and commodities markets were overheated and prices have peaked at 150-300% of the price level in the preceding period. The assessment in this report is based on the expectation that prices will decrease and return to price levels of a 'normal' market (i.e. not overheated).

This approach is based on cost data of recent major Gas-to-Liquids (GTL) projects. Although, actual cost information of these projects is not available in the public domain, *off-the-record* the required information can be obtained. The Total Capital Investment (TCI) of a GTL plant is composed of three positions: (1) Inside Battery Limit (ISBL) or main equipment costs; (2) Outside Battery Limit (OSBL) costs; and the (3) Owners Costs - representing 42%, 42%, and 16% of the TCI, respectively. Main equipment cost items are the Air Separation Unit (ASU), syngas manufacturing, and Fischer-Tropsch synthesis representing 30%, 20%, and 25% of the ISBL cost, respectively.

Reference for the calculations is the 34,000 bbld ORYX-1 GTL plant of Sasol-QP in Qatar with a TCI of 1,100 million US$. The TCI costs for difference scales were calculated using a simple constant scale factor of 0.7. There is a strong economy-of-scale effect in the TCI of fuel synthesis plants. For scales below 20,000 bbld the specific TCI increases more rapidly. However, for smaller scales this results probably in an underestimate of the TCI costs, as a smaller scale-factor would be more realistic, *i.e.* 0.6 or even 0.5 for 'real' small GTL plants.

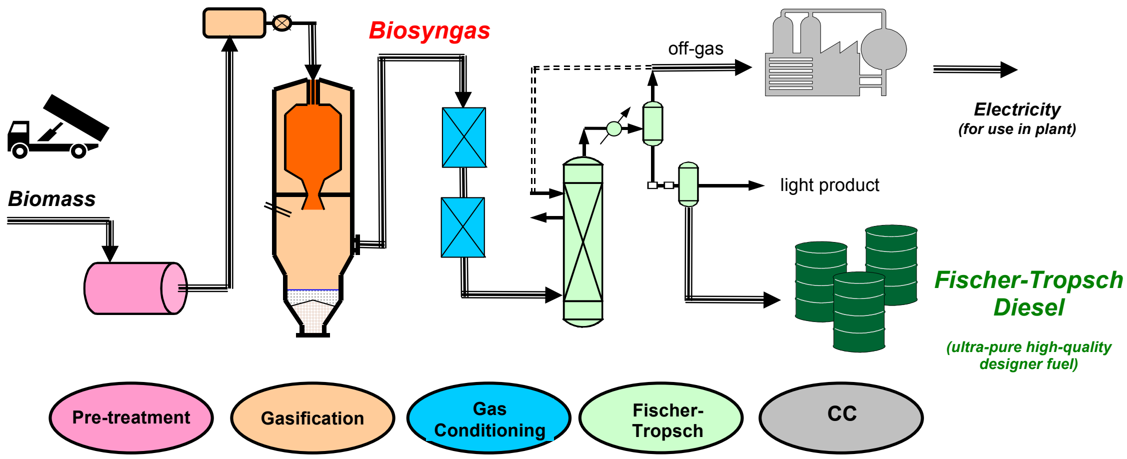
Biomass-to-Liquid plants deviate from GLT plants by the feedstock that is used, *i.e.* solid biomass instead of natural gas. This has impact on several parts of the line-up of the syngas production and Fischer-Tropsch synthesis system: (i) more extensive feedstock handling and preparation; (ii) application of a slagging entrained flow gasifier, which including all solids handling is typically 50% more expensive than a natural gas reformer, (iii) typically 50% higher oxygen demand, *i.e.* 50% larger

ASU capacity is required; and (iv) requirement of a Rectisol unit to remove higher load of impurities and CO_2. The TCI of a 34,000 bbld BTL plant is 1,800 million US$ or 52,000 $/bbld.

The relation between the specific TCI of a BTL plant and the plant scale (*i.e.* production capacity), can be described by equation below:

$$\text{Specific TCI (scale X)} \quad = \quad 52{,}000 \times \left(\frac{34{,}000\ [\text{bbld}]}{\text{scale X}\ [\text{bbld}]} \right)^{(1-0.7)} \qquad [\$/\text{bbld}]$$

The schematic line-up of the integrated biomass gasification and Fischer-Tropsch synthesis (BTL) plant is shown in the Figure below. The heart of the process is a pressurised oxygen-blown entrained flow gasifier. This technology is the optimum technology for biosyngas production as it has the advantages of: (i) high efficiency to biosyngas, (ii) fuel flexibility, (iii) scalability from hundred to a few thousand megawatt, and (iv) possibility to operate on coal as back-up fuel.



Schematic line-up of the integrated BTL plant.

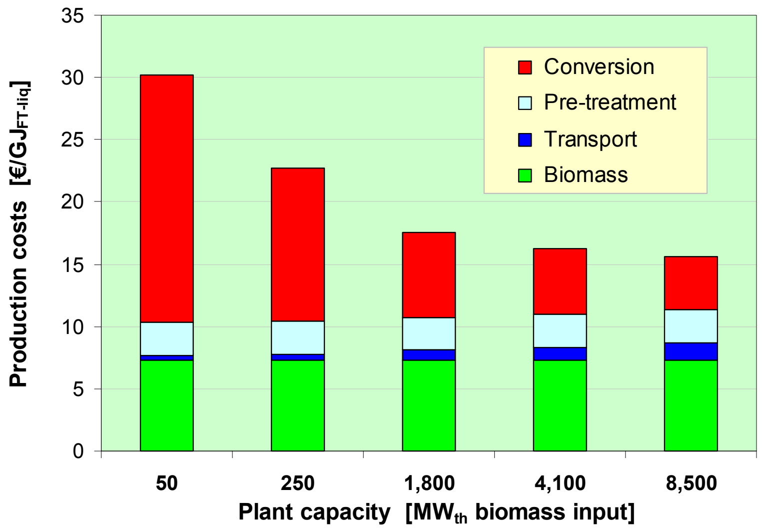
Biomass requires significant pre-treatment to allow stable feeding into the gasifier without excessive inert gas consumption. Torrefaction is one of the most promising routes, as it has an efficiency of up to 97% and torrefied biomass can be handled and fed to the gasifier with existing coal infrastructure.

The raw syngas from the gasifier needs significant conditioning and treating to be suitable for catalytic synthesis. Biosyngas can be cleaned to meet FT specifications with proven and commercial available technologies. There are no biomass-specific impurities that require a totally different gas cleaning approach. Fischer-Tropsch synthesis is an established technology and the two companies Shell and Sasol have already commercialised their FT technology. It is assumed that commercial FT processes are applied in BTL plants.

To determine the (economic) optimum scale for BTL fuel production a simple logistics system based on local biomass (*i.e.* no overseas import) was used. The fuel production costs are composed of the costs for the biomass feedstock material, transport, transhipment, and storage, pre-treatment, and the conversion (gasification, cleaning, synthesis, and product upgrading).

In the assessed system, it is assumed that the BTL plant is located in the centre of a circular forest area. The radius of the area, and resultantly the average transport distances, depends on the scale of the BTL plant, *i.e.* on the amount of biomass feedstock required. Woody biomass from the forest is chipped and dried to 7% moisture. The dried chips (4 €/GJ_{BM}) are transported by truck to a BTL plant. On site of the BTL plant, the biomass is pre-treated by torrefaction with 97% efficiency, to yield a material that can be fed to the gasifier and allows stable gasification. The pre-treatment costs are fixed at 1.5 €/GJ of pre-treated material. In the oxygen-blown entrained flow gasifier the biomass is converted into biosyngas with 80% chemical efficiency. The raw biosyngas is cooled, conditioned, and cleaned from the impurities. The on-specification biosyngas is used for Fischer-Tropsch synthesis to produce C_5+ liquid fuels. Conversion efficiency from biosyngas to FT C_5+ liquids is 71%. All FT liquids products are equally considered as a fuel. The capital costs for the BTL plant are calculated with the derived equation. Annual capital (CAPEX) and operational (OPEX) costs are calculated with a depreciation period of 15 years (linear), a required IRR of 12%, operation and maintenance (O&M) costs of 5%, and a plant availability of 8,000 h a year.

In the Figure below, the cumulative FT fuel production costs are shown for five typical scales. The production costs decrease from 30 €/GJ_{FT} for a 50 MW_{th} plant to just above 15 €/GJ_{FT} at a scale of 8,500 MW_{th}. The latter scale of the projected Shell Qatar plant is comparable to a conventional oil refinery. At large scale the biomass costs of 7.3 €/GJ_{FT} make up half of the fuel costs. At small scale the investments costs is are determining cost item, *i.e.* two-third of the fuel costs.



Scale dependency of FT fuel production costs.
For illustration: 15 €/GJ_{FT} ≈ 55 €ct/L.

The transport, transhipment, and storage costs are only a small cost item, independent of the scale and related transport distances. The results also show that no advantage can be taken from decreasing the plant size, as the decrease in transport costs is completely outweighed by the increasing investment costs.

The economy of BTL plants is very dependent on the production scale and large-scale facilities are required to benefit from the economy of scale. Upon increasing plant sizes, the decrease in investments costs is much more significant than the increase in transport costs. Large-scale plants in the gigawatt range yield the lowest fuel production costs. In large BTL plants the FT fuel production costs are approximately 15 €/GJ or 55 €ct/L. This means that at the current oil price of ~60 $/bbl the biomass-based Fischer-Tropsch fuels are competitive.

The scope of this study was to answer the question: "what is the (economic) optimum scale for BTL fuel production". Considering all aspects related to required production capacity, implementation aspects, biomass logistics, and fuel production economy, according the author the "The optimum scale of a BTL plant lies in the range of 2,000 to 4,000 MW_{th} (or 16,000 to 32,000 bbld)".

1. Introduction

1.1 Biofuels targets

Biomass is heading for a great future as renewable energy source. It not only is available in large quantities, it also is the only renewable energy source that is suitable for the sustainable production of (generally carbon containing) transportation fuels and chemicals. A promising option to do so is to convert biomass into a biosyngas by gasification and subsequently synthesize the required products. This potential of biomass is very important within the policy targets of the European Union to increase the share of alternative transport fuels and biofuels). The motivation or 'drivers' for this policy are:

- Climate change. Reduction of greenhouse gas (GHG) emissions, and especially CO_2, according the Kyoto protocol. The transport sector accounts for more than 30% of the GHG emissions and it is the only sector with increasing emissions.
- Security of supply. More than 60% of all crude oil reserves are concentrated in one (political unstable) region.
- Fuel diversification. Decrease the dependency on crude oil.
- Agricultural development. By using biofuels produced in the EU, rural regions are stimulated and jobs are created.
- Fossil fuel reserves. The crude oil is the first fossil fuel of which the reserves run out, probably somewhere in the next 20 to 40 years.

In the 2001 Directive proposal, the EU defined targets for biofuels and alternative fuels for the years 2005 till 2020 (see Figure 1.1). The biofuel targets for 2005 and 2010 were confirmed in the 2003 Directive. For the member states, these targets are not mandatory, however, deviations should be motivated and if unjustified, the EU may make the targets mandatory.

	2005	2010	2015	2020	new proposal 2020
biofuels	2%	5.75%	7%	8%	15%
natural gas		2%	5%	10%	10%
LPG					5%
H_2		-	2%	5%	a few %
Total	2%	7.75%	14%	23%	> 30%

Figure 1.1*. Target shares for biofuels and alternative fuels within the EU Directives and proposals.*

In 2005, the EU Alternative Fuels Contact Group prepared a new proposal for targets for the period beyond 2010. These targets are even more ambitious and include an almost doubled contribution from biofuels (*i.e.* 8 to 15%). At the same time, the 2005 targets were not reached by most member states, *i.e.* the EU-25 average the share of biofuels was only 1.5% [1]. Therefore, several countries are preparing legislation for mandatory biofuel blending.

1.2 Biofuel potential markets

The volume of the potential biofuels market for the period till 2020 can be calculated from the targeted substitution percentages and the expected total transport fuel market [2]. Table 1.1 shows the energy equivalents of the volume of the projected biofuels markets.

***Table 1.1**. Fuel market and biofuels potential in the EU-25.*

Year		2005	2010	2015	2020
Biofuels substitution	[%]	2.0	5.75	7	15*
Total transport fuel market	[Mtoe]	293	317	343	371
Biofuels market	[Mtoe]	6	18	24	56
Energy equivalents	[PJ]	250	760	1,000	2,330

**: for 2020 the target value proposed by the EU Alternative Fuels Contact Group is taken.*

1.2.1 First generation biofuels

In 2005, the complete biofuels market existed of the so-called "first-generation" biofuels. These liquid biofuels comprise the already available fuels like pure plant oil (PPO) from oil crops, biodiesel from esterfication of PPO or waste vegetable oils, bio-ethanol from sugar or starch crops fermentation, and ethanol derivate ETBE (*i.e.* the *t*-butyl ether of ethanol). Upgraded biogas (*i.e.* Synthetic Natural Gas) is an example of a gaseous biofuel suitable for natural gas substitution.

The potential of the first generation biofuels is limited, as production requires specific feedstock crops. The production capacity in the EU-25 is estimated at 3-4% of the total transport fuel consumption, which can be increased to a maximum of 7-8%, which however, requires significant changes in the agriculture. Therefore, a reasonable estimate for the potential would be 5-6%, *i.e.* approximately the 2010 target. To be able to meet the targets beyond 2010, it is a necessity to utilize more abundant and cheaper ligno-cellulose biomass (*i.e.* woody, grassy, and straw-like materials) for biofuel production. An additional motivation to look for other biofuels is that PPO, biodiesel, and conventional bio-ethanol have a relative low environmental efficiency compared to the second generation fuels, *i.e.* the overall avoided CO_2 emission of the biomass-to-fuel chain is maximum 50% for the first generation biofuels and may be over 80% for the second generation fuels. Furthermore, the fuel quality of bio-diesel and PPO is not excellent, which limits their utilization potential in (future) high performance car engines with catalytic exhaust systems.

1.2.2 Second-generation biofuels

The main biofuels for the medium and long term, *i.e.* after 2010, will be the so-called "second-generation" or synthetic biofuels. Characteristics of these fuels are the production from ligno-cellulose biomass and the high quality of the fuels. The preferred production routes comprise bio-ethanol from ligno-cellulose and Fischer-Tropsch fuel production, respectively, for gasoline and diesel substitution. The latter route is based on conversion of biomass into syngas followed by Fischer-Tropsch synthesis to yield the high-quality 'designer fuel'. This so-called biomass-to-liquids (BTL) fuel has a much higher environmental efficiency compared to the first-generation fuels like biodiesel. Alternative, synthetic biofuels are methanol, DME, and mixed alcohols, while hydrogen might prove to be an option for the long-term. An alternative second generation *gaseous* biofuel is SNG produced via gasification of biomass and subsequent methanation of the product gas. Advantage of this route is the high potential biomass-to-fuel efficiency of 70% [3].

To meet the ambitious EU-25 biofuel targets, 2,330 PJ of fuels have to be produced annually in 2020. In the case that the 2010 targets are met primarily with first-generation fuels, the resulting market volume for the second-generation biofuels would be 1,570 PJ or 38 Mtoe. Assuming a roughly 1:1

ratio of diesel and gasoline in the fuel mix, the required 2020 production capacities for both ligno-cellulose bio-ethanol and Fischer-Tropsch diesel are 785 PJ.

1.3 BTL implementation

To meet the EU-25 biofuel targets, a Fischer-Tropsch diesel production capacity of 785 PJ is required in 2020. In Table 1.2 is indicatively shown how many BTL plants are required to meet the 2015 and 2020 targets, as a function of the BTL plant capacity. References are made to scales of planned and existing GTL projects, as well as to scales of biomass gasifiers:

- Shell GTL PEARL project in Qatar (70,000 bbld, first line).
- Sasol-QP GTL ORYX-1 project (34,000 bbld), which will go on stream mid 2006.
- Shell GTL first (small) commercial plant in Bintulu, Malaysia (14,700 bbld).
- Projected commercial scale for a biomass circulating fluidised bed gasifier (250 MW_{th}).
- Scale of a today's typical fluidised bed gasifier (50 MW_{th}).

Table 1.2*. Number of BTL plants required to meet EU-25 biofuel targets in 2015 and 2020, as a function of the plant capacity for diesel market in addition to the first generation diesel substitutes.*

Target Year 2015	Target Year 2020		Biomass input [1] [MW_{th}]	Reference	Capacity [bblday]
1	6	BTL plants of	8,500	Shell Qatar	70,000
2	12	BTL plants of	4,100	Sasol Qatar	34,000
4	28	BTL plants of	1,800	Shell Malaysia	14,700
31	199	BTL plants of	250	Future Biomass	2,100
154	997	BTL plants of	50	Typical Biomass	410

Table 1.2 shows clearly the impact of the BTL plant scale on the number of plants required to meet the biofuel targets. In the case of only small-scale plants, almost one thousand 50 MW_{th} BTL plants should be in operation in 2020, which corresponds to an average of forty plants per EU country. In the opposite case with only the largest plants, only six plants of 8,500 MW_{th} would be required.

The first case with a large number of small plants is fairly unrealistic, as there are insufficient suitable locations considering logistics, integration options, and more important the permitting legislation. Resultantly, following the route of small-scale initiatives delays implementation and it is questionable if the targets can ever be reached (Figure 1.2). A smaller number of large(r) plants is required to allow thriving implementation and to reach the targets.

In addition to the implementation aspects, it should also be considered that most EU-25 countries have insufficient biomass resources to meet their targets, therefore, large-scale biomass import to the EU will have to be established. This biomass is preferentially converted into biofuels in large facilities close to harbours to avoid further biomass transport to the hinterland and the additional related costs. Therefore, a BTL plant is preferably build close to the harbour, which also allows integration in the existing chemical infrastructure that is typically also located at the larger port sites.

From the implementation perspective, it is expected that BTL plants of 1,000 to 5,000 MW_{th} are optimal, *i.e.* or ten to fifty plants in the whole EU-25. Considering the fact that in Europe there are approximately one hundred oil refineries, it implies that a BTL plant has to be build on every third refinery. The advantages of the existing infrastructure and site conditions in this case are evident.

1. Efficiencies: biomass pre-treatment by torrefaction: 97%; pre-treated biomass to biosyngas via gasification: 80%, biosyngas to FT C_5+-liquids conversion: 71% (it is assumed that all liquids are upgraded to diesel fuel).

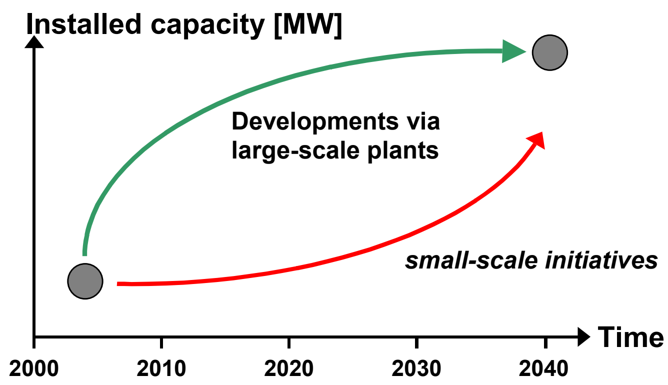


***Figure 1.2**. Alternative routes for BTL implementation.*

1.4 BTL economy

The economy of the BTL fuel production, however, is the most important consideration to determine the optimum scale of each individual BTL project. Fuel synthesis is associated with high investment costs. Therefore, large-scale is required to benefit from economy-of-scale due to high investment cost. However, small-scale plants may use of cheap local biomass and the transport costs are lower, which may compensate for the higher investment costs.

To be able to answer the question: "what is the (economic) optimum scale for BTL fuel production", information on the economy of the whole chain from biomass to Fischer-Tropsch diesel must be available. Information on costs of biomass, various transport systems, and pre-treatment technologies are available in public literature. Reliable information on the investment and operational costs of BTL plants can hardly be found. Furthermore, the data available is generally based on (academic) extrapolating estimated equipment costs of individual parts of the system. The apparent risk of this approach is that often not all parts of the system are included in the assessment. Furthermore, in this approach often the costs of the utilities are significantly underestimated. In general it can be stated that estimates based on this approach are much too positive although they give a (wrong) impression of accurateness due to the detailed assessment.

1.5 Scope of this report

The scope of the study in this report is to answer the question: "what is the (economic) optimum scale for BTL fuel production". For this purpose the production costs of Fischer-Tropsch diesel will be calculated as a function of the plant scale. In this study a very simple engineering approach is followed to determine the investment costs.

In Chapter 2, the relation between investment costs of a BTL plant as a function of the plant scale is determined. In Chapter 3, with an even simple model, the Fischer-Tropsch diesel production costs are calculated as function of the plant scale. Results are discussed in Chapter 4.

Note: at time of publication of the report (May 2006) the EPC and commodities markets were overheated and prices have peaked at 150-300% of the price level in the preceding period. The assessment in this report is based on the expectation that prices will decrease and return to price levels of a 'normal' market (i.e. not overheated).

2. Capital investment

In this chapter, the relation between capital investment costs of a BTL plant as a function of the plant scale is determined with a very simple engineering approach. This approach is based on cost data of recent major Gas-to-Liquids (GTL) projects in progress or in planning. Actual cost information of these projects is of course strictly confidential and not available in the public domain. Experts in the field, however, know many of the relevant details and *off-the-record* the required information can be obtained. The discussion in this chapter is therefore presented without references.

2.1 Gas-to-Liquids (GTL) plants

The assessment of the investment costs of BTL plants is derived from data for GTL plants. The line-up of a typical GTL plant is shown in Figure 2.1. The feed natural gas is converted into syngas either by reforming or partial oxidation. Pure oxygen from the Air Separation Unit (ASU) is used as gasifying agent. Depending on the quality of the natural gas, cleaning or treatment of the natural gas feed may be required, *e.g.* to remove high concentrations of CO_2 or natural gas liquids (*i.e.* higher hydrocarbons). Treatment of the natural gas feedstock is not included in the scope and related costs are considered included in the natural gas feedstock price.

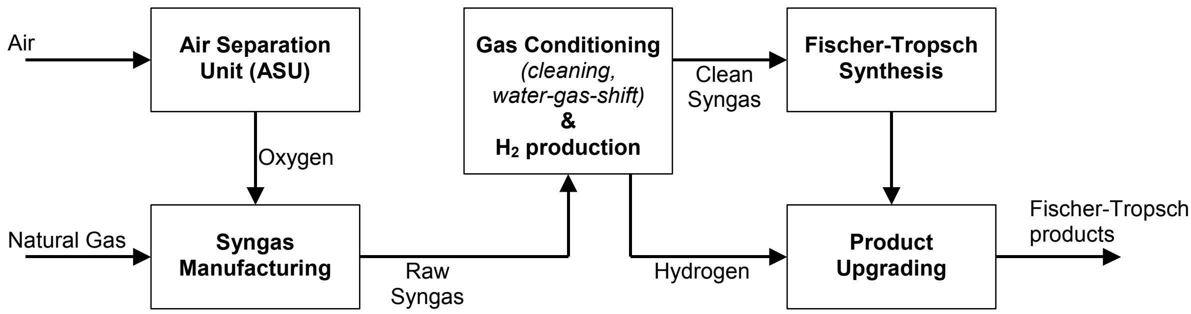


Figure 2.1. *Schematic line-up of a typical Gas-to-Liquids plant.*

The raw syngas is cooled and subsequently conditioned to meet Fischer-Tropsch synthesis specifications. Conditioning comprises gas cleaning and adjustment of the H_2/CO ratio, as well as production of additional hydrogen for utilization in the product upgrading. The clean and conditioned syngas is fed to the Fischer-Tropsch synthesis section and the crude products are upgraded (hydrotreated) to yield a range of FT products. Typically, the FT product slate comprises naphtha, which is an important high quality chemical feedstock, diesel transport fuels, and waxes (lubricants). *N.B. in the scope of this study it is assumed that all FT products are upgraded to yield diesel.*

2.1.1 Investment costs breakdown of GTL plants

The Total Capital Investment (TCI) of a GTL plant is composed of three positions:
1. Inside Battery Limit (ISBL) or main equipment costs;
2. Outside Battery Limit (OSBL) costs; and the
3. Owners Costs.

The breakdown of the ISBL or main equipment costs is shown in Table 2.1. The main cost item is the oxygen production (ASU; 30%). The actual syngas production and conditioning accounts in total also for 30% of the ISBL costs, while the actual synthesis and product upgrading represents 40% of the costs (*i.e.* with 25% for the synthesis and 15% for the upgrading, respectively). Note, that the syngas manufacturing unit (reformer or partial oxidation reactor), although often considered as the most expensive unit, accounts for only 20% of the equipment costs.

In further discussion in this report, all cost data are expressed relative to the main equipment or ISBL costs of a GTL plant, i.e. GTL ISBL = "100 units".

Table 2.1. *Breakdown of Total Capital Investment (TCI) of a GTL plant.*

Cost items		
ISBL or main equipment costs		**100**
- ASU	*30*	
- Syngas manufacturing	*20*	
- H_2 manufacturing + Syngas conditioning	*10*	
- Fischer-Tropsch synthesis	*25*	
- Product upgrading	*15*	
OSBL (100% of ISBL)	*100*	
EPC scope (ISBL + OSBL)		**200**
Owner's costs (20% of EPC scope)	*40*	
Total Capital Investment (EPC + Owner's costs)		**240**

The Outside Battery Limit (OSBL) costs comprise items like auxiliary buildings, site improvements, utility and service facilities, storage and distribution, land purchase. In this assessment the OSBL costs are fixed at 100% of the ISBL costs. For typical chemical plants, the OSBL costs are only 20% of the ISBL costs. However, in a GTL plant the volumes of the side streams are very high, *i.e.* the oxygen and nitrogen from the ASU as well as water by-product from the FT synthesis. Handling and treatment of these streams require correspondingly more auxiliary operations.

The sum of the ISBL and OSBL costs is the total costs of the EPC-scope (*i.e.* Engineering, Procurement, and Contracting or turn-key delivery). These EPC costs are in most cases referred to when investment costs of GTL plants are published.

The Owners Costs comprise (a) Indirect Costs for up-front R&D, up-front license, engineering, construction, contractor's fee, and contingencies, (b) Working Capital, *i.e.* inventories, salaries and wages due, receivables less payables, and cash, and (c) Start-up Costs, *i.e.* modifications, start-up labour, and loss in production. In this assessment the Owners Costs are fixed at 20% of the ECP scope.

2.1.2 TCI of GTL reference plants

There is limited data available for actual investment costs of GTL plants. At the end of 2005, three large GTL projects were under construction. Specifications of these projects are shown in Table 2.2, including published data for the EPC costs. The derived TCI costs are also included.

The ORYX plant is built in an existing industrial location in Qatar. The (large) difference in TCI costs between the ORYX plant and the projected plant in Nigeria with the same capacity is caused by three factors:

1. The Nigeria plant is really 'green field', *i.e.* no existing infrastructure.
2. A higher location factor applies.
3. The contractor costs have increased in recent years due to scarcity caused by the large number of large projects in the world. This item accounts for 40% of the cost difference.

Table 2.2. Investment cost data of ongoing GTL projects.

Project, country, party	Scale [bblday]	EPC costs [million $]	TCI [million $]
ORYX-1, Qatar, Sasol-Chevron-QP	34,000	**900**[a]	**1,100**
PEARL, Qatar, Shell	70,000	**unpublished**	
Nigeria, Sasol-Chevron	34,000	**1,700**	**2,000**
a: costs that would apply for 2005 conditions.			

2.1.3 TCI Calculation as function of GTL plant scale

The TCI data of the reference GTL projects give a good reference for the estimation of TCI costs for GTL plants at other scales. A typical scale-factor number is “0.7”. In Figure 2.2, the specific TCI costs are shown for GTL plants in the range of 1,000 to 100,000 bbld. The specific TCI costs are calculated with as reference the ORYX-1 plant (specific TCI: 32,400 $/bbld) and a constant scale-factor of “0.7”.

The plot in Figure 2.2 clearly shows the strong economy-of-scale of GTL plants. Note, that the economy-of-scale effect is independent of the chosen reference case. For scales below 20,000 bbld the specific TCI increases very rapidly and GTL plants below this scale do not seem attractive and economically feasible.

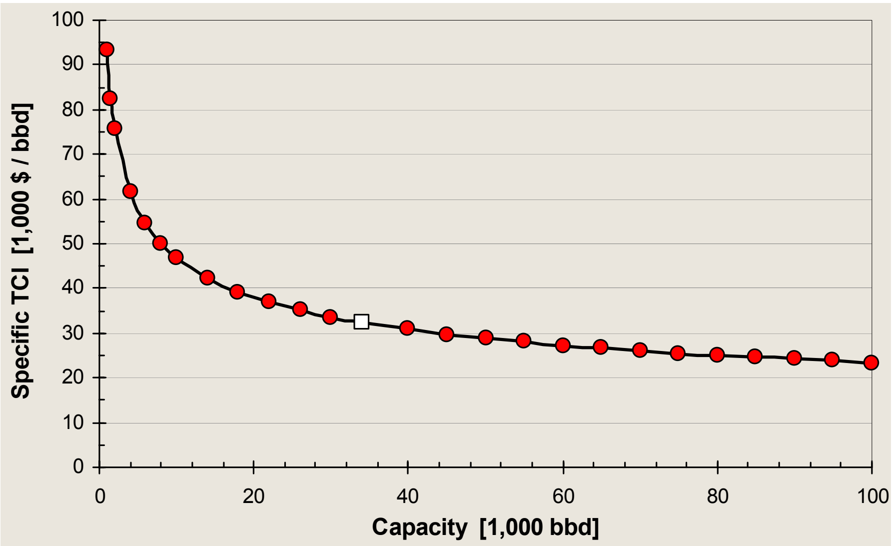


Figure 2.2. *Scale-dependency of specific TCI for GTL plants. Scale-factor “0.7” for capacity range of 1,000 to 100,000 bbld. The open box indicates the reference plant.*

It should be realised that a constant scale-factor over the complete scale-range is not realistic and too simple - even within the scope of the current simple engineering approach. In general, at higher scales the scale-factor will be higher as the advantage of scaling up is less. At smaller scales a smaller scale-factor is realistic, *i.e.* 0.6 or even 0.5 for ‘real’ small GTL plants. In Figure 2.3 it is illustrated what the effect would be of applying lower scale factors for smaller scale plants and a higher scale factor for larger plants, *i.e.* a scale-factor “0.5” for capacity range of 1,000 to 5,000 bbld; “0.6” for 5,000 to 20,000 bbld; “0.7” for 20,000 to 60,000 bbld; and “0.9” for 60,000 to 100,000 bbld. At larger scales, the specific TCI becomes almost independent of the scale, while at smaller scales the specific TCI is 25 to 40% higher compared to the case in which a constant scale factor was applied.

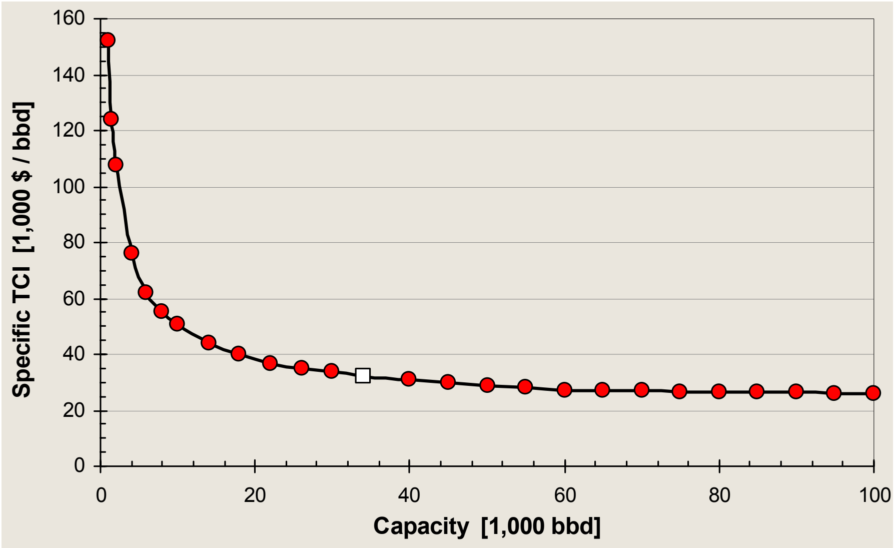


Figure 2.3. *Scale-dependency of specific TCI for GTL plants with varying scale-factors. Scale-factor "0.5" for capacity range of 1,000 to 5,000 bbld; "0.6" for 5,000 to 20,000 bbld; "0.7" for 20,000 to 60,000 bbld; and "0.9" for 60,000 to 100,000 bbld. The open box indicates the reference plant.*

2.2 Biomass-to-Liquids (BTL) plants

2.2.1 Relation with Coal-to-Liquids (CTL) plants

In discussing the difference between a BTL and a GTL Plant, the same considerations apply for BTL as for Coal-to-Liquids (CTL) plants. In Figure 2.4, a schematic line-up of a BTL or CTL plant is shown.

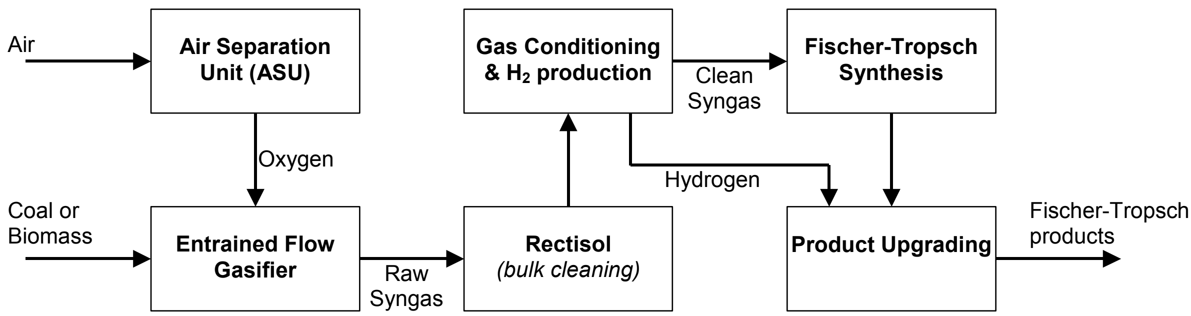


Figure 2.4*. Schematic line-up of typical Biomass and Coal-to-Liquids plants.*

Coal-to-Liquid plants deviate from GLT plants by the feedstock that is used, *i.e.* coal instead of natural gas. This has impact on several parts of the line-up of the syngas production and Fischer-Tropsch synthesis system:

- Coal is a solid and much more extensive feedstock handling and preparation is required.
- Coal is converted into syngas in a slagging entrained flow gasifier, which is a much more complex unit than a natural gas reformer or partial oxidation reactor. A coal gasifier, including all the feedstock handling, is typically 50% more expensive than a natural gas reformer.
- Syngas production from coal requires typically 50% more oxygen than natural gas (for an equivalent amount of heating value syngas), *i.e.* a 50% larger ASU capacity is required.

- Coal contains much more (trace) impurities and coal-based syngas requires much deeper cleaning. Typically, a Rectisol unit will be included in the system for CO_2 removal and bulk gas cleaning.

For Biomass-to-Liquids plants the same considerations apply as for CTL plants, *i.e.* for biomass gasification also a slagging entrained flow gasifier will be selected. Furthermore, biomass gasification also requires significant solid feedstock handling, as well as 50% more oxygen and more extensive gas cleaning (*i.e.* application of a Rectisol unit).

2.2.2 Investment costs breakdown of BTL plant

The investment costs of the BTL plant can be calculated in a similar way as for GTL plants (see Table 2.3). The GTL case is also taken as reference (*i.e.* the GTL ISBL costs = 100 units).

Table 2.3. *Breakdown of Total Capital Investment (TCI) of a BTL plant.*

Cost items			***Compared to GTL***
ISBL or main equipment costs		**160**	
- ASU	*45*		*50% more expensive*
- Gasifier	*30*		*50% more expensive*
- H_2 manufacturing + Syngas conditioning	*10*		
- Rectisol unit	*35*		*New cost item*
- Fischer-Tropsch synthesis	*25*		
- Product upgrading	*15*		
OSBL (100% of ISBL)	*160*		
EPC scope (ISBL + OSBL)		**320**	
Owner's costs (20% of EPC scope)	*64*		
Total capital Investment (EPC + Owners' costs)		**385**	*60% more expensive*

In the BTL plant, the ASU makes up 45 units, and the gasifier 30 units. The items syngas conditioning & H_2 production, Fischer-Tropsch synthesis, and product upgrading are similar to the GTL plant and do not increase in cost. An additional, very significant, cost item is the Rectisol unit, which adds 35 units to the ISBL costs. Resultantly, the ISBL costs for a BTL plants are 160 units or 60% more expensive than a GTL plant.

The OSBL costs are fixed at 100% of the ISBL costs (*i.e.* 160 units), therefore, the costs of the EPC scope are 320 units and the Owners Costs are 20% of the EPC scope (*i.e.* 64 units). Resultantly, the TCI of a typical BTL plant is 384 units, which is 60% higher than for a GLT plant with a similar capacity (*i.e.* 240 units). If we assume large-scale BTL plants to be constructed on site-of or close to existing refinery infrastructures, the ORYX-1 project of Sasol in Qatar is the most suitable reference. In this case the resultant specific TCI of a 34,000 bbld BTL plant is 52,000 $/bbld, *i.e.* 60 higher than the ORXY plant.

2.2.3 TCI calculation as function of BTL plant scale

The TCI of a BTL or CTL plant are 60% higher than for a similar GTL plant. With the same approach as followed for GTL, the scale-decency of the specific TCI for BTL and CTL plants can be determined (see Figure 2.5). Also in this case a constant scale-factor of 0.7 over the complete scale-range is probably an over-simplification. Nevertheless, within the scope of this assessment this constant value will be applied.

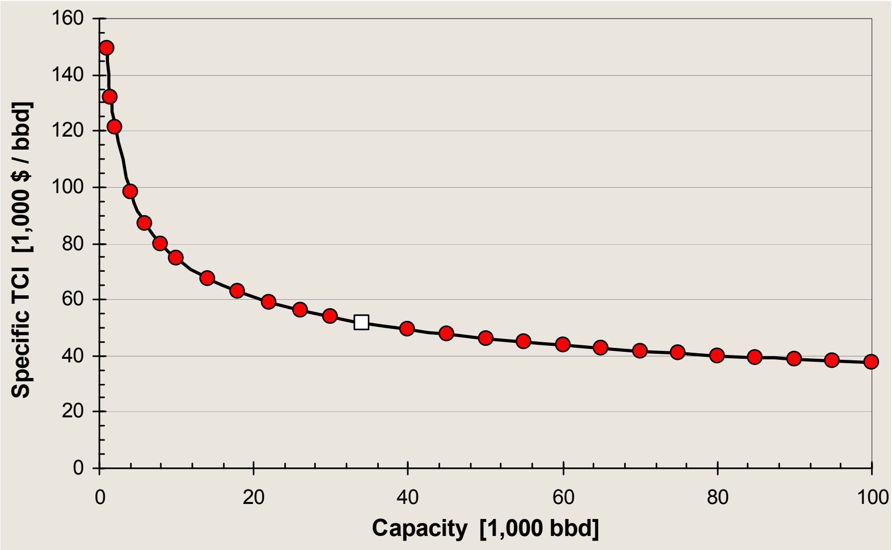


Figure 2.5. *Scale-dependency of specific TCI for BLT and CTL plants. Legend as in Figure 2.2.*

The outcome of this analysis is a relation between the TCI of a BTL plant and the plant scale (*i.e.* production capacity), which is described by equation (2.1):

$$\text{TCI (scale X)} \quad = \quad 1{,}800 \times \left(\frac{\text{scale X [bbld]}}{34{,}000 \text{ [bbld]}} \right)^{0.7} \quad \text{[million \$]} \tag{2.1}$$

Resultantly, equation (2.2) describes the relation between the specific TCI of a BTL plant and the plant scale:

$$\text{Specific TCI (scale X)} \quad = \quad 52{,}000 \times \left(\frac{34{,}000 \text{ [bbld]}}{\text{scale X [bbld]}} \right)^{(1-0.7)} \quad \text{[\$ / bbld]} \tag{2.2}$$

2.3 FT synthesis downstream existing plants

In the view of ECN future BTL plants should be large scale (*i.e.* typically more than one GW biomass input or more than 10,000 bbld output) and based on entrained flow gasification technology. However, today both the technology as well as the biomass logistics infrastructure is still in development. In the biomass gasification community, therefore, some parties suggest to aim at Fischer-Tropsch synthesis downstream existing gasifiers.

Typically the scale of these projects will be at maximum a few hundred MW biomass input. For illustration, in Table 2.4 the relation is shown between biomass input, syngas production, and capacity of FT products production. *N.B. to calculate the data in the table it is assumed that all biomass is converted into biosyngas (CO+H_2). Most today's fluidized bed gasifiers yield a product gas, of which only half comprises of H_2 and CO. In these cases approximately the double biomass input is required to produce the indicated amount of FT products. For definitions and discussion on the product gas versus biosyngas issue see references* 4 *and* 5.

2.3.1 Economy of additional FT synthesis

For calculation of the *additional costs* for the addition of a Fischer-Tropsch section to an existing plant, it is most relevant to determine the additional ISBL or main equipment costs. The OSBL and Owners Costs for an existing plant and site are very case specific and probably (significantly) lower than used in this paper for a new BLT plant. The ISBL costs for a BTL plant make up (160/384 =) 42% of the TCI costs (*cf.* Table 2.3).

The cost breakdown of the ISBL main equipment costs can be used to determine the investment costs of a separate FT synthesis section and product upgrading with upstream gas polishing. *N.B. it should be noted that "gas polising" in this case represents trace removal of impurities; bulk removal is in a BTL plant achieved in the Rectisol unit.* The gas cleaning, FT synthesis, and upgrading represent 31% of the ISBL costs (*i.e.* 10+25+15 of 160 units). If the upgrading of the crude FT product is performed in a central refinery, the upgrading can be excluded (15 cost units). In that case the additional costs are 22% of the ISBL costs, *i.e.* (10+25)/160 units (*cf.* Table 2.3).

Table 2.4. *Relation between biomass input, syngas production, and capacity of FT products production.*

Biomass input [MW]	Biosyngas [a] [MW]	FT products [b] [MW]	FT products [bbld] [c]
10	8	6	85
50	40	28	425
100	80	57	850
200	160	115	1,700
400	320	225	3,400
1,000	800	570	8,500
2,000	1,600	1,100	17,000
4,000	3,200	2,300	34,000
7,000	5,600	4,000	59,500
10,000	8,000	5,700	85,000
12,000	9,600	6,800	102,000

[a] Conversion efficiency biomass to biosyngas in gasifier = 80%;
[b] Conversion efficiency biosyngas to Fischer-Tropsch C_5+ products = 71%;
[c] Energy value FT C_5+ products = 36.3 MJ/l; one barrel = 159 l.

2.3.2 Example 1: 160 MW_{th} syngas & diesel production

Consider an existing biomass gasification plant that produces a 160 MW_{th} syngas and a synthesis with 1,700 bbld FT production capacity. It is assumed that bulk gas cleaning is already in place and that product upgrading is performed on-site to yield FT diesel as product.

The TCI for a complete BTL plant of 1,700 bbl production capacity would be 220 million dollar, equation (2.1), with ISBL costs of 90 million dollar (42%). Gas polishing, FT syntheses, and product upgrading represent 31% of the ISBL costs or 28 million dollar.

In case a Rectisol unit would be required for bulk gas cleaning, this would add 20 million dollar to the costs (22% of ISBL).

2.3.3 Example 2: 80 MW_{th} syngas & crude production

Consider an existing biomass gasification plant that produces a gasification gas, which represents 80 MW_{th} syngas. The gas is used for 850 bbld FT production. It is assumed that bulk gas cleaning is already in place and that product upgrading is performed elsewhere. This example covers the following gasification systems:

- A low-temperature fluidized bed gasifier of typically 200 MW_{th} biomass input and a *product gas* output of 160 MW_{th}. Approximately half of the energy in the product gas is contained in the syngas components H_2 and CO (*i.e.* 80 MW_{th}).
- 100 MW_{th} input high-temperature gasifier with 80 MW_{th} syngas output.
- 100 MW_{th} low-temperature gasifier with a thermal or catalytic cracker to convert the product gas into 80 MW_{th} syngas.

The TCI for a complete BTL plant of this production scale would be 135 million dollar with ISBL costs of 55 million dollar (42%). Gas polishing and FT syntheses represent 22% of the ISBL costs or 12 million dollar.

3. BTL diesel production costs

In the previous chapter the relation between the specific TCI of a BTL plant and the plant scale (*i.e.* production capacity) is determined. In this chapter, the production costs of the BTL diesel fuel are calculated with a simple model. The aim is to determine the (economic) optimum scale for BTL fuel production.

The fuel production costs are composed of the costs for the biomass feedstock material, transport, transhipment, and storage, pre-treatment, and the conversion (gasification, cleaning, synthesis, and product upgrading). To calculate the production costs of BTL Fischer-Tropsch fuel an approach was used based on a case of a simple logistics system based on local biomass (*i.e.* no overseas import).

3.1 Technology

The schematic line-up of the integrated biomass gasification and Fischer-Tropsch synthesis (BTL) plant is shown in Figure 3.1.

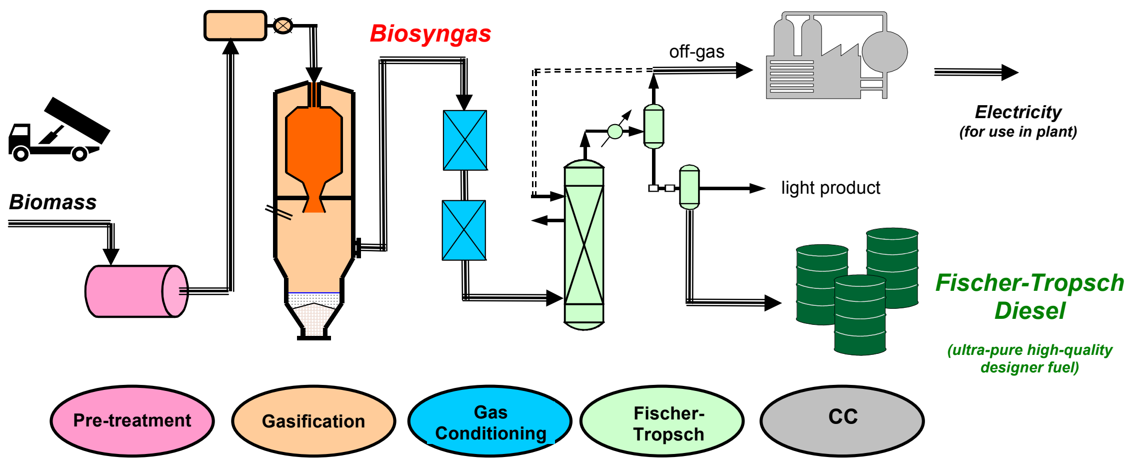


***Figure 3.1**. Schematic line-up of the integrated BTL plant.*

3.1.1 Gasification

The heart of the process is a pressurised oxygen-blown entrained flow gasifier. This technology was identified as optimum technology for biosyngas production as it has the advantages of: (i) high efficiency to biosyngas [5], (ii) fuel flexibility for all types of biomass, *e.g.* wood, straw, and grassy materials, (iii) suitability for scales of several hundreds to a few thousand megawatt, and (iv) possibility to operate on coal as back-up fuel [4]. Entrained flow gasification for coal is a well-established and commercial technology.

3.1.2 Pre-treatment

Biomass, however, is different from coal in many respects; the most relevant relates to feeding. Biomass requires significant pre-treatment to allow stable feeding into the gasifier without excessive inert gas consumption [6].

Several pre-treatment options can be chosen. The two most promising are (1) torrefaction and (2) flash-pyrolysis to produce a bio-slurry. In this assessment pre-treatment by torrefaction is assumed. Torrefaction is a mild thermal treatment in which CO_2 and H_2O are evaded and the material is made brittle and very easy to mill. The process is suitable for a wide range of biomass materials and has a high energy efficiency of up to 97%. The torrefied material can be handled and fed to the gasifier within existing coal infrastructure [7].

In addition to the requirement to pre-treat the biomass for feeding, it may also be desired for purpose of densification of the material. Due to the smaller volume transport costs are reduced and the stability of the gasifier operation is increased, due to the higher energy density of the feed. However, in the approach in this chapter no pre-treatment prior to transport is performed; pre-treatment is carried out prior to gasification.

3.1.3 Biosyngas conditioning

The raw syngas from the gasifier needs significant cleaning and conditioning and treating to be suitable for catalytic synthesis. A typical gas condition line-up comprises gas cooling, water-gas shift, CO_2 removal, and impurities removal (*e.g.* H_2S, COS, HCN, volatile metals). Cooling can be achieved with a cooler or water quench. The advantage of a cooler is that the latent heat in the gas can be utilised, however, in the case of biomass firing, there is an increased risk of fouling due to the relative high alkaline and chloride concentrations compared with coal. In a water quench fouling problems are avoided. Except for the gas cooling, the biosyngas conditioning and treating is similar to fossil-based syngas, *e.g.* a Coal-to-Liquids (CTL) plant. Biosyngas can be cleaned to meet FT specifications with proven and commercial available technologies. There are no biomass-specific impurities that require a totally different gas cleaning approach [5].

3.1.4 Fischer-Tropsch synthesis

Fischer-Tropsch synthesis is an established technology and the two companies Shell and Sasol have already commercialised their FT technology (*cf.* Table 1.2). It is assumed that a commercial FT process is applied in the BTL plant.

3.2 Integrated BTL production system

In the assessed system, it is assumed that the BTL plant is located in the centre of a circular forest area (Figure 3.2). Of the area 38% is production forest of which 50% is exploitable with an annual biomass production yield of 10 ton dry solids per hectare. The radius of the area depends on the scale of the BTL plant, *i.e.* on the amount of biomass feedstock required.

The biomass is assumed to be chipped and dried (7% moisture; bulk density 202 kg/m^3; calorific value LHV_{ar} 16.2 MJ/kg) in the forest, the costs of which are included in the biomass price of 4.0 €/GJ_{BM}. The dried chips are transported by truck to a BTL plant (loading costs 0.073 €/m^3; variable transport costs 0.08 €/ton/km; fixed transport costs 2.0 €/ton). The average transport distance to the BTL equals two-third of the area radius multiplied by 1.2 to accommodate for imperfectness of the existing road network.

On site of the BTL plant, the biomass is intermediary stored (one week capacity; 5.3 €/m^3 per year) before it is pre-treated by torrefaction with 97% efficiency, to yield a material that can be fed to the gasifier and allows stable gasification. The pre-treatment costs are fixed at 1.5 €/GJ_{ptt} of pre-treated material.

In the oxygen-blown entrained flow gasifier the biomass is converted into biosyngas with 80% chemical efficiency. The raw biosyngas is cooled, conditioned, and cleaned from the impurities. The on-specification biosyngas is used for Fischer-Tropsch synthesis to produce C_5+ liquid fuels (*cf.*

Figure 3.1). Conversion efficiency from biosyngas to FT C_5+ liquids is 71%. All FT liquids products are equally considered as diesel fuel.

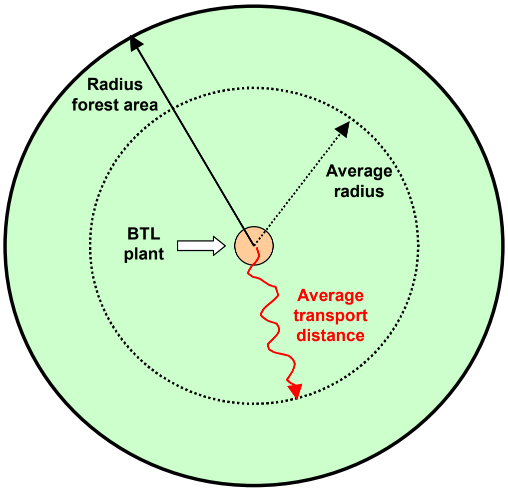


***Figure 3.2**. Biomass production area with BTL plant.*

The capital costs for the BTL plant are calculated with equation (2.1). Annual capital (CAPEX) and operational (OPEX) costs are calculated with a depreciation period of 15 years (linear), a required IRR of 12%, operation and maintenance (O&M) costs of 5%, and a plant availability of 8,000 h per year.

In Table 3.1 all input parameters of the simple model to calculate the BTL diesel production costs are summarised.

***Table 3.1.** Input parameters for the economic assessment of production costs of BTL diesel fuel.*

Parameter	Unit	Value
BIOMASS		
Forest fraction of land	[%]	38
Exploitable fraction of forest	[%]	50
Biomass production	[ton_{ds}/ha/year]	10
Biomass bulk density	[kg/m^3]	202
Biomass calorific value [LHV_{ar}]	[MJ/kg]	16.2
TRANSPORT		
Loading in forest	[€/m^3]	0.073
Biomass transport costs (truck) - fixed	[€/ton]	2.0
Biomass transport costs (truck) - variable	[€/ton/km]	0.08
Road distance efficiency	[-]	1.2
Storage costs at BTL plant (one week)	[€/m^3/year]	5.3
EFFICIENCIES		
Efficiency pre-treatment (chips to torrefied biomass)	[%]	97
Efficiency gasifier (torrefied biomass-to-biosyngas)	[%]	80
Efficiency fuel synthesis (biosyngas to FT C_5+ liquids)	[%]	71
Plant availability	[h/year]	8,000

Table 3.1. Continued.

Parameter	Unit	Value
ECONOMY		
Biomass costs (as received in forest: 7% moisture wood chips)	[€/GJ_{BM}]	4.0
Costs pre-treatment by torrefaction (fixed)	[€/GJ_{ptt}]	1.5
Required IRR	[%]	12
Depreciation period (linear)	[year]	15
Operation and Maintenance (O&M) costs	[%of annual investment]	5
Scale-up factor (constant)	[-]	0.7
CONVERSION CONSTANTS		
Barrel	[l]	159
Energy value FT C_5+ products	[MJ/l]	36.3
Exchange rate (historic average)	[US$/EURO]	1.00

3.3 BTL diesel production costs

The results of the assessment are presented in Figure 3.3. It is clear that the costs for the conversion (*i.e.* the annual CAPEX and OPEX) are the dominant cost factor at plant scales below approximately 2,000 MW_{th} biomass input.

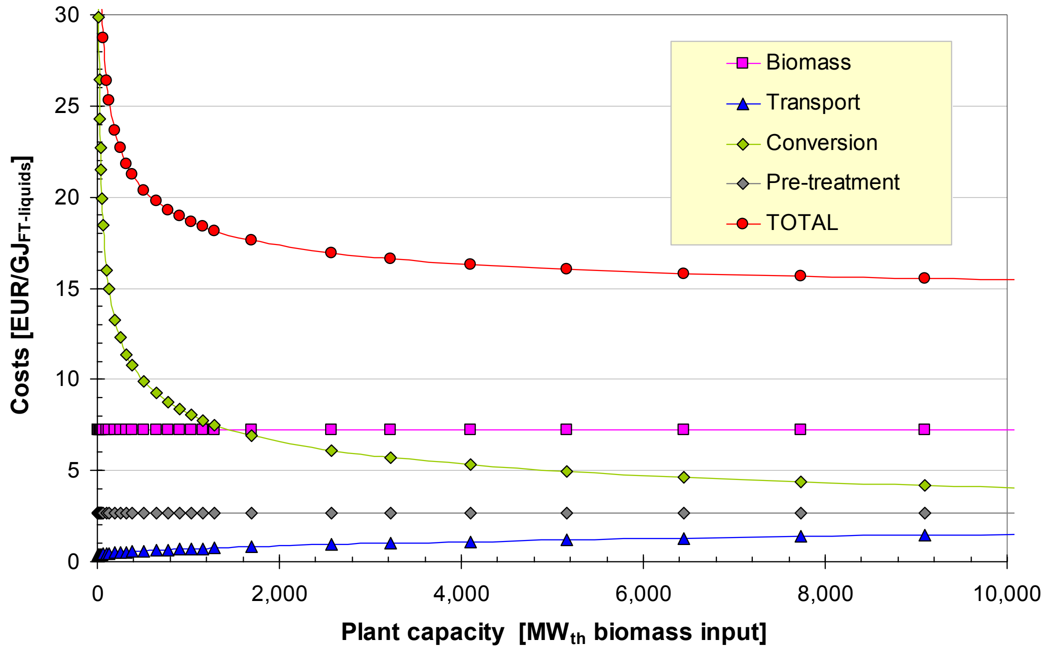


***Figure 3.3**. Scale dependency of Fischer-Tropsch diesel fuel production costs, including contributions of biomass feedstock costs, transport and storage, pre-treatment, and the conversion of the biomass into fuel.*

3.3.1 Impact of transport distances

The transport, transhipment, and storage costs are only a small cost item, independent of the scale and related transport distances. The results also show that, in the assessed case, no advantage can be taken from decreasing the plant size, as the decrease in transport costs is completely outweighed by the increasing investment costs.

In this assessment only land transport by truck is considered. In reference 8 various scenario's based on overseas biomass import are compared. In general can be stated that overseas transport would add approximately 1 €/GJ$_{FT}$ to the fuel costs.

3.3.2 Impact of scale

In Figure 3.4, the cumulative FT fuel production costs are shown in an alternative way, for the five previously discussed scales (*cf.* Table 1.2). The production costs decrease from 30 €/GJ$_{FT}$ for a 50 MW$_{th}$ plant to just above 15 €/GJ$_{FT}$ at a scale of 9,100 MW$_{th}$. The latter scale of the projected Shell Qatar plant is comparable to a conventional oil refinery. At large scale the biomass costs of 7.3 €/GJ$_{FT}$ make up half of the fuel costs. At small scale the investments costs is are determining cost item, *i.e.* two-third of the fuel costs.

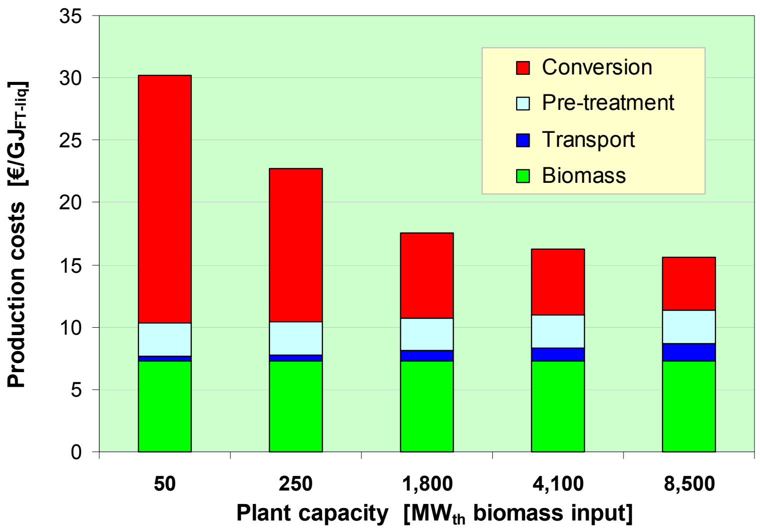


***Figure 3.4**. Scale dependency of FT fuel production costs for five reference scales (cf. Table 1.2). For illustration: 15 €/GJ$_{FT}$ ≈ 55 €ct/l.*

3.3.3 Impact biomass price

The costs of the biomass add 7.3 €/GJ$_{FT}$ to the FT diesel fuel costs (independent of the scale). The 7.3 €/GJ$_{FT}$ follows from the overall biomass-to-fuel conversion efficiency of 56%, *i.e.* for each GJ of FT fuel 1.8 GJ of biomass is required. This illustrates the importance of systems with high biomass to fuel efficiencies.

Operating a smaller BTL plant might be advantageous when cheap local biomass is available. In the case that biomass is available at 0.6 €/GJ$_{BM}$, FT fuels can be produced at 15 €/GJ$_{FT}$ already in a 150 MW$_{th}$ biomass plant. However, one can question how many of these locations will exist within a global biomass market. Therefore, based on economic considerations, it is advisable to direct technology development towards large BTL facilities. Additionally, it should be noted that the use of a scale factor of 0.7 for calculating the investment costs, most likely results in an underestimation of the costs for scales below 2,500 MW$_{th}$ (or 20,000 bbld). A factor of 0.6 for these smaller scales is probably more accurate, while a factor of 0.5 should be used for the even smaller scales below 5,000 bbld (600 MW$_{th}$).

4. Discussion & Conclusions

The scope of the study in this report was to answer the question: "what is the (economic) optimum scale for BTL fuel production". For this purpose the production costs of Fischer-Tropsch diesel were calculated as a function of the plant scale. In this study a very simple engineering approach was followed to determine the investment costs for a BTL plant. An even simple model was used to calculate the Fischer-Tropsch diesel production costs as function of the plant scale.

4.1 Discussion

Reliable cost data for GTL projects are not available. Therefore, the investment cost relation was derived from the *off-the-record* information on the EPC cost of the 34,000 bbld GTL plant built by Sasol-QP in Qatar. From this information the total capital investments (TCI) were determined and with a constant scale factor of 0.7, the TCI was calculated for the whole scale range from 10 to 100,000 bbld. However, for smaller scales this results probably in an underestimate of the TCI costs as a smaller scale-factor would be more realistic, *i.e.* 0.6 or even 0.5 for 'real' small GTL plants.

Based on assessment of the main equipments cost items of a BTL plant, it was concluded that the TCI for a BTL plant is typically 60% more expensive than a GTL plant with the same capacity, which is caused by the 50% higher ASU capacity, the 50% more expensive gasifier due to the solids handling, and the requirement of a Rectisol unit for bulk gas cleaning. Although the approach followed is very simple, the results are just as good or probably even more accurate than in-depth studies based on detailed assessment of equipment cost items.

The relation between the specific TCI of a BTL plant and the plant scale (*i.e.* production capacity), is described by the relation below, which afford a TCI of 1,800 million US$ for a 34,000 bbld BTL plant or 52,000 $/bbld.

$$\text{Specific TCI (scale X)} \quad = \quad 52{,}000 \times \left(\frac{34{,}000 \ \text{[bbld]}}{\text{scale X} \ \text{[bbld]}} \right)^{(1-0.7)} \qquad [\$ / \text{bbld}]$$

The preferred gasification technology for a BTL plant is pressurised oxygen-blown entrained flow gasifier because of the advantages of: (i) high efficiency to biosyngas, (ii) fuel flexibility, (iii) scalability from hundred to a few thousand megawatt, and (iv) possibility to operate on coal as back-up fuel. Biomass requires significant pre-treatment to allow stable feeding into the gasifier without excessive inert gas consumption. Torrefaction is one of the most promising routes, as it has an efficiency of up to 97% and torrefied biomass can be handled and fed to the gasifier with existing coal infrastructure.

Biosyngas can be cleaned to meet FT specifications with proven and commercial available technologies. There are no biomass-specific impurities that require a totally different gas cleaning approach. While Fischer-Tropsch synthesis is an established technology and commercial FT processes can be applied in BTL plants.

To determine the (economic) optimum scale for BTL fuel production a simple logistics system based on local biomass (*i.e.* no overseas import) was used. The fuel production costs are composed of the costs for the biomass feedstock material, transport, transhipment, and storage, pre-treatment, and the conversion (gasification, cleaning, synthesis, and product upgrading).

The economy of BTL plants is very dependent on the production scale and large-scale facilities are required to benefit from the economy of scale. Upon increasing plant sizes, the decrease in investments costs is much more significant than the increase in transport costs. Large-scale plants in the gigawatt range yield the lowest fuel production costs. In large BTL plants the FT fuel production costs are approximately 15 €/GJ or 55 €ct/L. This means that at the current oil price of ~60 $/bbl the biomass-based Fischer-Tropsch fuels are competitive.

4.2 Concluding

The main statements and findings of this study can be summarised as follows:

- To meet the ambitious biofuel targets of the European Commission a total installed BTL production capacity of 785 PJ is required by 2020.
- From the implementation perspective, BTL plants of 1,000 to 5,000 MW_{th} are optimal, *i.e.* ten to fifty plants in the whole EU-25.
- There is a strong economy-of-scale effect in the TCI of fuel synthesis plants. For scales below 20,000 bbld the specific TCI increases very rapidly.
- TCI costs of BTL plants are typically 60% higher than for corresponding GTL plants.
- The TCI of a 34,000 bbld BTL plant is 1,800 million US$ or 52,000 $/bbld.
- The heart of a BTL plant is a pressurised oxygen-blown slagging entrained flow gasifier; this technology was identified as optimum technology for biosyngas production.
- Torrefaction is the optimum biomass pre-treatment technology for entrained flow gasification.
- Commercial available technologies can be applied for biosyngas cleaning and conditioning, as well as for Fischer-Tropsch synthesis.
- The economy of BTL fuel production is very dependent on the production scale and large-scale facilities are required to benefit from the economy of scale.
- The decrease in investments costs is much more significant than the increase in transport costs.
- Large-scale plants in the gigawatt range yield the lowest fuel production costs, *i.e.* approximately 15 €/GJ or 55 €ct/L.
- At an oil price of ~60 $/bbl the biomass-based BTL Fischer-Tropsch fuels are competitive.

The scope of this study was to answer the question: “what is the (economic) optimum scale for BTL fuel production”. Considering all aspects related to required production capacity, implementation aspects, biomass logistics, and fuel production economy, according the author the “The optimum scale of a BTL plant lies in the range of 2,000 to 4,000 MW_{th} (or 16,000 to 32,000 bbld)”.

5. References

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