Memo**: Report on bus ticket no.E3**
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IMPORT OF BIOMASS: LOGISTIC ADVANTAGES OF OVERSEAS PRE-TREATMENT

Definition of the problem
In the very near future the Netherlands will need huge amounts of biomass, most of which will be imported, for co-combustion in existing coal plants. Furthermore, there will be substantial extra demand for biomass for liquid and gaseous biofuels. Pre-treatment of solid biomass prior to import, and the related costs and efficiency losses, are the key issues that determine the technological and economic potential of the biomass import.

Questions
i. Which pre-treatment technologies need to be included?
ii. Which biomass intermediates or products should be transported?
iii. Which locations will be most suitable to establish pre-treatment plants?
iv. Which scale is the most feasible?
v. What will be the approximate investment costs involved?

1. Introduction

As biomass is envisaged to play a major role in fulfilling national targets concerning the reduction of CO_2-emissions and the introduction of renewable energy sources, ambitious targets have been set. In the EOS-LT program, with respect to co-firing, 25% biomass co-firing (on energy basis) is foreseen for 2020, whereas in 2040 40% biomass co-firing should be realised. In the overall long-term vision of covering 30% of the total energy consumption of the Netherlands by biomass energy in 2040, and covering 20-45% of the feed-stock requirements of the chemical industry with biomass, large-scale import of biomass (either wood or grass-like) will be required.

The Netherlands have a considerable domestic biomass potential, however, this domestic potential may even not be sufficient to reach the short-term targets for 2010 for biofuels (5.75% of demand) and renewable electricity (9% of demand).

2. Large-scale biomass plants

Realising the objective of 30% biomass energy involves approximately 1200 PJ of biomass, which corresponds to 45 GW_{th} of biomass capacity. For comparison, the total installed capacity of all coal-fired power stations in the Netherlands is approximately 10 GW_{th}, whereas the largest size available at this moment for a biomass plant is roughly 100 MW_{th}.

The domestic biomass potential, *i.e.* various waste streams adding up to approximately 100-120 PJ and theoretically another 50 PJ made by "energy farming", might be converted through (de-central) small scale biomass plants (not discussed further in this report). As for the Netherlands, however, most biomass required has to be imported and thus will be available in large quantities at only few places, the (central) biomass plants will generally have to become larger, possibly up to 10 GW_{th}.

These large-scale plants have the advantage of *(i)* economy of scale, *(ii)* higher efficiency, and *(iii)* easier/cheaper to meet emission limits. Furthermore, finding suitable locations for thousands of small-scale plants in a densely populated country is extremely difficult, and large-scale plants better fit to the present situation where most energy is produced at only few places where permits and logistics are suited. This is all very similar to the present situation with coal as fuel.

3. Biomass feedstock, intermediates and final products

Considering the whole route of conversion of overseas biomass to bioproduct (being either electricity, fuels or chemicals) in the Netherlands, numerous processing steps at different locations along the route can be defined. If the large-scale biomass plant is located in the Netherlands, the required biomass can be imported as original feedstock (*e.g.* wood logs or chips) or as biomass intermediate (*e.g.* pellets, pyrolysis slurry, torrefied wood, TOP pellets). Depending on the final product, the final biomass conversion facility might also be located overseas. In that case, the Netherlands would import the product (*e.g.* methanol, diesel, chemicals, SNG, LNG) rather than the biomass feedstock/intermediate.

An overview of an overall system for products from imported biomass is presented in figure 1. The biomass is collected at a number of production locations and transported to collection facilities, from where it will be transported to and stored at a central port. From the central port, the biomass is transported (*i.e.* by ship or train) to a large-scale biomass conversion facility, in this specific case located at the port of destination.

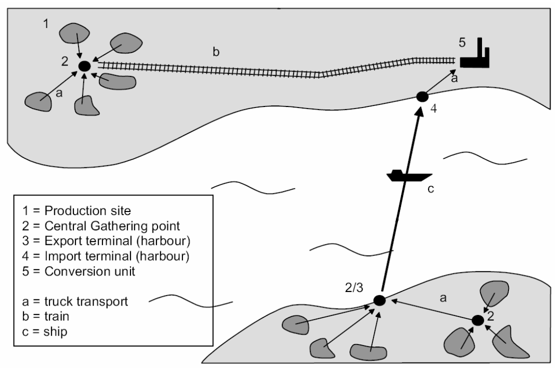

Figure 1 *Overview of an overall system for products from imported biomass* [1]

The biomass conversion facility might also be located at the central gathering point or the export terminal. As all biomass, however, has to be transported by land to this facility and land transport is relatively expensive the distances between production site and central gathering point, as well as between central gathering point and export terminal should be kept small (< 100 km). As a result, the maximum scale of the conversion facility is restricted by the biomass supply (*e.g.* roughly 150 MW_{th} for the central gathering point and 1 GW_{th} for the export terminal) and, hence, the facility might, depending on the scale-up potential of that facility, become relatively more expensive than a 10 GW_{th} conversion facility at the port of destination [2, 3].

Biomass pre-treatment plants, however, are often limited in scale and therefore constructed modular. As a result, biomass can be pre-treated in the export terminal or even in the central gathering point without being burdened by the economy-of-scale effect. As for transport of biomass over longer distances, biomass should preferably be converted into a form that is suitable for bulk handling, the pre-treatment plant should be located preferably near the production location of the biomass, hence at the central gathering point (< 150 MW_{th} scale). The biomass conversion facility, in order to benefit from the economy-of-scale, should at least be located at the export terminal (± 1 GW_{th} scale), but preferably at the port of destination (up to 10 GW_{th} scale) [4].

4. Fischer-Tropsch diesel production as reference case for transportation fuels

The logistic advantages of overseas pre-treatment on import of biomass can be illustrated by the assessment of Fischer-Tropsch diesel production routes. In these Biomass-to-Liquids (BtL) routes biomass is converted into syngas, subsequently fuel is produced via Fischer-Tropsch (FT) synthesis. Entrained-flow (EF) gasification is identified as the optimum process for large scale production of syngas from (a variety of) solid biomass streams (*e.g.* woody biomass and straw and herbaceous material). As the assessment will illuminate, pre-treatment of solid biomass, and the related costs and efficiency losses, are key issues that determine the technological and economic potential [4].

4.1 System definition

Integrated systems from biomass overseas to FT-products on an 8 GW syngas scale are assessed, a scale at which the actual FT synthesis and product upgrading are economically feasible. The biomass production is assumed in the Baltic States and the Rotterdam harbour is taken as final location. The harvested biomass is naturally dried in the forest before transport to a pre-treatment plant. The first step of the pre-treatment is size reduction and further active drying after which the actual pre-treatment takes place. The product (pre-treated biomass) is then transported to the BtL plant, where it is compressed to the required pressure for gasification, fed to the gasifier, converted into syngas, synthesised to FT-crude, and upgraded to FT-product (*i.e.* diesel).

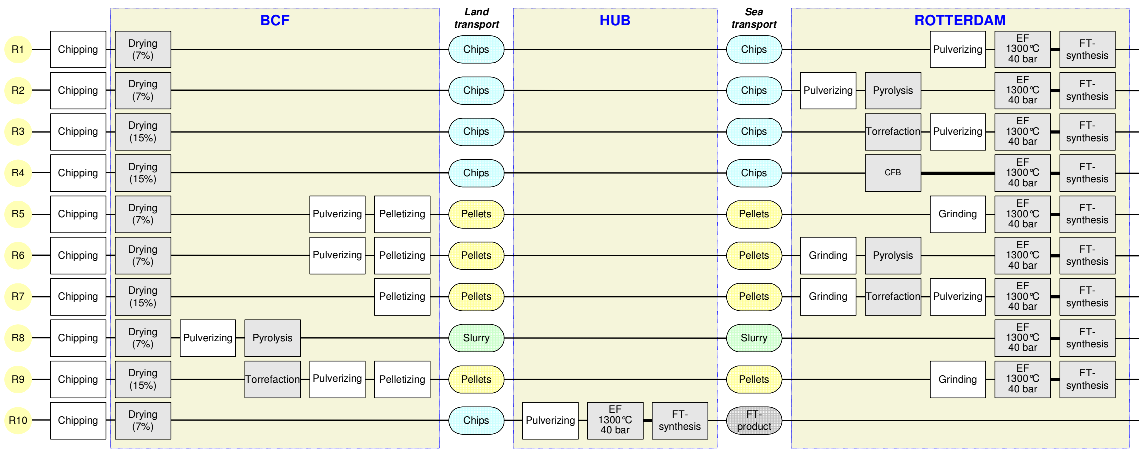

Figure 2 *Overview of the considered Biomass-to-Liquids (BtL) production routes* [4]

The evaluated BtL production routes, as presented in figure 2, comprise the whole chain of biomass collection, transport, syngas production, gas cleaning, FT-synthesis and product upgrading. The biomass is collected in a number of production locations and transported to 80 biomass collection facilities (BCF), from where the (pre-treated) biomass is transported to and stored at 8 central ports (HUB). In order to assess advantages of pre-treatment on transport and storage, several pre-treatment technologies are considered in the BCF. From the central ports, the (pre-treated) biomass is shipped to the location of one syngas production facility. At this facility with intermediate storage capacity, the biomass is (additionally) pre-treated and subsequently gasified. Pre-treatment of biomass in BtL systems may be required to enable feeding into the gasifier, as well as desired for transport costs reduction or improved gasifier operation.

The gasification and synthesis plant is chosen to be located in a Western European port, *e.g.* Rotterdam, based on *(i)* the port infrastructure being appropriate and *(ii)* the port being an existing HUB in production and distribution of transportation fuels. Short term implementation of a BtL route might strongly benefit from a good chemical and petrochemical infrastructure nearby. However, a reference route is considered as well, in which gasification and synthesis are located in the HUB.

4.2 Biomass feeding considerations

When conventional feeding systems are to be applied, biomass needs to be pre-treated to become similar to coal or converted into a pumpable liquid. In order to mill biomass to *particles* with the required size (*i.e.* ~100 μm) the electricity consumption is approximately 7% of the energy value of the biomass. Furthermore, milled wood still cannot be fed with conventional systems, due to the fibrous nature of the biomass. It does not fluidise and fluffs are formed that plug the piping. Therefore, milling of biomass to a size of 100 μm is not considered a feasible option. Alternatively, *char* might be used, obtained from (slow) pyrolysis. The char, however, contains only 40-60% of the energy of the biomass. The remainder is contained in the (tar rich) pyrolysis gas, which has to be used on site and is not available for BtL production if the FT process is located elsewhere. Therefore, char is considered not a feasible general option due to the low overall chain efficiency. *Torrefaction* is a mild thermal treatment in which the biomass looses its resilient and fibrous properties. It becomes dry, brittle, and can be easily milled. The energy efficiency of the torrefaction step is up to 95%. The remainder is torrefaction gas mainly containing H_2O, CO_2, and small amounts of light (oxygenated) hydrocarbons. This combustible gas can be used to provide heat for the torrefaction process. Torrefaction is considered as a suitable pre-treatment option.

Options based on liquid feeding involve pyrolysis. By (fast) pyrolysis a liquid, *bio-oil*, is produced containing up to 70% of the energy of the biomass. The remainder of the energy is for ~15% in the pyrolysis gas and ~15% in the char. The gas can be used to generate the electricity for the plant and about half of the char is required to produce the heat for the pyrolysis process. The other half is surplus. However, in most cases it is burned inside the process as well resulting in additional waste heat. Overall the efficiency is low and, therefore, bio-oil is considered not a feasible option. *Bio-slurry* is produced in a (fast) pyrolysis process similar to bio-oil production, with the exception that all produced char and oil are isolated as a slurry. This process is developed by Forschungs Zentrum Karlsruhe (FZK) in Germany. The energy efficiency of this FZK process is approximately 85-90%, the pyrolysis gas is used to provide the heat for the process. With this higher efficiency bio-slurry is considered a feasible candidate option.

Alternatively to converting biomass into liquids or coal-like material, new feeding systems for biomass can be developed. In a *low-temperature gasifier* the biomass is converted into product gas and a small amount of char. The gas with entrained char is fed into the EF gasifier. Advantages are that no extensive biomass pre-treatment is required, as circulating fluidised bed (CFB) gasifiers can handle relatively large fuel particles. The efficiency is nearly 100%. The easiest solution of feeding biomass to the entrained-flow gasifier is direct piston screw *feeding of 1 mm particles*. Electricity consumption for milling is only in the order of 1-2% and there are no conversion losses. The challenge, however, is to ensure stable feeding and dosing to the gasifier burner to establish a stable flame.

4.3 Biomass transport considerations

For transport of biomass over longer distances, biomass should preferably be converted into a form that is suitable for bulk handling. Therefore, the pre-treatment plant should be located preferably near the biomass production location. Biomass forms that are suitable for cost-effective transport over longer distances (considering the biomass feeding issues described before), and allow transshipment with bulk handling processes, are: chips, pellets, bio-slurry and torrefaction pellets (TOP).

When chipping wood the biomass is also dried to 7-15% moisture prior to the process to reduce the electricity consumption. *Wood chips* are readily transported and transshipped by bulk handling processes, however due to the relatively low bulk density (~350 kg/m³) and the risk of rotting, costs of transport, transshipment, and storage are relatively high. The production of *pellets* leads to an increase of the bulk density of the biomass (~450-650 kg/m³). Pellets are suitable for bulk handling as well. Alternatively, biomass materials can be converted into a bio-slurry or into torrefied material. The *bio-slurry* has the advantage of a very high bulk density (~1200 kg/m³) and it can be transported and handled as a liquid (comparable to heavy oil). However, HSE (health, safety, and environmental) aspects of bio-slurry are not yet clear.

In case of torrefaction, the biomass can be transported as *torrefied wood* chips, which are suitable for bulk handling. However, the torrefied branches, leaves, needles and straw contain too many fines. Pelletisation is therefore preferred to produce the so-called “TOP pellets”. Additional advantage of pelletisation is the increase in both material and energy density (~850 kg/m³). This also happens in normal pellets, however, due to the resilient nature of fresh biomass the increase in density is much smaller. Further advantages of torrefied biomass with respect to handling and further processing are the hydrophobic nature of the material and the lower electricity demand during pulverisation. Increasing the energy density is even more advantageous than increasing the mass density as from certain densities a higher mass density has no logistic advantages anymore (i.e. the mass becomes the limiting factor in ship transport instead of the volume).

4.4 BtL production routes

The ten assessed BtL production routes as presented in figure 2 can be divided into three groups, *i.e.* routes *(i)* based on sole chips transport (R1 to R4), *(ii)* in which biomass is pelletized conventionally before transport (R5 to R7), and *(iii)* with some kind of thermochemical conversion performed before transport (R8 to R10). When transporting biomass as chips to the syngas facility in Rotterdam four concepts are evaluated; 1 mm powder feeding (R1) to the EF gasifier and bio-slurry production (R2), torrefaction (R3) or CFB gasification (R4) before EF gasification.

Conventional pellets have to be ground in Rotterdam to be fed either straight into the EF gasifier (R5), or to be pyrolysed (R6) or torrefied (R7) in order to simplify the feeding system of the EF gasifier. The torrefaction process still contains a pelletisation step, as temporary storage of the torrefied wood at Rotterdam is desired. TOP pellets are fed to the EF gasifier by lock hoppers, intermediate disintegration to 100 µm particles, and a pneumatic feeding system, whereas bio-slurry uses a pump, and 1 mm particles a piston compressor for pressurisation and screw feeding system. In routes R8 and R9 the pyrolysis and torrefaction are performed in the BCF in order to benefit from logistic advantages. CFB gasification within the BCF as a pre-treatment step is not considered, as this would require syngas transport from the BCF to Rotterdam.

The final route R10 is based on EF gasification and FT-synthesis in the HUB. As the FT-synthesis generates more than one product this requires additional storage facilities at the HUB for transport of all these products to take place at an economically attractive scale, i.e. with large-scale overseas transport. In order to benefit from the economy of scale this would imply that only one HUB should be considered instead of eight. However, from (road) transport of the biomass point of view, one HUB is less interesting. This route therefore is evaluated on the basis of both one and of eight HUBs. The routes R1 to R9 all are based on the existence of eight HUBs (and eighty BCFs).

4.5 Assumptions

The assessment of the BtL routes is based on the general assumption that biomass, *i.e.* chipped wood logs with a moisture content of 35%, in all routes is delivered at the BCF at a fixed price of 4.0 €/GJ or 45 €/ton. The efficiencies of the different routes, in combination with the different economy of these processing steps and logistic costs, determine the final production costs of the FT product. With the efficiencies of the individual processing steps as presented in table 1 the overall efficiencies from biomass with 35% moisture content to FT diesel become as presented in table 2. The highest efficiencies are obtained when 1mm particles can be fed to the EF gasifier (57.8%), the lowest when the biomass is converted to bio-slurry before being gasified in the EF gasifier (53.5%).

Table 1 *LHV efficiencies of process steps*

Drying	
To 7% moisture	106.5
To 15% moisture	105.1
Pre-treatment	
Chipping, pelletising, pulverising, grinding	100
Pyrolysis	90
Torrefaction	95
CFB gasification	99

EF gasification	
1 mm particles	72.8
Bio-slurry	74.9
TOP pellets (disintegrated)	73.6
CFB gas	71.1
FT-synthesis yields	
C_{1-4}	4.5
C_{5-10}	6.2
C_{11+}	68.4

Table 2 *LHV efficiencies of total process*

Feeding system EF	Individual processing steps	Overall
1mm particles feeding	1.065 x 0.728 x (0.062+0.684)	57.8%
Bio-slurry	1.065 x 0.90 x 0.749 x (0.062+0.684)	53.5%
TOP pellets	1.051 x 0.95 x 0.736 x (0.062+0.684)	54.8%
CFB gas	1.051 x 0.99 x 0.711 x (0.062+0.684)	55.2%

Efficiencies of chipping, pelletising, pulverizing, and grinding are set to be equal to 100%, although in reality some small losses might be expected. Energy demands of drying and transport are accounted for as utility costs and not included in the overall LHV efficiencies. Only C_{5+} is considered to be upgraded to FT diesel.

The investment costs for the different routes are presented in table 3. The lowest investment costs are obtained when 1mm particles or the gas from the CFB gasifier are fed to the EF gasifier situated in Rotterdam (3.2 billion €), the highest when the biomass is thermally converted into bio-slurry or TOP pellets in the Baltic States (>5.4 billion €) when the biomass is converted to bio-slurry before being gasified in the EF gasifier (53.5%).

Table 2 *Investment costs in billion €*

Route	Description	BCF	HUB	Rotterdam	Overall
R1	Chips transported to Rotterdam and EF gasified as 1mm chips	0.2	0.0	3.1	3.3
R2	Chips transported to Rotterdam and pyrolysed before EF gasification	0.2	0.0	4.3	4.5
R3	Chips transported to Rotterdam and torrefied before EF gasification	0.1	0.0	4.2	4.3
R4	Chips transported to Rotterdam and CFB gasified before EF gasification	0.1	0.0	3.1	3.3
R5	Pellets transported to Rotterdam and EF gasified as 1mm chips	1.8	0.0	2.8	4.6
R6	Pellets transported to Rotterdam and pyrolysed before EF gasification	1.9	0.0	4.1	6.0
R7	Pellets transported to Rotterdam and torrefied before EF gasification	1.3	0.0	4.2	5.5
R8	Bio-slurry transported to Rotterdam and EF gasified	2.8	0.0	2.3	5.1
R9	TOP pellets transported to Rotterdam and EF gasified	1.9	0.0	2.7	4.6
R10[a]	Chips transported to HUB and EF gasified as 1mm chips in 1 EF plant	0.2	3.1	0.0	3.3
R10[b]	Chips transported to HUB and EF gasified as 1mm chips in 8 EF plants	0.2	4.1	0.0	4.3

4.6 Production costs

In figure 3 the cost breakdown as well as the overall fuel costs in Rotterdam are shown. The resulting total production costs of the FT-product at Rotterdam vary between 12.4 and 19.0 €/GJ. When looking at the cost breakdown of the FT-product, the influence of pre-treatment (*i.e.* densification) of the biomass on the final production costs of the FT-product is clearly demonstrated. In the cost breakdown the production costs are divided into biomass costs, transshipment (*i.e.* loading and unloading), transportation and storage costs (*i.e.* the logistics), capital costs, operation and maintenance costs, and utility, by- and rest product costs.

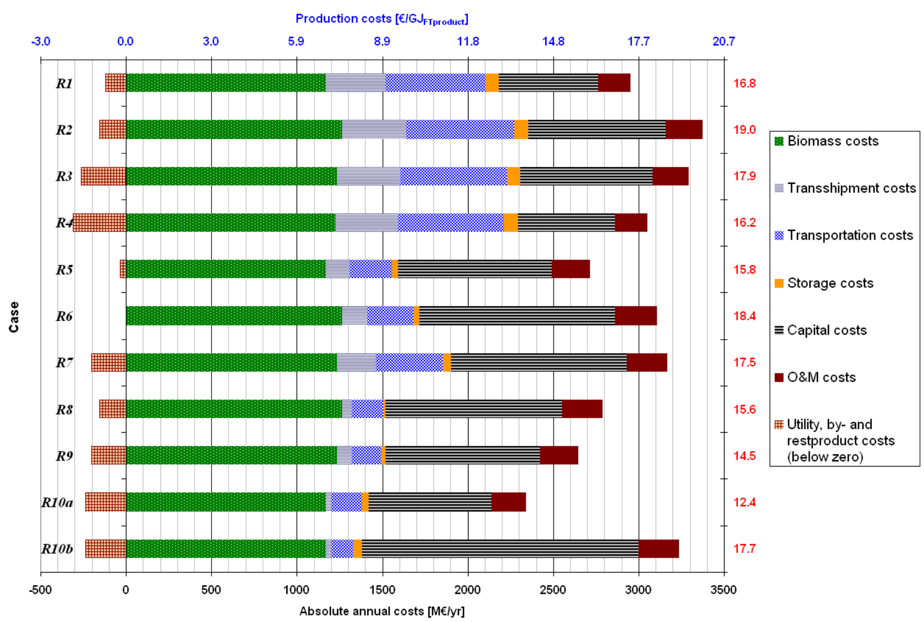

Figure 3 *Cost breakdown of the production costs of FT-product*

The lowest production costs for FT-product (12.4 €/GJ) are achieved by placing the synthesis plant in one HUB and not in Rotterdam (R10), however, from transportation point of view (*i.e.* the amount of trucks required to the centralized plant) one HUB is not realistic. Therefore this case is evaluated on the basis of eight HUBs as well, demonstrating clearly the (dis)advantage of economy of scale as the production costs increase drastically to 17.7 €/GJ.

Second to fourth best routes are based on pre-treatment by torrefaction (R9), pyrolysis (R8) or pelletisation (R5) in the BCF. When compared with the same conversion technologies applied in Rotterdam (R6 and R7) the advantage of pre-treatment at the front-end of the BtL production route is clearly demonstrated. This effect can also be observed when comparing the routes based on chips transport with similar routes based on conventional pellets transport (R1 versus R5, R2 versus R6 and R3 versus R7), however (conventional) pelletising is less interesting than more advanced pre-treatment (*i.e.* pyrolysis and torrefaction) overseas.

The low-temperature CFB gasification concept was evaluated on the basis of chips transport (R4). This route is the most interesting one of the routes with pre-treatment in Rotterdam (R1 to R4). However, CFB gasification as a feeding system for EF gasification will not be able to compete with overseas torrefaction and/or pyrolysis. The advantages of densification before transport outweigh the advantage of the CFB feeding. CFB gasification can still be considered as feeding system in case of an overseas synthesis plant, however, based on logistic problems overseas (as discussed before) one overseas plant is not realistic and the advantage of CFB gasification will be compensated by the need for multiple overseas plants, and, hence, the disadvantage of economy of scale.

The cost breakdown reflects that the actual biomass costs, *i.e.* initially 4.0 €/$GJ_{biomass}$ at the BCF or, taking into account overall production efficiencies, even up to 7.0 €/$GJ_{FT\ product}$, account for a significant part of the overall production costs, however, on an annual basis the actual biomass costs do not differ significantly for the evaluated BtL routes, hence the differences in production efficiency of the different BtL routes has a limited influence on the feasibility of the specific routes.
It also shows that in case of chip transport the logistic costs might run up to approximately one-third of the total production costs, hence providing some financial margin for pre-treatment (*i.e.* densification) steps in the front-end of the BtL production route. The additional investments related to these pre-treatment steps are less than the associated logistic cost reduction.

4.7 Conclusions for the BtL assessment

The main conclusions of the assessment of ten Biomass-to-Liquids (BtL) production routes, with regards to possible logistic advantages of overseas pre-treatment are (i) pre-treatment (*i.e.* densification) of the biomass at the front-end of the BtL route significantly increases the economic feasibility of the BtL production route, (ii) advanced overseas pre-treatment by means of torrefaction is more attractive then pyrolysis or conventional pelletisation and (iii) a large scale central overseas synthesis plant (8 GW_{th}) would be the most attractive route for BtL production, demonstrating that import of the final product instead of the biomass (intermediate) might be interesting as well. Local logistic aspects, however, require construction of several “small scale” synthesis plants (1GW_{th}) causing significant disadvantages due to economy of scale.

5. The distinction between transportation fuels and electricity, gaseous fuels, and chemicals

Although there are a lot of similarities between the BtL routes and biomass-to-electricity (BtE), biomass-to-gaseous fuels (BtG) and biomass-to-chemicals (BtC) some differences along the routes might cause some of the conclusions drawn from the BtL assessment to be invalid for the BtE, BtG and BtC route. Therefore the main distinctions between transportation fuels and electricity, gaseous fuels, and chemicals are discussed in this paragraph, as well as the effect of these distinctions on the conclusions drawn with regards to possible logistic advantages of overseas pre-treatment.

5.1 Electricity

The main difference between the BtL route and the BtE route is that import of electricity has to be excluded. Hence, in case of large scale implementation of BtE all BtE routes are solely based on import of biomass (intermediates). The intermediates that might be considered are basically the same as in the BtL routes, hence wood chips, pellets, bio-slurry, and TOP pellets, although biomass will not always need to be pre-treated to be similar to coal or converted into a pumpable liquid (§4.1). As, however, densification of the biomass is more important than the loss of efficiency (as concluded in §4.6) it seems to be legitimate to conclude that overseas pre-treatment either by torrefaction or (for BtL routes) slightly less interesting pyrolysis or pelletisation will also significantly increase the economic feasibility of the BtE production route.

5.2 Gaseous fuels & chemicals

In contrast to electricity, gaseous fuels and chemicals can be imported from overseas, hence BtG and BtC routes should not only consider import of biomass (intermediates), but also the import of the final products gaseous fuels (*e.g.* as compressed natural gas CNG or liquefied natural gas LNG) and chemicals. The difference with BtL routes might be that whereas BtL plants aim at large scale implementation in order for the synthesis and product upgrading to be economically feasible, BtG and

BtC plants might already be economically attractive at smaller scales. As a result, the implementation of a smaller scale BtG or BtC plant in the HUB might become attractive, whereas for BtL this was not realistic (as mentioned in §4.6). Hence, not only the overseas pre-treatment, but also overseas production of the final product, might significantly increase the economic feasibility of the BtG and BtC production route.

Onshore transport of (synthetic) natural gas by pipeline, for example, is still economical and convenient, especially taking into account the existing natural gas grid. Major obstacle, however, is the realisation of required huge investments in this gas infrastructure over the next 20 years [5]. For offshore transport of natural gas, pipelines become challenging as the water depth and the transport distance increase, hence LNG or CNG become effective means of transporting (synthetic) natural gas (from overseas biomass) [6].

Cooling natural gas at atmospheric pressure until it condenses at minus 160°C into liquid form produces liquefied Natural Gas (LNG), reducing its volume tremendously to just $^{1}/_{600}{}^{th}$ of its gaseous volume. This reduction of volume was the main reason for developing natural gas liquefaction processes as it addresses the need to transport large quantities of natural gas across oceans and to other continents in special cryogenic tankers or stored in heavily-insulated tanks [7, 8]. Compressed Natural Gas (CNG), *i.e.* natural gas compressed at pressures ranging from 100 to 180 bar, provides an effective way for shorter-distance transport of gas, *i.e.* for distances up to 4000 kilometres, especially in case of offshore reserves not linked to existing gas grids. At distances above 4000 kilometres the cost of delivering gas as CNG becomes essentially the same as the LNG and market demands play the deciding role [6]. A typical LNG import would require a gas demand of 5 GW_{th}. When substituting a significant amount of the Dutch annual natural gas consumption according to national renewable targets, the 5 GW_{th} scale will easily be reached.

In case of LNG, the costs of field development, liquefaction and regasification are independent of the distance to be travelled, whereas the costs of tankers are both volumetric size and travelling distance related. With just 30% of the costs being travelling distance related [8] it's obvious that LNG is something especially interesting when long distances have to be overcome, as is illustrated in figure 4. The costs of pipelining natural gas benefit substantially from economies of scale (*i.e.* large diameter pipelines are not that more expensive to lay), but do increase significantly with increasing transport distances. Considering that biomass is most likely to be obtained over long distances (*e.g.* the Baltic States, Latin America, Africa or British Columbia), LNG produced overseas from biomass might end up being economically more attractive than transporting the biomass (intermediates) and convert it into SNG in Europe.

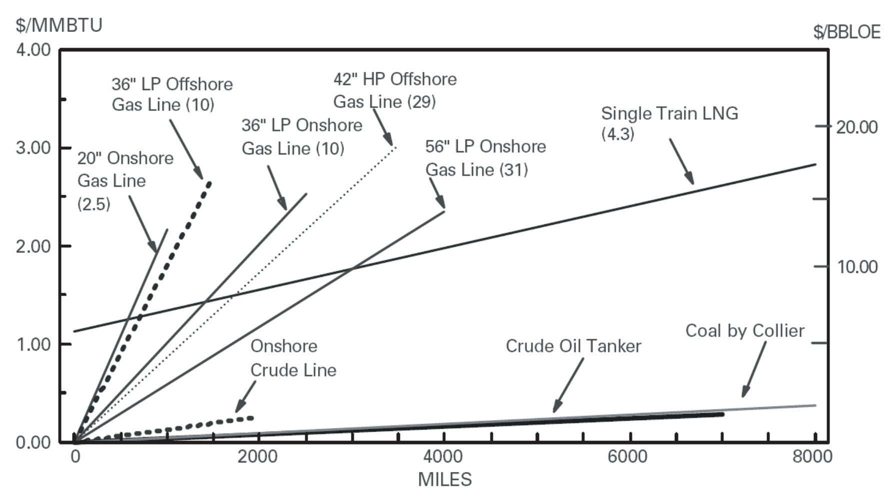

Figure 4 *Illustrative costs of gas, oil and coal transportation* [8]

An estimate of the costs (including liquefaction and regasification) might be obtained from the single train LNG equation, which would result in 1.5 $/MMBTU SNG (approximately 1.2 €/GJ SNG) when transporting the gas over a distance of 2500 kilometres (approximately 1550 miles). This distance is also used within the evaluation of FT diesel production routes, where costs of biomass (intermediate) transport where calculated for, among others, wood chips, slurry, and TOP pellets. Transport costs amounted to 0.7 €/GJ for slurry and TOP pellets and 2.3 €/GJ for wood chips. Taking into account an efficiency of SNG production of 70%, the actual transportation costs would become ~3.3 €/GJ SNG for wood chips and ~ 1.0 €/GJ SNG for bio-slurry or TOP pellets. These costs do not yet include costs of pyrolysis or torrefaction, when accounting for these costs as well the costs for having the biomass transported over a distance of 2500 km to a Western European port, *e.g.* from the Baltic States, will definitely be higher than the 1.2 €/GJ required for transporting liquefied SNG. In case of biomass being over even longer distances (*e.g.* Latin America, British Columbia), the advantage of LNG transport will probably have even a bigger impact. A more detailed evaluation will, however, have to be performed to confirm this preliminary conclusion.

6. Conclusions and recommendations

1. In order to fulfil national targets concerning the reduction of CO_2-emissions and the introduction of renewable energy sources, most biomass required has to be imported and thus will be available in large quantities at only a few central large-scale biomass plants.

2. The domestic biomass potential might be converted through (decentralised) small scale biomass plants. As for the Netherlands, however, most biomass required has to be imported and thus will be available in large quantities at only few places, the (central) biomass plants will generally have to become larger, possibly up to 10 GW_{th}.

3. Pre-treatment (i.e. densification) of the biomass at the front-end of the Biomass-to-Product (BtP) route significantly increases the economic feasibility of the BtP production route.

4. In order to reduce logistic costs biomass should be pre-treated in the biomass collection facility (BCF) before being transported by land to a central port (HUB) and by ship to Western Europe.

5. The size of the BCF is determined by the typical scales of pre-treatment processes as well as limitations in surface area (*i.e.* travelling distance) of the biomass production site. As most pre-treatment processes have limited scales and are constructed modular, the BCF will have a typical biomass throughput up to 150 MW_{th}.

6. In case of Fischer-Tropsch diesel production advanced overseas pre-treatment by means of torrefaction is more attractive than pyrolysis or conventional pelletisation. It is expected that in case of biomass-to-electricity (BtE), biomass-to-chemicals (BtC) or biomass-to-gaseous fuels (BtG) torrefaction will also be the most attractive pre-treatment option.

7. Due to economy-of-scale aspects overseas Fischer-Tropsch diesel production in the HUB is less interesting. For BtE routes overseas electricity production makes no sense, whereas for BtC and BtG routes importing the final product might be considered as an alternative for importing the biomass (intermediate).

8. The size of the HUB is determined by the desired transport distance between BCF and HUB as well as typical scales of (non-modular) biomass conversion processes. When supplying a HUB from 8 BCFs the transport distance between BCF and HUB is limited (below 100 km) whereas the biomass throughput of approximately 1 GW_{th} might enable economically feasible conversion of biomass in to the final product in the HUB as well.

9. With the biomass throughput of the HUB being approximately 1 GW_{th} production of chemicals and/or gaseous fuels in the HUB, unlike FT synthesis, might be economically attractive. For Synthetic Natural Gas (SNG) from biomass transporting the gas as LNG or CNG to Western Europe might already have some major logistic advantages taking into consideration that biomass has to be imported from the Baltic States. Biomass import from further away (*e.g.* British Columbia, Latin America) will probably just enlarge this advantage.

10. In case chemicals and or gaseous fuels are desired in Western Europe, a more detailed evaluation will have to be performed to confirm the preliminary conclusion that importing the final product instead of the biomass (intermediate) might have significant logistic advantages.

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