VALUE CHAINS FOR PRODUCTION OF RENEWABLE TRANSPORTATION FUELS USING INTERMEDIATES

CASE STUDIES FOR BIO-OILS IN REFINERY APPLICATIONS AND BIO-SNG

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BACKGROUND

An increased share of renewable transportation fuels requires utilisation of new low-cost sources of bio-based raw materials other than what is currently used in the pulp and paper industry and for power and district heat generation in the bioenergy sector. Currently, proposed raw material includes forest residues (branches and tops), stumps, waste round wood and different by-products from pulp and paper industry and sawmills. Of these, forest residues and stumps have, by far, the largest potential for increased utilisation. However, these types of raw materials are often voluminous and heterogeneous and are difficult to handle in existing refineries for production of transportation fuels. The cost of transporting this type of raw material over large distances in order to supply a larger plant is often said to be high. This report includes an analysis of the possible advantages and disadvantages of transforming forest-based biomass to an intermediate product with a higher energy density that is more homogeneous and easier to handle during transport and during final conversion to transportation fuel.

INVESTIGATED VALUE CHAINS

Two value chains are investigated as case studies:

a) bio-SNG production using forest residues, bark and sawdust as raw material, and

b) bio-oil production from forest residues, lignin in black liquor and tall oil, which can be upgraded to transportation fuels at a refinery.

In the study we have assumed that the conversion of the original biomass to an intermediate product mainly takes place at a pulp mill, since the pulp mill is often located in areas with high availability of forest raw material, there is an infrastructure available in form of road access, wood yard and handling facilities, and a lot of know-how with respect to handling and conversion of forest-based biomass and opportunities for process and energy integration. The intermediate conversion technologies included for value chain a) are drying and pelletizing and for value chain b) pyrolysis and distillation. The final conversion to end product bio-SNG takes place in connection to a district heating system, and the final deoxygenation and upgrading of bio-oil to hydrodeoxygenated (HDO) oil takes place at an oil refinery.

The value chains *with* intermediates are compared with value chains *without* intermediates where the entire conversion process to final product is located in connection to a district heating system in value chain a) and at a stand-alone plant near to a refinery in value chain b). The value chains are studied from a well-to-gate perspective, from extraction of the forest biomass to produced bio-SNG/HDO bio-oil. A direct comparison between value chains for bio-SNG and bio-oil production should be avoided. They are based on different reference data that are not synchronized. A direct comparison between the chains should in addition be done in a well-to-wheel perspective.

RESULTS

The results show that the initial hypothesis that local production of a more energy dense intermediate would reduce transportation costs could not be verified. The reason is primarily the introduction of a second transport step to transport the intermediate to the final conversion site in addition to the transport of the raw material. The transport costs are associated with relatively high fixed costs, especially for ship and train transport, so the introduction of a second relatively high fixed transport cost of the intermediate has a dominating effect.

With the above said, it can also be concluded that the transport cost makes up a relatively small share of the total production cost of the final product, in the order of 10%, and in a few cases up to 20%. There is therefore a relatively small difference in total specific production cost for the final product between value chains with and without intermediates considering the level of uncertainty in the input data and the assumptions behind the scenarios studied.

Decentralised production of intermediates in several smaller plants can lead to increased total production cost. This is the case when the capital cost of the intermediate conversion plant is high. The exception is when the intermediate conversion plant has a low capital cost, for instance just a drier. In cases where e.g. low temperature excess heat is used in the conversion to intermediates, several smaller plants could be preferred since the availability of excess heat is limited at each plant (mill).

An example of results regarding energy efficiency, specific net CO_2 emissions and production costs for the bio-SNG value chain is presented in Table A. The case without intermediate means transportation of forest biomass directly to the bio-SNG plant, whereas the case with intermediate here refers to drying of forest biomass at pulp mills before (further) transport to the SNG plant. There are two factors working in opposite directions, almost cancelling each other out and making the total cost for the case with and without intermediates similar (as can be seen in Table A). The total transportation costs are somewhat increased for the case with intermediates, due to the introduction of an additional transportation step. However, the benefit of drying the biomass using excess heat at pulp mills, is that excess heat is “moved” from a place where it could be hard to find profitable ways to use it, to the SNG plant where the excess heat can be used for district heating. The results within brackets in Table A refer to cases where the biomass feedstock is falling bark instead of forest residues. This option offers the opportunities to lower the cost somewhat. However, there is a high uncertainty regarding how much bark that can be used in the bio-SNG process.

Table A. Example of results for the bio-SNG value chain.

Specific production cost (EUR/MWh)		**Specific net CO_2 emissions (kg_CO_2/MWh)**		**Energy efficiency ($MW_{heleq\ net\ output}$/$MWh_{eleq\ net\ input}$, %)**	
Bio-SNG without intermediate	Bio-SNG with intermediate	Bio-SNG without intermediate	Bio-SNG with intermediate	Bio-SNG without intermediate	Bio-SNG with intermediate
59 (59)	59 (55)	3 (-2)	0 (-3)	86 (87)	88 (88)

To use pellets is the most expensive and clearly the least energy efficient option (70%) out of the studied alternatives. This shows that further pretreatment than necessary (drying is required by the SNG process) is not energy efficient and not profitable. The total cost is dominated by the raw material and capital cost. The cost is reduced with increased SNG production rate (the results in Table A are for production of 300 MW SNG). The cost for the case with intermediates is reduced somewhat more than the case without intermediates when the SNG production rate is increased. The results here, as well as in general, emphasize the importance of large scale production. Then, the relevance of intermediates could increase for this value chain if larger and larger plants are being built.

For the bio-oil value chain, an example of the results regarding energy efficiency, specific CO_2 emissions and production costs is presented in Table B. The results of the forest-based value chains with and without intermediate product production (pyrolysis oil) are similar, particularly regarding energy efficiency and specific CO_2 emissions. The results within brackets in Table B refer to a value chain with intermediate product production where lignin extracted from black liquor is used as raw material (instead of forest residues).

The specific production cost for the value chain without intermediate product is lower than with intermediate. This is not because there is no intermediate product production, but rather because a single large facility is used instead of three smaller ones. Therefore, benefits related to economies of scale can be reaped. This was confirmed by another value chain studied (PYR1, not shown in Table B) where the intermediate product was produced at a single facility. For this case, the specific production cost was 86 EUR/MWh. The results indicate that economies of scale play a more important role than the choice of where to produce the pyrolysis oil and how it is transported.

Table B. Example of results for the bio-oil value chain.

Specific production cost (EUR/MWh)		**Specific net CO_2 emissions (kg CO_2/MWh)**		**Energy efficiency ($MWh_{eleq\ net\ output}$/$MWh_{eleq\ net\ input}$, %)**	
HDO-oil without intermediate. Case REF_R	HDO-oil with intermediate. Case PYR3 (LIG3)	HDO-oil without intermediate. Case REF_R.	HDO-oil with intermediate. Case PYR3 (LIG3)	HDO-oil without intermediate (Case REF_R)	HDO-oil with intermediate. Case PYR3 (LIG3)
87	90 (94)	93	92 (85)	74	74 (84)

Besides the economies of scale, other parameters appeared to be important, e.g. the oxygen content in the bio crude pyrolysis oil as it determines the necessary amount of hydrogen for hydride-oxygenation. The hydrogen consumption has, in turn, a significant effect on energy efficiency, specific CO_2 emissions and production costs. For the value chain with lignin as a raw material, significantly higher energy efficiency and lower specific CO_2 emissions are obtained. This is due to the lower oxygen content of lignin-oil compared to bio-oil from forest residues.

The production costs of lignin-oil are higher than those for the chains with forest residues. This is because the separation of lignin from the black liquor results in a reduced electricity production at the mill. With the current electricity price and the possibility to receive green electricity certificates, the production cost of bio-oil from lignin is higher than for bio-oil from forest residues. However, in this study, no credit has been included for the potential pulp production capacity increase. Lignin separation can enable an increased pulp production, in case the recovery boiler is the main bottleneck for a capacity increase. If the alternative cost for enabling such a capacity increase would have be deducted from the lignin case, this case would probably be more economically attractive despite the loss of electricity production. Moreover, no consideration has been taken to the fact that the produced lignin-oil may have a higher value than pyrolysis crude-oil from forest residues due to valuable molecular structures (e.g. aromatics).

The lower oxygen content in the lignin-oil compared to the crude pyrolysis oil from forest residues makes this value chain particularly attractive if the hydrogen price is higher than in the base case scenario. In a sensitivity analysis the price of hydrogen was increased by 80%. This could represent a case in which hydrogen is produced by methane reformation at a cost similar to the highest in the last 4 years. In this case, the production cost for the lignin value chain is 101 EUR/MWh whereas the cost for the forest residues chain with intermediates (PYR3) is 107 EUR/MWh.

CONCLUSIONS

Summarizing, the results indicate that the production costs are highly sensitive to the economies of scale, oxygen content in the bio-crude oil and raw material costs (forest residues price or electricity price in the case where lignin is used as raw material). Transportation costs have, comparatively, a little effect in the total production cost.

Even though this study could not prove a clear economic benefit of intermediate products, there are other important advantages related to transformation to intermediate products that need to be emphasised. These advantages are valid when the intermediate conversion is located at an already existing industrial plant handling biomass such as a pulp mill as in this study. These include opportunities to utilise industrial by-products in the intermediate conversion plant, utilisation of existing infrastructure in the form of access roads and receiving stations for biomass handling, power generation, steam, process water, cooling water and waste water purification at a low marginal cost, use of excess heat from the industrial plant to provide energy for the upgrading to intermediate, opportunities to integrate the intermediate production with the industrial plant to valorise by-products and excess heat from the conversion to intermediate. An important factor is also that the existing know-how related to handling of biomass that takes time to build up, could also be available at the intermediate conversion plant. Safety aspects related to handling of biomass could also have an influence on where it is possible to locate a biomass conversion plant and how it can be integrated with existing industry. The advantages should be investigated in more detail in a follow-up study, with the goal of determining the monetary value of these opportunities.

A case for production of an intermediate that could be advantageous is when the industrial plant connected to the conversion to intermediate is located in an area with high excess of forest residue raw material close by. Low market price of the raw material could then result in a low production cost of the intermediate, as the raw material cost is one of the dominating factors in the total cost. Other important advantages of intermediate conversion processes identified include easier build-up of a new value chain if the produced intermediate can be easier linked to the existing production of the final product. An example of this is the intermediate conversion of forest residues to a bio-oil that can be linked in to the production in an oil refinery compared to having the oil refinery organisation build up a whole new operation for production of bio-oil from forest residues at the vicinity of the refinery. An already existing good biomass market insight might also benefit the intermediate conversion plant, including own assets in forest resources and a mature biomass procurement organisation. The business model and strategy as well as the competitive situation on the market for intermediate and final products for the actors along the chain will also have a great influence on the potential for building up value chain with intermediates, and where in the value chain that it is possible to generate profits. These aspects have not been included in the current study and should be further considered and investigated.

The part of the report concerning the bio-SNG value chains is based on a scientific paper:

Pettersson K, Lundberg V, Anheden M, Ehn C, Fuglesang M (2016). Systems analysis of different value chains based on domestic forest biomass for the production of bio SNG. Submitted for publication.