A Techno-Economic Assessment of a Second Generation Biofuel Concept for Southern Thailand

Magnus Fröhling, Frederik Trippe, Kannokorn Hussaro, and Frank Schultmann

***Abstract*— *Biomass valorization concepts such as second generation biofuels aim at decreasing the dependency on limited fossil resources and reducing climate relevant CO_2 emissions. Besides these aspects the elaboration of bio-economy concepts offers great economic potentials all along the value chain. Accordingly, numerous process chains are discussed and developed. Crucial factors regarding the economic feasibility of such concepts are the availability and costs of the feedstock, i.e. the biogenic raw material. It is one central task to ensure the provision of the necessary amounts and qualities of biogenic raw material at reasonable costs. South-East Asian and Latin American countries open new opportunities through often large amounts of so far unused biogenic raw materials. The aim of this contribution is to carry out a techno-economic assessment of one promising second generation biofuel concept for southern Thailand and compare it with findings of similar studies for Germany.*

***Keywords*— Biomass-to-liquid fuel (BtL) production, palm kernel shells, techno-economic assessment, Thailand.**

1. INTRODUCTION

A large variety of valorization chains for biogenic raw materials is currently under discussion and development. Aim of these valorization chains is to substitute limited fossil resources and reduce the dependency on these, reduce fossil-based CO_2-emissions in order to meet the challenge to decrease the anthropogenic climate change and to open economic development possibilities. Crucial for the economic viability of such concepts is a secure supply of the necessary amount and quality of the feedstock material at reasonable cost. As they offer often large amounts of so far unused raw materials such concepts are widely discussed also for South-East-Asian and Latin American countries. Nevertheless, before detailed studies can be carried out, pilot or industrial scale plants have to be built. Promising concepts should be evaluated to prove the assumptions and identify key parameters for a successful implementation.

This study aims at carrying out such a first techno-economic assessment of one possible biomass valorization chain for biomass-to-liquid (BtL) fuel production, a second generation biofuel production via fast pyrolysis, gasification, gas cleaning and conditioning and Fischer-Tropsch synthesis. In the following section we describe our methodological approach. Afterwards we present the results and discuss these before we draw conclusions from our study.

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2. METHODOLOGICAL APPROACH

Reference configuration of a BtL production chain

To carry out the techno-economic assessment we refer to a reference configuration of a BtL production chain in order to achieve results which are comparable to similar studies carried out e.g. for Germany (see e.g. **Error! Reference source not found.**, **Error! Reference source not found.**). In our reference configuration the biomass is dried and milled in order to achieve optimal conditions for the subsequent fast pyrolysis. The pyrolysis step is taken out in five decentralized plants with a capacity of about 100 MW thermal input. The produced intermediate – the so called slurry or biosyncrude – is gasified in an entrained-flow reactor under high pressure (40 bar) and high temperature (1,200 °C). Thus, a tar-free synthesis gas is produced. In order to fulfill the requirements of the FT synthesis, the gas is cleaned from its pollutants by using conventional low-temperature gas cleaning techniques, i.e. cyclone, bag filter and a wet scrubber. To reach optimal synthesis conditions a H_2/CO molar ratio of 2:1 is required. Therefore a CO conversion is installed. After the FT synthesis in a fixed bed reactor with cobalt as catalyst, the synthesis products are separated by distillation into wax, diesel and gasoline. The gained waxes are converted with a hydrocracker into diesel and gasoline, leading to an increased biofuel production. The described reference configuration is depicted in **Fig. 1**.

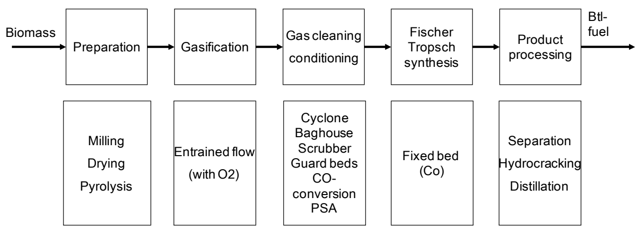

Fig. 1: Reference process chain.

Biomass potential analysis

Based on the requirements of this reference configuration a biomass potential analysis is carried out. Therefore biogenic residues in Thailand are investigated in terms of available amounts, locations of accruance, chemical characteristics and prices. Thus a suitable feedstock for the further studies is identified.

BtL production network design

On the basis of the reference configuration and the results from biomass potential analysis a BtL production network is elaborated. Sources for the feedstock, locations and structure of the fast pyrolysis and the gasification plants are determined as well as feedstock supply, transport distances and costs.

Material and energy balancing

For the described reference configuration a mass and energy flow balancing is carried out. For the first step, i.e. the pyrolysis plant a detailed analysis based on spreadsheet simulation is performed. The second processing step, i.e. gasification, is done using literature data. The further steps are balanced using the flowsheeting system Aspen Plus, which is capable to model thermodynamic reactions by the use of pre-defined reactor modules and comprehensive material data bases (cf. **Error! Reference source not found.**, **Error! Reference source not found.**). The results of this balancing are characteristic dimensions of the processing units such as reactor sizes, needed thermal power etc. and the material and energy input and output flows. These serve as a basis for the further economic assessment which is described in the following sections.

Economic assessment

The economic assessment aims for determining production costs of BtL fuel and to compare these with market prices for fossil based gasoline and diesel. Further the production cost of the intermediate, the so called slurry or biosyncrude is compared with the market prices for coal and gas which are the raw materials in coal-to-liquid (CtL) and gas-to-liquid (GtL) plants and which could be partly replaced by biosyncrude. To achieve this, the total capital investment (TCI) for several decentralized fast pyrolysis plants and the centralized gasification and synthesis plant has to be estimated at first. For this purpose, all main equipment components have to be designed according to the mass and energy flows and their investment data has to be gathered.

Investment data for the main equipment components are taken from Peters et al. **Error! Reference source not found.** for standardized components. For special components, vendor quotes from respective suppliers are taken into account. The values derived from literature data are scaled up or down using specific scaling factors for the components in order to reach the needed dimensions. Since the investment data provided by Peters et al. **Error! Reference source not found.** dates back to the year 2002, they have to be updated to 2008. To do so, the average Chemical Engineering Plant Cost Index for the year 2008 is used. Finally the investment data are converted from US$ to € using the yearly average exchange rate of 1.483 US$ per € in 2008.

Based on the investment data for the main equipment components, the total capital investment can be estimated using ratio factors for direct and indirect capital investment for each component. Differentiated additional charges Z_i (“overall installation factors”) are added to consider additional direct (instrumentation and control, buildings, grid connections, site preparation, civil works, electronics and piping) and indirect costs (engineering, building interest, project contingency, fees, overheads, profits, start-up costs). Thus, the total capital investment is estimated according to equation 1. As the direct costs decrease with increasing capacities, the factor A_i for the direct costs is scaled in dependency on the component capacity P_i in comparison to a basic capacity P_{basis} with a factor of -0.82. Where no differentiated factors are available a factor of 1.995 is used for Z_i, comprising a factor of $A_i = 0.33$ for the direct and a factor of 0.5 for the indirect costs B_i. The equations 1-3 show the described relationships.

$$Total\ Capital\ Investment\ (TCI) = I_{ME} \cdot \sum_{i=1}^{m} Z_i \qquad (1)$$

I_{ME} *Investment for main equipment components*

Z_i *Factor for direct/indirect capital investment* *i = 1...m*

$$Z_i = (1 + A_i) \cdot (1 + B) \qquad (2)$$

$$A_i = 0.33 \cdot \left(\frac{P_i}{P_{basis}} \right)^{-0.82} \qquad (3)$$

The factors are adapted to process conditions, design complexity and required materials of the BtL facilities considered in this study. The applied factor method implies uncertainties of plus/minus 20.

After estimating the total capital investment, annual production costs can be derived. The annual production costs consist of investment dependent, personnel and consumption dependent costs. The investment dependent costs in turn are comprised of capital costs, maintenance as well as taxes and insurance. Biomass feedstock and transportation, slag disposal, electricity and cooling water make up the consumption dependent costs. Finally the costs for producing BtL fuels are reduced by the revenues from selling excess electricity to the grid. The composition of the annual production costs is summarized by Equation 4.

$$\begin{aligned} C_{Produtcion} &= TCI \cdot (p_a + p_m + p_t + p_i) + C_{Personnel} \\ &+ C_{Biomass} + C_{Electricity} + C_{Cooling\ Water} \\ &+ C_{Slag} - R_{Electricity} \end{aligned} \qquad (4)$$

p_a *Annuity factor*

p_m *Percentage of TCI for maintenance*

p_t *Percentage of TCI for taxes*

p_i *Percentage of TCI for insurance*

The annuity method translates the initial investment, which is assumed to be the TCI estimated before, into a stream of identical payments for a given number of years. These identical payments represent interests on and depreciation of the capital investment. The annuity factor is calculated according to Equation 5 and states a percentage of TCI.

$$p_a = \frac{(1+i)^n \cdot i}{(1+i)^n - 1} \quad (5)$$

i *Interest rate*

n *Expected lifetime*

The parameters used in this study to calculate the production cost of BtL fuel in Thailand are an interest rate of 5.875% p.a. and 20 years expected lifetime. The interest rate is believed to be the average rate over the 20 years time span in Thailand. The recovery value of the BtL production facilities after the expected lifetime of 20 years is assumed to equal zero.

The average annual maintenance costs for the pyrolysis plant and the gasification and synthesis plant equal about 4% of the BtL facilities' TCI per year.

Finally it is assumed, that insurance and taxes contribute with annually 1% of TCI each to the annual production costs of the biosyncrude.

The personnel demand and costs estimation is based on average data for workforce in Thailand. Personnel costs equal on average about 10,000 € per employee and year. The overall number of personnel needed in three shift operation sums up to 46 employees.

Costs for consumption dependent material flows depend on plant availability. On average 7,000 operating hours per year are assumed in the five pyrolysis plants and 7,500 operating hours in the gasification and synthesis plant, which correspond to about 80% and 85%, respectively, plant availability during the expected lifetime. The price of electricity equals the average in Thailand of 49.30 €/MWh. The excess electricity in the gasification and synthesis plant is assumed to be sold at the same price to the existing grid. Cooling water is assumed to be available at a price of 2 €/m^3 and the slag is considered to be disposed of at 30 €/t. Since the prices for biomass feedstock, electricity and cooling water will vary during the considered life time, these prices should be regarded as average values.

3. RESULTS

Biomass potentials

To avoid conflicts with the food or other established agricultural chains we focus on a number of promising biogenic residues. Thailand has a potential of so far unused biogenic residues of more than 30 m t **Error! Reference source not found.**. Besides cassava rhizomes, rice straw, which is mainly burned on the fields, and corn straw especially residues from sugarcane, rice and palm oil production come into focus. They accrue in orders of magnitude which are interesting for an industrial scale BtL plant. Contrary to e.g. rice and corn straw they accrue in processing plants and therefore have no or only very small costs of capture. Further, the lower heating values (LHV) for sugarcane trash, rice husk and especially palm kernel shells make them interesting for further investigations (see Table 1).

Table 1: Biomass potentials in Thailand (2008)

Biomass	Produc-tion [10^6 t]	Biomass residues	Residues [10^6 t]	LHV [kJ/kg]
Sugarcane	73.5	Sugarcane trash	21.315	15.479
Rice	31.47	Rice husk	6.923	14.204
Palm oil	9	Palm kernel shells	1.71	16.900
		Empty fruit bunch	2.07	7.240

Source: [5]

Looking at the chemical analysis of the named promising biogenic residues shows, that especially palm oil shells are well suited as they have acceptable moisture content, the highest amount of carbon combined with the lowest or very low ash, chlorine and sulfur contents (see Table 2).

Table 2: Analysis of the selected biomass residues

Composition	Sugarcane trash [%]	Rice husk [%]	Palm oil shell [%]
Moisture	9.2	8.2	12
Fixed-C	18.61	21.46	18.5
Volatile	74.67	64.16	77.5
Ash	6.72	14.38	4
C	45.82	42.59	50.52
H	5.59	4.89	5.69
O	41.22	37.8	39.43
N	0.45	0.2	0.32
Cl	0.01	0.1	0.02
S	0.2	0.04	0.02

Source: [4]

Further the geographical location of the accruance of the palm kernel shells is favorable in comparison to the other biomass types. Currently there are somewhat more than 50 palm oil mills located in the southern part of the country. These are spread about seven provinces. The biomass potentials in these seven provinces are given in Table 3. The palm oil mills in southern Thailand supply combined an amount of nearly 850,000 t per year on a dry basis. This amount is sufficient to provide the feedstock for an industrial scale realization of the BtL plant.

Therefore palm kernel shells are selected as the most promising biomass type for the further considerations of this study. It is assumed that with an average price of 26 €/t on a dry basis the necessary amount of feedstock can be secured. The price includes the transportation from the palm oil mill to a collection point or the pyrolysis plant within the province.

Table 3: Palm kernel shell accruance in southern Thailand

Province	Amount of Palm oil shells [t/a]
Surat Thani	253,499
Krabi	222,870
Chumphon	180,145
Trang	101,430
Songkhla (Hat yai)	44,988
Satun	34,500
Phangnga	2,243
Total	839,675

Source: [5]

BtL production network design

Taking into account the transport distances by rail and truck (see Table 4) and the corresponding transportation costs for biomass from the collection point to a pyrolysis plant and for the slurry from the pyrolysis plants to the gasification plant a BtL production network is elaborated.

Table 4: Transport distances between the provinces in southern Thailand

Transport distances	*Distance (rail) [km]*	*Distance (truck) [km]*
Chumphon – Surat Thani	117	197
Krabi – Surat Thani	-	211
Trang – Surat Thani	220	226
Phangnga – Krabi	-	86
Satun – Trang	140	140
Songkhla (Hat yai) – Trang	-	148

This network comprises five fast pyrolysis plants in four locations (Chumphon, 2x Surat Thani, Krabi and Thrang) and one central 500 MW gasification and synthesis plant located in Surat Thani). The needed biomass for the fast pyrolysis plants is supplied by these regions, to utilize the built capacities the available amounts from Phangnga are delivered to Krabi and from Satun and Songkhla to Trang. The production network is given in **Fig. 2**. This BtL production network serves as a basis for the further calculations.

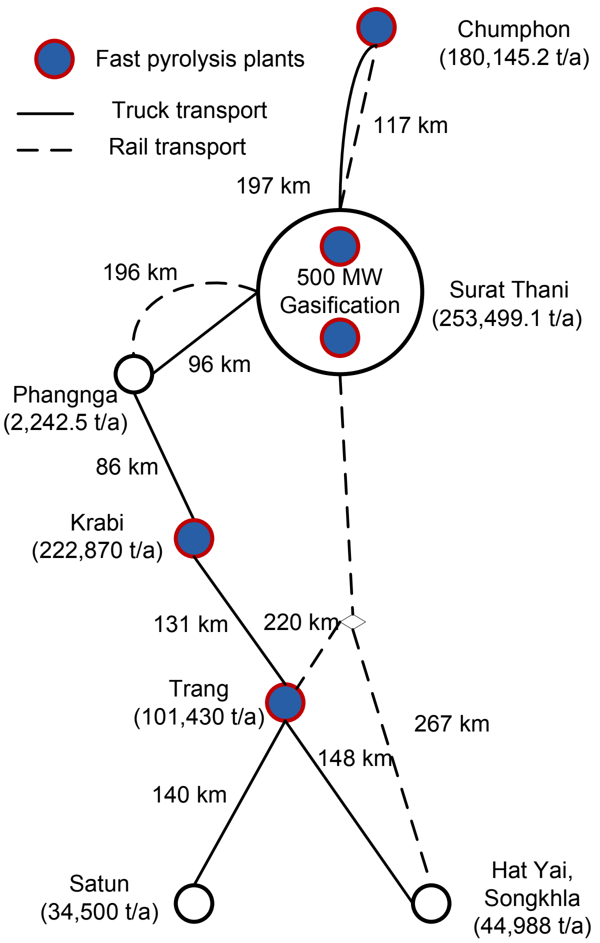

Fig. 2. BtL production network.

Resulting material and energy flows

The mass and energy flow balancing leads to an estimated production of approximately 120,000 t of fuel and a generation of excess electrical power of about 5.5 MW_{el} in the centralized gasification and synthesis plant. This output is met by setting up the network of five decentralized pyrolysis plant with each about 100 MW thermal input capacity. With a lower heating value of about 14 MJ per kg palm oil residues on a wet basis, a single pyrolysis consumes on average 25 t of biomass per hour. On a mass basis around 70% of the palm oil residues remain in the biosyncrude. The mass losses are mainly caused by drying and burning of pyrolysis gas which cannot be integrated into the biosyncrude and is therefore used to supply the thermal energy in the decentralized pyrolysis plants. On an energy basis 85% of the heating value remain in the biosyncrude, resulting in a higher heating value of about 18.5 MJ per kg biosyncrude. On a yearly basis the five decentralized pyrolysis plants deliver combined about 600,000 t Slurry to the centralized gasification and synthesis plant. The gasification of the delivered slurry yields about 125,000 t per year of raw synthesis gas. The entrained flow gasification is performed at high pressure (40 bar) and high temperature (1,200 °C) in order to avoid the building of tar. Pure Oxygen is used as gasification agent. Maintaining the high gasification temperature requires a relatively high amount of oxygen. On a yearly basis around 300,000 t oxygen are needed which corresponds to a lambda value of about 0.4. After cleaning the raw synthesis gas, the Fischer-Tropsch synthesis produces about 120,000 t of BtL fuel per year from the cleaned and conditioned synthesis gas, i.e. carbon monoxide and hydrogen. An overview of the resulting mass flows is given in **Fig. 3**.

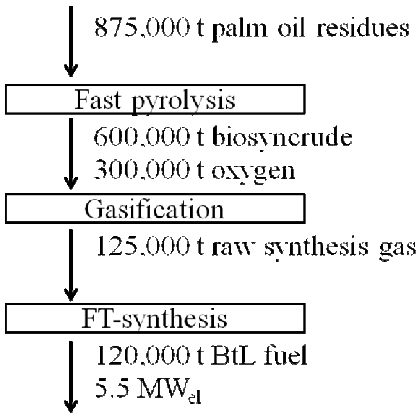

Fig. 3. Resulting main mass and energy flows for the considered process chain on a yearly basis

Economic results

The aim of the economic assessment is twofold. The most interesting problem to be solved is determining the production costs of BtL fuel and to compare these with market prices for fossil based gasoline and Diesel. Previous studies revealed that producing BtL fuels in Europe or the US is highly capital intensive. Total capital investment needed to build a complete network of pyrolysis and gasification and synthesis plant is most likely to excess the amount of 1 billion €. This in turn leads to the assumption that the starting point for setting up a BtL facility network could be a first pyrolysis plant. Therefore the production cost of the intermediate slurry biosyncrude is compared to the market prices for coal and gas which are the raw materials in CtL and GtL plants and which could be partly replaced by biosyncrude.

Another aspect is to estimate the competitive advantage of South-East Asian countries, such as Thailand for biofuel production due to their relatively low prices for biogenic resources. This effect can be demonstrated impressively at the production cost of the intermediate biosyncrude.

To build a pyrolysis plant with an thermal input capacity capacity of about 100 MW would require a total capital investment of about 40 million €. Summing up the constituents of production costs on an annual basis and dividing it by the annual slurry production on a HHV basis leads to the specific production costs of the biosyncrude. With the assumed annual operation time of 7,000 hours the pyrolysis plant is able to produce approximately 617,000 MWh biosyncrude or slurry on a HHV basis.

Fig. 4 states the production costs per MWh biosyncrude in comparison with the market prices for oil and gas in Thailand. To demonstrate the regional advantage of Thailand the production cost for Germany are presented as well.

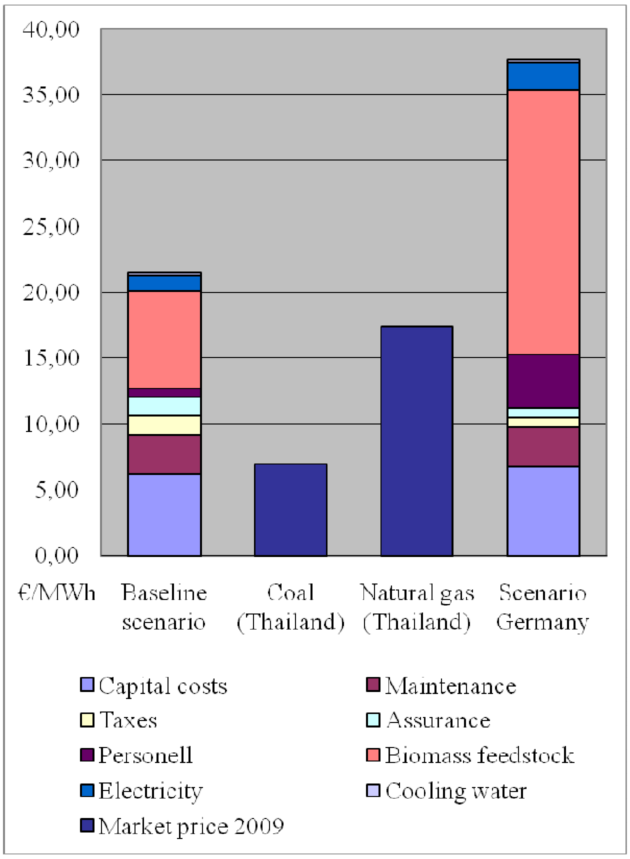

Fig. 4. Production costs of slurry

As indicated by the baseline scenario in the

Fig. 4, investment dependent costs make up a 57% share, personnel a 3% share and consumption dependent costs a 40% share of production costs. Within the consumption dependent costs the biomass feedstock is the most important contributor which amounts to about 34% of total production costs. The slurry can be produced at costs of about 22 €/MWh in Thailand.

An indicator for the competitiveness of biosyncrude compared to other resources for XtL-technologies is the comparison of the biosyncrude production costs to coal and gas market prices. Obviously the biosyncrude is not competitive in Thailand at the moment.

But there are strategies to market biosyncrude from Thailand. For example via exporting biosyncrude to Germany where it is almost twice as expensive to produce due to higher biomass feedstock prices as well as higher costs for workforce. A viable option for the realization of a BtL production network would be to place the pyrolysis plants in Thailand with relatively low capital investments and process the biosyncrude in the capital intensive gasification and synthesis plant in Europe.

Concerning the determination of the production costs for BtL fuels in Thailand the total capital investment for this network producing about 120,000 t of BtL fuel per year sums up to about 650 million €. The corresponding annual production cost divided by the annual production of BtL fuel result in the specific production cost per liter fuel. BtL fuel could be produced at costs of about 0.93 € per liter. This is above current market prices for gasoline and diesel which are currently about 0.70 €/l (see, e.g., **Error! Reference source not found.**). The composition of the BtL production costs is shown in **Fig. 5**.

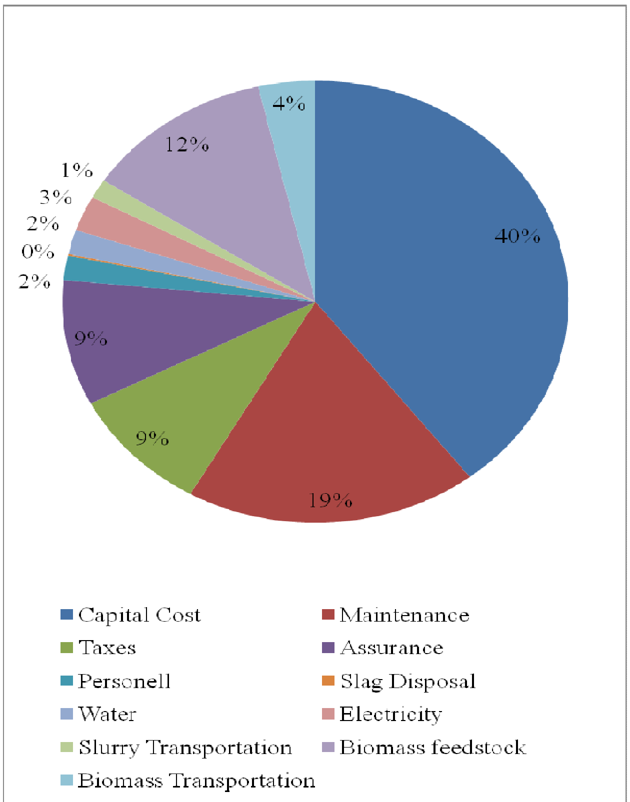

Fig. 5. Composition of production costs of BtL fuel.

The composition of these costs indicates the capital intensity of the BtL fuel production network. Implying the capital dependent costs cost from the slurry production, the share of capital dependent costs in the total production costs of BtL fuel amounts to about three quarters. The slurry production and transportation to the gasification and synthesis plant contributes about 47% to the production costs of the final BtL fuel.

4. SUMMARY AND CONCLUSIONS

In this contribution a first techno-economic assessment of a potential BtL concept is made for Thailand. Based on a biomass potential analysis a BtL production network is elaborated and economically assessed.

A possible BtL production in Thailand can be located in the southern part of the country. A promising feedstock in terms of location of accruance, amounts, chemical characterization and price are palm kernel shells which can be collected from the about 50 palm oil mills in southern Thailand. They are estimated to be provided to a collection point or a pyrolysis plant in each of the seven considered provinces at about 26 €/t on a dry basis.

The economic assessment of the BtL production shows that additional development efforts are needed in order to make the process chain profitable. The production of the intermediate slurry or biosyncrude shows lower costs per MWh in comparison to estimations for Germany. Nevertheless these costs are still higher than those of comparable fuels for XtL technologies, i.e. coal and natural gas. As the slurry/biosyncrude has a volumetric energy density comparable to crude oil they are economically shippable and international market potentials exist in a export e.g. to European countries. Starting point for further developments is the capital intensity of the BtL production chain. Both, for the production of slurry/biosyncrude via fast pyrolysis and diesel via the whole process chain investment dependent cost make up the most important parts of the annual costs (57% and 77%). When one succeeds in reductions here and/or crude oil prices rise without affecting the prices for the biogenic residues the gap to profitability may be closed.

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