COMSYN

"Compact Gasification and Synthesis process for Transport Fuels"

Business concepts for COMSYN technology

Excerpt from the upcoming publication on the results of validation campaigns of the COMSYN technology

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INTRODUCTION

The global CO_2 emissions have been in steady increase for more than 50 years inducing global warming. The CO_2 emissions mainly derive from the use of fossil fuels, i.e. oil, natural gas and coal. Today, more than 80% of total primary energy is produced globally by fossil fuels. In order to cut down CO_2 emissions, the fossil resources have to be at least partially replaced by renewable alternatives.

The renewable resources are diverse and often subject to seasonal and local availability changes. Therefore, a wide range of flexible technologies are needed for the renewable energy production. The major bottleneck in many of the available technologies are the investment and production costs. The Compact Gasification and Synthesis process for Transport Fuels (COMSYN) project combined latest technological innovations for development of a feasible biofuel production concept.

The aim of the project was to develop a new biomass-to-liquid (BTL) production concept that would reduce biofuel production cost up to 35 % compared to alternative routes. This means less than 0,80 €/l production cost for biodiesel. The production concept (Figure 1) was based on:

- Utilization of diverse supply of biomass residues.
- Distributed primary conversion by biomass gasification and Fischer-Tropsch synthesis located close to biomass resources.
- Primary conversion from biomass to Fischer-Tropsch products in small-to-medium scale units (10-50 kt/a Fischer-Tropsch products)
- Integration of the primary conversion to local heat and power production resulting in 80 % energy efficiency in biomass utilization.
- Refining of FT products to high quality drop-in transport fuels at existing oil refineries.

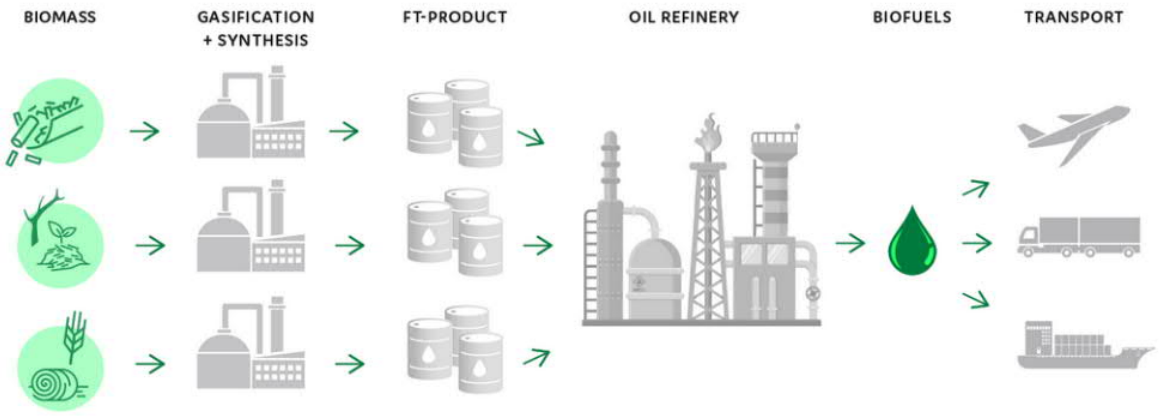

Figure 1. Decentralized production concept of the COMSYN project.

In order to improve the process economics and advance the commercialization of the technology, the COMSYN concept aimed for the following seven improvements:

1. Use diverse raw materials for biomass gasification to cut down raw material costs.
2. Increase the filtration temperature of biomass gasification gas to improves process thermal efficiency.
3. Use membrane technology for oxygen feed to avoid the use of an expensive oxygen plant.
4. Remove sulfur from product gas by sorbents to avoid expensive chemical processing.
5. Use intensified, modular Fischer-Tropsch technology for the liquid fuel production to decrease investment costs.
6. Take advantage of the economics of scale by upgrading the Fischer-Tropsch products in an existing oil refinery.
7. Screen the most advantageous process integration, concept design and business possibilities for easy commercialization.

The implementation of the COMSYN project had two major goals: technical validation of the process concept in pilot scale and production of an in-depth data set for the technology commercialization including techno-economic and life cycle assessments, market studies and business concept studies. The technology development covered all the process steps from biomass gasification to biofuel upgrading in an oil refinery. The process was validated with two test campaigns at VTT Bioruukki piloting facilities, where the process train consisting of gasification, filtration, steam reforming, gas ultra-cleaning and Fischer-Tropsch synthesis,

was fully integrated and tested. The produced Fischer-Tropsch biocrude was analysed and upgraded in oil refinery research facilities.

This study report is part of an upcoming larger publication on the technical development steps and results from the pilot scale test campaigns of the COMSYN project. The obtained data from the test runs was used in techno-economic and business case studies. This study report focuses on the final results of the business concept development.

TECHNOLOGY OVERVIEW

European biomass resources are diverse and the supplies are locally and seasonally limited. The use of agro residues, demolition wood, municipal waste and other available low-cost biomass is estimated to decrease the raw material costs of biofuel production by half. On the downside, these materials contain higher levels of impurities than forest biomass. Therefore, a fuel-flexible and robust biomass conversion is essential for achieving low production cost of biofuel.

In the COMSYN project, the use of a dual fluidized bed gasifier (DFB) was validated for wood residues and agro biomass. Biomass gasification gas contains similar impurities as traditional wood combustion produces. The gas flow from the gasifier carries ash, tar, hydrocarbons, ammonia and sulfur onwards in the process. The Fischer-Tropsch synthesis is sensitive to these impurities and therefore a thorough gas cleaning process is needed by using filtration, steam reforming, and sorbents. A schematic process diagram of the pilot unit used in the COMSYN project is given in Figure 2.

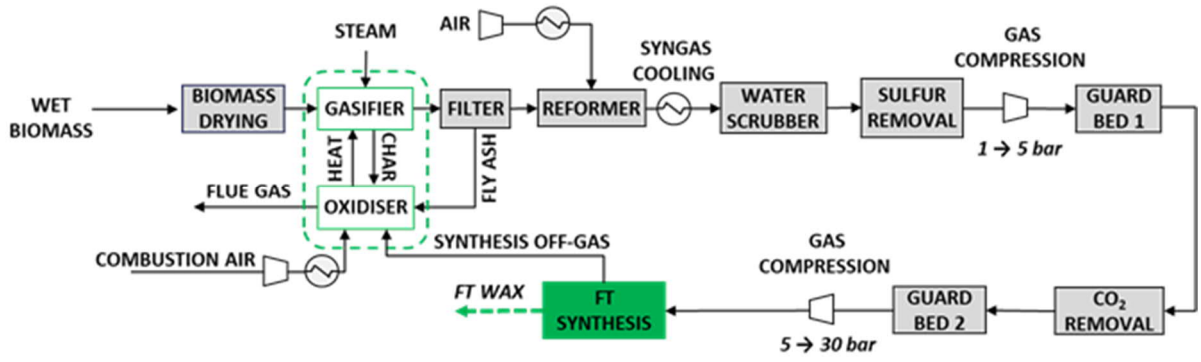

Figure 2. Schematic process diagram of the COMSYN process concept.

With the COMSYN concept it is possible to build an ecosystem that utilizes flexibly even relatively small biomass resources for the biofuel production. Using Fischer-Tropsch as the synthesis route allows the production of high-quality biofuels that are suitable as such or can be mixed with fossil based fuels with any mixing ratio. In order to obtain the lowest production cost for the biofuel, the process economics have to be optimized. This requires understanding of process optimization, integration possibilities, local scenarios, and biofuel markets. The COMSYN project has a multifaceted approach to the concept optimization, with three project partners, Foster Wheeler, DLR and AFRY, concentrating on this topic. The test data was used to forecast the performance of an industrial-scale production unit and to create detailed feasibility studies aiming for optimal production concepts with maximal integration benefits. Two concrete case studies was developed for North-Europe and Central-Europe sites, representing different feedstock basis and different options for energy integration. Market understanding was created by surveys and concepts studies, which provided the background for the business concepts and commercialization of the process. The results of the market study were published in an open-access article[1].

The COMSYN concept is developed for intermediate-scale of 50-200 MW biomass input, corresponding to 15-70 $kt_{oe}a^{-1}$ production of transportation liquids. The units should therefore have substantially lower investment costs (200-300 M€), and they are located close to biomass sources and heat integrated to industrial sites or district heating networks. Final refining of Fischer-Tropsch hydrocarbons into high-quality transportation liquids takes place in existing oil refineries, where the economies of scale can be fully exploited and the product portfolio can be tailored according to the market needs. Thus, the co-production concept is based on double integration principle. To realize economic renewable transportation fuel production, the process is simplified and can therefore be economically realised already at smaller scale. In the area of final gas cleaning and synthesis technology, most BtL concepts utilize existing technologies that originate from fossil fuel conversion. Significant cost saving benefits could be achieved by designing downstream processes in an optimal way for relatively small biomass conversion plants. Approximate costs for the biocrude production and further upgrading at an existing refinery were defined for several business case and process

[1] J. Wahlström, J. Kihlman, M. Kurkela, COMSYN: Compact option for next generation biofuels, Open Access Government (OAG) edition 30, April 2021.

configuration options. An approximate production cost from biomass to biofuel is estimated to be ca. 1.10 €/L[1,2].

BUSINESS CONCEPTS FOR COMSYN TECHNOLOGY

Demand for advanced biofuels

EU Renewable Energy Directive II (REDII) targets to increase the renewable energy, part of which concerns transport sector. The overall target is that 32% EU's gross final energy consumption and 14% of energy used in the transport sector is from renewable sources by 2030. The REDII also sets a binding sub-target of 3.5% for usage of advanced biofuels produced from specified feedstocks such as lignocellulosic residues and waste. Moreover, usage of food and feed crops and used cooking oil (UCO) feedstocks for biofuels counted to the renewable energy target is limited. It is estimated that REDII increases the market size of advanced biofuels to at least 10 Mtoe in 2030. In 2019, the consumption of advanced biofuels was approximately 3 Mtoe in the EU and 80% of constituted of UCO based biofuels. Hence, investments to the lignocellulostics based biofuel production are needed to cover the demand for biofuels.

Business concepts in Northern and Central European conditions

The prerequisites for feasible business concept are availability of low cost feedstocks, possibility to utilise the excess heat for power production and district or process heat sales, and suitability of the produced biocrude to be processed in refineries located within feasible transport distance.

The feasibility of COMSYN process was studied in Northern and Central European conditions. In Nordics the available low-cost materials are wood-based residues, demolition wood and SRF. These feedstocks could be supplemented with forest chips that also have a good availability in the Nordics. The forest industry by-products (e.g. bark, saw dust) are available at pulp mills and saw mills, which would make them a good location for biocrude production. Moreover, these sites have own heat and power generation facilities and it would be beneficial to integrate the COMSYN plant with them to produce electricity and avoid

[2] V. Tota, Techno-economic studies for COMSYN process, presentation in Compact Gasification and Synthesis for Flexible Production of Transport Fuels and Heat webinar on January 19th, 2021.

investments in additional steam cycle. In pulp mill condition additional benefit would be gained utilising the F-T tail gas to replace oil consumption in pulp mill's lime kiln. In terms of energy integration suitable locations could also be towns where there is demand for district heating and investments in new district heating production capacity is needed. In these location different waste streams are available together with forest chips.

The following possible business concept were identified and studied for the Northern European conditions (Figure 3):

- City refinery: feedstock 150 MW of demolition wood and forest residues, F-T products 53 kt/a, district heat production 60 MW, Electricity demand 18 MW
- Pulp mill: feedstock 200 MW of bark and forest chips, F-T products 70 kt/a, self-sufficient in terms of electricity and steam, 18 MW of FT tail gas to lime kiln
- Saw mill: feedstock 80 MW of forest industry by-products, F-T products 28 kt/a, district heating 5 MW, self sufficient in terms of electricity (assuming utilisation of saw mill steam turbine)

The refineries containing hydrocracking unit and HVO unit nearby are estimated to be most suitable refineries for biocrude refining and such refineries can be found in the Nordic countries.

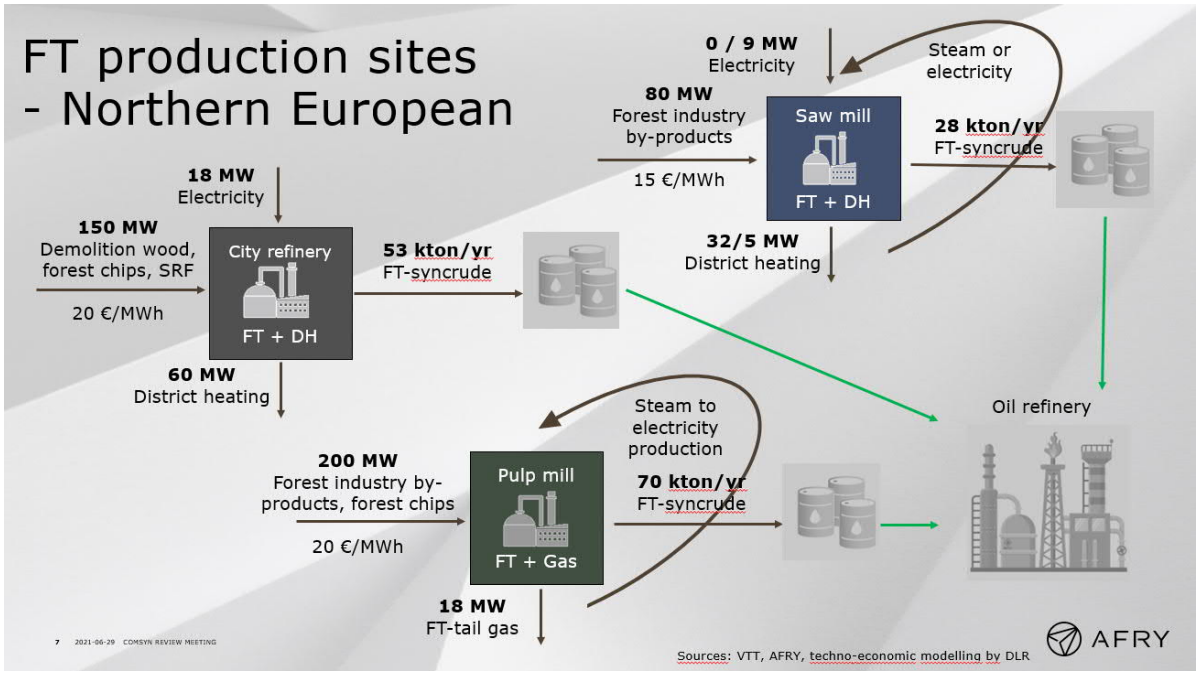

Figure 3. Northern Europe business concepts.

In Central European conditions (Czech republic, Poland, Germany) raw material for the process could be straw that is estimated to be available and increasing its utilisation for energy and biofuel purposes is on the agenda in several countries. Due to REDII targets there is a large need to replace fossil fuel based heat production with renewable energy sources and industrial waste heat. Hence, the excess heat from COMSYN process would be utilised for district heating or process industry purposes. In countries with high electricity price, the excess heat would be utilised to cover the electricity consumption of the gasification, gas cleaning and synthesis units. The feasible gasification unit sizes are estimated to be 100-200 MWth and resulting bio crude production 30-50 kt/a. The unit size shall be dimensioned according to local availability of straw. The bio crude could be transported for co-processing to Litvinov refinery. In the business concept study the following business concepts were analysed (Figure 4):

- Utility/industry site, heat production only: feedstock 200 MW of straw, F-T products 60 kt/a, district heating 96 MW, electricity demand 26 MW
- Utility/industry site, investment in own steam cycle: feedstock 200 MW of straw, F-T products 60 kt/a, district heating 70 MW, electricity demand 3 MW, electricity production with own steam cycle for own consumption
- Utility/industry site, investment in own steam cycle: feedstock 200 MW of straw, F-T products 60 kt/a, electricity production with own steam cycle for own consumption, additional electricity sales 2 MW

In the first two Central European cases the district heat production amount is large and thus the biocrude plant should be located by a large city district heat network. Alternatively it could provide district heat combined with industrial heat to a large industrial consumer.

The prices of feedstock, electricity and district heat, annual fixed and variable costs and estimated capital costs are shown in Table 1. In the pulp mill case it is assumed that half of the feedstock is bark available at the site and another half is forest chips. The availability of bark depends on the pulp mill size and the share of it could be higher at large pulp mill sites. Income tax rate used is 20%.

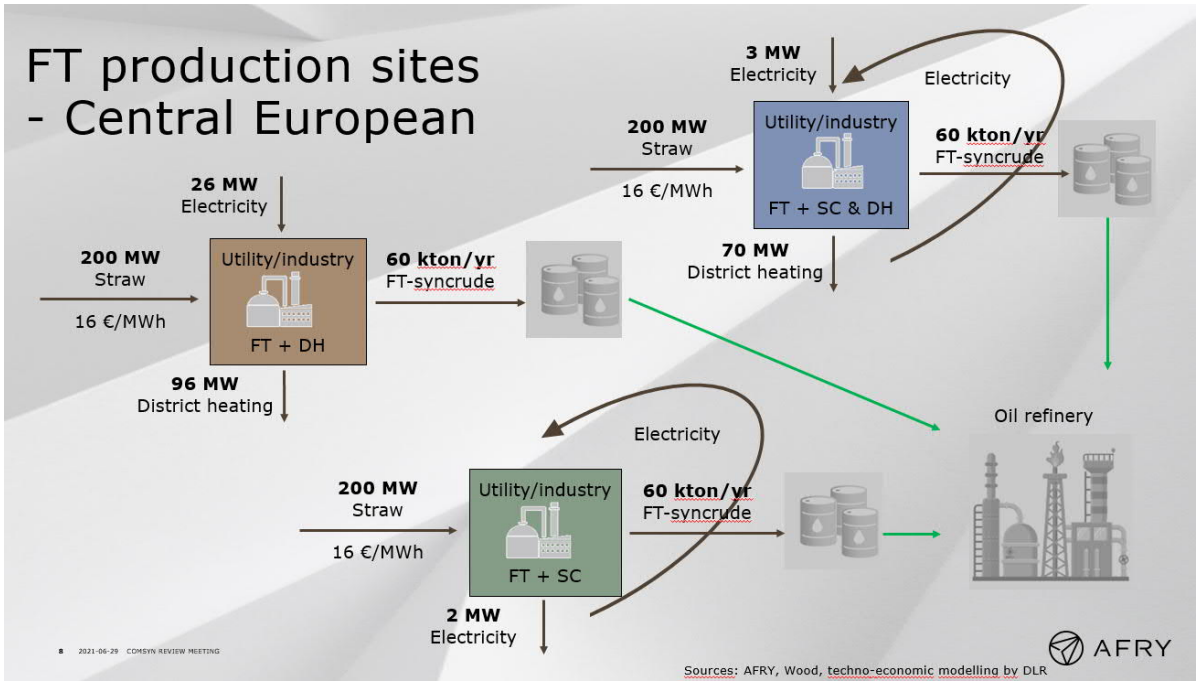

Figure 4. Central Europe business cases.

Table 1. Assumptions for business concept evaluation

	NE: city refinery	NE: pulp mill	NE: saw mill	CE: DH only	CE: DH+SC	CE: SC
Feedstock (€/MWh)	20	20	15	19	19	18
District heat (€/MWh)	30	-	30	34	34	32
Purchased/sold electricity (€/MWh)	60 / -	60 / -	60 / -	70 / -	70 / -	- / 80
FT tail gas sales (€/MWh)		30	-			
Capex (M€)	241	281	151	296	337	329
Fixed opex (€/a)	14	16	9	16	18	18
Variable opex (€/a)	11	14	8	16	16	16

The business concepts were evaluated by calculating the break-even price for FT biocrude. The break-even price is calculated based on free cash flow analysis assuming WACC of 7%-12%. The estimated price for advanced biofuels in 2030 has been estimated to 1.5-2.0 EUR/kg and upgrading costs at the refinery to 0.2-0.3 EUR/kg. Therefore it can be estimated that the

maximum price of the biocrude to refinery is 1.2-1.8 EUR/kg. The upgrading cost depends on the refinery conditions.

The results of the analysis of the business concepts are illustrated in Figure 5. The pulp mill and city refinery cases have the lowest break-even price so they are the most feasible concepts in economic terms. With these concepts biocrude break-even price is approximately 1.4-1.6 EUR/kg with WACC 7-12% respectively. The straw based alternatives with district heat production have a break-even biocrude price of 1.5-1.7 EUR/kg with WACC 7%-12%. The largest unit sizes obtain benefit of economy of scale in capex and maintenance costs. In Northern European cases the utilisation of existing steam turbine for own electricity production is also beneficial for the economic performance. In general securing sufficient feedstock amount with low price and demand for excess heat are key aspects for viable business case.

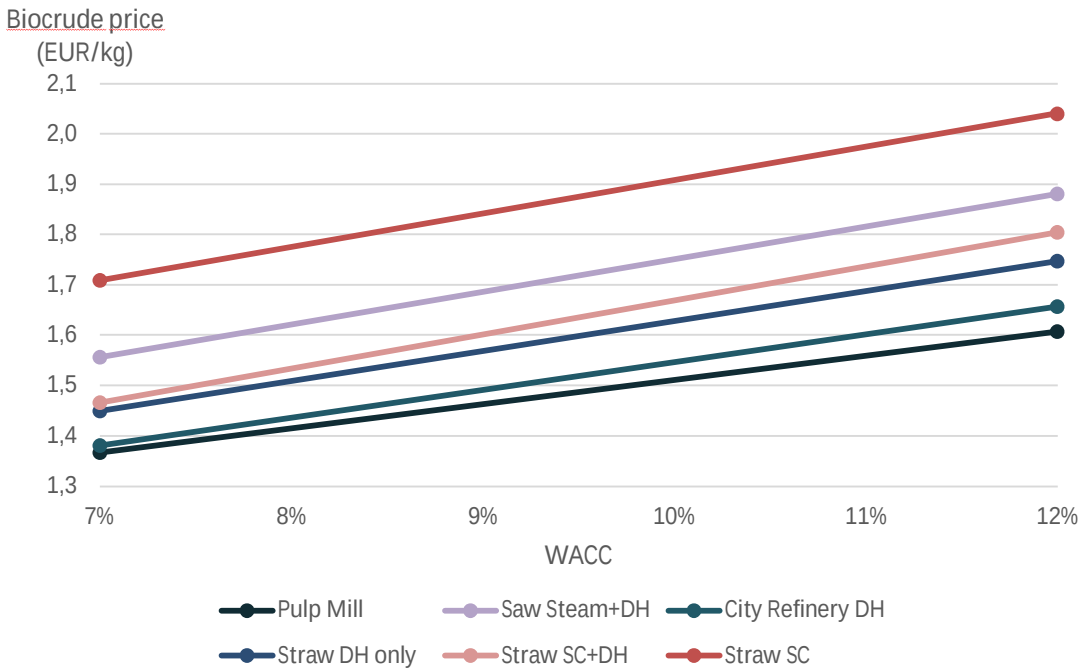

Figure 5. Biocrude break-even prices with different WACCs.

NEXT STEPS TO EXPLOIT COMSYN RESULTS

The key technologies and processes of COMSYN are developed to TRL 5. The whole production process is validated with diverse feedstocks and several techno-economic studies have been conducted to analyse the feasibility. Successful studies and experimental tests have

shown that the technology for production of advanced biofuels is already developed to such state of the art that demonstration of the technology in an industrial scale would be possible. Next, demonstration plants are needed to be built in different kinds of environments with different biomass feedstocks. These demonstration plants would need research support for investment and operation to be economically viable. Success of the demonstration plants together with regulatory support would encourage the market and investors to start large-scale production and distribution business. The demonstration phase is assumed to take approximately 2-3 years. Some additional time will be needed for financing, contracting, engineering and construction between the pilot, demonstration and commercial phases. The main demonstration alternatives are demonstration at industrial site or utilisation of VTT's research facilities for demonstration project. With industrial demonstration higher capacity plant (10-50 MW feedstock input) could be built but the costs are also higher. In this case the gasfier could remain to be utilised at the site also after the demonstration period which could bring additional value for the investment. The demonstration at VTT's research facility would allow a plant capacity of only a 1-2 MW which might cause challenges to scale the process to 100-150 MW size range. However, this would be a lower cost solution to demonstrate the technology and operation of the whole value chain.

CONCLUSIONS

Considering the European targets for the renewable fuels there is a clear opportunity for the biomass based advanced transportation fuels. Even in the case of increasing electrification of the transportation, sectors such as aviation and heavy transportation are expected to operate on liquid fuels. The COMSYN project has validated the biomass gasification and Fischer-Tropsch based technology to be feasible in the scale of 100 - 200 MW of biomass feed input. This study report summarized the findings for the most suitable business concepts in Northern Europe and Central Europe. All proposed concepts are based on the integration of the COMSYN production plant with the local industries and infrastructures. This will enable utilisation of local low cost feedstocks and the excess heat from the process can be utilised to produce renewable heating for the local utility and industrial demands. It is estimated that the biocrude can be competitive feedstock for existing oil refineries when the demand for advanced biofuels increase. The next step in the commercialization of the COMSYN technology is therefore proposed to include a ca. 10-50 MW demonstration unit in a suitable location which would offer integration possibilities and local biomass feedstock.