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HIGH EFFICIENCY CO-PRODUCTION OF SUBSTITUTE NATURAL GAS (SNG) AND FISCHER-TROPSCH (FT) TRANSPORTATION FUELS FROM BIOMASS

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HIGH EFFICIENCY CO-PRODUCTION OF SUBSTITUTE NATURAL GAS (SNG) AND FISCHER-TROPSCH (FT) TRANSPORTATION FUELS FROM BIOMASS

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ABSTRACT: The technical, economic and ecological feasibility was studied of the co-production of 50 PJ of Fischer-Tropsch (FT) transportation liquids and 150 PJ of Substitute Natural Gas (SNG) per year (*i.e.* 10% of the 2001 Dutch consumption). In the co-production concepts part of the SNG is produced by methanation of the FT off-gas, which already contains significant amounts of C_1-C_4 SNG compounds. The additional required SNG is produced by dedicated methanation of part of the gasification product gas. Co-production results in higher biomass-to-fuel efficiencies, lower biomass input requirements and less negative Net Present Values (NPVs) compared to the case of complete separate production of both fuels. Co-production concepts based on pressurised oxygen-blown gasification result in the lowest CO_2 emission reduction costs of about 100 €/tonne. Co-production of "green" FT transportation fuels and "green" SNG will be an economic feasible process in the Netherlands, when both energy carriers receive the same tax exemptions as currently is given to green electricity.
Keywords: co-production, Substitute Natural Gas (SNG), Fischer Tropsch

1 INTRODUCTION

Biomass is one of the most promising renewable energy sources to replace fossil fuels and has the unique characteristic that it is a feedstock for the production of chemicals as well as gaseous and liquid fuels. In the Dutch situation, especially natural gas and transportation fuels are important products with a total current (2001) consumption of approximately 2000 PJ/year[1][2]. Production of "green" substitute natural gas (SNG) as well as "green" transportation fuels will allow the use of the existing natural gas and transportation fuels infrastructure and, hence, make a gradual transition from the present fossil fuel-based energy supply system to a complete renewable fuel-based economy possible. Gasification of biomass generates a product gas or synthesis gas that can be used to synthesise SNG and transportation fuels by methanation and Fischer-Tropsch (FT) synthesis, respectively (the FT system is shown in figure 1).

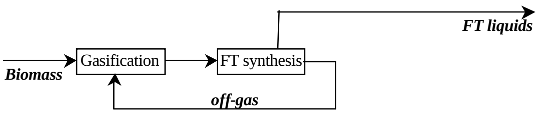

Figure 1: System for the production of FT liquids from biomass

During the conduction of a study to develop gas cleaning for integrated biomass / FT processes[3][4][5][6], it was recognised that typical off-gases from FT synthesis, due to the high amount of CH_4 and higher hydrocarbons, resemble the composition of Groningen natural gas[7]. The idea was postulated that by upgrading this off-gas FT transportation fuels and SNG could be co-produced (figure 2) and with probably a higher overall efficiency compared to two separate production processes. However, the technical and economic bases for this concept were far from well investigated.

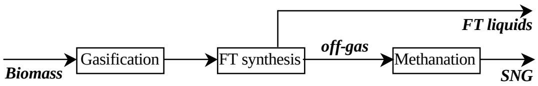

Figure 2: System for the co-generation of FT liquids and SNG from biomass

The objective of the study was to determine the technical and economic feasibility of large-scale systems of co-generation of "green" FT transportation fuels and "green" SNG from biomass. The systems were assessed assuming a targeted annual production of 50 PJ of FT transportation fuels and 150 PJ of SNG, which equals 10% of the current (2001) Dutch consumption of these energy-carriers[1][2]. Co-production of 50 PJ/yr of FT transportation fuels and 150 PJ/yr of SNG leads to an annual CO_2 emission reduction of approximately 12.5 Mtonne.

2 SYSTEM DEFINITION

The evaluated overall system comprises the whole chain of biomass collection, transport, syngas production by gasification, gas cleaning, and FT and SNG synthesis, similar to a previous study on the feasibility of large-scale synthesis gas production from biomass (*i.e.* virgin wood) imported from the Baltic States[8].

In case of co-production part of the thermal biomass input is converted to liquid fuels by FT synthesis and the off-gas is methanated to afford SNG. The amount of SNG produced will depend on both the chosen gasification concept and the operating conditions of the FT synthesis. If additional SNG is required to meet the objective of replacing 10% of the annual Dutch natural gas consumption it needs to be produced in a separate dedicated process (figure 3). In the integrated co-production concept part of the product gas is used for FT synthesis and the other part for SNG synthesis, whereas in the parallel co-production concepts two different gasification processes are used.

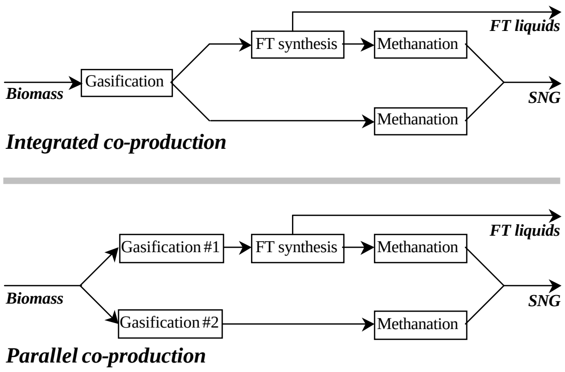

Figure 3: Co-production of FT liquids and SNG

For all evaluated systems an Aspen+ model was constructed in order to determine the mass, heat and work balances of the processes. Six combinations were considered of gasifier type, operating pressures, and pressurisation gas. The FT synthesis is operated at a temperature of 220°C and a partial pressure of the syngas components (H_2 and CO) of 40 bar.

The FT feed-gas is shifted to a H_2/CO ratio of two and all CO_2 is removed. The FT off-gas is shifted to a H_2/CO ratio of three, necessary for the methanation (at 66 bar). The produced SNG has a Wobbe-index of 43.7 MJ/m_n^3 (regulated by either CO_2 removal after methanation or by adding a part of the CO_2 removed before the FT synthesis)[7][9].

3 FEASIBILITY OF CO-GENERATION

In the co-generation concept, 50 PJ/yr of FT liquids is produced with SNG as “spin-off” product from FT-synthesis. The assessment is concentrated on four gasification technologies, *viz.*:

- Atmospheric O_2-blown CFB gasification.
- Pressurised O_2-blown CFB gasification.
- Indirect steam-blown gasification (atmospheric).
- Entrained-flow O_2-blown gasification (pressurised).

Overall efficiencies for a given gasification option are effectively independent of the energy carrier produced (*i.e.* FT liquids or SNG). This means that there is no incentive to produce either energy carrier over the other, with respect to optimising the energy efficiency of a process. The efficiencies for the independent energy carriers SNG ($\bullet_{SNG}$) and FT liquids ($\bullet_{FT}$), however, depend strongly on the CO-conversion in FT synthesis ($\bullet_c$), which was demonstrated by lab-scale FT synthesis experiments[10].

The amount of SNG produced in addition to the 50 PJ/yr of FT liquids depends on both the chosen gasification concept and the operating conditions of the FT synthesis. When the FT synthesis is operated at maximum FT production conditions of $\bullet_c$ equal to 0.95, the amount of SNG produced will be (well) below the desired 150 PJ/yr.

Considering both economic and product quality arguments it is, however, best to operate the FT synthesis with maximum conversion and chain growth probability. At these conditions the additional SNG required to meet the 150 PJ/yr production target, should be produced by methanation in a separate dedicated SNG section.

4 INTEGRATED & PARALLEL CO-PRODUCTION

The production of additional SNG can be carried out in an integrated or parallel co-production concept. In these concepts either a side-stream of the gasifier is used for methanation or the product gas of a separate gasifier. Five co-production concepts were considered:

- Integrated co-production with indirect steam-blown gasification
- Integrated co-production with pressurised O_2-blown CFB gasification
- Integrated co-production with entrained-flow O_2-blown gasification
- Parallel co-production with indirect steam-blown & entrained-flow O_2-blown gasification
- Parallel co-production with pressurised O_2-blown CFB & entrained-flow O_2-blown gasification

In the parallel systems, the FT liquids production is based on co-generation with EF gasification as then (by far) the highest yield to FT liquids is achieved. Although in all concepts the same amounts of FT liquids and SNG are produced, there is a huge variation in the required biomass input due to the different overall energy efficiencies. The integrated co-production concepts with indirect and pressurised CFB gasification require approximately 10% less biomass compared to both parallel concepts.

The expected values for the CO_2 emission reduction costs range from approximately 100 to 175 €/tonne, based on a biomass price of 2.3 €/GJ. The Net Present Value (NPV) is negative for all concepts, which means that co-production of "green" FT transportation fuels and SNG requires some financial (governmental) incentives or tax exemptions to become market competitive. Integrated co-production of FT liquids and SNG by pressurised O_2-blown CFB gasification, or indirect gasification, is economically more attractive than by pressurised O_2-blown entrained-flow gasification. Both concepts with parallel SNG production appear as less interesting, however, considering the uncertainties the differences are not significant.

5 CONCLUSIONS

The major conclusions with respect to the technical feasibility of producing SNG as "spin-off" product from FT synthesis (*i.e.* by co-generation) are:

- There is no incentive to produce either SNG or FT liquids as the conversion efficiencies to both products are essentially equal.
- The overall efficiencies (FT liquids plus SNG) are higher for CFB and indirect gasification concepts compared to EF gasification as already much CH_4 and C_2 compounds are present in the product gas. On the other hand, the efficiency to FT liquids is much higher for EF gasification resulting from the presence of all the chemical energy in the gas as syngas compounds (CO and H_2).
- Additional SNG can be produced either by "integrated co-production", in which a side-stream of the product gas of the gasifier is used for dedicated methanation or by "parallel co-production", in which part of the biomass is fed to a second gasifier coupled to a dedicated stand-alone methanation reactor.
- Integrated or parallel SNG co-production is preferred over operating the FT synthesis at non-maximum conditions.

The major conclusions of the economic evaluation with respect to producing fixed amounts of 50 and 150 PJ of FT transportation fuels and SNG, respectively, are:

- The integrated co-production concepts have generally higher net energy efficiencies compared to the parallel co-production concepts.
- None of the co-production concepts is economically feasible at current conditions, without financial incentives or tax exemptions, and with a biomass price of 2.3 €/GJ, as follows from the negative net present values (NPV).
- The CO_2 emission reduction costs range from approximately 100 to 175 €/tonne. The trend in CO_2 costs corresponds to the trend in efficiencies.

- In general, pressurised O_2-blown CFB gasification and indirect steam-blown gasification are the most suitable technologies for co-production (figure 4), with CO_2 reduction costs in the range of the energy tax exemption for "green power" in the Netherlands of 100 €/tonne[11].

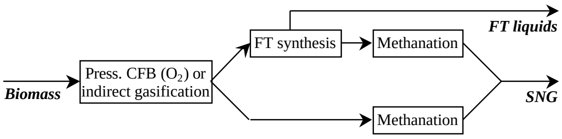

Figure 4: Optimal system for (integrated) co-production of "green" FT transportation fuels and "green" SNG.

The main overall conclusion of the study is that the co-production of Fischer-Tropsch transportation fuels and Substitute Natural Gas (SNG) from biomass is economically more feasible than the production of energy carriers in separate processes. Co-production of "green" FT transportation fuels and "green" SNG will become an economic feasible process in the Netherlands, when both energy carriers receive the same tax exemptions as currently is given to green electricity.

ACKNOWLEDGEMENTS

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RELATED AND FUTURE WORK

ECN has defined an R&D programme for the production of SNG from biomass, with the objective to prepare a future demonstration in The Netherlands. Part of the work carried out within the framework of this programme is reported in the paper "Biomass and waste-related SNG production technologies" by Mozaffarian and Zwart.

More detailed results on both the production of SNG and of Fischer-Tropsch transportation fuels will be presented soon.

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