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Technical, economic and ecological feasibility

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BIOMASS AND WASTE-RELATED SNG PRODUCTION TECHNOLOGIES
TECHNICAL, ECONOMIC AND ECOLOGICAL FEASIBILITY

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ABSTRACT: Based on comparable assumptions, a technical, economic, and ecological assessment has been performed for several biomass/waste-related SNG production technologies, with the objective to make a selection for future implementation of the most promising options. Based on the modelling results, the upstream pressurised oxygen-blown CFB or indirect atmospheric steam-blown gasification with downstream methanation routes were identified to be the most promising options for SNG production from biomass. In combination with downstream methanation, SNG production efficiencies up to 70% (LHV) can be achieved. The successful integrated lab-scale demonstration of "Green Gas" production confirmed the potential of the ECN gas cleanup concept to deliver a product gas, that can satisfy among others the specifications for downstream methanation. For a 100 MW_{th} system and biomass costs of 2.3 €/GJ, the SNG production costs range from 7.8 to 8.5 €/GJ and the CO_2 emission reduction costs range from approximately 80 to 95 €/tonne. "Green Gas" production via biomass gasification with downstream methanation can be an economic feasible process in the Netherlands, if comparable stimulating measures would be considered for green gas, as are now the case for green power.
Keywords: green gas, substitute natural gas (SNG), methanation

1 INTRODUCTION

"Green Gas" (or Substitute Natural Gas, SNG) is a sustainable gas from biomass with natural gas specifications. Therefore, it can be transported through the existing gas infrastructure, substituting natural gas in all existing applications.

Within the Dutch sustainable energy policy an important role is foreseen for the application of biomass and waste. 10% of the total primary energy supply in 2020 should be delivered by renewable energy sources[1][2]. About 50% of this policy target has to be realised by biomass and waste. For the long-term (2040) the Dutch Ministry of Economic Affairs has proposed a Biomass Vision within the Energy Transition activities, declaring that 30% of the fossil fuels in the electricity and transportation sectors, and 20-45% of the fossil-based raw materials in the chemical industry has to be substituted by biomass[3].

Compared to other biomass conversion routes, the major advantage of the "Green Gas" concept is the potential to use the existing dense Dutch and European gas infrastructure for large-scale introduction of bio-energy. For Europe this will contribute to the security of gas supply, which will be more and more dependent from import, while for the Netherlands it will save the natural gas resources for a longer period.

Large amounts of primary fuels are consumed for distributed heat production. The use of centralised produced SNG (economy of scale) for heat production in households and small and medium sized enterprises is economic competitive with alternative options like distributed CHP plants and electrical heating. SNG can also be stored in old gas fields for (seasonal) peak shaving. Promising near future applications for "Green Gas" are co-generation at household level (especially in fuel cells), and as alternative fuel for transportation (i.e. CNG, LNG). Concerning the future use of alternative transportation fuels in the EU, the European Commission has a targeted natural gas market share for road transport of 10% by 2020 (based on percentage of the total fuel consumption for transportation). A main driving force for the large-scale introduction of CNG as motor fuel is concern for the security of supply for the transport sector, currently solely dependent on oil products[4][5]. Besides, application of CNG will result in less emissions of NO_x, CO_2, aromatics, and sulphur compounds, compared to petrol or diesel[5][6]. Similar to CNG, "Green Gas" can also be used as a motor fuel, with the advantage of being an almost CO_2-neutral fuel.

The objective of this project, which is carried out in co-operation with the Dutch Gasunie Trade & Supply, was to make a selection for future implementation of the most promising technologies for the production of SNG from biomass and waste.

The following gasification-based SNG production routes have been considered within this study[7]:

- Pressurised O_2-blown CFB gasification followed by methanation.
- Atmospheric indirect steam-blown gasification followed by methanation.
- Pressurised BFB hydrogasification followed by methanation.
- Pressurised O_2-blown CFB gasification followed by Fischer-Tropsch synthesis and methanation.
- Atmospheric indirect gasification followed by Fischer-Tropsch synthesis and methanation.

The first three stand-alone SNG production concepts are considered in this paper. In the co-production FT-SNG concept the off-gases from FT synthesis are used for SNG production through methanation. This concept can be considered as an alternative route to stand-alone FT synthesis, in which large amounts of off-gases would be recycled to the gasification step, requiring a large amount of auxiliary power. The co-production FT-SNG concept has been evaluated in the paper "High efficiency co-production of SNG and FT transportation fuels from biomass" by Zwart and Boerrigter[8].

The main pre-conditions for the stand-alone gasification concepts were production of a tar-free, low-nitrogen, and high methane content product gas, and the up-scaling potential of the technology to a commercial scale. Air-blown CFB gasification due to a high nitrogen content of the produced gas, and entrained-flow gasification due to zero methane content of the produced gas have, therefore, been left out of consideration.

2 MODELLING WORK

A block scheme of the stand-alone SNG production systems is presented in figure 1. In all cases the product gas from gasifier, after a low-temperature cleanup, and passing through a methanation step, is used for the production of SNG as main product.

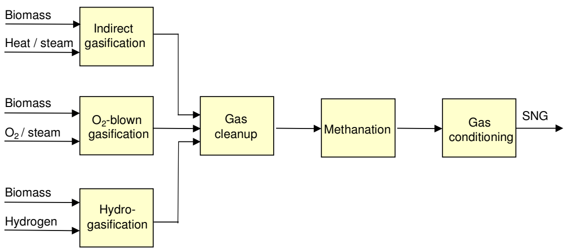

Figure 1: "Green Gas" (SNG) production by biomass gasification / hydrogasification

In order to determine the mass and energy balances of these processes, three Aspen Plus models were developed. The operating temperature of the gasifiers is 850°C. The gasifier pressure is respectively 1 bar for indirect gasification, 15 bar for oxygen-blown gasification, and 30 bar for hydrogasification. In case of indirect gasification, the product gas after cleanup is compressed to 15 bar, before entering the methanation section. In case of pressurised options a CO_2 stream is used as transport gas. The cleanup step consists of a dust filter, deep tar removal with the ECN oil-based gas washer (the OLGA unit), water scrubbing for removal of NH_3 and halides, and guard beds for final protection of methanation catalyst. The methanation process is based on the inter-cooled methanation process, used within the Lurgi coal-to-SNG process[9]. The conditioning step consists of gas cooling and drying, followed by partial removal of CO_2 (if necessary), in order to bring the Wobbe-index of the gas within the Dutch natural gas specification (*i.e.* between 43.46 and 44.41 MJ/Nm^3). The heat generated at various points in each process is used for steam and electricity generation in a steam cycle, in order to satisfy the demand within the system.

The modelling results show, that the upstream atmospheric steam-blown indirect gasification or pressurised oxygen-blown gasification with downstream methanation routes are the most promising options for SNG production from biomass. In combination with downstream methanation, SNG production efficiencies up to approximately 70% (on LHV basis) can be achieved. The specific investment costs of a system with a thermal biomass input of 100 MW are higher for pressurised oxygen-blown gasification (480 €/kW_{th}) compared to indirect steam-blown gasification (450 €/kW_{th}), mainly due to the requirement of an oxygen plant. The SNG production costs for a 100 MW_{th} system and biomass costs of 2.3 €/GJ range from 7.8 to 8.5 €/GJ, while based on the Dutch stimulating measures, valid in 2002, the actual market price for green gas was calculated to be in the range of 8.5 to 8.9 €/GJ. The CO_2 emission reduction costs range from approximately 80 to 95 €/tonne, which is lower than the 100 €/tonne tax exemption for green power.

The up-scaling potential of the indirect gasification technology is expected to be less than the pressurised oxygen-blown gasification, due to the complicated heat exchange between the gasifier and the combustor. This makes the technology mainly suitable for decentralised SNG plants (< 100 MW_{th}). The fact that this technology does not require an oxygen plant is another positive aspect of this technology for decentralised applications. In contrary, the pressurised oxygen-blown gasification will be more suitable for centralised applications (> 100 MW_{th}).

With respect to biomass hydrogasification, higher SNG production efficiencies (up to 80% LHV) and lower SNG production costs (5.6 €/GJ) can be achieved, compared to biomass gasification/ methanation routes. However, the limited availability (until 2020), as well as the origin (fossil-based) of the applied hydrogen result in lower SNG production potential and CO_2 emission reduction, and higher CO_2 emission reduction costs (115 €/tonne). Fossil-based hydrogen lowers the market price for SNG from hydrogasification process, as only a part of the produced SNG can be considered green.

3 EXPERIMENTAL WORK

"Green Gas" production via biomass gasification, gas cleaning, and methanation was successfully demonstrated in December 2003.

Gas cleaning is the major technical challenge in the application of product gases from biomass gasification for SNG production, as the methanation catalysts are very sensitive to impurities, especially sulphur, halides, and tar compounds. In the integrated test, beech wood (1 kg/hr) was converted into a product gas (composition: CH_4 (11%), CO (31%), H_2 (21%), C_2H_4 (3.6%), CO_2 (29%), with balance mainly N_2, C_2H_6, and C_2H_2) by oxygen/steam-blown gasification in one of the *ECN biomass* lab-scale (bubbling) fluidised bed gasifiers. The gas was completely de-dusted with a high-temperature ceramic filter (400°C), followed by deep tar removal with the lab-scale OLGA unit, and water scrubbing for removal of NH_3 and halides. In order to achieve the desired H_2/CO ratio for methanation, extra hydrogen was added to the gas. Then the gas was led to the so-called AGAF facility (Advanced Gas Application Facility), consisting of respectively a water condensor, a compressor (up to 60 bar), ZnO filters for sulphur removal, and active carbon filters for final protection. The clean gas was then used as feed for our micro-flow fixed-bed methanation reactor with a Ru-based catalyst, operated at 30 bar and 260°C.

The suitability of the cleaned biomass product gas for SNG synthesis was proven by stable catalyst performance during the 150-hours integrated methanation test. The deactivation rate was comparable with our reference case, in which a "clean" synthetic mixed gas was used as feed stream.

4 CONCLUSIONS

- Atmospheric indirect steam-blown gasification or pressurised oxygen-blown CFB gasification with downstream methanation are the most promising routes for SNG production from biomass, resulting in SNG production efficiencies up to 70% LHV.
- Atmospheric indirect steam-blown gasification is more suitable for decentralised (< 100 MW_{th}) applications, while pressurised oxygen-blown CFB gasification is more suitable for centralised (> 100 MW_{th}) applications.
- The successful integrated lab-scale demonstration of "Green Gas" production confirms the potential of the ECN gas cleanup concept to deliver a product gas, that can satisfy among others the specifications for downstream methanation.
- For a 100 MW_{th} system and biomass costs of 2.3 €/GJ the SNG production costs range from 7.8 to 8.5 €/GJ and the CO_2 emission reduction costs range from approximately 80 to 95 €/tonne, which is lower than the 100 €/tonne tax exemption for green power.
- "Green Gas" production by atmospheric indirect steam-blown gasification or pressurised oxygen-blown CFB gasification with downstream methanation can be economic feasible processes in the Netherlands, if comparable stimulating measures would be considered for green gas, as is now the case for green electricity.

5 FUTURE WORK

The "Green Gas" technology developments at ECN will be continued in 2004-2005, in co-operation with the Dutch Gasunie Trade & Supply (GU T&S) and Gastransport Services (GtS). A bench-scale integrated gasification, gas cleaning, and methanation system will be constructed and operated. The new so-called MILENA gasifier, with thermal inputs up to 25 kW (5 kg/hr biomass), can be operated at direct oxygen-blown gasification mode, as well as at indirect steam-blown gasification mode. The integrated system should enable the proof of production of a gas, that satisfies the specifications for downstream methanation. The R&D activities are aimed at optimisation of the gasification conditions (agglomeration behaviour, gas composition), gas cleaning (removal of tar and other components) and conditioning, and an extensive methanation test programme. The R&D activities should result in a conceptual design for a pilot-scale integrated biomass gasification SNG plant, to be realised and operated in 2005-2008. Commercial units are expected after 2008.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] *Derde energienota.* Ministerie van Economische Zaken, Den Haag, 1995.

[2] *Duurzame energie in opmars, actieprogramma 1997-2000.* Ministerie van Economische Zaken, Den Haag, 1997.

[3] *Biomassa: de groene motor in transitie; stand van zaken na de tweede etappe.* Ministerie van Economische Zaken, Den Haag, December 2003.

[4] *Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions on alternative fuels for road transportation and on a set of measures to promote the use of biofuels.* Commission of the European Communities, COM (2001) 547 final, Brussels, November 2001.

[5] *Market development of alternative fuels.* Report of the European Commission's alternative fuels Contact Group, December 2003.

[6] Hendriksen, P., R.J. Vermeulen, R.C. Rijkeboer, D. Bremmers, R.T.M. Smokers, R.G. Winkel: *Evaluation of the environmental impact of modern passenger car on petrol, diesel, automotive LPG and CNG,* TNO report: 03.OR.VM.055.1/PHE, December 2003.

[7] Mozaffarian, M., Zwart, R.W.R.: *Feasibility of biomass/waste-related SNG production technologies.* Final report, ECN-C--03-066, ECN, Petten, The Netherlands, July 2003.

[8] Zwart, R.W.R., Boerrigter, H.: *High efficiency co-production of substitute natural gas (SNG) and Fischer-Tropsch (FT) transportation fuels from biomass.* Oral presentation (B4.2) at the 2nd world conference and technology exhibition on biomass for energy, industry and climate protection, Rome, Italy, 10-14 May 2004.

[9] *Catalyst Handbook.* Second edition, edited by M.V. Twigg, ISBN 1874545359, 1996.

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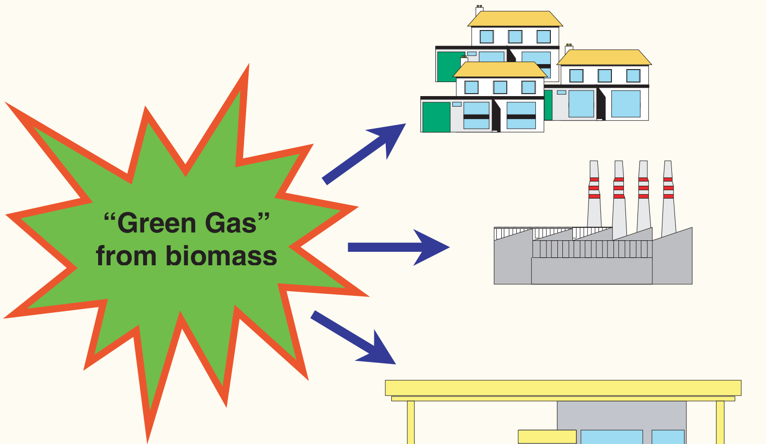

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