

**ABSTRACTS ECN BIOMASS TO THE
“2ND WORLD CONFERENCE AND TECHNOLOGY
EXHIBITION ON BIOMASS FOR ENERGY AND
INDUSTRY”**

10-14 May 2004, Rome, Italy

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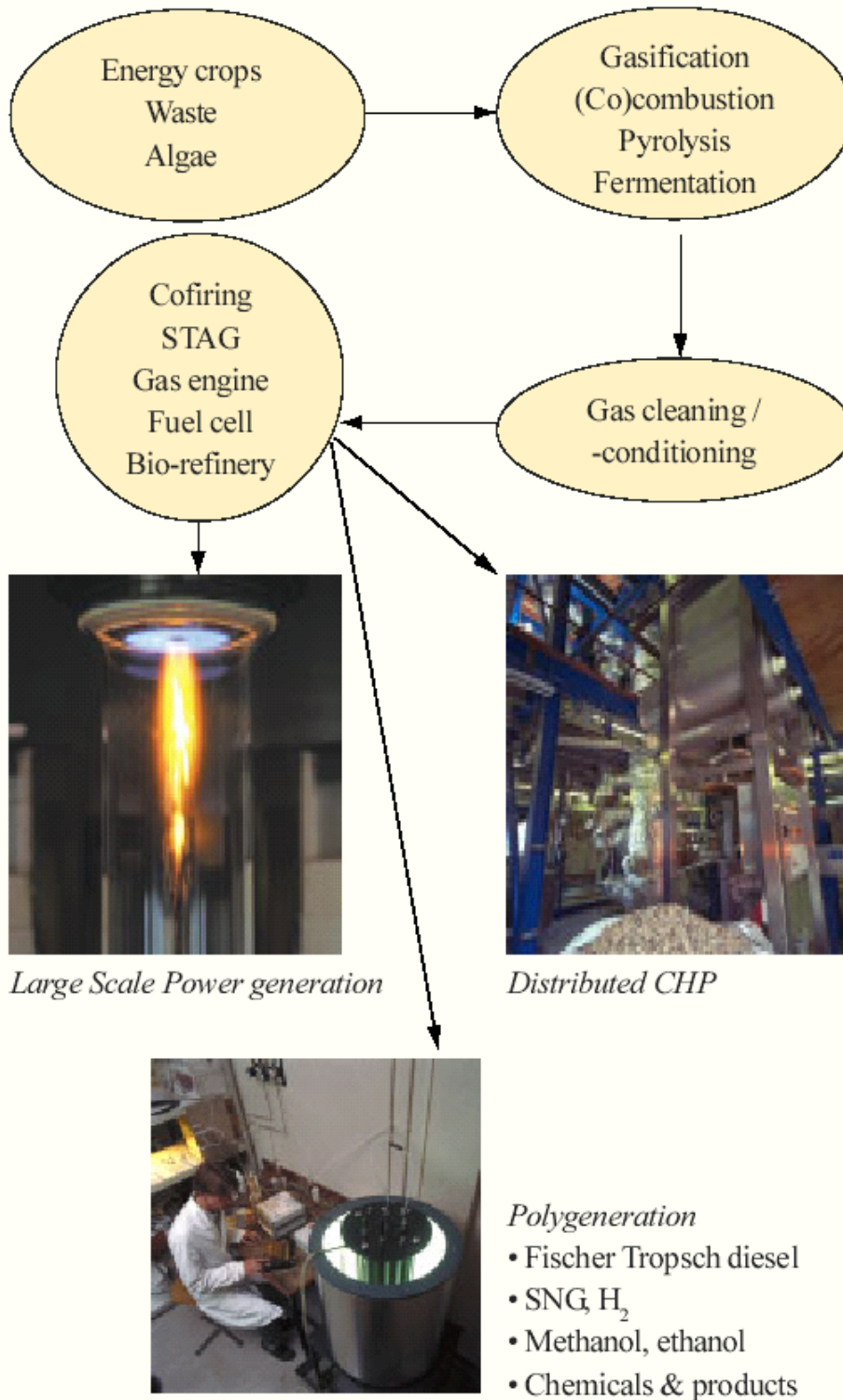
ECN Biomass

H.J. Veringa

Acknowledgement/Preface

This report contains the abstracts of the Energy research Centre of the Netherlands (ECN) to the “2nd World Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection”, held in Rome, Italy on 10-14 May 2004.

ECN BIOMASS



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INTEGRATED BIOMASS GASIFICATION AND GAS CLEANING FACILITY; ECN PILOT-PLANT FOR BIOMASS RESEARCH

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Purpose of the work

Gasification of biomass into product gas can convert biomass of various shape and origin into an energy source of more consistent quality, suitable for direct combustion, application in prime movers like engines, turbines, and fuel cells, or for the production of SNG and transportation fuels (*e.g.* Fischer-Tropsch diesel). Solids, tars, and ammonia are the main components in product gas that interfere with applications (fouling), result in contaminated waste stream (condense water), or lead to unacceptable emissions (*e.g.* NO_x). The raw product gas needs to be cooled and cleaned to meet the demands of a selected application.

Approach

Based on ten years experience, ECN has extended its existing test infrastructure and constructed a complete integrated biomass gasification and gas cleaning facility in 2003. This complete facility is available for research on all aspects of gas cooling, cleaning, and application (*see Figure*), including downstream lab-scale test units, like two Fischer-Tropsch reactors, a SNG reactor, and SOFC stacks (*not shown*).

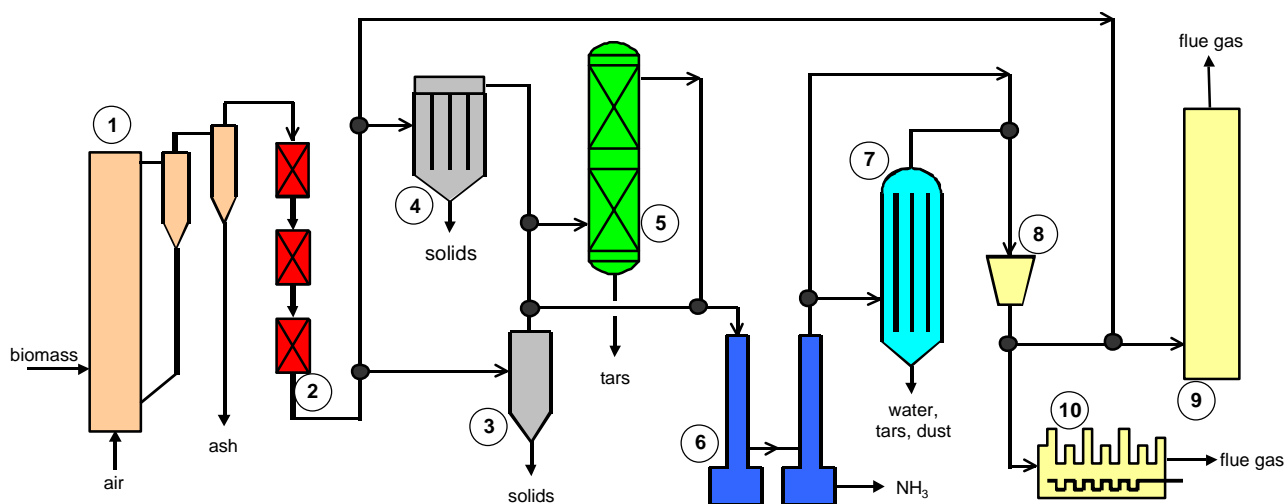


Figure. Complete scheme of integrated biomass gasification and gas cleaning facilities at ECN: (1) 500 kW_{th} circulating fluidised bed (CFB) gasifier; (2) three-stage gas cooler to cool to ~300/350°C; (3) cyclone at 300°C; (4) hot gas filter with sinter metal candles at ~350°C; (5) OLGA tar removal unit; (6) two-stage water (NH₃) scrubber; (7) wet Electro-Static Precipitator (ESP); (8) booster; (9) low-NO_x-burner; and (10) gas engine (optional). The black circles indicate valves. *Process integrations of heat and residual streams (i.e. NH₃ and tars to gasifier) are not shown.*

Scientific innovation and relevance

With the research facility the development of three systems for commercial relevant gas applications is supported: i) gasification for direct combustion or co-firing [1-2-9]; ii) gasification for CHP with gas engines [1-2-3-6-7-10]; and iii) gasification for turbines, fuel cells, or catalytic processes [1-2-4-5-6-8].

Results and Conclusion

In the last quarter of 2003 a complete operational test programme was successfully carried out for the different units and system configurations. Results showed that the system could be optimised for each gas application. At the biomass conference in Rome detailed results will be presented, including the progress of the 1000 hours test.

Acknowledgement

The independent units of the complete integrated installation are developed and realised within the framework of complementary projects with different project partners: Dahlman Industrial Group, Essent, Habo Lek, HoSt, Stork Thermec, and the Technical University of Eindhoven. Financial support was provided by the Netherlands Agency for Energy and the Environment (Novem) and the Agency for Research in Sustainable Energy (SDE).

MECHANISM FOR FORMATION OF CARBON-RICH DEPOSITION ON COOLER PIPES IN BIOMASS GASIFIERS

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Purpose of the work

The goal of the research was to establish a mechanism that describes the formation of the carbon-rich deposition found in the cooler of biomass fluidised-bed gasifier. The mechanism must describe the principal composition of the deposition layer, the growth rate under several conditions and most importantly the effects on heat transfer. A further objective of the work was to use the observed results and the mechanism to design a cooler where the thermal insulation due to deposition is minimised.

Approach

Metal probes are inserted in a producer gas flow of a 0.5 MWth CFB biomass gasifier. The probes are air cooled keeping the surface temperature of the probes constant by controlling the air flow. The probes are made of stainless steel and represent cooler pipes. Changes in the air flow rate correspond to the formation of a thermally insulating layer. The various depositions found on the probes after runs ended were extensively investigated using Scanning Electron Microscopy and chemical analyses. In some runs, on-line sandblasting of the probes was tried to see whether deposition formation could be prevented.

Scientific innovation and relevance

Tar and ash deposition is among the most difficult technical problems that need to be solved in the gasification of biomass. Both play a role in the rapid formation of a deposition layer on the cooling pipes, resulting in thermal insulation with a loss of up to 80% of the cooling capacity. Elucidation of the deposition mechanism that forms this thermal insulation is urgently needed. When the mechanism is known, counter measures can be taken that target specific parts of the deposition mechanism. Ultimately, the deposition and hence the loss of heat transfer should be prevented or stabilised at a low level.

Results

Close inspection of the deposition layers revealed that the deposition on the cooled probes consists of a hard, non-porous char under layer and a brittle, porous upper layer. The outer layer is formed by deposition of primary char particles from the gas phase. The under layer grows inside the upper layer as a result of tar deposition close to the metal surface and dehydrogenation of the tar forming secondary char. The upper layer forms under all conditions, while the formation rate of the under layer strongly depends on the local temperature. Typically below a probe temperature of 350°C, the dew point of the tars, an under layer is formed. The formation of the under layer was not observed at higher probe temperatures, but theoretically the growth of an under layer is predicted even at 500°C. The duration of the runs was probably too short to confirm this and a long run is needed to verify the mechanism. Inorganic components in the gas phase, ash and salt, nor the material of the probe seem to be of importance.

Continuous sandblasting strongly inhibits the formation of an upper layer, but the formation of a very thin under layer could not be prevented. The loss in heat transfer was relatively small and stabilised quickly. A combination of a relatively high probe temperature and continuous sandblasting was tested for the duration of 4 hours and resulted in the formation of a very thin under layer and a small and constant thermal insulation.

Conclusion

A qualitative mechanism was established for the formation of depositions on cooled surfaces in the producer gas of a biomass gasifier. Deposition of primary char and formation of secondary char from condensed tar are the key factors. Continuous sand blasting was found to be an effective means of suppressing deposition formation.

Acknowledgement

This work was financially supported by NOVEM. The authors wish to thank Essent Energy Production for the open and fruitful discussion on the results when comparing them to the findings in the AMER-CFB.

OLGA TAR REMOVAL IN BIOMASS CHP PLANTS; PILOT-PLANT COMMISSIONING AND TEST PROGRAMME RESULTS

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Purpose of the work

In spite of all the research efforts directed towards the development of integrated biomass gasification CHP plants, the break-through of this technology still has to take place. The lack of reliable and cost-effective technologies hampers the implementation. The presence of tars in the product gas has probably been the major issue in biomass gasification as it causes technical problems like fouling and water pollution, which results in economic penalties due to loss of operational hours and additional maintenance and wastewater treatment costs.

Urged by the importance to solve the tar-related 'problems', ECN Biomass developed the OLGA tar removal technology, which was protected by a patent. A complete lab-scale OLGA was constructed and tested to deliver the Proof-of-Principle. To deliver the Proof-of-Concept (POC) a pilot-scale OLGA was designed and constructed down-stream the ECN 500 kW_{th} circulating fluidised bed (CFB) gasifier in co-operation with Dahlman Industrial Group. After successful conclusion of the POC test programme the OLGA technology is ready for first demonstration projects.

Approach

In essence an OLGA unit comprises a scrubber to wash the tars from the gas and a stripper to regenerate the washing liquid. The characteristic features are the use of a special organic liquid and the temperature operating range. The gas inlet temperature of OLGA has to be higher than the tar dew point (typically >300°C) to prevent tar fouling upstream the OLGA. The gas outlet temperature is kept above the water dew point to avoid mixing of condensed water and scrubbing liquid (loaded with tars).

Ideally, the OLGA unit is the heart of an integrated biomass CHP plant. After cooling and solids removal (with a hot gas filter) the product gas is cleaned from tars in the OLGA scrubber. Subsequently, NH₃ is washed out in an aqueous scrubber, affording a very clean gas to be supplied to the gas engine. The gasification air is used to strip the NH₃ the water, allowing discharge of the excess process water to the sewer, and subsequently to regenerate the OLGA scrubbing liquid. Both the NH₃ and the tars are destructed in the gasifier. By this integrated approach, the plant has no waste streams.

Scientific innovation and relevance

The OLGA is an innovative tar removal technology that removes tar with an efficiency well above 99%, typically affording a tar dew point below -10°C. The scope of the OLGA technology, however, is not limited to a specific type of gasifier or to biomass CHP applications. The performance is also independent of the tar load in the gas, which was shown by cleaning WOB product gas from oxygen-blown gasification containing ~20 g/m³ of tars. The suitability of the OLGA to meet very stringent tar specifications was proven by successfully using this tar-free gas (after removal of inorganic impurities) as feed for a 500 hours Fischer-Tropsch synthesis run.

Results

At the biomass conference in Rome detailed results of the commissioning test programme of the pilot-scale OLGA and the coupled hot gas filter will be presented. The presentation will include economic data for the investment and operational costs of an OLGA unit downstream a 10 MW_{th} gasifier.

Conclusion

The OLGA is a reliable and cost-effective tar removal technology and a breakthrough in tar removal research. The performance of OLGA is unmatched by the alternative approach of wet scrubbing plus ESP

as with OLGA also the very stringent specifications for catalytic processes can be met (*e.g.* Fischer-Tropsch synthesis).

Acknowledgement

The work presented in this abstract has been carried out with financial support from the Netherlands Agency for Energy and the Environment (Novem).

Explanatory Pages

DESIGN OF OLGA

PROCESS OBJECTIVES

The (ambitious) objective in the design of OLGA was the creation of a new process that eliminates issues involved with tar condensation and water solubility. The process to develop should be competitive with competing technologies.

PROCESS TASKS

The approach to design a process for complete and selective tar removal in a controlled way, started with a definition of the required tasks for such a process. Primary and secondary tasks are distinguished (see Table 1). Primary tasks deal directly with the objective. Secondary tasks are additional and need to be accomplished to obtain a system that also meets specifications from, for instance, the economic and legislation points of view. In contrast to the primary tasks, the secondary tasks are only indirectly responsible for the technical feasibility of the system.

Table 1. Primary and secondary tasks of OLGA.

Primary tasks
1. Selective tar removal (<i>viz.</i> no water removal).
2. Deep removal of tar components resulting in a syngas quality for which no tar condensation or tar desublimation occurs, and simultaneously absence of tar aerosols, while applying the desired operating conditions.
3. Specific removal of heterocyclic tar components (in particularly phenol), to avoid water contamination in the wet syngas cleaning that is necessary to remove contaminants like NH ₃ and HCl.
Secondary tasks
4. Avoiding waste streams
5. Avoiding a (too) high scrubbing liquid consumption. This is in particularly important with respect to process economics, but surely also with respect to de sustainable image of biomass gasification.
6. Removing dust and/or fines that have not been removed by dust separators upstream of OLGA.
7. Preventing a high gas-side pressure drop over de gas cleaning system.

BASIC PROCESS STRUCTURE

The biggest challenge is to remove tar selective from the syngas (task 1). In particular the applied scrubbing liquid must not absorb water, as that would still lead to the pollution of process water. Similarly, the permanent gas components in the biosyngas (*e.g.* CO, H₂, and CO₂) should not dissolve in, or be absorbed by, the scrubbing liquid. This would not contribute to the simplicity of the process.

Deep removal of classes 1 and 5 tars is desired in order to decrease the tar dewpoint and to eliminate condensation problems (task 2). Complete collection of these tar classes yields a dewpoint below 100°C (*cf.* Figure 2). Furthermore, to operate end-use applications that require syngas temperature below 50°C, without the risk of tar condensation, classes 2 and 4 tars need to be removed partly. The required collection efficiency depends on the actual amount and composition of the tars in the syngas. Although the collection efficiency of class 2 tars (the heterocyclic tars) needs not to be complete from the

condensation point of view, essentially quantitative removal is required to avoid of pollution of process water (task 3).

The elimination of all condensation-related issues means also that no tar condensation may occur upstream OLGA. Hence, the syngas inlet temperature of OLGA must be higher than the tar dewpoint of the raw syngas. As a consequence of task 1, water present in the syngas may not condense simultaneously with tar. Therefore, the exit temperature of OLGA must remain above the water dewpoint of the syngas. Figure 1 illustrates this further by positioning OLGA with respect to both the tar and the water dewpoint.

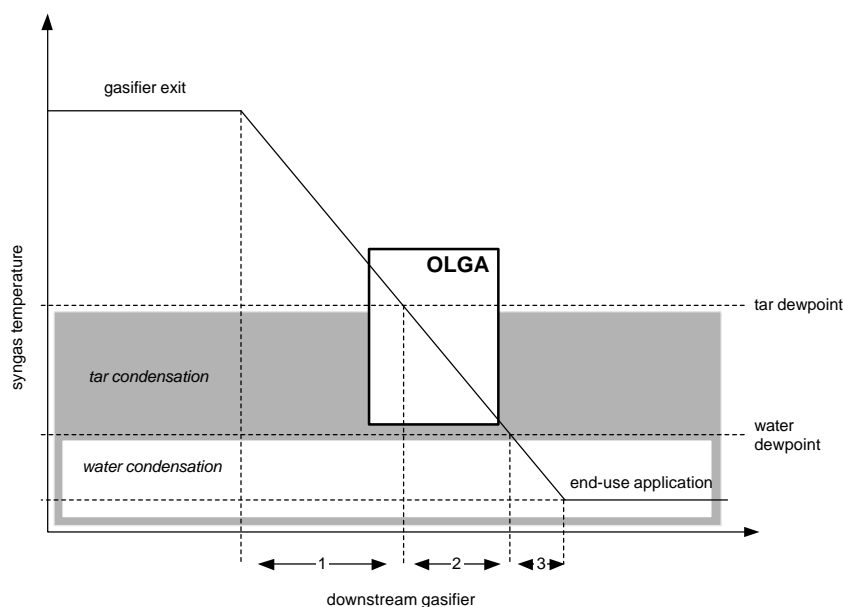


Figure 1. The position of OLGA with respect to the syngas temperature and to the dewpoints of water and tar. Explanation on zones 1, 2, and 3 downstream the gasifier: (tar phase/ water phase) 1: (G/G), 2: (L/G), 3: (L/L)

Upon cooling of the biosyngas, the temperature decreases below the tar dewpoint and tar condensation gradually takes place until syngas is not cooled further. At the resulting temperature, between the dewpoint of tars and water, a liquid/gas (L/G) phase system is obtained (L represents liquid tar). The scrubbing liquid acts as the medium to collect these liquid tars. The remaining tars are collected into the scrubbing liquid by absorption (*i.e.* the scrubbing liquid acts as absorption medium). Figure 2 illustrates this. The degree of absorption latter can be controlled by changing the operation conditions and will be determined by the desired tar dewpoint of the outlet syngas. In the regeneration of the scrubbing liquid the tar is removed upon which some scrubbing liquid may evaporate.

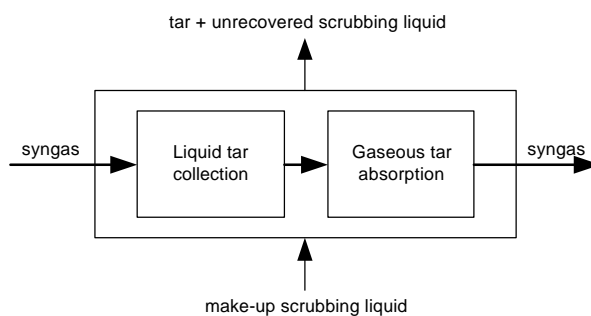


Figure 2. Basic structure of OLGA.

CONCEPTUAL PROCESS STRUCTURE

Figure 3 depicts the general concept of the air-blown biomass gasification process using OLGA. The produced syngas is first cooled and de-dusted upstream of OLGA. Downstream OLGA, the main (inorganic) non-tars impurities NH_3 and HCl are removed by wet scrubbing and water is condensed out

due to further cooling of the gas. The syngas is then suitable for most of end-use applications as it is free of condensable tars, tar aerosols, as well as inorganic impurities. Tar and unrecovered scrubbing liquid are fed to the gasification process and also the separated NH_3 is recycled to the gasification process. Similarly to the tar recycling, separate experiments at ECN have shown that NH_3 is converted to nitrogen in the gasifier.

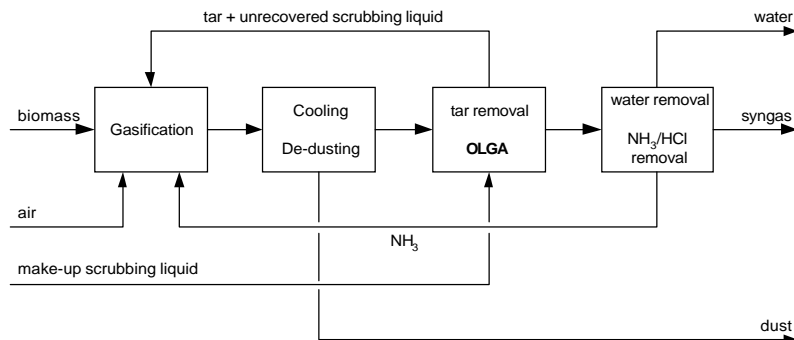


Figure 3. General concept of air-blown biomass gasification using OLGA for tar removal.

Although the major part of dust and/or fines will be collected upstream OLGA, it is inherent to the use of a scrubbing liquid as medium that fines will be collected in the scrubbing liquid. The removal of small particles in OLGA is considered as a secondary task (task 6) that is optimised as much as possible so that small particles do not have to be dealt with further downstream. It is considered as one of the interesting and economical attractive optimisation options of OLGA to remove the full dust load from the biosyngas, making the separated dust removal step upstream obsolete.

Intrinsically related to the use of a scrubbing liquid as process utility, is the consumption of liquid due to bleed streams and volatilisation upon stripping the tar. Even if the scrubbing liquid is very effective and the losses minimal, the process may not create another waste stream (task 4) as this causes an economic penalty for the waste handling.

It is furthermore undesirable as the consumption of scrubbing liquid creates an image for the process, which is in contradiction with the 'green' nature of the biomass gasification. The necessity to minimise scrubbing liquid losses motivated the inclusion and design of a regeneration step and has been a major selection criterion for the scrubbing liquid to be applied (task 5). The collected tar and the unrecovered scrubbing liquid from the regeneration step are recycled to the gasifier, preventing a waste stream. Separate experiments carried out at ECN have shown that tars can be recycled and gasified without accumulation.

FISCHER-TROPSCH 'GREEN' DIESEL FROM BIOMASS; OPTIMUM GASIFICATION AND GAS CLEANING SYSTEMS FOR BIOSYNGAS PRODUCTION

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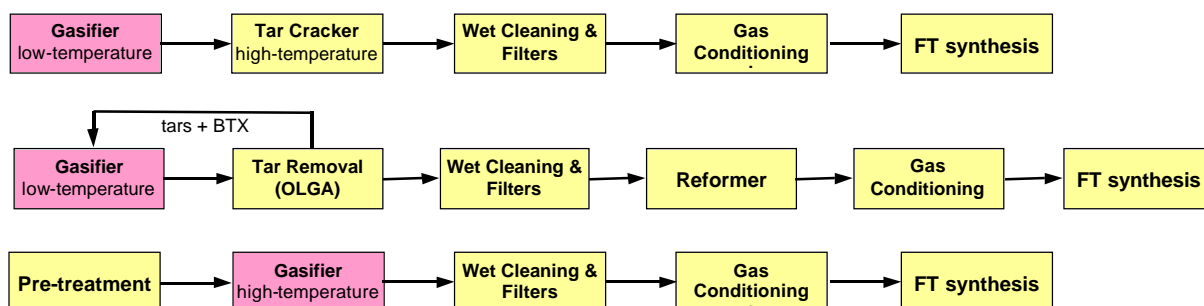
Purpose of the work

The emission of the greenhouse gas CO₂ can significantly be reduced by replacing fossil derived transportation fuels by renewable alternatives, *i.e.* 'bio-fuels'. The most promising renewable liquid fuel is 'green diesel' produced via Fischer-Tropsch (FT) synthesis with biosyngas generated by biomass gasification (BG). FT diesel is a high quality hydrocarbon fuel without aromatic or sulphur, which can easily be incorporated in the existing fuel infrastructure and used in existing car engines. In spite of these excellent properties of green diesel the realisation of demonstration plants is hampered by the poor economics. A bio-fuel will be at least two to three times more expensive than their fossil equivalents (excluding subsidies). The high cost of biomass is a major cost driver, which and accounts typically already for 50% of the bio-fuel production costs.

Approach

The research of biomass gasification Fischer-Tropsch synthesis (BG-FT) systems was initially directed towards the development of the gas cleaning to make biosyngas suitable as FT feed gas especially with respect to the removal of the tars. In a joint ECN-Shell project two tar removal approaches were developed: tar destruction with a thermal cracker and complete tar removal with the OLGA technology. Both systems were demonstrated in integrated test runs of gasification and 500 hours Fischer-Tropsch synthesis (in December 2001 and March 2003, respectively). Their success was proven by the stable operation of the reactor and performance (selectivity and productivity) of the catalyst.

High biomass-to-biosyngas conversion efficiencies are crucial in the economics of liquid fuel production. After demonstrating the technical feasibility of the gas cleaning, therefore, the technical developments at ECN are now directed towards overall gasification systems with the highest yield to biosyngas. ECN is assessing two concepts based on low-temperature oxygen-blown gasification and, in addition, the concept of one-step high-temperature entrained-flow gasification of pre-treated solid biomass. These three concepts are shown below, where the cleaning comprises water scrubbing and ZnO guard beds and the conditioning comprises H₂/CO shift and CO₂ removal.



Scientific innovation and relevance

The development of the ECN concepts is directed towards large-scale integrated BG-FT systems, as large-scales are required for economic feasible fuel production (in the future). Only in centralised integrated systems maximum energy integration can be achieved, which is essential to achieve the highest efficiency possible. In addition a large economy-of-scale factor applies for the Fischer-Tropsch synthesis plant.

Results & Conclusion

At the conference, in addition to the detailed results from integrated BG-FT test runs, an economical assessment will be presented of the (expected) green diesel production costs for each concept. The preferred concept for short-term implementation for large-scale syngas production will be selected.

Acknowledgement

Financial support from the Dutch Agency for Research in Sustainable Energy (SDE) is acknowledged.

HIGH EFFICIENT CO-PRODUCTION OF FISCHER-TROPSCH TRANSPORTATION FUELS AND SUBSTITUTE NATURAL GAS FROM BIOMASS

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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 consumption of approximately 2000 PJ/year. Production of “green” substitute natural gas (SNG) and “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 that can be used to synthesise SNG as well as transportation fuels by methanation and Fischer-Tropsch (FT) synthesis, respectively. Due to the high amount of CH₄ and higher hydrocarbons, typical off-gases from FT synthesis resemble the composition of Groningen natural gas. The idea was postulated that by upgrading these off-gases SNG could be co-produced with probably a higher overall efficiency compared to two separate production processes.

Objective

The objective of the study is to determine the technical, economic and ecological feasibility of large-scale systems of co-generation of “green” FT transportation fuels and “green” SNG from biomass. The systems are assessed assuming a targeted annual production equal to 10% of the current Dutch consumption of these energy carriers. The assessment is concentrated on four gasification technologies: atmospheric and pressurised oxygen-blown CFB gasification, indirect atmospheric steam-blown gasification and pressurised oxygen-blown entrained-flow (EF) gasification.

Results

Considering the production of an amount of both FT transportation fuels and SNG equal to 10% of the current Dutch transportation fuel and natural gas consumption (*i.e.* 500 and 1500 PJ, respectively), SNG cannot be produced solely from the FT-synthesis off-gas. The 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). Integrated co-production concepts have generally higher net efficiencies compared to the parallel co-production concepts. Co-production is preferred over operating the FT synthesis under sub-optimal conditions in a co-generation concept.

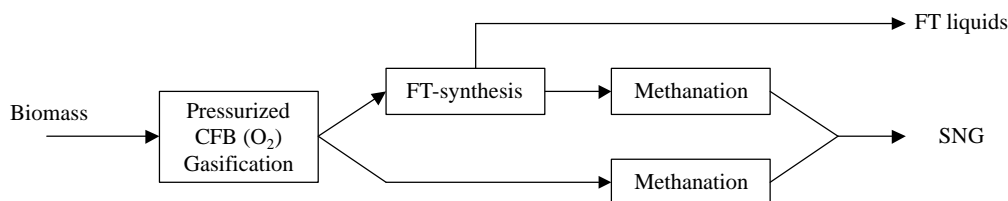


Figure 1 Optimal system for co-production of “green” FT transportation fuels and “green” SNG

Conclusion

The main conclusion of the study is that co-production of FT transportation fuels and 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.

Acknowledgement

Shell Global Solutions has supported the project by participating in the project meetings and providing information as well as experimental facilities. Financial support from the Netherlands agency for energy and the environment (Novem) is gratefully acknowledged.

PRODUCTION OF LOW-N₂ GAS IN NEW ECN GASIFICATION TEST FACILITY: MILENA

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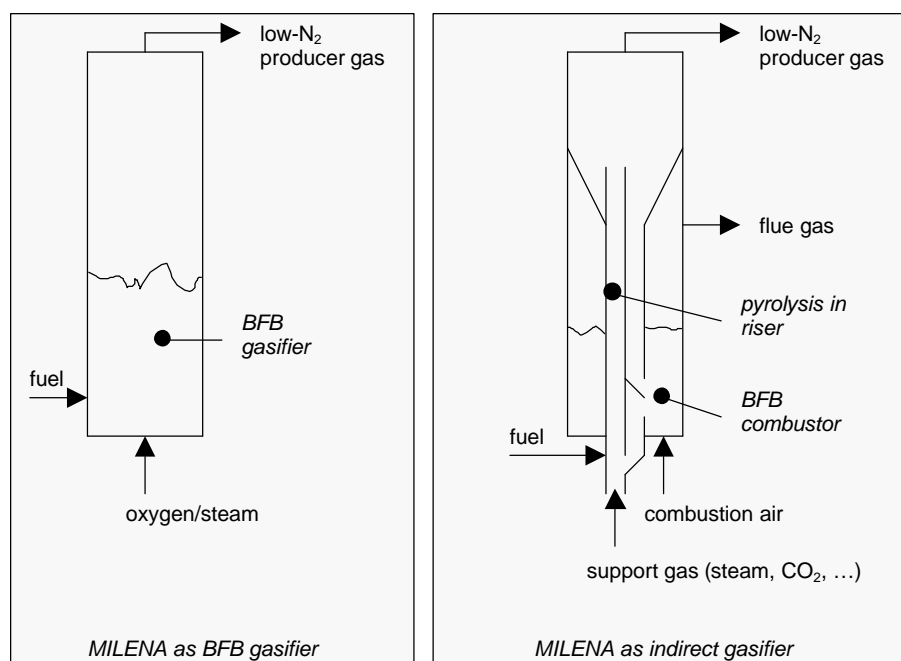
Introduction

By gasification of biomass a producer gas is produced that can be used for different applications. For any process it can be stated that it is desirable to have a producer gas with the highest possible heating value. For applications like gas engines and gas turbines this would mean less gas volume to clean and/or compress resulting in lower investment and/or operational costs downstream the gasifier. For applications like the synthesis of methanol and Fischer-Tropsch diesel, low-calorific gas (because of the presence of N₂) in practice means that the synthesis reactor is once-through (avoiding large recycle volumes). High efficiencies towards methanol or FT-diesel therefor require (almost) N₂-free producer gas. If synthetic natural gas is to be produced from producer gas, the absence of N₂ is essential because the SNG has to meet Wobbe-index requirements and N₂ cannot easily be removed from the gas.

Producing a low-N₂ producer gas from biomass can be done in two ways: (1) using pure oxygen instead of air or (2) separating heat production (air-blown combustion) and gasification. The last option, also called indirect gasification, produces two gases: low-N₂ producer gas and a hot flue-gas.

Results

ECN has built a 5 MW_{th} test facility, which can either be used as oxygen/steam-blown fluidised bed or indirect gasifier. The facility will be ready in November 2003. During the conference, test results will be presented. Items to be researched are: agglomeration risk, tar formation, tar destruction (if recycled from gas cleaning), minimum steam consumption, gas composition as function of conditions, etc.



Two options of atmospheric ECN bench-scale installation "MILENA" for the production of low-N₂ producer gas from biomass: steam/oxygen-blown bubbling fluidised bed (left) and indirect gasifier (right).

RENEWABLE ENERGY IN THE PAPER INDUSTRY IN THE CHINA; REPLACING COAL BY CO-FIRING OF WHEAT STRAW REJECT (WSR) IN EXISTING BOILERS

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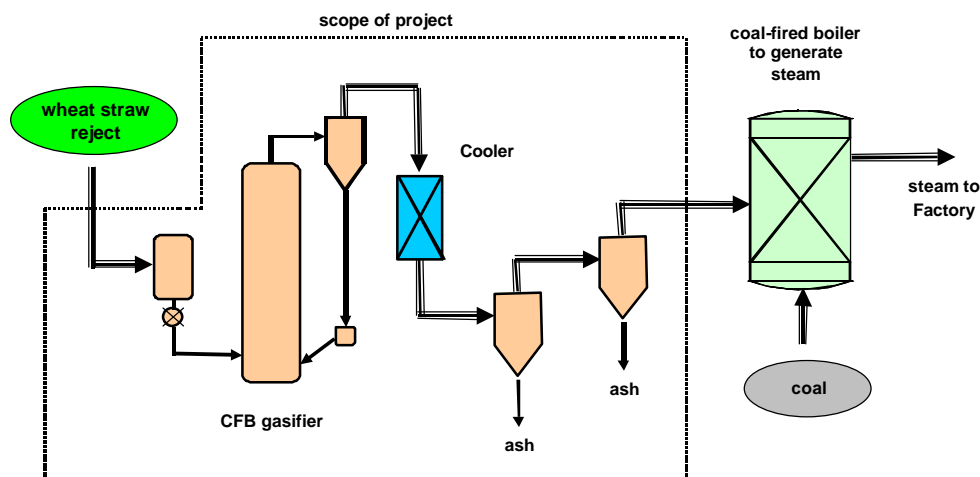
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Purpose of the work

In China 6 million tonnes of paper is produced from wheat straw annually; where approx. 14 million tonnes of straw is used. Of this straw 15% is reject. Much of this reject is burned on the fields giving rise to enormous seasonal pollution. The wheat straw reject (WSR) represents valuable energy that can be used as energy source for the paper mill enterprises. WSR can be used to generate steam by gasification of the material and co-firing of the product gas in the boiler thus reducing the consumption of polluting coal. In China currently no commercial technology is available for the processing of WSR. In a joint project ECN, HoSt, and ERI investigated the technical and economical feasibility of applying a circulating fluidised bed (CFB) gasifier in a system as shown below.



Approach

In the project the technical feasibility was proven in gasification tests of Chinese WSR (shipped to the Netherlands) in the ECN pilot gasifier. An economical assessment was made for the implementation of a 2 tonnes per hour CFB gasifier in the Dezhou Paper Mill in Linyi County.

Scientific innovation and relevance

WSR is a difficult fuel to process by means of any thermal process. The successful gasification is an important break-through and allows implementation of the use of renewable energy in rural areas in developing countries. The environmental impact of the use of WSR is significant: processing 2 ton/hour of straw (7 MW_{th}) will save annually 7,500 ton of coal and consequently 22,500 tonnes of CO₂ and 188 tonnes of SO₂ per year.

Results & Conclusion

In the pilot test the gasifier could be operated stable on raw WSR (no pelletisation necessary) and no indication of agglomeration was detected. The project showed that it is technically feasible to process

WSR with a CFB gasifier. For the Dezhou Paper Mill the economics of installing the gasifier look promising, *i.e.* a simple payback time of 2.0 years was calculated. In addition, replacing coal brings about major environmental benefits.

Acknowledgement

The work presented in this abstract has been carried out with financial support from Senter, an agency of the Dutch Ministry of Economic Affairs.

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

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Within the Dutch renewable energy policy an important role is foreseen for the application of biomass and waste. In order to satisfy the long-term (> 10 years) expectations of using biomass in the future Dutch energy infrastructure, this renewable energy source should, beside applications in the heat and power market, also be used as a substitute for fossil fuels in other market sectors. This requires the development of conversion technologies, to produce secondary energy carriers from biomass, substituting the present conventional energy carriers based on petroleum and natural gas. One of such conversion routes is the production of SNG (Substitute Natural Gas) from biomass. The produced “green gas” can be transported through the existing natural gas infrastructure to places where it could be used for the desired energy functions, such as CHP applications or as a transportation fuel, replacing CNG or LNG. The objective of this project, which is carried out in co-operation with the 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.

Anaerobic digestion, upstream steam-blown indirect gasification and pressurised oxygen-blown gasification with downstream methanation, hydrogasification followed by methanation, and, in less extent, the co-production of both Fischer-Tropsch diesel and SNG have been studied within this project. Results of the technical, economic, and ecological feasibility of the different biomass/waste-related SNG production technologies and future perspectives for development of the selected SNG production routes are presented and discussed in this paper.

The modelling results show, that the upstream steam-blown indirect gasification or pressurised oxygen-blown gasification with downstream methanation routes are the most promising options for SNG production from biomass. The indirect gasification technology, when fully developed, will score better with respect to technical, economic, and ecological aspects, compared to pressurised oxygen-blown CFB gasification, and therefore it has been selected for future development for SNG production. This gasification technology (with a carbon conversion of almost 100%) results in a tar-free (by using the ECN OLGA process), low-nitrogen, and high-hydrocarbon content synthesis gas. The technology has also the potential of upscaling to a commercially interesting scale. In combination with downstream methanation, SNG production efficiencies up to 70% (on LHV basis) can be achieved. It has been calculated that the SNG production costs for this process are lower than the current fictitious Dutch market price for green gas. Assuming a Dutch market share of 1.5% for SNG (approximately 22.5 PJ a year), this process has the potential to fulfil approximately 7.5% of the Dutch renewable energy target in 2020, or even 30% of the biomass-related target. The SNG production capacity of this process until 2020 is 190 PJ. The cost per tonne CO₂ avoided is €3, and the total avoided CO₂ emission until 2020 is 11 Mtonne.

While the separate main process steps of SNG production, namely biomass (hydro)gasification and methanation, are not new, the integration of these processes is. The concept is especially interesting for the transition phase to a future hydrogen economy, as the produced SNG can be transported through the existing gas infrastructure.

Although substitute natural gas has not yet been incorporated as an alternative fuel in the Dutch and European renewable energy policies, it can play an important role in realisation of their climate and renewable energy targets. To support the implementation of this studied technology, ECN is currently constructing a bench-scale gasification facility, that will be installed upstream of the already existing gas clean-up infrastructure. This installation should enable the proof of production of a synthesis gas, that satisfies the specifications for downstream methanation. An extensive R&D programme will be coupled

to the realisation of this installation, mainly in the field of analysis of the optimal gasification conditions (agglomeration behaviour, gas composition) and gas clean-up (removal of tar and other components). The extension of this installation to a fully integrated SNG production facility, as part of a market supported R&D-project, is foreseen for 2004.

Acknowledgement

Financial supports from the Netherlands agency for energy and the environment (Novem), and the Gasunie Trade & Supply, are gratefully acknowledged.

THE ROLE OF BIOMASS IN A HYDROGEN ECONOMY

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Purpose of the work

Hydrogen, generated from renewable sources, is likely to play an important role as an energy carrier in the future energy supply. Due to the global environmental damage caused by fossil fuels, the world has to switch gradually to other primary energy sources. In the long term, only biomass and other renewable resources such as water, wind, and sun will be available. Today it is not clear what the real application potential is of biomass related hydrogen production technologies. It is unclear what the technical, ecological and economic perspective is of the huge variety / diversity of technologies (thermochemical, biochemical) that are developed these days.

Approach

The objective of the project is to support the implementation of biomass related hydrogen production technologies. This is done by a:

- Market analyses of the application potential of hydrogen within the future Dutch energy infrastructure. With the emphasis on the period to 2020 and with a glance through to 2050.
- Technology analysis by means of determination of the important technical, ecological and economic figures of biomass related hydrogen production technologies, and a comparison with other alternative conventional and renewable hydrogen production technologies.
- An analysis of the industrial interest for the final implementation of biomass related hydrogen production technologies.
- The project results in a selection of two biomass related hydrogen production technologies on the basis of a market analysis, technology analysis and the industrial interest that is most attractive for the real market implementation in the period to 2020.

Scientific innovation and relevance

Determine if hydrogen, generated from renewable sources, is likely to play an important role as an energy carrier in the future energy supply.

Results and Conclusions

From the study and round-table discussion the following conclusions can be drawn for the market analysis, technology analysis and technology/market combinations of hydrogen from biomass.

Market analysis: In the long term centralised hydrogen production is the most attractive option, because of low costs of hydrogen production. For the short- and midterm decentralised H₂ production is an option as an intermediate solution.

Technology analysis: For the conversion of biomass to H₂ there are four thermochemical processes and five biochemical processes. In general thermochemical processes are large-scale, high efficiency, lab/pilot status with expensive feedstock. Biochemical processes are small-scale, low efficiency, lab/pilot status with gate-fee priced feedstock.

Market-Technology combinations: Small-scale markets such as ‘micro-CHP’ and ‘mixing of hydrogen and natural gas’ are only expected in the transition phase (2020- 2050). Large-scale markets such as the hydrogen production for the national pipeline for refuelling stations will be developed after 2050. The pipeline on city scale is feasible for the short term as well for the long term. The most promising combinations are, viz.: 1) hydrogen production by supercritical water gasification of wet (polluted) biomass for the markets ‘pipeline distribution (city)’ and ‘highway refuelling station’ and 2) hydrogen production by ‘entrained flow gasification’ of biomass for the market ‘pipeline station (national)’.

Acknowledgement

Financial support from NOVEM is gratefully acknowledged.

TECHNOLOGY DEVELOPMENT FOR MICROALGAL CO-PRODUCTION OF FINE CHEMICALS AND BIOFUELS COMBINED WITH WATER PURIFICATION

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Purpose and approach of the work

An integrated microalgal process for co-production of fine chemicals and biofuels is being developed in the Netherlands in a 3.5-year project by a consortium of R&D institutes and industry¹⁾. The aim is to use microalgae culture in effluents from agro-industrial activity for final stage N and P removal ('polishing') with supply of CO₂ from flue gas, to reach an acceptable water quality to permit recycling. The projected benefit of simultaneous water purification substantially reduces the net production costs of algal biomass.

Results

In the project, a novel type of cultivation system has been developed. It is composed of an array of 'bubble column type' photobioreactors for inoculum production of the targeted algal species, which is fed continuously into a cascade-type open cultivation system with a number of basins placed in series. This concept leads to a rapid culture build-up and employs a 'once through' hydraulic regime which is expected to reduce the build up of contaminating algae in the final biomass to a minimal level (< 1%). In principle the system thus allows the cultivation of a large range of algal species at moderate costs. Work on the bubble columns was performed both indoors and outdoors, including model development. Results show that the bubble column provides a robust production system, allowing mono-algal cultivation for periods exceeding 9 months.

Cultivation of two microalgal species was tested in an experimental integrated system outdoors consisting of 8 bubble columns placed in parallel. The experiments disclosed an imbalance between optimal CO₂ supply and prevalent light intensity changes. Especially at high irradiance conditions the needed flux of air for sufficient CO₂ supply would render an adverse effect through shear stress on cells in culture. The basins as well would benefit from addition of CO₂ to the air flow. It will allow higher operational biomass densities at restricted gas flow velocities. Modification of the open basins also requires improvement of the hydraulic mixing regime. Lab scale experiments have shown that algal cultivation with actual industrial effluents for substrate is possible and suits well the target of removal of N and P compounds from the wastewater.

Effective harvesting (and final water conditioning) is a crucial issue due to the relatively high investment costs of equipment, the need for cost-effective algal biomass concentration, *and* the requirement to meet the quality standards for industrial water re-use. A range of harvesting/water conditioning technologies were tested in co-operation with commercial suppliers either on laboratory or pilot scale. Preliminary results indicate that flocculant aided DAF, followed by centrifugation and sand filtration and/or DAF followed by UF has the best performance for both algal biomass concentration and water conditioning with respect to costs and energy use.

The harvested algal biomass is intended as a feedstock for extraction of high value fine chemicals with the residues used for production of biofuels. Processing development focused amongst others on extraction using food-grade solvents²⁾ and innovative Simulated Moving Bed (SMB) chromatography³⁾ for fractionation of complex fatty acid mixtures. For energy conversion of the residual biomass both thermal conversion by combustion or gasification and anaerobic methane digestion were tested and evaluated. Results show that both routes are feasible, although the energy potential is limited.

Acknowledgements

1) This project is supported with a grant of the Dutch Programme EET (Economy, Ecology, Technology) a joint initiative of the Ministries of Economic Affairs, Education, Culture and Sciences and of Housing,

Spatial Planning and the Environment. The programme is run by the EET Programme Office, a partnership of Senter and Novem

2) This part of the work was performed by L. Sijtsma and co-workers, Agrotechnological Research Institute ATO BV, BU Renewable Resources, Dept. Bioconversion, Wageningen, The Netherlands.

3) This part of the work was performed by M. Ottens, L. van der Wielen and co-workers, Dept. Of Biotechnology, Bioseparation Technology, TUDelft, The Netherlands.

THERMAL BIO-REFINERY; HIGH-EFFICIENT INTEGRATED PRODUCTION OF RENEWABLE CHEMICALS, (TRANSPORTATION) FUELS, AND PRODUCTS FROM BIOMASS

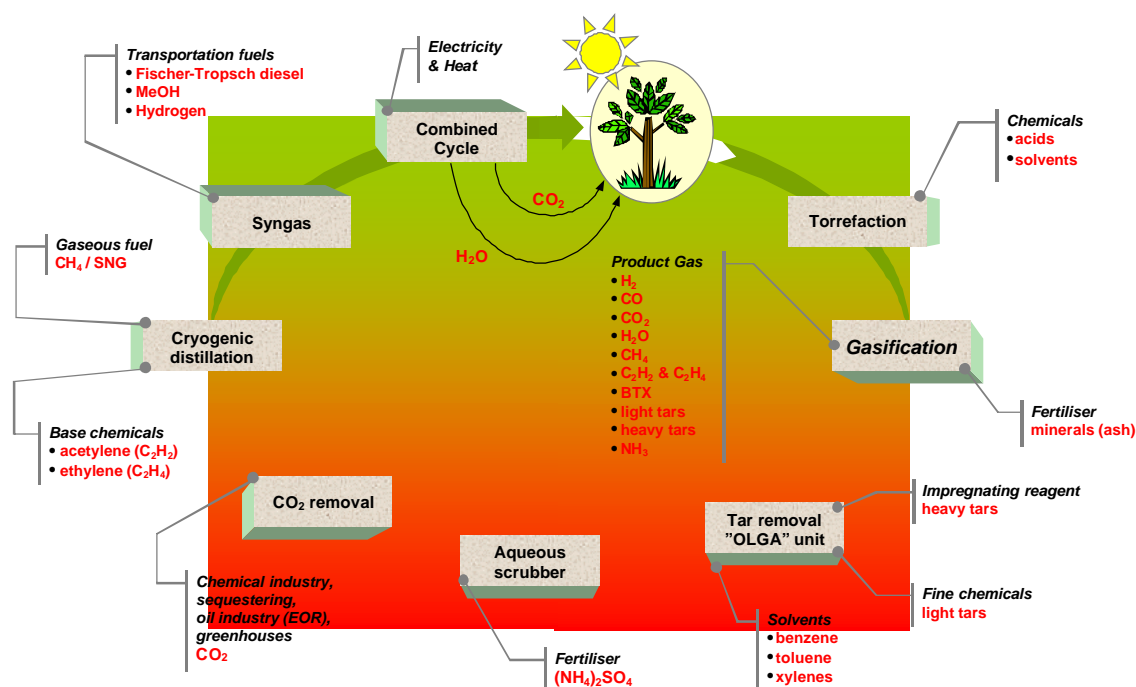
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Purpose of the work

To date, all transportation fuels and most materials, fuels, and chemicals are produced from crude oil or natural gas. At a certain moment in the future, an alternative carbon source is required due to the decreasing reserves of these fossil materials and/or to meet environmentally based policy goals. Biomass is the only renewable carbon source and will therefore be the future feedstock for the production of chemicals, (transportation) fuels, and products. Both biological and thermal conversions can be used, depending on the feedstock and the desired products.

Approach

In the thermal route, gasification of the biomass and conversion into a product gas is the key step. The gasification gas contains a mixture of CO/H₂ as main product and, in addition, raw materials for chemicals production as well as a number of valuable chemical products that can be directly separated. Due to the analogy with crude oil refining, the fractionating and recovery of products after thermal conversion of biomass is called **Thermal Refining of biomass**. The closed CO₂ cycle, when using the Thermal Bio-Refinery concept, is illustrated in the Figure below.



Scientific innovation and relevance

Currently, the utilisation of biomass is mainly directed towards the production of (green) electricity and heat. As biomass is the only renewable carbon source, the production of fuels and chemicals will become the major application in the future. The innovation is found in developing a complete concept, and optimising individual unit-operations, to maximise the production of chemicals, (transportation) fuels, and products with the proper specifications.

Results & Conclusion

At the conference the first results will be presented of the system assessment of the overall Thermal Bio-Refinery "Circle". This will include experimental results on the correlation between the gasification conditions and the formation of individual compounds in the product gas.

AMMONIA RECYCLING AND DESTRUCTION IN A CFB GASIFIER

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Purpose of the work

Biomass contains nitrogen that is converted to NO_x on combustion. Conversion of biomass into producer gas by thermal gasification offers an opportunity to reduce NO_x -emissions by NH_3 removal from the producer gas prior to combustion. Several options are available to dispose off NH_3 that is removed from producer gas. The present work considers recycling within the gasification process.

Approach

Experiments have been performed in a 500 kW_{th} CFB gasifier operated with dry wood fuel and air at atmospheric pressure. NH_3 is injected into the gasification air to simulate recycling of NH_3 removed from producer gas. Comparison of the measured increase in NH_3 concentration in producer gas with the theoretical increase from NH_3 injection yields the amount of destruction. Measurements have been performed for gasifier operating temperatures between 780°C and 860°C.

Scientific innovation and relevance

Previous work has concentrated on thermal or catalytic destruction of NH_3 in producer gas prior to combustion or NO_x removal from flue gas after combustion. If producer gas is cooled before application, NH_3 removal by wet scrubbing is a more attractive and effective option, provided the NH_3 can be disposed off in an environmentally friendly way. Recycling within the gasification process offers a simple solution, especially for small installations.

Results

Destruction of recycled NH_3 requires a temperature above 800°C and is nearly complete at 850°C. Clearly, the presence of O_2 at the injection point leads to a much higher rate of NH_3 destruction than observed for pure thermal cracking. Although measurement of the NO_x concentration in producer gas is disturbed by other components, the observed signal is low enough to conclude that hardly any NH_3 is converted to NO_x .

Conclusion

Recycling of NH_3 has negligible effect on the system efficiency or producer gas composition. However, it offers an elegant way to dispose off a waste stream at low costs and without harm to the environment. The required temperatures of 800°C to 850°C lie within the usual operating range of CFB gasifiers.

Acknowledgement

The installation and work reported have been realised with financial support from the EWAB programme of the Netherlands Organisation for Energy and the Environment (Novem) and from the Agency for Research in Sustainable Energy (SDE). Additional funds have been supplied by the Dutch Ministry of Economic Affairs to the Energy Research Centre of the Netherlands ECN as part of the "Samenwerkings" (Co-operation) programme.

BIO-SYNGAS: KEY INTERMEDIATE FOR LARGE SCALE SIMULTANEOUS PRODUCTION OF BIOFUELS, POWER AND HEAT

Production technologies, economics, ecological aspects and research issues

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Purpose of the work

To meet the European Directive concerning the substitution of fossil fuel derived transportation fuels by alternative fuels, i.e. 2% substitution by biofuels in 2005, 5.75% in 2010, and probably an even larger percentage in the period after 2010, a huge biofuel production capacity has to be realised.

At the moment, only straight vegetable oils, biodiesel and conventional bioethanol are being produced and used in some specific countries in the EU. Biodiesel is used purely or as blend to substitute conventional diesel; whereas conventional bioethanol, produced from sugar and starch crops, is used in the same way to substitute gasoline. To meet the short term European policy goal the current production capacity of these biofuels has to be increased significantly; whereas these fuels will have to be transported within the EU to a variety of countries to meet a broader use.

To meet the longer term (2010 and further) policy goals more efficient and ecologically friendly biofuels have to become available, that can be produced from both a large variety of available organic waste streams and specifically grown energy crops. Potential interesting biofuels that probably will be produced and used at that time are: cellulosic bioethanol/ETBE, biomethanol/DME/MTBE, Fischer-Tropsch diesel, CNG/LNG, and (bio)H₂.

However, the integral technology to produce these promising biofuels is lacking at the moment. Two main key technology developments that are necessary are: 1) the development of cost effective and ecologically sound pre-treatment/hydrolysis and C5-sugars fermentation technology for the large scale production of cellulosic bioethanol from widely available and relatively cheap (ligno)cellulosic biomass materials, and 2) the development of cost effective and ecologically sound biomass gasification/gas clean-up and conditioning technology, to produce a specified biomass-derived syngas for downstream (catalytic) processing to a variety of biofuels (i.e. biomethanol/DME/MTBE, Fischer-Tropsch diesel, bioethanol, CNG/LNG, and (bio)H₂).

The goal of this presentation is to inform the public about the current technological status, the economics and the ecological aspects of the different integral technological conversion chains to produce a variety of biofuels from biomass by the intermediate syngas, to select the most favourable technology for further development, and to give an indication of the necessary RD&D-traject (addressing the most important R&D-issues) necessary before large scale market implementation could be effectuated

Approach/Scientific innovation and relevance/Results/Conclusion

This paper presentation will be fully aggravated to the second necessary key technology development, viz. the production of the key intermediate bio-syngas. The following aspects will be discussed:

- Production technologies: stand-alone gasification (oxygen-blown CFB, air-blown indirect and oxygen-blown entrained-flow) and fast pyrolysis concepts, and integrated concepts of pyrolysis/gasification.
- Economics of full biomass - product chains (Euro/GJ and Euro/l biofuel).
- Ecological aspects of full biomass - product chains (main emissions and quality solid waste streams).
- Main research issues (biomass pre-treatment and feeding, biomass gasification behaviour, gas clean-up, ...).
- Necessary RD&D-traject(s) to support final market implementation.

This presentation will be given by a highly experienced assistant of the Biomass Department of the Energy research Centre of the Netherlands (ECN). The Biomass Department of ECN is an internationally admitted research group working in the areas of 1) direct/indirect cofiring of biomass in conventional fossil fuel fired power plants, 2) CHP production by decentralised biomass conversion (gasification, pyrolysis) and 3) the production of gaseous energy carriers, transportation fuels and chemicals/products from biomass. The key technology developments ECN Biomass is working on are: biomass pre-treatment and feeding, biomass gasification and syngas clean-up; whereas also related aspects as integral system assessments and conversion related ecological aspects are part of the working programme.

BIOMASS BIOCHEMICAL DATA IN PHYLLIS DATABASE

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Purpose of the work

The existing Phyllis database (www.ecn.nl/phyllis) contained mainly data relevant to thermal conversion of biomass into energy, like ash and moisture content, heating value and chemical composition. The extension of the Phyllis database with biochemical data is aimed at users interested in biomass use as base material or feedstock in biochemical processes. The present contribution explains the database structure and contents and illustrates user options.

Approach

In co-operation with a group of likely users the authors have drawn a list of compositional data relevant to biochemical processes. The database structure has been modified to accommodate the additional parameters. New options have been added to allow users to focus on either chemical or (specific) biochemical information. Data have been gathered from open literature and from analyses performed by Agrotechnology and Food Innovations B.V.. When available, both biochemical data and data on chemical composition and heating value are included in the database.

Scientific innovation and relevance

Analyses of biomass materials are usually restricted to information relevant for a specific purpose. The inclusion of a wide range of parameters in a database offers the opportunity to combine data on similar materials from different sources and consider their use in different applications. Moreover, the Phyllis database allows statistical analysis of data to assess the variance between materials and reliability of specific data.

Results

Biochemical data included in the Phyllis database, apart from the main structural components cellulose, hemicellulose and lignin, are proteins, lipids, starch and pectin, fractions soluble in hot water, alcohol or an alcohol-toluene mixture and the proportion of C5 and C6 sugars. The total number of material analyses in the Phyllis database has been increased from about 1900 to 2250.

Conclusion

Nearly 1000 visits each month to the website of the Phyllis database are proof of its value to users. The database extension with biochemical data broadens the scope of applications. The present work is part of a continuous effort to increase the amount of data, to improve the reliability and enhance the user friendliness of the Phyllis database.

Acknowledgement

The work reported has been realised with financial support from the DEN programme of the Netherlands Organisation for Energy and the Environment (Novem). Additional funds have been supplied by the Dutch Ministry of Economic Affairs to the Energy Research Centre of the Netherlands ECN as part of the "Samenwerkings" (Co-operation) programme and by Agrotechnology and Food Innovations B.V. (till October 2003 ATO B.V.). The Phyllis database is also sponsored by Shell Global Solutions, Eneco energie and HoSt.

COST-EFFECTIVE SCREENING OF BIOMASS MATERIALS FOR CO-FIRING

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Purpose of the work

To provide staff of coal-fired power plants with cost-effective methods for assessing biomass materials as a secondary fuel.

Approach

The approach is to deliver evaluation tools which actually test a fuel *before* going to the level of pilot or full-scale testing. Although key fuel parameters are quite well-understood for coal, this is much less the case for biomass. Especially the relation between fuel parameters and combustion behaviour is relatively unexplored and, moreover, the large variability among biomass properties currently prohibits a general approach.

Therefore, lab-scale test methods are developed to screen specific aspects of potential biomass fuels in a cost-effective way. The Lab-scale Combustion Simulator (LCS) is designed to reproduce the temperatures and residence times found in large utility boilers. Sampling and analytical procedures are developed to assess the impact of biomass co-firing on industrial issues such as carbon burnout (LOI), NO_x formation, fouling and slagging, fly ash quality, trace element behaviour and the performance of air pollution control devices.

In time, key fuel parameters and combustion correlations will be identified for use with predictive models.

Scientific innovation and relevance

Reproduction on a lab-scale of the industrial combustion behaviour of solid fuels, in terms of heating rate, temperatures, flue gas composition and residence time. Relevant testing of specific full-scale behaviour can be executed at low cost on a lab-scale.

Results

Methods have been developed for fuel characterisation as well as fuel combustion testing. Possibilities to characterise the particle size and shape distribution of particles from a single fuel have been extended to coal/biomass blends. Procedures based on the ash tracer technique have been developed to test the reactivity of a fuel or fuel blend from very short residence times up to complete burnout. These data can be used for a direct assessment of e.g. carbon burnout levels, but can also be transformed into kinetic data for use with combustion models.

With the LCS, small fly ash samples have been produced and subjected to a procedure to test their compliance with application criteria for concrete production. Requirements such as LOI, chloride/sulphate/CaO/SiO₂ content and particle fineness and morphology can be adequately tested using lab-scale fly ash. Properties of the (sub)micron-sized fly ash fraction can be used to evaluate potential dust emissions.

Ash deposition testing has been carried out using dedicated probes and SEM-EDX for deposit analysis. The procedure is especially useful to evaluate the influence of a biomass on deposit formation and properties such as thermal insulation, strength or corrosion potential.

Conclusion

Using the LCS in combination with dedicated sampling and analytical procedures, provides a versatile and cost-effective way to screen biomass materials as potential secondary fuels in coal-fired power stations.

HIGH EFFICIENCY ELECTRICITY AND PRODUCTS FROM BIOMASS AND WASTE; PROOF OF PRINCIPLE OF INTEGRATED STAGED GASIFICATION AND FUEL CELLS

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Purpose of the work, Scientific innovation and relevance

The use of biomass and waste for energy production contributes substantially in reduction of CO₂ emissions. System studies showed that gasification in combination with Solid Oxide Fuel Cell (SOFC) can achieve an overall efficiency of 50%. This is substantially higher than by means of modern IGCC application. In the framework of the NOVEM program “Energie Winning uit Afval en Biomassa (EWAB)”, a project was executed to test and proof the principle of connecting gasification and SOFC and measure its electrical output efficiency. The project is titled: “High efficiency production of electricity from biomass and waste: Proof of Principle” and was carried out by ECN Biomass and ECN Fuel Cell Technology.

Approach

ECN-Biomass is equipped with small (1-5 kg/h) gasifiers, in which several types of biomass and wastes were converted (in recent years) into fuel gas. ECN Fuel Cell Technology on the other hand is experienced in operating fuel cell (SOFC) stacks. Therefore a unique opportunity surfaced to connect these systems in a joint effort to test the viability of this integral principle. The integrated tests were performed with willow and Rofire as feedstock (pelletised paper recycling rejects).

Results and Conclusion

The outcome of this project showed that the principle works and the achieved overall efficiency is 40% LHV with an SOFC efficiency of 41% LHV. Some side effects were observed (e.g. soot formation) which influenced the outcome negatively. It is foreseen that optimisation of operating conditions will reduce these effects to a minimum.

The slight degradation of the SOFC stack during integral operation appeared to be not irreversible. The longest test run was approximately 48 hours (willow).

Higher efficiencies are expected in the near future based on ongoing SOFC development and system simplification.

Acknowledgement

The project was carried out in cooperation with Gipec with financial support of NOVEM. Both are greatly acknowledged for their support.

TORREFACTION FOR ENTRAINED FLOW GASIFICATION OF BIOMASS

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Purpose of the work

A major technical obstacle in entrained-flow gasification of biomass concerns size reduction and the subsequent pneumatic transport of the biomass powder. The fibrous structure of fresh biomass makes it very difficult and costly to reduce its particle size down to below 500 microns. Torrefaction partially destructs the fibrous structure of biomass and is therefore an interesting pretreatment option for this application. However, the influence of the torrefaction process conditions and used biomass on the grindability and pneumatic transport properties of biomass is nowhere quantified, as well as the responsible decomposition mechanisms and its kinetics. This work quantifies these relations with the aim to produce design data for entrained-flow gasification based bioenergy conversion chains.

Approach

An experimental torrefaction programme has been conducted in multiple reactors on both laboratory and bench scale, varying from 5 cc to 20 l batch wise capacity. In these facilities, intensive parametric testing has been carried out to provide insight in the thermochemical decomposition mechanisms during torrefaction. Subsequently, the produced torrefied biomass has been used to effectuate size reduction and fluidisation experiments to investigate its grindability and fluidisation behaviour. The size reduction experiments have been carried with a chipper mill, while a cold-flow bubbling fluidised bed has been applied to characterise fluidisation behaviour.

Scientific innovation and relevance

The application of torrefaction in biomass energy conversion chains is a development of the past few years. Although the possible advantages of torrefaction are qualitatively understood, most of these advantages have not been quantified and related to the decomposition mechanisms that occur during torrefaction.

Results

This work reveals the influence of the torrefaction temperature and residence time, feed particle size, and type of biomass on the main characteristics of product quality, size reduction (power consumption and capacity of a grinding device), and fluidisation (Geldart classification as a function of particle properties and gas phase velocity). Furthermore, possible mechanisms responsible for the observed changes in grindability and fluidisation behaviour are proposed.

Conclusion

Torrefaction leads to a very substantial improvement of the grindability behaviour. It therefore provides a solution to the problems concerned with entrained flow gasification related to size reduction of biomass and the subsequent pneumatic transport of the powder.

Acknowledgement

This work is sponsored by the Dutch Agency for Research in Sustainable Energy (SDE).

TAR FORMATION IN FLUIDISED-BED GASIFICATION - IMPACT OF GASIFIER OPERATING CONDITIONS

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Purpose of the work

In fluidised-bed biomass gasification, the presence of heavy tars in gasifier syngas may cause fouling and soot formation in downstream processes, and tars with high water solubility may cause wastewater problems. In general, the design and performance of downstream equipment such as syngas coolers and gas cleaning devices are largely dependent on the amount and composition of the tars produced in the gasifier. This tar production in itself is largely dependent on fuel properties and gasification conditions. In many previous studies, the focus has been mainly on total tar production. However, earlier work at ECN has revealed already that often (changes in) the tar composition is the dominant factor, when looking at the impact on downstream equipment. The objective of the present work is to assist designers and operators of fluidised-bed biomass gasification based systems by providing detailed data concerning the impact of gasification temperature and gas residence time on tar composition and concentrations of specific tar compounds for commercially relevant conditions.

Approach

Experiments were conducted in a small-scale bubbling-fluidised-bed gasifier using woody biomass fuels. The experiments were carried out at different gasification temperatures and gas residence times, while the air to fuel ratio was adapted to the gasification temperature to mimic the conditions in a 50 MWth gasifier. Tars were measured according to the Tar Guideline, which is currently being incorporated in a European Standard on tar measurement (EU-project ENK5-CT2002-80648, CEN Task Force 143). This sampling and analysis method allows for the determination of GC-detectable as well as gravimetric (GC-non-detectable) tars. By extending the analysis procedure with HPLC analysis, the gravimetric tars were subsequently characterised in more detail. This allows for a complete tar mass balance. Finally, the resulting tar composition and concentration data were interpreted in terms of overall tar dewpoint (using ECN's dedicated calculation programme), aerosol formation and water solubility to enable a translation into practical consequences.

Scientific innovation and relevance

The present work is unique in that it provides a thorough and full analysis of the tar content of fluidised-bed gasification syngas for commercially relevant conditions, and that it is discussed how to translate these data into practical consequences. Recent experience with various demonstration projects, where syngas cooling and gas cleaning are applied (e.g., the Amer 80 MWth wood gasifier), has confirmed that this type of information is extremely important for a proper design and operation of fluidised-bed biomass gasification based systems. It allows developers to optimise the overall gasification/cooling/gas cleaning system, and operators to better predict the impact of changes in gasification conditions on the performance of downstream equipment.

Results

The experiments reveal a decrease in total tar concentration by a factor of five with an increase in gasification temperature from 750°C to 950°C. Simultaneously, the tar composition shifts from alkyl-substituted Poly-Aromatic Hydrocarbons (PAHs) and oxygen and nitrogen containing tars to non-substituted PAHs. Above 800°C, the tars grow in molecular size leading to an increasing dewpoint with increasing temperature, despite the decrease in total tar concentration. An increase in gas residence time in the freeboard causes similar effects than an increase in gasification temperature, but less pronounced.

Conclusion

Changes in gasifier operating conditions, especially gasification temperature, appear to have a large effect on total tar concentration and composition. In terms of practical consequences, the changes in tar composition seem most important. Increasing the gasification temperature appears not a general remedy

against all tar-related problems. It may indeed lead to a strong decrease in heterocyclic tars like phenol, which may reduce wastewater problems drastically. On the other hand, it may lead to a considerable increase in tar dewpoint aggravating tar condensation and aerosol formation, despite considerably lower total tar concentrations.

Acknowledgement

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TAR REMOVAL WITH A WET ESP PARAMETRIC STUDY

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Purpose of the work

Several secondary methods are developed for the removal of tar from biomass product gases. A widely applicable method is the condensation of tar in a quench, and the capture of tar droplets (aerosols) with a wet Electrostatic Precipitator (ESP) downstream the quench. The saturated gas can subsequently be used as a fuel gas for a gas engine to generate electricity.

This gas cleaning method has successfully been applied downstream an updraft gasifier in Harboøre and a downdraft gasifier in Wiener Neustadt. ECN has tested this configuration downstream a 500 kW_{th} circulating fluidised bed gasifier. For a reliable operation and minimisation of the costs the operational area of the wet ESP must be known. The objective of this work is to determine the operational area of the wet ESP downstream a CFB gasifier in order to optimise costs without loss of reliability.

Approach

The basic principle of an ESP is simple: the gas is ionised in passing between a high voltage electrode (HV electrode) and a grounded (earthed) electrode. The dust particles and tar droplets become charged and are attracted to the grounded electrode. Water in the gas must ensure the continuous cleaning of the collector plates. The precipitated dust and droplets flow down by gravity forces together with water and this mixture is withdrawn in the bottom. The tar water mixture can be recycled to the gasifier.

Important parameters for the operational and collection efficiency of a wet ESP are the gas residence time, the voltage on the electrodes, the electrode configuration, and the water content in the gas. The gas residence time has an influence on the size and therewith the investment costs of the ESP. The voltage (and the current) mainly determines the energy consumption.

In order to optimise investment costs and energy consumption the gas residence time and the voltage on the HV-electrodes should be minimised. The specifications are that the specified collection efficiency is reached and the reliability of the ESP is ensured. In an ongoing project the influence of the gas residence time and voltage on the HV electrodes on the collection efficiency of both fine particles and tar aerosols is determined.

Scientific innovation and relevance

Two commercial biomass gasification plants in Europe are currently running a wet ESP for the removal of tar from Biomass producer gas. Both plants are running a fixed bed gasifier. A wet ESP downstream a fluidised bed gasifier is only running at ECN on pilot scale. Design parameters like optimal residence time and applied high voltage for an ESP downstream a CFB biomass gasifier is still unknown and will be published here.

Results

On the biomass conference in Rome detailed collection efficiency results of the test programme will be presented. The presentation will include economic data for the investment and energy costs of the wet ESP unit downstream a 10 MW_{th} gasifier.

Conclusion

A wet ESP is a reliable tar removal method that removes tar from different sources, which is demonstrated by the application downstream an updraft gasifier (mainly pyrolysis tars), a downdraft gasifier, and a fluidised bed gasifier. In all cases the gas is suitable for the application in a gas engine.

Acknowledgement

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TAR MEASUREMENT STANDARD

A joint effort for the standardisation of a method for measurement of tars and particulates in biomass producer gases

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Purpose of the work

So far no well-developed and standardised measurement method exists for tars in biomass producer gases, and different sampling and analysis methods are currently being used. In a previous EU-project (ERK6-CT1999-20002), a guideline for tar measurement (“the Guideline”) was developed in order to remove this obstacle. The Guideline aims at determination of both gravimetric tars as well as individual organic compounds. The measurement principle is based on the discontinuous sampling of a gas stream containing particles and condensable organic compounds. The overall objective of the present work is to expand the use of the Guideline and transfer it into a European (CEN) standard method.

Approach

Standardisation of the Guideline method is currently performed in a Task Force (BT/TF/143) installed directly under the CEN (European Committee for Standardisation). The Task Force comprises a core group of technical experts performing R&D activities, thus bringing in their expertise on tar measurement and use of the Guideline to define the specifications the Standard has to fulfil.

Extensive technical progress for the development of the Guideline was achieved in the previous EU-project. However, data on accuracy and reproducibility of the Guideline are still needed and essential in the process of Standardisation. For this purpose, a set of activities to optimise and validate the Guideline will be performed in a follow-up EU-project (ENK5-CT2002-80648), including, e.g. : 1) Round Robin Tests on GC and gravimetric tar analysis; 2) Parallel measurement campaigns for different types of gasifiers, where several institutions will apply the Guideline simultaneously; 3) Testing of the method at very low tar concentrations (1-100 mg/m³).

Scientific innovation and relevance

The current activities represent the ultimate step before that the Guideline method achieves the level of a standard. A standard on tar measurement will allow manufacturers of gasifiers, gas cleaning systems, and engine or turbine/generator sets to convince potential end-users on the technical performance of the sub-systems, and to define tolerances from which guarantees can be derived, thus decreasing the non-technical risks of the implementation of biomass gasification-based systems. In addition, the standard allows companies, institutions and universities that develop gasification technology to have a common method to measure the tar concentrations.

Results and conclusions

The main result of this project will be a CEN Standard for a method for the sampling, post-sampling and analysis of tar and particles in biomass producer gases. The official activities on the CEN standardisation have started in December 2002 and the achievement of the CEN Standard is scheduled for July 2005. The

current progress on the project and in particular on the experimental activities and gathering of the data on accuracy and reproducibility of the tar measurement will be reported in the present paper.

Acknowledgement

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SCENARIOS AND STRATEGIES FOR THE INCREASED USE OF BIOFUELS MODELLING THE EUROPEAN BIOFUEL MARKET

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Purpose of the work

Achieving a clear view on data and future perspectives of biofuels for transportation is the key drive of the EC-funded VIEWLS project. The VIEWLS project is co-ordinated by the Dutch Agency for Energy and the Environment (Novem). ECN and the Department of Science, Technology and Society of the University of Utrecht (UU-STS) are the technical co-ordinators of the project. In total, 19 organisations from Western and Eastern Europe, and North America are involved in the project.

One of the main objectives of the project is to develop a model for a quantitative analysis of scenarios and strategies for the large-scale application of biofuels in Europe. The main questions to be answered are:

- What are the costs of realising national and international targets for biofuels?
- Will there be international trade and if so, what trade flows will develop and what are the economic benefits for individual EU Member States?
- What will become the market price of different types of biofuel in the coming years / decades?
- Which combinations of energy crops and conversion technologies are likely to penetrate in the coming years?
- What will be the impact of different policy schemes?

Approach

Given the costs and potentials of biomass resources (including organic waste fractions and residues) in individual EU Member States (MS's) and Central and East European Countries (CEEC's), data on the possible conversion routes containing different process steps, data on the national and international transportation and handling of the different products involved and data on incentives, the BIOTRANS model generates a least cost scenario for realising a specified demand in the individual MS's and CEEC's. The model will be formulated as a multi commodity network flow model (linear programming approach). This will be done for on a year-to-year base up to 2050.

Scientific innovation and relevance

Large differences in the potential for the introduction of biofuels in the different MS's in terms of experience, available agricultural resources and production costs most probably will lead to different "burdens" for the individual MS's in achieving the indicative targets set in the EU Directive on the use of biofuels and other renewable fuels for transport (2003/30/EC). The same target for all MS's (as mentioned in the EU-directive) would lead to large differences in macro-economic impacts for the different MS's and large trade flows between these MS's. Apart from a negative environmental impact these would lead also to additional costs due to the transportation of biofuels. Although some research has been conducted on these issues, no integral quantitative analysis has been conducted so far. This analysis is a prerequisite for developing proper policies and implementation strategies on MS and EU level.

Results

The project will result in different scenarios for an increased use of biofuels as a transportation fuel in Europe. The scenarios will be analysed with the BIOTRANS-model and provide valuable information on the future price-level of biofuels, the costs for individual MS's and the EU as a whole, the allocation of biomass production, conversion routes, trade flows, and the impact of different strategies and policies.

Conclusion

The project will provide a framework for such an analysis and provide new knowledge and information on the large-scale implementation of biofuels, and thereby contribute towards the optimal implementation process in terms of efficiency and cost-effectiveness.

Explanatory Pages

DESCRIPTION OF THE BIOTRANS-MODEL

The first figure gives a general impression of the different modules that will be developed, the second figure provides more information on the way (inter)national transportation is dealt with. The central idea is that the BIOTRANS-model is 'choosing' the least-cost alternative, given a certain policy-context and demand. The model determines the economically most favourable combinations of resources and conversion technologies, taking into account costs for production and transportation. This will be done for the year 2000 (base year), up to 2050, but with a main focus on the period up to 2020. A change of the policy-context over the years as well as a change in production costs (e.g. a change in production costs for biomass crops or a reduction in technology investment costs as a result of technological learning or economies of scale) can be included. Thus the model also provides insight in the impact of future changes on the most favourable technological routes, future trade flows between countries, economic costs and benefits for individual countries, the average equilibrium price for biofuels on the European market, the impact of different policies / incentives, etc.

The modelling will be done on country-level for the different production chains. The countries included in the BIOTRANS model are all EU Member States and the CEECs, but also scenarios with large-scale imported streams from outside this group of countries can be analysed.

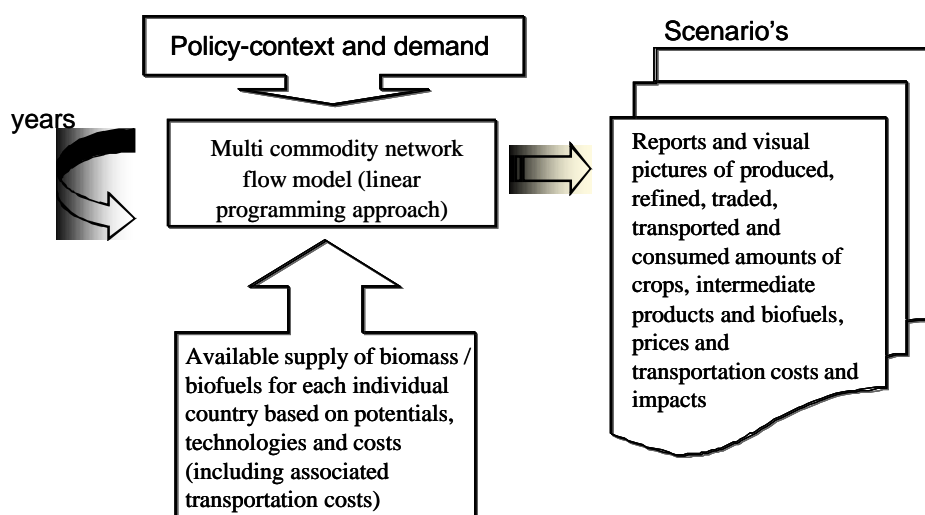


Figure 1.1 Schematic overview of the different modules of the BIOTRANS model

The different possible conversion routes for the production of different types of biofuels play a central role in the model. These conversion routes are defined by interlinked sub-processes, which are defined by input and output. Between two sub-processes, transportation of intermediate products may take place, possibly also including storage (this is indicated by arrows between sub-processes).

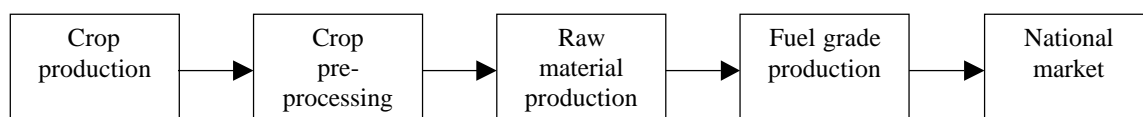


Figure 1.2 General outline of conversion route definition for the BIOTRANS model

A number of guiding principles are important to mention. Crop production denotes the production of biomass and biomass residues from agriculture, forestry and industry. The pre-processing of the crop may consist of several pre-treatment steps. After pre-processing of the biomass, it is converted into a raw material (for example bio-crude or raw ethanol), which serves as an input for the production of fuel grade biofuels. Both raw material production and fuel grade production may consist of several conversion processes. Finally, the produced biofuels are transported to the national market, where distribution to end-consumers takes place (in either pure form or blends with conventional automotive fuels). National transportation of input products and output products (including intermediate products) are treated separately in the BIOTRANS-model in case it is expected that the subprocesses are not on the same geographical location. From the national market, biofuels may also be exported to another country. This also applies to biomass crops and intermediate products, as they may also be traded internationally. Therefore, the possibility of international transportation of input products, output products and intermediate products is also included in the BIOTRANS model.