

## Final report of the OTC project

# “BIOSYNGAS; Multifunctional intermediary for the production of renewable electricity, gaseous energy carriers, transportation fuels, and chemicals from biomass”

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## PREFACE

The work described in this report was carried out within the framework of the project “*BIOSYNGAS: Multifunctional intermediary for the production of renewable power, gaseous energy carriers, transportation fuels, and chemicals from biomass*” and was co-financed by the SenterNovem (formerly: the Netherlands Agency for Energy and the Environment) within the framework of the OTC programme (“Ondersteuning Transitie-Coalities”, *i.e.* Supporting formation of Coalitions for Biomass Transition) under project number 5005-03-20-01-001 and order number 4800002894. Partners in the project were the unit ECN Biomass of the Energy research Centre of the Netherlands (ECN), the Agency for Research in Sustainable Energy (SDE), and TechnoInvent. Applicable ECN project number was 7.5268. The results of the ECN task in this project are reported in more detail in ECN report C--04-112.

## KEYWORDS

Biomass, biosyngas, gasification, entrained flow, large-scale, biomass import, R&D trajectory, implementation, pretreatment, feeding, biomass-to-biosyngas efficiency, ash and slag behaviour, gas cleaning.

## ABSTRACT

Renewable syngas from biomass, or “biosyngas” will be an important intermediate in the future energy infrastructure. A large total installed biosyngas production capacity with large individual plants is required. Distributed biosyngas production appears to have only limited relevance for renewable energy policies. A “Biosyngas Vision” was defined that describes the necessary R&D to come from the present situation to a sustainable society with an important role for biosyngas. Starting point is the existing coal-based gasification technology and the overall objective is to develop the technology for dedicated biomass-fired entrained flow gasification systems for reliable, high-efficient, and cost-effective production of biosyngas from multiple biomass streams. For large-scale biosyngas production, an international consortium was formed to carry out a major part of the R&D in the Sixth Framework project “POWERGAS”, while in addition national Dutch proposals will be submitted. A pilot plant for entrained flow gasification-based biosyngas production is an important element in the R&D trajectory. However, short-term realisation of a demonstration pilot plant in the Netherlands is not expected, as there already is an operational pilot plant available for research in Freiberg (Germany). Therefore, available funds are more effectively utilised by participation in international developments and not by duplication of existing technologies.

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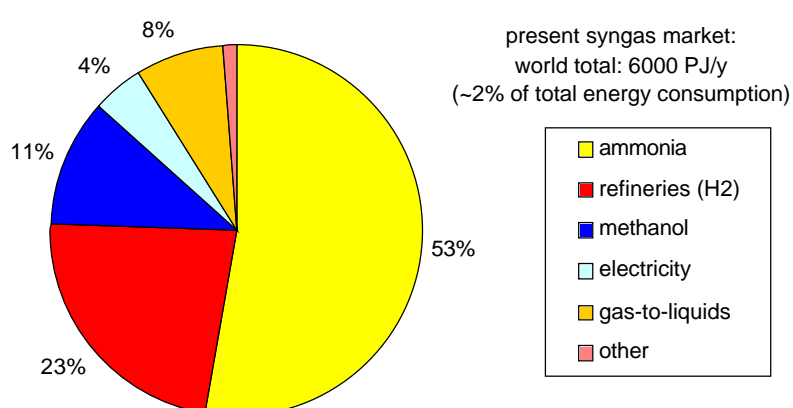
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# 1. INTRODUCTION

## 1.1. Background

To date, syngas is an important intermediate product in chemical industry. Annually, a total of about 6000 PJ of syngas is produced worldwide, corresponding to almost 2% of the present total worldwide energy consumption. The world market for syngas (mainly from fossil energy sources like coal, natural gas and oil/residues) is dominated by the ammonia industry (53%). Other main applications are found for the production of hydrogen for use in refineries, *e.g.* hydrogenation steps (23%), and for the production of methanol (11%). Figure 1.1 shows the present syngas market distribution [1].



**Figure 1.1.** Present world syngas market.

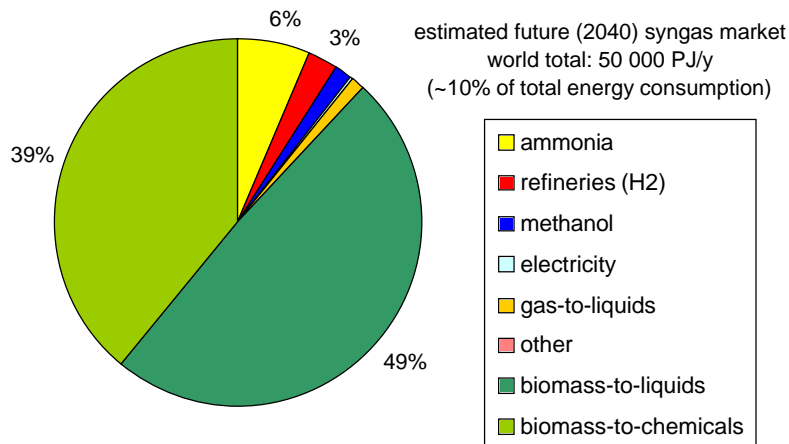
Today's, global use of syngas for the production of transportation fuels in the so-called "gas-to-liquids" processes (GTL) correspond to approx. 500 PJ per year, *i.e.* from the Fischer-Tropsch processes of Sasol in South Africa and of Shell in Bintulu, Malaysia. In the future, syngas will become increasingly important for the production of cleaner fuels to comply with the stringent emission standards, *e.g.* methanol/DME, ethanol, and/or Fischer-Tropsch diesel. The huge potential market for syngas is illustrated by the fact that approximately 30% of the world primary energy consumption is for the transportation fuels and chemicals [2].

Biomass is heading for a great future as renewable energy source. It not only is available in large quantities, it also is the only renewable energy source that is suitable for the sustainable production of (generally carbon containing) transportation fuels and chemicals. Therefore, the application of biomass as feedstock for the production of fuels and chemicals (and electricity) allows the reduction of fossil fuel consumption and the accompanying CO<sub>2</sub>-emissions [3,4,5].

In the Bio-fuel Directive of the European Commission a target of 5.75% is defined for substitution of fossil fuels by bio-fuels in 2010, while a targeted share of 15% bio-fuels is expected for 2020. In the Netherlands, the Ministry of Economic Affairs has developed a long-term biomass transition vision for 2040. Based on this Dutch concept vision, participating actors have projected a 20-45% substitution of fossil energy used in industry by biomass. Renewable syngas or "biosyngas", which is produced via gasification of biomass, is the key-intermediate in

the production of renewable fuels and chemicals. The fuels for the future will be ultra-clean designer fuels from GTL processes; transportation fuels directly produced from biomass (*e.g.* biodiesel, pyrolysis oils) will have only very limited application [6].

When an average of 30% substitution of fossil fuels by biosyngas is assumed, translated to the world energy consumption, the total annual syngas market will be increased to approx. 50,000 PJ in 2040. The world (bio) syngas market will then look as shown in Figure 1.2 (assuming no changes for the other applications). The major share of the syngas will be used for production of fuels (biomass-to-liquids; BTL) and another major part for the production of renewable chemicals (biomass-to-chemicals) [1].



**Figure 1.2.** Predicted world syngas market in 2040 (speculative).

The future biosyngas demand exceeds the present syngas consumption by a factor of eight. Therefore, it is clear that large biosyngas production capacities are needed to meet the European and national renewable energy and CO<sub>2</sub>-emission reduction targets. Not only are large installed capacities necessary, also the individual plants have to be large considering the typical plant scales for the two main applications, *i.e.*:

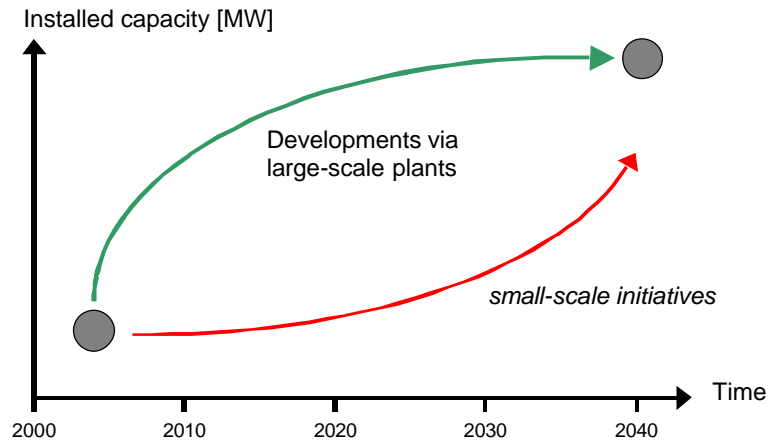
- Transportation fuels in BTL plants: several 1000 MW;
- Chemical sector: 50-200 MW.

## 1.2. Objective

A large total installed biosyngas production capacity with large individual plants is required to meet the ambitious renewable energy targets. This requires a robust, fuel-flexible, and high-efficient technology for optimum biomass utilisation and to guarantee availability. In developing a bio-fuelled power production, two possible routes can be followed, see Figure 1.3.

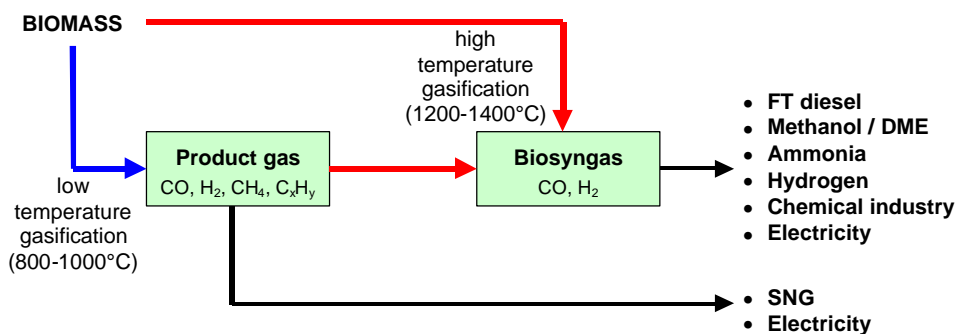
The first route comprises up-scaling of the small and medium scale gasification technologies that are currently mostly used for distributed heat and power (CHP) production. In this route it will take a long time before a significant biosyngas production capacity is installed. Either, a large number of plants have to be put in operation or the technology has to up-scaled, which will take an additional development period of a decade. Therefore, it is questionable if the ambitious renewable energy targets can be met by following this route.

The second and preferred route comprises adapting today's large-scale coal-based gasification technology. In this way the accumulated installed biosyngas capacity can be increased rapidly, as the basic technology is already proven on large scale.



**Figure 1.3.** Roadmap to reach for large-scale implementation of biosyngas, with two possible routes indicated.

High biomass-to-syngas yields are required to cost effectively produce biosyngas. This implies that upon gasification of biomass the maximum share of energy contained in the biomass should be converted into the syngas components  $H_2$  and  $CO$ , *i.e.* upon biomass gasification a *biosyngas* instead of a *product gas* must be produced (Figure 1.4) [7]. In *product gas* from low temperature gasification the syngas components  $H_2$  and  $CO$  typically contain only ~50% of the energy in the gas, while the remainder is contained in  $CH_4$  and higher (aromatic) hydrocarbons. Upon high temperature gasification ( $>1200^\circ C$ ) all the biomass is completely converted into *biosyngas*. Biosyngas is chemically similar to syngas derived from fossil sources and can replace its fossil equivalent in all applications.



**Figure 1.4.** Two biomass-derived gases via gasification at different temperature levels: 'biosyngas' and 'product gas' and their typical applications.

### 1.3. Issue definition

To date, no mature technology exists for large-scale biosyngas production via biomass gasification and to develop the appropriate technology, a research and development trajectory is

necessary. A strong consortium that is also capable of market implementation should carry out the development.

#### 1.4. Objectives

Objective of the project was to define the necessary research and development (R&D) trajectory to reach implementation of large-scale production of renewable syngas (*i.e.* biosyngas) from biomass and to form a (international) consortium to carry out the activities.

#### 1.5. This report

In Chapter 2 the project management aspects and the project approach are discussed. Chapter 3 the “Biosyngas Vision” and the R&D trajectory aimed at large-scale implementation are summarised. The full discussion is published separately in ECN report C--04-112. In Chapter 4 the case of distributed small-scale biosyngas production is addressed. Conclusions are presented in Chapter 5.

The projected results of the project are:

- Description of the necessary R&D trajectory;
- Formation of a strong (international) consortium;
- Final report describing the activities and results (*i.e.* underlying report).



## 2. PROJECT MANAGEMENT REPORT

### 2.1. General

The work described in this report was carried out within the framework of the OTC programme.<sup>1</sup> Objective of the project was to define the necessary research and development trajectory to reach implementation of large-scale production of renewable syngas (*i.e.* biosyngas) from biomass and to form a (international) consortium to carry out the defined activities. In addition, the options for distributed syngas production are addressed.

### 2.2. Project plan

The following activities were foreseen in the project:

Number	Activity
1.	Installation of (industrial) reference panel
2.	Large-scale biosyngas production
2.1	<i>Definition of necessary R&amp;D trajectory</i>
2.2	<i>Formation of coalition</i>
3.	Distributed biosyngas production
3.1	<i>Definition of technological and economical perspectives</i>
3.2	<i>Participation in demonstration projects aimed at short-term implementation</i>
4.	International developments
4.1	<i>Description of international technologic “State-of-the-Art” on biosyngas production technologies</i>
4.2	<i>Commitment of international key-players in new consortia for both large-scale and distributed biosyngas production</i>
5.	Chain analysis: techno-economic and environmental aspects
5.1	<i>Analysis of integrated biomass to biosyngas to end product chains</i>
5.2	<i>Extension of existing coalition(s)</i>
6.	Analysis of critical success factors
7.	Reporting

### 2.3. Project approach

#### 2.3.1. Installation of (industrial) reference panel

In the Transition activities already several panels and work groups were formed for the different Transition pathways and also many meetings were organised. The project team, therefore, has chosen not to establish a project specific project team, but to present the project results in meetings of the Syngas workgroups of both the Transition paths “New Gas” and

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1. OTC programme: Dutch abbreviation for “Ondersteuning Transitie-Coalities”, *i.e.* Supporting the formation of Coalitions for Biomass Transition.

“Modernisation of Energy Chains”. The results were also presented on an international biofuel conference. The meetings were:

1. **Workshop “Biosyngas”**, 19 December 2003, Amsterdam, ECN offices. Participating actors: Shell Global Solutions, TU Delft, Gasunie, SDE, SenterNovem, Ministry of Economic Affairs, and Port of Rotterdam. Slides of the meeting are available on request as ECN report CX--04-013.
2. **Transition Workshop “Renewable Synthesis gas”**, 10 February 2004, Utrecht, SenterNovem offices. Slides of the meeting are available as ECN report RX--04-014.
3. **Workshop “Action Plan Renewable Syngas”**, 16 March 2004, Amsterdam, ECN offices.
4. **MEK Workgroup “Renewable Syngas”**, 6 October 2004, Utrecht, SenterNovem offices. Participating actors from industry, SenterNovem, government, and R&D institutes
5. **Congress on Synthetic Biofuels - Technologies, Potentials, Prospects**, 3-4 November 2004, Wolfsburg, Germany, Volkswagen offices. Participating actors from (mainly German) automotive industry, agricultural organizations, national and regional government, industry, academics, and R&D institutes. Slides of the meeting are available as ECN report RX--04-119.

### 2.3.2. Large-scale biosyngas production

The approach followed was that first a “Biosyngas Vision” was determined. From the Vision follows what developments and R&D are necessary to come from the present situation to a sustainable society with an important role for biosyngas. The Biosyngas Vision and R&D trajectory are summarised in Chapter 3 and the full discussion is published separately in ECN report C--04-112 (*i.e.* reference 8).

An international consortium is formed that will carry out a major part of the R&D development within the framework of a Sixth Framework (FP6) Strategic Targeted Research Project “POWERGAS”. Partners in the consortium are:

No.	Partner	Country
1	Energy research Centre of the Netherlands (ECN)	NL
2	Forschungszentrum Karlsruhe (FZK)	DE
3	Thomas Koch Energi AS (TKE)	DK
4	Future Energy (FE)	DE
5	Elcogas	ES
6	Nuon Power	NL
7	Biomass Technology Group (BTG)	NL
8	University Duisburg-Essen (UDE)	DE
9	Siemens AG Power Generation	DE
10	Uhde GmbH	DE
11	Institute of Power Engineering (IEn)	PL
12	National Technical University of Athens (NTUA)	GR

Parallel a proposal will be submitted in the January 2005 EOS call that will address topics that are not included in POWERGAS. The Dutch partners from POWERGAS form the heart of the EOS consortium, but additional partners are welcome.

### 2.3.3. Distributed (small-scale) biosyngas production

Conclusion of the project is that the focus must be on large-scale biosyngas production as this is required reach a significant share of biosyngas in the renewable energy infrastructure and to meet the targets for renewable electricity, fuels, and chemicals. However, for some situations (locations with specific biomass availability and biosyngas demands) there can be a preference for smaller production plants. In Chapter 4 a description is given of a gasification process that could be used for these small-scale distributed applications, up to approx. 50 MW<sub>th</sub>. Therefore, these applications may be attractive for niche markets where cheap biomass is locally available. Only when these processes are available as standard units “of the shelf basis”, the “economy of multiplication” may enable them to compete economically with centralized facilities. Beforehand, the current state of the technology must mature and optimised. Facilities to enable this are currently organized by a consortium of the Port of Rotterdam, ECN, Microchemie, and TechnoInvent. Once these facilities are available relevant consortia will be developed.

At this stage, distributed biosyngas production appears to have limited relevance for renewable energy policies, and no attempts were made to form a consortium.

### 2.3.4. International developments

The description of international technological “State-of-the-Art” on biosyngas production is incorporated in Chapter 3. Commitment of international key-players for Biosyngas developments with strong Dutch involvement has been established by the formation of a consortium for the POWERGAS project.

### 2.3.5. Chain analysis: techno-economic and environmental aspects

Basis of the techno-economic and environmental chain analysis is the study on “*Preliminary techno-economic analysis of large-scale synthesis gas manufacturing from imported biomass feedstock*” that was carried out in 2002 by ECN, Shell, and BTG, with contributions from Utrecht University and Ecofys. The results are published in: *Pyrolysis and Gasification of Biomass and Waste*, Bridgewater, A.V. (ed.), CPL press, Newbury, United Kingdom, 2003, pp. 403-417 (*i.e.* reference 9).

The conclusions of that study are still valid as during the conduct of the project, by participation in national and international workshops and conferences, and in contact with (international) actors no new insights were generated with respect to critical issues.

### 2.3.6. Analysis of critical success factors

The critical success factors for the Biosyngas development trajectory are addressed in the discussion.

### 2.3.7. Reporting

The result of the OTC project is a description of the necessary research and development (R&D) trajectory to reach implementation of large-scale production of renewable syngas (*i.e.* biosyngas) from biomass and to form a (international) consortium to carry out the defined activities. The R&D trajectory is summarised in Chapter 3 and fully described in ECN report C--04-112 [8].

Furthermore, the slides of the Biosyngas workshops are available in the following ECN reports:

1. Boerrigter, H.; Drift, A. van der; Ree, R. van, Energy research Centre of the Netherlands (ECN), Petten, The Netherlands, report CX--04-013, February 2004, 37 pp. - *Biosyngas; markets, production technologies, and production concepts for biomass-based syngas.*
2. Veringa, H.J.; Boerrigter, H., Energy research Centre of the Netherlands (ECN), Petten, The Netherlands, report RX--04-014, February 2004, 32 pp. - *Duurzaam synthesesgas uit biomassa (in Dutch).*
3. Boerrigter, H.; Drift, A. van der, Energy research Centre of the Netherlands (ECN), Petten, The Netherlands, report RX--04-119, November 2004. - *Large-scale production of Fischer-Tropsch diesel from biomass: optimal gasification and gas cleaning systems.*

### 3. LARGE-SCALE BIOSYNGAS PRODUCTION

The approach followed was that first a “Biosyngas Vision” was determined, including reference to the current state-of-the-art of biosyngas production. The “Biosyngas Vision” is the basis of the R&D trajectory and direct what developments and R&D are necessary to come from the present situation to a sustainable society with an important role for biosyngas. In this Chapter it will be described which choices are made and what is the underlying motivation.

#### 3.1. Background

Biomass is relative expensive compared to the fossil fuels (on energy basis), therefore, the cost price of the biomass feedstock will significantly contribute to the production costs of the fuels or chemicals. This means that dedicated production processes (*i.e.* no tri-generation because of the higher specific costs) with maximum biomass-to-product and overall system efficiencies are needed to benefit from the economy of scale and for most cost-effective production [9].

#### 3.2. Scale and location of biosyngas production

Syngas demands for liquid fuel synthesis will typically be >1,000 MW (to benefit from economy of scale, which is necessary to reduce costs). The typical syngas demands for chemical processes correspond to 50-200 MW<sub>th</sub>. Even though the scale of an individual biosyngas plant may be relatively small, in most cases the plant will be part of a larger centralised chemical infrastructure with several other processes and plants to optimise energy and product integration (*i.e.* the syngas consumer). To ensure cost-effective biomass supply (*i.e.* avoid land transport; see below) biosyngas production plants will be constructed close to seaports or larger waterways. For the selection of the location the same considerations apply as for current coal-fired power plants and their coal logistics. Also the main large concentrations of chemical industry are located on locations easy accessible from water, *e.g.* the Maasvlakte near Rotterdam and the German Ruhrgebiet.

The transition to green alternatives therefore requires biomass, which should be available in large quantities. Since wood and grass-like material make up 70-90% of the total technically available amount of biomass worldwide, it is reasonable to focus on these biomass fuels as main renewable energy sources for chemicals and fuels [10].

#### 3.3. Optimum gasification technology (State-of-the-Art)

Several general types of gasification technologies are suitable for biomass gasification, *i.e.* fixed bed (either downdraft or updraft), fluidised bed, and entrained flow.

##### 3.3.1. Fixed bed gasifiers

Downdraft fixed-bed gasifiers are limited in scale and require a well-defined fuel, making them not fuel-flexible. Updraft fixed-bed gasifiers can be scaled up, however, they produce a product gas with very high tar concentrations. This tar should be removed for the major part from the

gas, creating a gas-cleaning problem. Examples of updraft gasifiers comprise the British Gas/Lurgi plant at Schwarze Pumpe (Germany), the Sasol plants (South Africa), and the Harboøre plant (Denmark). At Sasol they have chosen to work-up and fractionate the removed tar to produce chemicals (*i.e.* like a oil refinery). In the Harboøre CHP plant the water-tar mixture from the gas cleaning is processed in a parallel unit for district heating, whereas at Schwarze Pumpe the removed tars are fired on an entrained flow gasifier. In all cases the energy value of the tars is lost with respect to the biosyngas production.

### 3.3.2. Fluidised bed gasifiers

Fluidised bed gasifiers are typically operated at 800-1000°C (limited by the melting properties of the bed material) and are therefore not generally suitable for coal gasification,<sup>2</sup> as due to the lower reactivity of coal compared to biomass, a higher temperature is required (>1300°C) [11]. Even for biomass, the carbon conversion is only 90-98% (depending on the temperature and fuel); the unconverted carbon accounts for a significant loss in efficiency. Whereas in fluidised bed gasifiers the bed material imposes limitations on fuels and operation temperatures due to the fact that it may react with the biomass ash to form melts, in entrained flow gasifiers benefit is taken from these phenomena (see below).

### 3.3.3. Entrained flow gasifiers

Entrained flow (EF) gasifiers typically operated at high temperatures (1300-1500°C) at which the feed is completely converted in syngas, even at the short residence time of only a few seconds. In most cases, EF gasifiers are operated under pressure (typically 20-50 bar) and with pure oxygen and with capacities in the order of several hundreds of MW. The main technologies for coal-fired slagging EF gasification are characterised by coal-water slurry feedstock or by solid feedstocks of small particles (typically <100 µm), respectively [11]. The Texaco gasifier (since mid 2004: General Electric) is the main representative of the first type, while the Shell/Uhde gasifier (updraft fired) and the Future Energy (formerly: Noell; downdraft fired) are representatives of the second type.

To date, existing large-scale gasification power plants are all (mainly) coal-fired and based on (slagging) entrained-flow gasification technology, *e.g.* in Europe the Nuon (Buggenum) and Elcogas (Puertollano) plants. Entrained flow (EF) Integrated Gasification Combined Cycle (IGCC) for coal is now a well-proven innovative technology that has proven its reliability in large-scale applications (several hundreds up to a 1000 MW<sub>th</sub>). In co-gasification test in the Nuon and Elcogas plants the suitability of the EF gasifier for biomass conversion has been demonstrated. Biosyngas production based on slagging entrained flow gasification has additional technical advantages [12]:

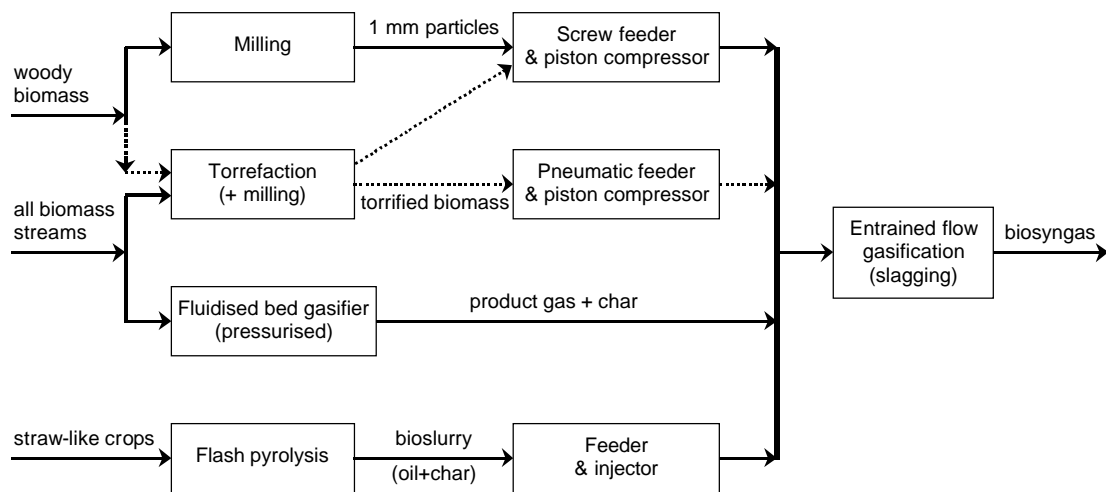
- Suitable for large-scale high-yield biosyngas production;
- Fuel-flexibility;
- Simple gas cleaning;
- Minimum waste & mineral recycling;
- Back-end flexibility.

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2. However, low rank coals and more reactive materials like peat, and lignite can be converted in fluidised bed gasifiers, as they are more reactive than hard coals.

### 3.4. Biomass feeding & pretreatment

Due to the high reactivity and volatile content of biomass (compared to coal) complete conversion is easily established at the temperatures typical for entrained flow gasification. The major issue, however, is the pretreatment of biomass and the feeding into the gasifier. Although the gasifier can operate both on coal and biomass, the coal feeding system is unsuitable for biomass. The development of new approaches to biomass feeding and pretreatment is necessary to reach high biomass-to-biosyngas (B-t-B) yields and high overall system efficiencies in biomass-fired entrained flow gasifier systems. In Figure 3.1 four possible specific pretreatment and feeding options are shown for different biomass streams. The pretreatment and feeding options are not competitive but complementary or an alternative to each other:



*Figure 3.1. Different biomass pretreatment and feeding option.*

### 3.5. Biosyngas Vision

In summary, the “Biosyngas Vision” can be described in the following lines [8]:

- Biosyngas is an important intermediary for the production of renewable chemicals and fuels.
- Biosyngas will be produced and consumed in large centralised industrial areas, preferable located close to ports for effective biomass logistics.
- The optimum gasification technology to establish the required high biomass-to-biosyngas yield is entrained flow gasification.
- Wood and straw will be the main biomass feedstocks for biosyngas production.
- Different pretreatment and feeding options have to be applied for the different feedstocks to achieve optimum biomass-to-biosyngas and overall system efficiencies:
- Pretreatment by torrefaction is the most promising for short term implementation as it converts the biomass into a coal-like product that can be applied in conventional coal feeding systems.

### 3.6. Research & development approach

The overall objective of the research and development trajectory is to develop the technology for dedicated biomass-fired entrained flow gasification systems for reliable, high-efficient, and

cost-effective production of biosyngas from multiple biomass streams. The technology should be proven in a full-scale (>100 MW<sub>th</sub>) demonstration plant.

Starting point of the development is the existing coal-based gasification technology that will be adapted for biomass firing. To bridge the gap between the existing and proven technology for coal and the implementation of biomass-fired entrained flow gasifiers, a research and development trajectory is necessary with focus on four interrelated themes:

1. Biomass pretreatment & feeding;
2. Gasification & burner design;
3. Ash and slag behaviour;
4. Hot gas treatment (cooling, cleaning, and conditioning).



## 4. DISTRIBUTED BIOSYNGAS PRODUCTION

The text in this appendix is based on a memo (in Dutch) that was prepared by TechnoInvent as subtask in the project, with the title “*Economisch vergassen op decentrale schaal met het Koepelovenproces*” (i.e. Distributed gasification with the arc furnace process).

### 4.1. Economisch vergassen op decentrale schaal met het Koepelovenproces

Vergassen op decentrale schaal is aantrekkelijk, als voldaan wordt aan de volgende voorwaarden:

- er is voldoende biomassa beschikbaar in de directe omgeving zeg 50-200 km<sup>2</sup>
- er is voldoende vraag naar de producten
- de installatie is rendabel

Afval is een bron voor biomassa. Vergassen op decentrale schaal impliceert, dat de vergasser in staat moet zijn afval(componenten) te verwerken. In dat geval zijn de kosten voor de invoer negatief omdat kan worden bespaard op verwerkingskosten.

De kracht van vergassen ligt in de hoogwaardigheid van de producten. Productgas kan worden ingezet voor het vervangen van minerale brandstoffen, voor het opwekken van elektriciteit in hoog rendement systemen zoals gasmotoren, gasturbines en brandstofcellen, maar ook voor de productie van waterstof, koolmonoxide, Synthetic Natural Gas (SNG), alcoholen, FT-olie, ammoniak, e.d. Daarmee kan met vergassen in vergelijking met verbranden van biomassa relatief veel primaire energie worden bespaard.

Een decentraal op te stellen vergassingsinstallatie moet geschikt zijn voor een zeer breed scala aan invoerstromen zodat de kosten voor voorbehandeling laag kunnen blijven en een zo groot mogelijk deel van de lokaal beschikbare stromen kan worden benut. Verder moet het proces modulair zijn opgebouwd. Met standaard modules kan aanzienlijk worden bespaard op kosten voor investering en bedrijf. De vergassingsmodules moeten een productgas opleveren, dat geschikt is voor die producten, die lokaal kunnen worden afgezet. Tenslotte moet het proces milieuhygiënisch inpasbaar zijn: geen of minimale emissies naar bodem, water en lucht.

Een aantrekkelijke vergassingsmodule is de koepeloven. De (over de weg te transporteren) standaardmodule heeft een thermisch vermogen van ca. 40 MW, ca. 50-60 kton droge invoer. Deze vergassings module heeft een aantal inherente voordelen:

- De invoer kan zeer grof zijn (tot enkele tientallen) centimeters. Daarom kan de voorbewerking van de invoer in het algemeen beperkt blijven tot zeven en knippen. Chippen en/of malen is niet nodig.
- De vergassingsmodule is geïntegreerd met een gesloten droger die bedreven wordt met afvalwarmte. De droger dient tevens voor het doseren van de invoer en voorkomt intrede van leklucht in de vergasser.
- De aanwezigheid van (zware) metalen, kunststof, as, zout, chloor is geen bezwaar, want metalen en mineralen worden als toepasbare bijproducten gewonnen. Chloorhoudende verbindingen worden restloos afgebroken tot HCl en Cl<sub>2</sub>. Daarom hoeft de invoer niet te

worden voorberekt om ongewenste componenten zoals batterijen en metaalhoudende voorwerpen af te scheiden.

- Door de opbouw van het koepelovenproces (zie onder) is het ketelrendement hoog en bevat het gas slechts sporen teer. Het syngas kan daarom goed en goedkoop worden gereinigd.
- Het koepelovenproces wordt bedreven met verrijkte lucht (minder dan 20% N<sub>2</sub>) of zuurstof. Daardoor bevat het productgas weinig inert gas, is de in de nareiniging te behandelen gashoeveelheid relatief klein en in het gas geschikt als vervanging van aardgas voor energieopwekking, de productie van waterstof en de productie van synthesegas voor tal van hoogwaardige producten zoals FT-olie en methanol.

Zoals voor alle vergassingsprocessen geldt, dat met het oog op de kwaliteit van het productgas en het ketelrendement het vochtgehalte niet hoger moet zijn dan ca 15%. Door de integratie met de droger en gebruik van afvalwarmte kan invoer met een vochtgehalte tot meer dan 40% zonder verdere voorbereking worden ingezet. Met uitzondering van zeer natte biomassa-stromen kunnen vrijwel alle normaal voorkomende afvalcategorieën en biomassa stromen worden vergast met een hoog thermisch rendement.

## 4.2. Werking van het koepelovenproces

Het koepeloven proces werkt als volgt (zie Figure 4.1): invoer wordt eerst ontgast bij ca. 450°C (pyrolyse). Hierbij wordt de invoer gesplitst in een teerrijke damp (pyrolysegas) en een koolhoudend residu (pyrolyseresidu). Ongeveer 30-60% van de invoer komt terecht in het pyrolyseresidu, afhankelijk van de samenstelling van de invoer. De teerrijke damp wordt gekraakt (afgebroken tot een mengsel van waterstof en koolmonoxide) bij ca. 1200°C. De kraakreactie is endotherm (verbruikt warmte). Warmte voor het verhogen van de gastemperatuur en het doen verlopen van de kraakreactie wordt geleverd door partiële verbranding van de teerrijke damp. Hierbij ontstaat kooldioxide. Bij 1200°C wordt het thermodynamisch evenwicht van de kraakreactie in tienden van seconden bereikt. Daardoor bevat het kraakgas weinig of geen teer en vluchtige koolwaterstoffen.

*Figure 4.1. Het Koepelovenproces.*

Het hete kraakgas en het pyrolyseresidu lopen naar beneden. Kooldioxide en water, dat is gevormd in de kraakstap reageert met de pyrolysekoel tot koolmonoxide en waterstof. Ook dit is een endotherme reactie. Zo wordt de warmte van het hete gas omgezet in chemische energie (een chemische quench) en daalt de temperatuur tot onder 750°C. Het gas verlaat de vergassingsreactor.

Het niet omgezette deel van het pyrolyseresidu zakt naar de smeltsectie, het onderste deel van de vergasser. Hier wordt zuurstof toegevoerd en verbrandt de rest van de kool. De temperatuur loopt daarbij op tot ca. 1500°C. De as smelt en de daarin aanwezige metalen worden gereduceerd. Vluchtige metalen dampen uit, de overige metalen smelten tot een gesmolten metaallegering. In het vergassingsproces worden alle zwavelverbindingen, dus ook gips, omgezet in zwavelwaterstof. Onder in de vergasser vormen zich twee lagen: onderin een gesmolten metaallaag en daarboven een gesmolten mineraallaag (slak). De lagen worden afgetapt.

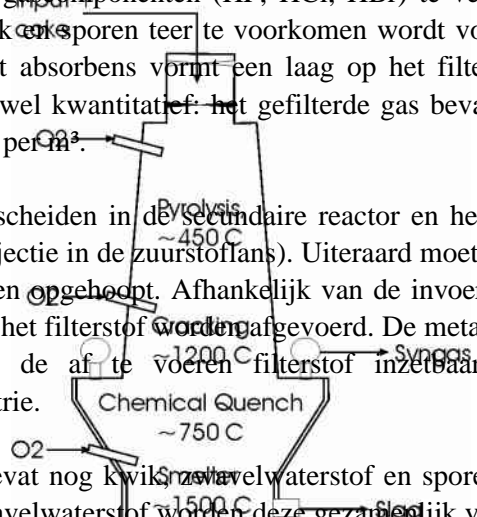
Door de verschillende stappen die de invoer in een enkele reactor doorloopt is de verblijftijd in de vergasser goed regelbaar en wordt de kool voor 100% omgezet. De vergasser heeft geen last van lage asverweking temperatuur en is niet gevoelig voor verstopping. Ook het in de onderste sectie gevormde gas wordt gekoeld in de chemische quench. Het ketelrendement is daarom hoog en het afgas is makkelijk te reinigen doordat bij de uitlaatemperatuur weinig of geen vluchtige componenten meer in het gas aanwezig zijn: uitgedampt metaal en zouten condenseren en vormen fijn stof (vliegias). Het gehalte aan teer en vaste stof wordt in een nageschakelde secundaire reactor met 70-80% verminderd. Na de secundaire reactor bevat het gas slechts een kleine hoeveelheid (ca. 100 mg/m<sup>3</sup>) lichte koolwaterstoffen (hoofdzakelijk benzeen en toluen) en niet klevende stoffdelen. Daardoor kan warmte worden teruggewonnen en is het gas makkelijk te reinigen.

### 4.3. De gasreiniging

Het gas wordt gereinigd op een doekenfilter. Het filter wordt bedreven bij ca. 200°C zodat verstopping van het filter door condensatie van water op hygroscopische componenten wordt vermeden. Om zure gascomponenten (HF, HCl, HBr) te verwijderen en verstopping van het filter door metaalrook te voorkomen wordt voor het filter vast adsorbens in het gas geïnjecteerd. Het adsorbens vormt een laag op het filterdoek en verwijdert stof en zure gascomponenten vrijwel kwantitatief: het gefilterde gas bevat nog slechts enkele mg zure gas componenten en stof per m<sup>3</sup>.

Stof, dat wordt afgescheiden in de secundaire reactor en het gasfilter kan worden gerecycled naar de vergasser (injectie in de zuurstoflans). Uiteraard moet worden voorkomen, dat vluchtige zware metalen worden opgehoopt. Afhankelijk van de invoerhoeveelheid zware metalen, moet daarom een deel van het filterstof worden afgevoerd. De metaalconcentratie kan oplopen tot 20-40%. Daarmee kan de af te voeren filterstof inzetbaar zijn als ertsvervanging in de metallurgische industrie.

Het gefilterde gas bevat nog kwik, zwavelwaterstof en sporen lichtkokende teercomponenten. Bij lage gehalten zwavelwaterstof worden deze gezamenlijk verwijderd op een speciaal mengsel van actieve kool. Bij hogere gehalten zwavelwaterstof wordt dit apart verwijderd in een regeneratief wassysteem. Daarbij wordt zwavelwaterstof omgezet in elementaire zwavel.



#### 4.4. Performance van het proces

Het koepeloven-proces kan ook zeer verontreinigde biomassa aan. Zware metalen, gechloreerde verbindingen en een hoog as- en metaal gehalte verstoren het proces niet. Organo chloorverbindingen worden substantieel afgebroken, metaal (chromium, koper, nikkel, molybdeen) wordt als gesmolten legering teruggewonnen. Zware metalen (zink, lood, cadmium, tin, zilver, arseen en antimoon) worden gereduceerd, verdampen uit de slak en kunnen als concentraat in de gasreiniging worden teruggewonnen. De slak voldoet aan de eisen voor multifunctionele toepassing. De smeltsectie werkt dus als een pyrometallurgische raffinage stap analoog aan de werking van een hoogoven.

Omdat afvalwarmte kan worden teruggewonnen en ingezet voor het opwekken van oververhitte stoom kan een belangrijk deel van de elektriciteitsbehoefte worden gedekt met een eenvoudige expansieturbine. De geëxpandeerde stoom is zeer geschikt voor het voordrogen van de invoer. Daarom is het thermisch rendement van het proces hoog.

Bij gebruik van zuivere zuurstof bevat het biosyngas ca. 2-5% N<sub>2</sub> (en minimaal 10% CO<sub>2</sub>). De hoeveelheid verontreinigingen is zo laag dat het zonder bezwaar kan worden ingezet voor de vervanging van aardgas en als hoogwaardig synthesegas voor de productie van vloeibare en gasvormige producten zoals waterstof, koolmonoxide, alcoholen en Fischer-Tropsch olie.

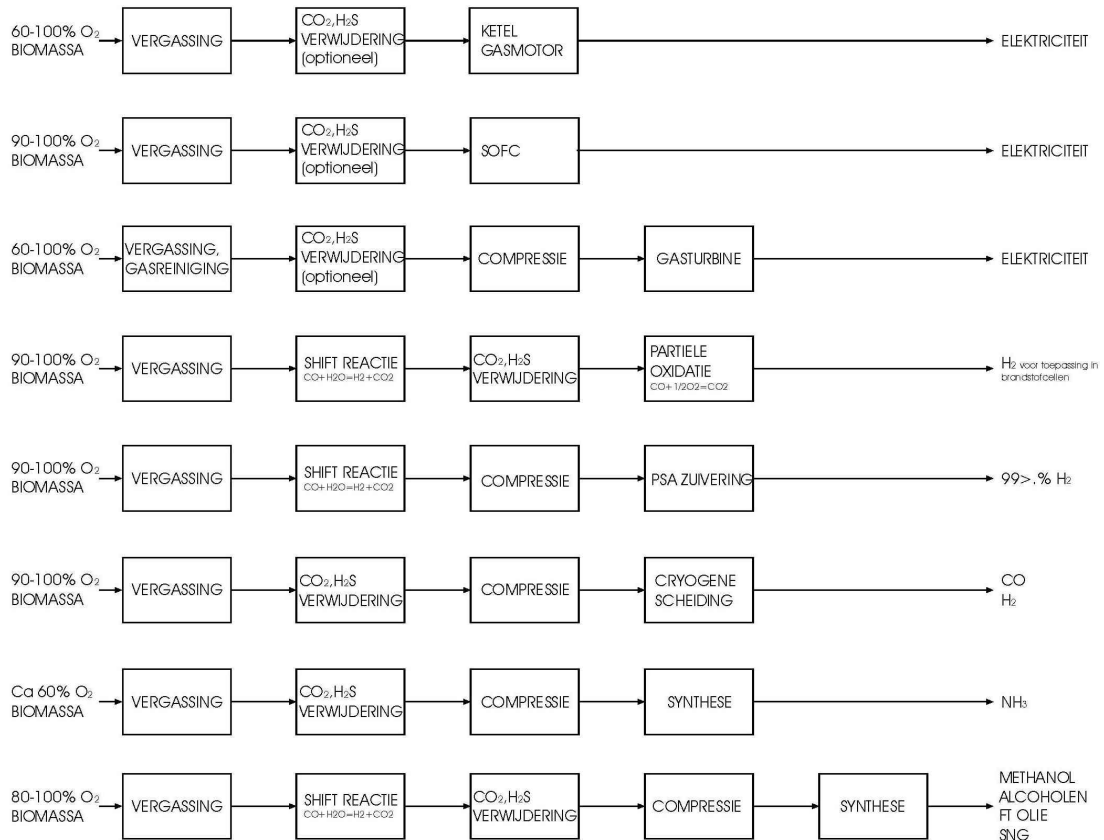
Op 3 MW schaal is aangetoond, dat het koepelovenproces zeer geschikt is voor het vergassen van een zeer breed pakket van invoerstromen, van houtchips tot aan volledige voorwerpen computers en autobanden en bijzonder afval, zoals niet verwerkbaar chemisch afval. Feitelijk is de minimale deeltjesgrootte de enige beperking. Daarom moet de fractie <5 mm afgezeefd en gegraneerd worden. Steeds kon worden voldaan aan de kwaliteitseisen voor het synthesegas, werden mineralen omgezet in vrij toepasbaar "synthetisch basalt" en werden metalen teruggewonnen als "pig iron" en metaalconcentraat, werd geen afvalwater geproduceerd en voldaan aan de milieueisen.

#### 4.5. Toepassing van het biosyngas

De samenstelling van het biosyngas is relatief onafhankelijk van de samenstelling van de invoer. Typisch bevat het gas ca. 60-65% CO en 25-30% H<sub>2</sub>. Het gehalte aan CO<sub>2</sub> en stikstof bedraagt ruim tien procent. Dit is het gevolg van de bovenbeschreven chemische quench waarin kool en CO<sub>2</sub> worden omgezet in CO en het gebruik van zuurstof. Bij inzet van ca 90% zuivere zuurstof heeft het biosyngas een calorische waarde van ruim 10 MJ/m<sub>n</sub><sup>3</sup>. Hoogwaardige toepassingsroutes zijn in Figure 4.2 gegeven.

De koepeloven vergasser wordt bedreven op atmosferische druk tot een geringe overdruk. Voor de shift reactie en de CO<sub>2</sub>/H<sub>2</sub>S verwijdering en toepassing in gasmotoren en brandstofcellen volstaat een geringe overdruk. Toepassing van CO<sub>2</sub>/H<sub>2</sub>S verwijdering is afhankelijk van de toepassing en het zwavelgehalte in de invoer. Voor de synthesesreacties en toepassing in een gasturbine is een druk die varieert tussen ca. 15-100 bar nodig. Compressie is hier dus noodzakelijk. Om het energiegebruik voor de compressie laag te houden, is het in het algemeen aantrekkelijk, de shiftreactie en de CO<sub>2</sub>/H<sub>2</sub>S verwijdering bij lage druk uit te voeren.

De in te zetten kwaliteit van zuurstof hangt af van de toepassing. Als het gas wordt ingezet als stookgas voor een ketel, een gasmotor of een gasturbine of voor de productie van ammoniak



**Figure 4.2.** Routes voor toepassing Biosyngas.

kan worden volstaan met verrijkte lucht. Voor de overige toepassingen is >90% zuivere zuurstof gewenst.

Enkele voorbeelden:

- Voor de productie van syngas bedraagt het thermisch rendement van het koepelovenproces ca. 85%. Per kg droge asvrije biomassa van 17 MJ/kg en een omzettingsrendement in de gasmotor van 35% kan ongeveer 1,4 kWh<sub>e</sub> worden geproduceerd.
- Een installatie met 40 MW vermogen kan ca. 10.000 m<sup>3</sup> per uur synthesegas produceren.
- Uit een kg droge asvrije biomassa kan ruim 0,6 kilo methanol worden geproduceerd. Betrokken op verbrandingswaarde van methanol (19,9 MJ/kg) komt dat overeen met 3,3 kWh, dat wil zeggen een omzettingsrendement van bijna 70%.
- In een installatie met 7 MW vermogen kan ca 2500 m<sup>3</sup>/h waterstof worden geproduceerd met een zuiverheid van >99,9% geschikt voor inzet in een brandstofcel.
- In een installatie met 40 MW vermogen kan tot ca. 100.000 ton gemengd afval worden verwerkt (gem. 20% as, 30% vocht) in ca 30.000 ton alcoholen. De specifieke investering van zo'n installatie bedraagt ca. €250/ton verwerkingscapaciteit per jaar.
- In vergelijking met afvalverbranding is vergassing substantieel goedkoper: zowel de vaste en variabele kosten zijn lager, de productopbrengst is aanzienlijk hoger.



## 5. CONCLUSIONS & CONTINUATION

### 5.1. Conclusions

Renewable syngas from biomass, or “biosyngas” will be an important intermediate in the future energy infrastructure for the production of renewable electricity, gaseous energy carriers, transportation fuels, and chemicals. A large total installed biosyngas production capacity with large individual plants is required to reach a significant share of biosyngas in the renewable energy infrastructure and to meet the ambitious targets for renewable electricity, fuels, and chemicals. A “Biosyngas Vision” was defined that describes what developments and R&D are necessary to come from the present situation to a sustainable society with an important role for biosyngas.

To bridge the gap between the existing and proven technology for coal and the implementation of biomass-fired entrained flow gasifiers, a phased research and development trajectory is necessary. Starting point is the existing coal-based gasification technology. The overall objective of the research and development trajectory is to develop the technology for dedicated biomass-fired entrained flow gasification systems for reliable, high-efficient, and cost-effective production of biosyngas from multiple biomass streams. The technology should be proven in a full-scale (>100 MW<sub>th</sub>) demonstration plant.

### 5.2. Continuation

Distributed biosyngas production appears to have only limited relevance for renewable energy policies, therefore, the project partners have made no attempts to form a consortium for further development and/or demonstration. However, for a specific situation (*i.e.* biomass availability or biosyngas demand) there can be an incentive to build a smaller production plant. In that case the project partners will pursue this opportunity.

For large-scale biosyngas production, an international consortium was formed that will carry out a major part of the defined R&D development within the framework of the project “POWERGAS”, which was submitted in December 2004 call of the Sixth Framework. Parallel a proposal will be submitted in the January 2005 EOS call that will address topics that are not included in POWERGAS. The Dutch partners from POWERGAS will form the heart of the EOS consortium.

A pilot plant for entrained flow gasification-based biosyngas production is an important element in the R&D trajectory, as well as for the ‘public relations’ of this important technology route. Considering the importance of biosyngas in the Dutch biomass transition, realisation of a pilot plant in the Netherlands is therefore desirable.

However, short-term realisation of a demonstration pilot plant in the Netherlands is not expected, as there already is an operational pilot plant in Freiberg (Germany) that is available for research. General consensus of the parties in the Dutch Biosyngas workgroups (*cf.* section 2.3.1) was that available funds from R&D and demonstration programmes are more effectively utilised by participation in international developments and not by duplication of existing technologies.





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