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Survey on European 2nd Generation Biofuels Technology Suppliers

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List of Abbreviations

a	Anno
AFEX	Ammonia Fiber Expansion
BtL	Biomass to Liquid process
CBP	Consolidated BioProcessing
CFB	Circulating Fluidized Bed
CHP	Combined Heat and Power plant/ process
CNG	Comprised Natural Gas
COD	Chemical oxygen demand
CtL	Coal to Liquid
d	Day
DME	Dimethylether
el	Electric
FT	Fischer Tropsch process
GtL	Gas to Liquid process
HDS	Hydrodesulphurisation
kW(h)	Kilo Watt (hours)
l	Litre
Nm^3	Normal m^3
PN	Pressure stage
ppm	Parts per million
PSA	Pressure swing adsorption
SFB	Stationery fluidized bed gasifier
SHF	Separate Hydrolysis and Fermentation
SNG	Synthetic Natural Gas
SSCF	Simultaneous Sacchariffication and Co-Current Fermentation
SSF	Simultaneous Sacchariffication and Fermentation
t	Ton
therm	Thermal
UASB	Upflow anaerobic sludge blanket
MW	Megawatt
WCS	Whole crop silage

1 Introduction

The present report covers an overview of the European companies as well as selected R&D institutions dealing with 2nd generation biofuel technologies. Following production technologies are covered:

1. Ethanol made from lignocelluloses
2. Biofuels made from synthesis gas; synthesis gas made from thermal gasification
3. Synthetic natural gas gained from thermal gasification
4. Biogas made through fermentation of wet biomass

The selection of the listed institutions was based on the expected attractiveness for the Canadian industry and politics.

1.1 Nomenclature

The categorization of the biofuels used in this report is as follows:

1st Generation Biofuels: are produced from natural resources with high energy density like vegetable oil, sugar or starch.
The typical representatives of 1st generation biofuels are: biodiesel, bio-ethanol, vegetable oil and biogas.
2nd Generation Biofuels: are made from the overall biomass (ligno-cellulosis = overall plant).
The typical representatives of 2nd generation process are ligno-cellulosic ethanol, Biomass to Liquid (BtL) and synthetic natural gas (SNG).

The principle ways of processing 2nd generation biofuels are shown in figure 1 below:

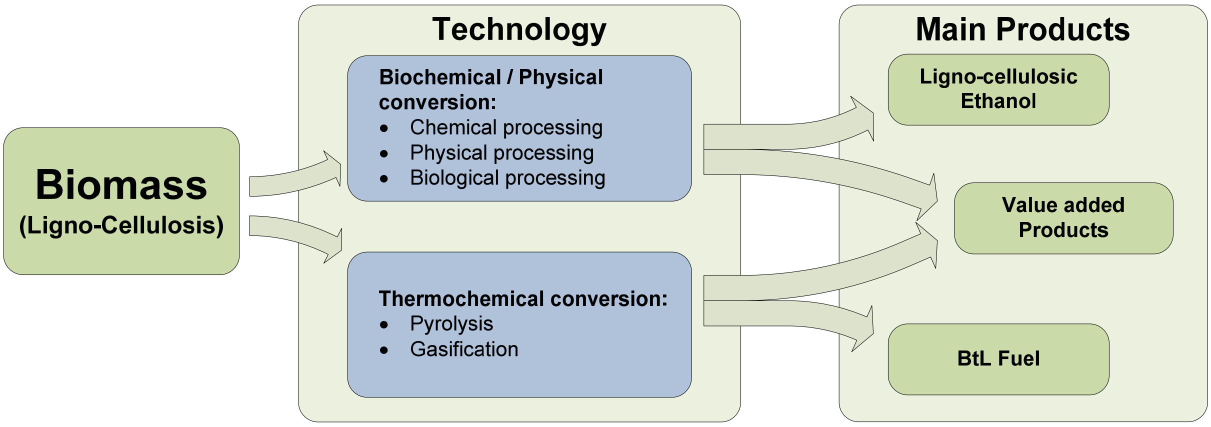


Figure 1: 2nd generation biofuel processing ways and products from cellulosic biomass

When multiple products are derived from biomass conversion processes like fuel, power and value added chemicals, this is often referred to as a biorefinery.

2 Overview on 2nd generation biofuel production

2.1 Production of Ligno-cellulosic Ethanol

In contrast to the traditional bio-ethanol production from sugar and starch, the production based on ligno-cellulosic material requires additional processing steps. The reason is that the cellulose (source of C_6 sugars such as glucose) as well as hemi-cellulose (mainly source of C_5 sugars such as xylose) is not accessible to the traditional bio-ethanol producing micro-organisms.
Following processing steps may be found in a general ligno-cellulose to bio-ethanol production process:

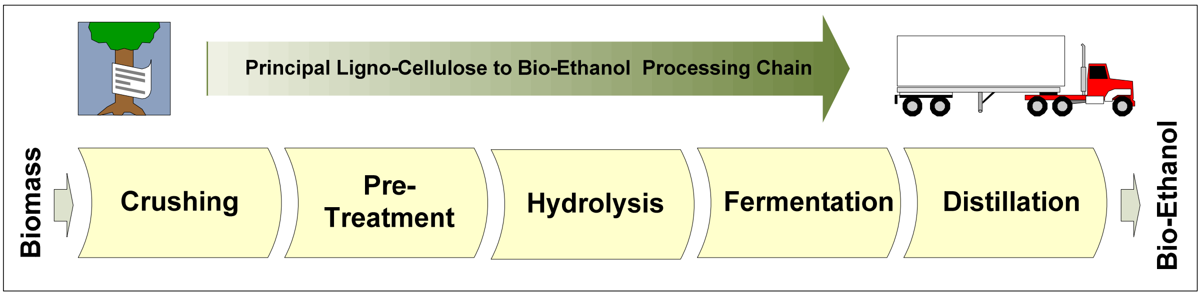


Figure 2: Ligno-cellulose to bio-ethanol processing chain

2.1.1 Crushing

Within the crushing step the biomass is milled or chipped to a smaller size better suitable for the further accessing in pre-treatment. This step is technologically proved.

2.1.2 Pre-Treatment

The main purpose of the pre-treatment is the destruction of the lignin shell protecting the cellulose and hemi-cellulose material, decreasing the crystallinity of the cellulose and increasing the porosity of the material. Only after breaking this shell the sugar containing materials become accessible for hydrolysis. The main products of this processing step are the released cellulose, hemi-cellulose and fragments of lignin.
In dependance of the intensity of the pre-treatment various undesired side-products may be obtained (such as phenol-compounds from lignin or organic acids, anorganic salts) often inhibiting the

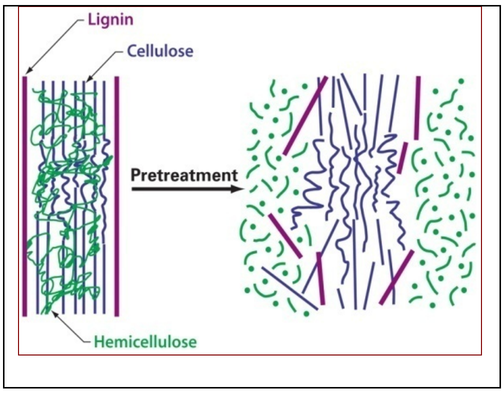


Figure 3: Pre-treatment of ligno-cellulose for bio-ethanol production according. Source: Genome Management Information System ORNL

consecutive micro-biological hydrolysis and/or fermentation processing steps.

A general classification of the pre-treatment methods into three groups may be undertaken:

- Chemical pre-treatment

  The chemical pre-treatment is one of the first methods known and used in pratice. The typical methods are using acids or lyes to access the ligno-cellulose. The big disandantage of the chemical pre-treatment methods are corrosion problems, enviromental problems as well as the risk of processed material degradation. The curret R&D focus in chemical pre-treatment lies in the use of organosolv and ionic liquids.

- Physical pre-treatment

  The most common representant of the physical pre-treatment of ligno-celluloses is the stream explosion methods. Withing this approach the biomass is mixed with steam of high pressure and temperature (20-75 bar and 180-280°C) und suddenly expanded. Several demostration facilitites are currently using the steam explosion method for pre-treatment. The obtained cellulosis is highly porous and suitable for hydrolysis. The disadvantage of this method is the high energy demand.

  Similar methods can be based on other media as well, such as amonia (AFEX Amonia Fiber Explosion), CO_2 explosion or water (LHW – Liquid Hot Water method)

- Biological pre-treatment

  The biological pre-treatment methods are in a strong focus of R&D. The principles are based on the use of funghies (white-rot funghi, brown-rot funghi,…) or selected bacterias degrading the structure of ligno-cellulose. The advantages are obvious: low energy consumption, almoust no chemicals, no corrosion problems. The current big disadvantage is the duration of the degradation process (usually measured in weeks) leading to incaceptable duration in terms of industrial use.

2.1.3 Hydrolysis

The main purpose of the hydrolysis is the splitting of the polymeric structure of lignin-free cellulosic material into sugar monomers in order to make them ready for fermentation. At this stage we should distinguish between the hydrolysis of the C_5 dominated hemi-celluloses and the hydrolysis of the C_6 dominated celluloses.

Hydrolysis of the Celluloses: also acid hydrolysis of the celluloses is possible and has been applied previously; the current state-of-art method is the enzymatic hydrolysis by cellulase enzyme complex produced for example by the fungus Trichoderma Reesei.

Hydrolysis if the Hemi-Celluloses: In contrast to the crystalline structure of cellulose, the hemi-cellulose has mainly an amorphous structure. This results in a significantly easier way of hydrolysis. The hydrolysis of hemi-celluloses may be performed by diluted acids, bases or by appropriate hemi-cellulose enzymes. In several process set-ups these hydrolysis happens already in the pre-treatment step.

2.1.4 Fermentation

The fermentation of the C_5 and C_6 sugars obtained from the pre-treatment and hydrolysis of ligno-cellulose faces several challenges:

- Inhibition from various by-products of pre-treatment and hydrolysis such as acetates, furfural and lignin. The impact of these inhibitors is even lager on the C_5 sugar processing.
- Inhibition form the product itself = inhibition by bio-ethanol leading to low titer (ethanol concentration)
- Low conversion rates for the C_5 sugars

The mentioned difficulties are leading to higher investment costs, high energy and process water demand due to low titer (yield of ethanol in fermentation) as well as high demand for enzymes.

2.1.5 Distillation

The upgrading of ethanol from the lower concentrations in beer towards the required 99,6% $^V/_V$ is performed using the known and widely applied technological steps:

- Evaporation of ethanol from beer: in this step the first evaporation of ethanol is performed in order to obtain 'crude' ethanol with concentration ~45% $^V/_V$.
- Rectification: in rectification the ethanol concentration in increased to ~96% $^V/_V$
- Dehydration: In the dehydration the remaining azeotropic water is removed in order to obtain the fuel bio-ethanol with concentration 98,7% $^m/_m$ and water content below 0,3% $^m/_m$.

2.1.6 Overall process integration

Particularly in case of enzymatic hydrolysis various overall process integrations are possible. Common toi all processes is the pre-treatment requirement. The processes shown in the figure differ in the alignment of the hydrolysis, C_5 fermentation and C_6 fermentation steps. It is clear, that in the practical implementation there will be various modifications to the mentioned methods.

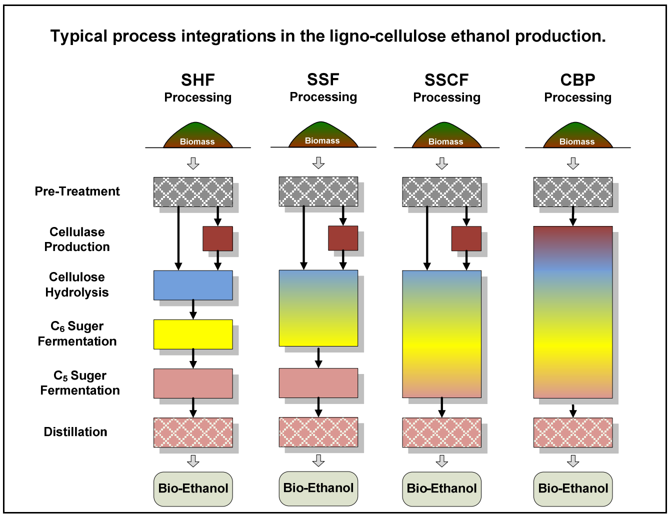
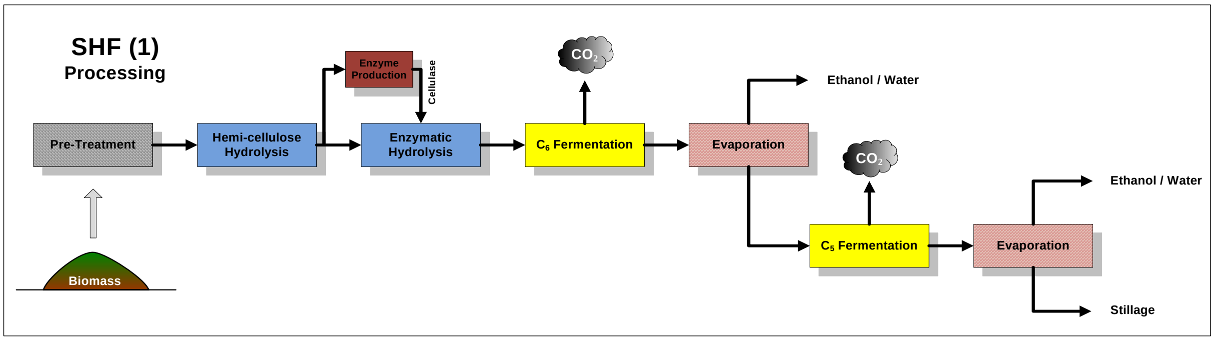


Figure 4: Process integration steps in the ligno-cellulose ethanol production

SHF – Separate Hydrolysis and Fermentation

There are two variations of the SHF process. In the first processing variant the C_5 and C_6 fermentation is performed sequentially. The overall material enters the enzymatic hydrolysis, and then the C_6 fermentation is performed, followed by ethanol distillation continued by C_5 fermentation. In the second variant the soluble C_5 sugars are separated already in the hemi-cellulose hydrolysis (means shortly after pre-treatment), the C_5 and C_6 fermentation is performed in parallel leading to a common beer distillation step.



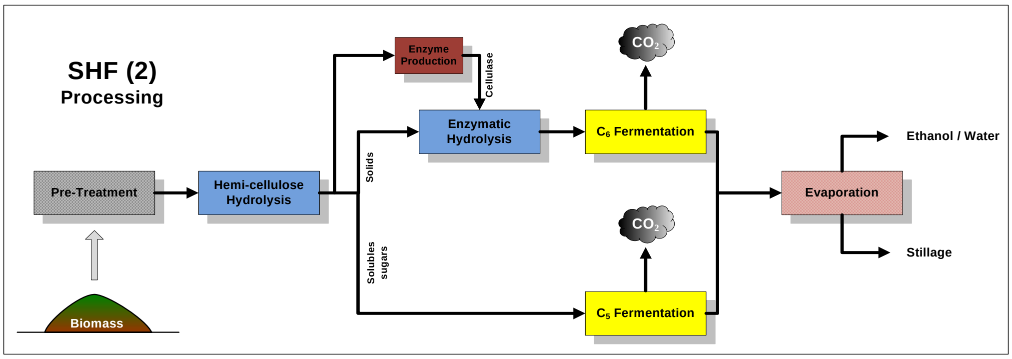


Figure 5: Two basic variants in the SHF process integration

SSF – Simultaneous Sacchariffication and Fermentation

For the SSF process integration it is characteristic, that the C_6 hydrolysis und C_6 fermentation are performed in one common step. Beside this a hemi-cellulose hydrolysis (if not integrated in the pre-treatment step) and the C_5 fermentation are performed.

SSCF - *Simultaneous Sacchariffication and Co-Current Fermentation*

In the SSCF process the saccharificaton of C_5 and C_6 sugars as well as the co-current fermentation of both sugars is performed directly after the pre-treatment. It is obvious, that such a set-up is more advanced comparing to SHF and SSF processes, due to a significant technology simplification leading to investment cost savings.

CBP - Consolidated BioProcessing

The CBP - Consolidated BioProcessing means the unification of the cellulase production, hydrolysis and fermentation of the C_5 and C_6 sugars into a single processing step. This is possible only by the "creation" of a suitable organism community providing the required enzymes directly within the reactor. Hence, the processing focus is shifted from an enzymatic towards a microbial approach. From today's point of view, the establishment of CBP as the consolidation of the 4 mentioned steps within the biomass to bio-ethanol conversion would mark the significant step forward, in terms of efficiency and simplicity of the process.

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2.2 Production of Synthetic Biofuels via Gasification

The production of biofuels using the biomass-to-liquid process (BtL) differs significantly from the ligno-cellulosic ethanol production. Within the BtL production scheme the biomass is first thermally fragmented to (product / synthesis) gas, consisting of rather simple molecules such as: hydrogen, carbon monoxide, carbon dioxide, water, methane... After gas upgrading the synthesis gas is used for BtL fuel production.

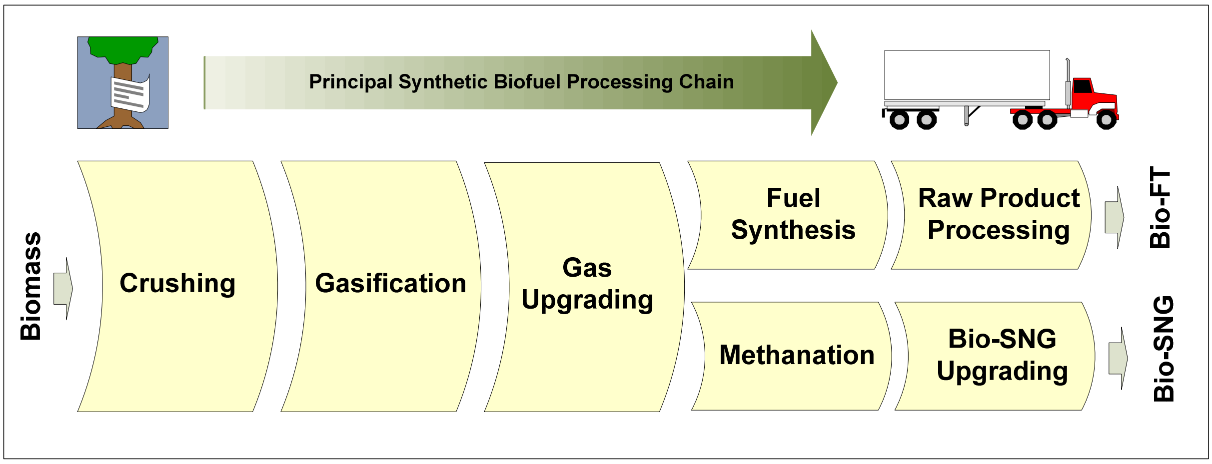

Figure 6: Synthetic biofuel processing chain

2.2.1 Crushing

Before the biomass material enters the gasifier it hat to be broken-up to a suitable size. The size is dependant on the type on the type of gasification.

2.2.2 Gasification

Gasification differs significantly from combustion as well as from pyrolysis and liquification. Combustion takes place under excess of air ($\lambda > 1$) and under high temperatures, resulting in heat production, exhaust gas and ashes, leading to complete oxidation of the fuel.

Gasification takes place under shortage of oxygen (typical $\lambda = 0{,}2\text{-}0{,}5$) with two products: product gas and solid by-product (either char or ashes).

The gasification processes may be divided according to the used gasification agent and the way of the heat supply. Typical gasification agents are: oxygen, water, and air (not suitable for consecutive bio-fuels production due to nitrogen content). In dependence of the heat supply we distinguish between two process types. Within the autotherm processes the heat is provided through a partial combustion of the processes material within the gasification stage. In the second type of processes, the allotherm processes, the heat is provided externally via heat exchangers or heat transferring medium. In this processes the heat may come from a combustion of the processed material (means, combustion and gasification are physically separated) or from external sources.

Types of gasifiers

Based on the way, how the fuel is brought into contact with the gasification agent, there are three main types of gasifiers:

- Fixed-bed gasifier
  - Updraft gasifier
  - Downdraft gasifier
- Fluidized bed gasifier
  - Stationery fluidized bed (SFB) gasifier
  - Circulating fluidized bed (CFB) gasifier
- Entrained flow gasifier

For biomass production typically only fluidized bed gasifier and fuel gasifier are used, which are described in the following sections.

Stationery fluidized bed (SFB) gasifier

In the fluidized bed gasifier the bed material behaves like a highly turbulent fluid leading to a fast mixing of the fuel material with the bed material. This results in a rapid pyrolysis and uniform processing conditions within the reactor (no reaction zones are observable as typical for the fixed-bed reactors). The bed material (for example quartz sand) forms a suspended, “bubbling”, highly turbulent fluidized bed with an observable bed surface.

The fluid-bed gasifier can process materials with higher ash-content as typical for biomass and in general this type of gasifiers is better suitable for large-scale operations (typically above 10 MW_{th}).

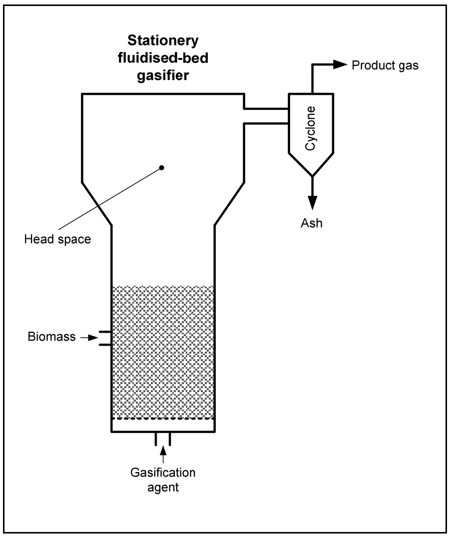

Figure 7: Stationary fluidized bed (SFB) gasifier

Circulating fluidized bed (CFB) gasifier

The set-up of the circulating fluid-bed gasifier is similar to the stationary fluid-bed gasifier with the main difference that gasification agent enters the reactor in velocities leading to carry away of the bed material. Comparing to the SFB gasifiers, there is no bed surface observable. The bed material is distributed in the complete reactor with higher densities in bottom sections. The bed material as well as ash are separated from the product gas in the cyclone stage and are recycled back to the reactor.

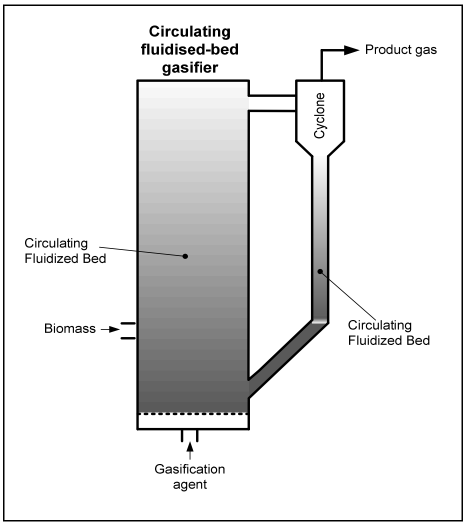

Figure 8: Circulating fluidized bed (CFB) gasifier

Fluid-bed gasifier: Circulating fluidized two-bed gasifier

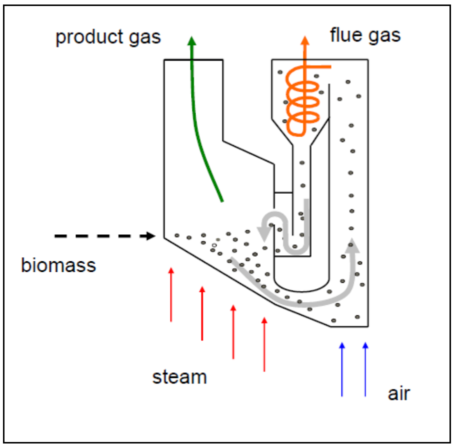

Figure 9: Circulating fluidized two-bed gasifier [1]

In the circulating fluidized two-bed gasifier the circulating bed material is used as heat carrier. In this set-up the gasification is performed in one fluidized bed, the bed material is transferred into the second bed, where the required gasification heat is generated by combustion of a part of the processed. The heated-up bed material is transferred back to the gasification bed. The main advantages of this system are the possibility to optimize the combustion and gasification part separately.

Entrained Flow Gasifier

The entrained flow gasifier differs significantly from the gasifiers described previously. The processed material enters the gasifier at the top, together with the gasification agent. Comparing to other gasifiers there is an additional pilot flame providing the initial energy demand.

The entrained flow gasifier is typically used for the gasification of fossil sources (crude oil, natural gas and charcoal). However, in combination with an upstream low-temperature pyrolysis step this process may be applied to biomass material as well (otherwise a suitable external pilot flame feed is required). In this case the pyrolysis gas from the low temperature step is used as pilot flame fuel and the pyrolysis char is the processed material.

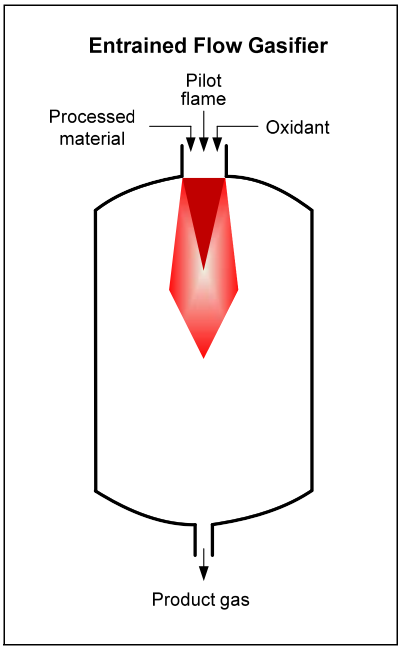

Figure 10: Entrained flow gasifier

2.2.3 Gas cleaning & upgrading

After leaving the gasifier, the product gas has to be cleaned and in dependence on the further processing steps upgraded.

Gas cleaning

The obvious reasons for gas cleaning are the prevention of corrosion, erosion and deposits in the process lines as well as the prevention of poisoning of catalysts. Following typical impurities are found in the product gas:

- Dust and alkali metal compounds
- Tar
- Sulfur compounds
- Nitrogen and chloride (halogenide) compounds

Gas upgrading

Several processed are subsumed under the term gas upgrading:

- Water-gas-shift (WGS) reaction:
  Using the (reversible) water-gas-shift reaction:
  $CO + H_2O \leftrightarrow CO_2 + H_2$
  the CO / H_2 ration may be modified in order of obtain the ration of H_2 / CO = 1,5-3,0 as typically required by the consecutive fuel synthesis reaction

- Gas reforming:

  Using the gas reforming reactions, the short-chain organic molecules may be converted to CO and H_2 be the following endothermic reaction (example for steam – methane reforming):

  $CH_4 + H_2O \leftrightarrow CO + 3\ H_2$
- Removal of inert gas fractions – mainly CO_2:

  CO_2 is on one hand inert in the subsequent reactions, however, it will increase the requirements for apparatuses and energy demand (for example for compression steps), and hence a removal is advantageous.

2.2.4 Fuel synthesis

Starting from the synthesis gas (=the cleaned und upgraded product gas from the gasification) several fuel processing ways are possible. Using (thermo-) chemical processes such as Fischer-Tropsch (providing diesel / gas like biofuel) or methanol synthesis also biotechnological processing towards alcohols are possible.

Fischer-Tropsch Synthesis

The most widely used fuel synthesis process is the FT process invented in the 1920-ties by Germans Franz Fischer and Hans Tropsch. Currently the FT reaction is successfully used for fuel production from coal (CtL = Coal-to-Liquid) or natural gas (GtL = Gas-to-Liquid).

Based on the reaction temperatures and pressures, there are two process types used for the FT synthesis:

- HTFT – High Temperature Fischer-Tropsch Synthesis:

  The typical HTFT process conditions are temperatures of 300-350°C and pressures of 20-40 bar. The products obtained at this temperature have “light” character, means this process may be used for production of the basic petrochemical materials (ethylene, propylene…) as well as gas production.

- LTFT – Low Temperature Fischer-Tropsch Synthesis:

  The low temperature FT – counterpart takes place at temperatures about 200-220°C and pressures below 20 bar. This technology provides higher-boiling products, hence is more suitable for diesel production.

The FT synthesis is catalyzed by various catalysts based on iron, cobalt, ruthenium, nickel. Due to economic reasons currently only iron (HTFT) and cobalt (HTFT & LTFT) catalysts are widely used.

Upgrading of the raw FT Product

The raw Fischer-Tropsch product as provided by the synthesis consists of a distribution of molecules, ranging from gaseous compound, through liquid fraction ending with solid wax fraction (at room temperature) the direct use as fuel is not possible. Even the amount of the desired fraction (petrol or diesel) may be significantly increased through a suitable process control; following additional upgrading steps may be required:

- Distillation: using distillation the obtained row FT product is splitted into fraction, the fractions may be further processes as required
- Hydration and isomerization of the C_5-C_6 fraction (for petrol use): in order to increase the octane number the mainly linear alkanes are isomerized
- Reforming of the C_7-C_{10} fraction (for petrol use): is used to increase the octane number (as well as the content of aromatics)
- (Hydro- / fluid catalytic) cracking: converting long-chain fractions into petrol and diesel fraction by application of hydrogen under high pressure

2.2.6 Bio-SNG production

The product gas obtained by gasification may be alternatively used to produce bio-SNG (synthetic natural gas). Starting from the product gas the first step, which has to be performed is the methanation:

Methanation

In the methanation the carbon monoxide and the hydrogen react to methane and water:

$CO + 3\ H_2 \leftrightarrow CH_4 + H_2O$ (reverse to the steam methane reforming reaction)

$CO_2 + 4\ H_2 \leftrightarrow CH_4 + 2\ H_2O$

The reaction is catalyzed typically by nickel oxide catalysts. The formation of carbon (coking) is a possible undesired side reaction of this process.

Bio-SNG upgrading

The upgrading of the raw bio-SNG obtained by methanation consists mainly of increase of the CH_4 concentration and cleaning. These steps are similar to the biogas upgrading technology described in the section 2.3.3. Further a compression of the obtained product is required (see also 2.3.4).

2.2.7 Other Biofuels obtainable via Gasification

The gas obtained by gasification of biomass may be used to produce a variety of chemical compound hence also to produce biofuels. Selection of some alternatives is listed below:

Dimethylether (DME)

DME may be used as fuel or as a basis of the synthesis of other chemicals. The production of DME from the synthesis gas is based on the following exothermic reactions:

$$2\ CO + 4\ H_2 \leftrightarrow H_3C\text{-}O\text{-}CH_3 + H_2O$$

$$3\ CO + 3\ H_2 \leftrightarrow H_3C\text{-}O\text{-}CH_3 + CO_2$$

The above reactions can be performed in continuous fixed bed or slurry reactors. The catalysts are based on a mixture of cupper, zinc- and aluminium oxides.

Ethanol and higher alcohols

Beside DME also alcohols may be produced from synthesis gas. For example the ethanol synthesis follows the following reaction:

$$3\ CO + 3\ H_2 \leftrightarrow C_2H_5OH + CO_2$$

This way of ethanol production may be seen as alternative to the ligno-cellulosic ethanol production.

2.2.8 References

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2.3 Anaerobic Fermentation for Biogas Production

Biogas can be obtained from a broad range of input material consisting of proteins, carbohydrates and lipids like biowaste, animal manure, silage etc. After a preparation stage the substrate is decomposed and fermented under anaerobic condition by enzyme releasing bacteria. For reaching a higher energy value the produced biogas may be cleaned and up-graded to natural gas quality as well as compressed, see Figure 11. The final product, Bio-Methane can be used as vehicle fuel.

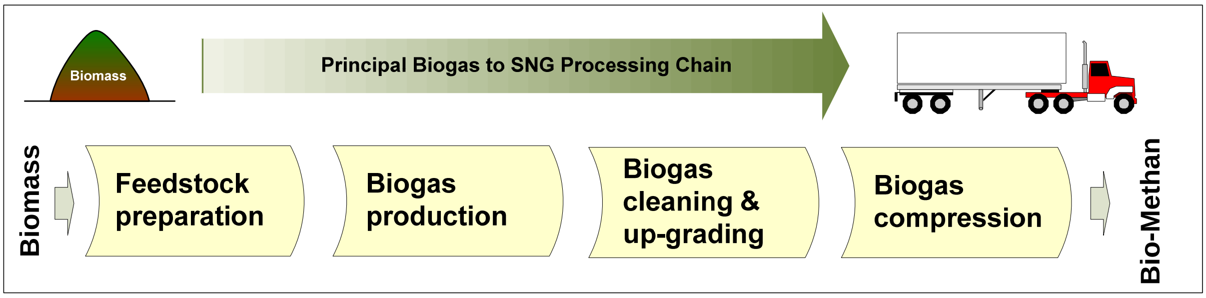

Figure 11: Biomass to bio SNG (upgraded biogas) processing chain

2.3.1 Feedstock Preparation

The process and amount of substrate preparation decides on the degradation rate of substrates and thus the exploitation of the energetic substrate potential. Thereby the pre-treatment has to cope with both legal requirements like sanitation and the living conditions of micro organisms, which create the aimed product methane. The following processes are carried out for the pre-treatment of substrates:

- **Sorting and Separation of extraneous material** such as rock, particularly appearing in biowaste
- **Sanitation** through heating up materials to 70 °C (often legally required)
- **Crushing** to open up the substrate surface for biological degradation
- **Slurrying** for producing pumpable substrates suitable for substrate transport into the digester (i.e. through adding liquid manure or water)
- **Homogenisation** of the pumpable substrates is achieved by paddle mixers/ agitators important for producing a homogenous substrate composition and thus for stabilisation of the fermentation process

2.3.2 Biogas production

Hydrolysis

The waste processed material consists mainly of carbohydrates, lipids, proteins and inorganic materials. In the first processing step, the hydrolysis, the complex compounds of the input material are decomposed into elementary organic compounds like amino acids, sugar and fatty acids. The bacteria taking active part in this process therefore release extracellular enzymes. This process is known as polymer breakdown stage. These enzymes decompose the material in a biochemical process. For example, the cellulose consisting of polymerized glucose is broken down to dimeric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria.

Acidogenic phase

After hydrolysis the formed intermediate products such as monomeric glucose are used in the acidogenic stage. Through acid-forming bacteria and under anaerobic condition the intermediate products with molecules of six atoms of carbon (glucose) are broken down into low fatty acids (acetic acid, propionic acid and butyric acid) and carbohydrates. Besides, lower amounts of alcohols (ethanol) and lactic acid are formed.

Acetogenic phase

In the acetogenic phase the products generated in the acidogenic phase are bacterially converted into precursor substances of biogas (acetic acid, hydrogen, CO_2). Too high contents of hydrogen are harmful for the acetic acid forming bacteria. Therefore the creators of acetic acid have to constitute a symbiotic community with the bacteria of the methanogenic phase. The latter consume hydrogen when creating methane and thus provide acceptable living conditions for the acetogenic bacteria.

Methanogenic phase

Within the methanogenic phase methane is formed out from the acetogenic products by methanogenic bacteria. The reactions taking place in the methanization process result in many products, by-products and intermediate products and follow several equations:

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Acetic acid → Methane + Carbon dioxide

$$2\ CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2\ CH_3COOH$$

Ethanol + Carbon dioxide → Methane + Acetic acid

$$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$$

Carbon dioxide + Hydrogen → Methane + Water

In single-stage plants all degrading stages are jointly proceeded in one digester, for which the different required environmental conditions for the degrading bacteria have to be balanced. In two-stage plants, where the first 2 and the last 2 steps are processed in place often higher decomposition performances can be reached.

Chemical composition of biogas

The produced biogas is a mixture of gases, which is composed of about one third carbon dioxide (CO_2) and two third methane (CH_4). The average composition of biogas by elements is presented in Table 1.

Table 1: Ingredients of biogas (average values) [2]

Element	Concentration (Variations)
Methane (CH_4)	50 -75 Vol.%
Carbon dioxide (CO_2)	25 – 45 Vol.%
Water (H_2O)	2 (20°C) – 7 (40°C) Vol. %
Hydrogen sulphide (H_2S)	20 – 20,000 ppm (2 Vol. %)
Nitrogen (N_2)	< 2 Vol. %
Oxygen (O_2)	< 2 Vol. %
Hydrogen (H_2)	< 1 Vol. %

For energetic use of biogas the methane content is relevant. The share of methane in the biogas mixture is influenceable only to a certain extent. Anyhow for the most common biogas production process via wet fermentation the methane concentration is dependent from several parameters like

- **Composition of input material**: For instance lipid rich and thus low in oxygen material produces higher quality gas than carbohydrates or proteins.
- **Water content of the substrate**: The thinner the fluid the more CO_2 is solved in water and the more methane is in the biogas.
- **Fermenting temperature**: The higher the temperature is the lower is the CO_2 content.
- **Dwell time, substrate pre-treatment** and the **degree of substrate decomposition**.

Besides wet fermentation the rather uncommon process of dry fermentation can be an alternative for not liquid or pumpable raw material. The conversion to biogas takes place in anaerobic condition and with a substrate moisture of 60 – 80 % (dry matter content of 20 – 40 %) in the digester. Particularly within discontinuous processes the digester content is not stirred. Though there are some dry fermentation providers on the market, the process is not completely developed.

2.3.3 Biogas Cleaning and Upgrading

Biogas has to be cleaned and upgraded for specific energetic uses. The removal of H_2S is most often an advantage, whilst the removal of CO_2 makes sense just for feed-in into the natural gas grid or for application as vehicle fuel.

Table 2: Necessity of biogas cleaning for different utilisation purposes [2]

	H_2S	H_2O	CO_2
Gas burner	> 0.1 Vol. %	No	No
CHP	> 0.05 Vol. %	No	No
Bio-SNG	Yes	Yes	Yes
natural gas grid	Yes	Yes	Yes
Torch	No	No	no

The cleaning and upgrading of biogas is particularly required for increasing the methane content and reaching natural gas quality, which consists of 98 % methane. For this upgrading primarily the processes drying, desulphurisation and the separation of methane and carbon dioxide are necessary.

Drying

In order to defend the gas processing aggregates from abrasion and destruction, the containing water vapour has to be separated from biogas. Through chilling of the gas most often within the gas pipeline a part of the water vapour is condensed. With the help of a gradient in the gas pipe and an installed condensate separator the water is collected.

Desulphurisation

For desulphurisation biological, chemical and physical processes can be applied. In general, the processes include a conversion of H_2S into elementary sulphur or prohibit the disposal of H_2S, which can be directly applied in the digester or outside.

Removal of Carbon Dioxide (Methane Accumulation)

With the removal of CO_2 from biogas the methane content in biogas is enriched and thus the energy value is enhanced. The following CO_2 removal processes are most common:

- **Water scrubbing:** In this physical absorption process the biogas is pressurised and fed to the bottom of a packed column where water is fed on the top and so the absorption process is operated counter-currently. Water scrubbing can also be used for selective removal of hydrogen sulphide since it is more soluble than CO_2 in water.
- **Pressure Swing Adsorption (PSA):** In this process the raw biogas is compressed to 4 – 7 bar. The compressed biogas is then streamed into an adsorption column on zeolites or activated carbon molecular sieves. The adsorption material adsorbs hydrogen sulphide irreversibly and is thus poisoned by hydrogen sulphide. For this reason a hydrogen sulphide removing step is often included in the PSA process.

Aggregates for these rather complex upgrading processes are currently produced in fewer quantities and thus are relatively expensive.

2.3.4 Biogas Compression

The raw biogas is available with pressure about 1 bar. For the access of the biogas facility to the natural gas grid several pressure stages have to be overcome. Depending from the respective grid the compression to pressure levels up to 20 bar are necessary.

For the use as vehicle fuel or storage in compressed gas cylinders a more intensely compression up to 200 bar is necessary to obtain adequate energy densities. In the latter case the targeted pressure can only be achieved by multistage compression.

2.3.5 Energetic Use of Biogas

Use as Biogas

Most gasoline driven vehicle engines can be adapted for additional operation with biogas. Several municipalities have introduced own bus fleets or disposal vehicles like in Sweden or Switzerland. For the use of biogas as Bio-SNG it has to be cleaned from CO_2, water vapour and H_2S (see 2.3.7) and comprised to 200 bar.

Natural gas feed-in

Particularly where there is no demand of heat, the feed-in of biogas into the natural gas grid makes sense. Therefore gas cleaning for removal of CO_2 and H_2S and gas drying (see 2.3.7) are pre-condition preparation steps.

Thermal use

Applicable along a broad range of biogas compositions, biogas can be used in most biogas capable combustion facilities for heat use only.

Use in CHP plants

Most common and highly efficient is the use of biogas in CHP plants with gas Otto engines, gas diesel engines or (for capacities between 1 and 10 MW) gas turbines. Thus produced power is used on-site or fed-in into the public power grid. The waste heat is conducted via heat transmission for heating of buildings or for use as process energy.

Use in combustion engines

Biogas is applicable for stationary and mobile combustion engines (most often in gasoline engines), thereby converted into mechanical energy. The gas mixture for gas engines has to be knock proof with a methane number between 78 and 98, which is then applicable for market available engines.

2.3.6 References

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3 Technology providers

3.1 Ligno-cellulosic ethanol

Company Name **Contact Details**	**ANDRITZ AG** Stattegger Strasse 18 8045 Graz Austria phone: +43 316 6902 2990 fax: +43 316 6902 453 **ANDRITZ Ltd. (Canada)** 2260 32nd Avenue, Lachine Quebec H8T 3H4 Canada phone: +1 (514) 631 7900 x 5231 fax: +1 (514) 631 3995 e-mail: thomas.pschorn@andritz.com web: www.andritz.com	
Core Competences	Andritz operates in the field of 2nd generation biofuels and provides the following technologies. **Bio-chemical / sugar platform** (pre-treatment systems for steam-explosion, advanced steam-explosion, AFEX, dilute acid): - Reactor and gasifier feed equipment, - Biomass Pre-treatment including impregnation, - Liquid/ Solid separation of bio-reactor slurries - Reactors/ digesters, in regular stainless steel and in higher corrosion resistance alloys like incoloy, hastelloy, zirconium - Decompression (steam explosion systems), - Washing and dewatering components Separate systems are available for C_5 and C_6 sugars, optimisation of heat/ energy balance, systems for merging, washing etc. Systems with processing several thousand tons of input material are available derived from those used in the cellulose production. **Thermo-chemical platform:** Andritz has own know-how in thermal gasification of biomass, gas cleaning etc. and biomass steam boiler, gasifier feed-systems. Andritz cooperates in this field with different customers.	

References	For the sugar platform Andritz has developed respective components for pilot & demo plants, some of them are running for a few months now. Andritz has also developed an own system for the „front end“ (advanced steam-explosion pre-treatment), installed before the enzymatic hydrolysis and fermentation. Several orders for this technology are executed by Andritz. Typical feedstocks are wood chips, particularly hard wood and wooden biomass (e.g. shrub willow, hybrid poplar), bagasse, energy crops like miscanthus, sorghum, switchgrass and agricultural residues (straw from cereals and maize, maize cobs).
Figure	 **Andritz special plug feeder / Modular Screw Device** feeding a high pressure reactor in a pre-treatment system for ligno-cellulosic ethanol, in operation since 2009 [3]

Company Name	**BioGasol ApS**	
Contact Details	Lautrupvang 2A 2750 Ballerup Denmark phone: +45 8820 4879 fax: +45 4468 4880 e-mail: info@biogasol.com web: www.biogasol.com	
Core Competences	BioGasol is a combined biotechnology and engineering company in the field of renewable energy. The core competences lie in the development and design of process technologies for the production of bio-ethanol and other energy products from ligno-cellulosic biomasses. BioGasol has developed a new highly efficient and cost effective pre-treatment process for the opening of ligno-cellulosic biomasses and a unique C5-fermentation which allows the conversion of all carbohydrates available in the biomass into ethanol and to increase and maximize the ethanol yield remarkably. It is combined with a biogas process The BioGasol Concept consists of the following process steps: • Pre-treatment • Hydrolysis • Fermentation • Anaerobic digestion of process water and recirculation	
Reference	**Ligno-cellulosic ethanol pilot plant, Ballerup (Sweden)** **Initial operation:** 2006 **Input:** ligno-cellulosic biomass **Output:** pilot plant 13 t/a; demonstration plant 6,000 t/a **Technology:** pre-treatment by steam explosion/ wet oxidation, hydrolysis, glucose fermentation by yeast, liquid fraction to xylose fermentation using thermophilic anaerobic bacterium, biogas production	

Company Name **Contact Details**	**SEKAB** Box 286 891 26 Örnsköldsvik Sweden phone: +46 (0)660 758 00 fax: +46 (0)660 549 03 e-mail: info@sekab.com web: www.sekab.com
Core Competences	SEKAB Group is one of Europe's leading ethanol producers. It produces and distributes bio-ethanol fuel and green chemical products. Moreover it works on the development of ligno-cellulose-based ethanol processing. SEKAB has built up a pilot plant next to its R&D department. During the first two years of the plant's operation, the focus has been on accessibility, operational safety and process monitoring. A large number of process refinements have been made, especially in regard to the hydrolysis reactors. Another EU-funded project SEKAB is involved as project partner is NILE (New Improvements for Ligno-cellulosic Ethanol). The project's over-arching goals are to develop cost-effective, environmentally-sound methods for the mass production of ethanol as a vehicle fuel. A commercial plant with 120,000 m^3/a is in projection and should be realised in 2014. *The further activities of SEKAB in the area of ligno-cellulosic ethanol are currently not clear, see:* *http://virtual.vtt.fi/virtual/amf/news/amfinewsletter2009_2april.pdf*
References	**Ligno-cellulosic bio-ethanol plant in Örnsköldsvik (Sweden) [4]** **Initial operation:** 2004 **Input:** wood chips from pine trees, bagasse from sugar cane, energy grass **Output:** 50 t/a **Technology:** Hydrolysis, fermentation, distillation; plant runs continuously by shifts 

3.2 Synthetic Biofuels via gasification of wood

Company Name	**Abengoa Bioenergy S.A.**	ABENGOA Innovative solutions for sustainability
Contact Details	Paseo de la Castellana, 31 - 3 Plat. 28046 Madrid Spain phone: +34 91 319 70 70 fax: +34 91 308 52 42 e-mail: abengoabioenergy@abengoa.com web: www.abengoabioenergy.es **Abengoa Corporate US, St. Louis** 16150 Main Circle Drive, Suite 300 Chesterfield MO 63017-4689 phone: +1 636 728 0508 fax: +1 636 728 1148 e-mail: abengoabioenergy@abengoa.com	
Core Competences	The Abengoa Bioenergy R&D division works on biorefinery processes with particular focus on ligno-cellulosic ethanol production through enzymatic hydrolysis and gasification of biomass to synthetic biofuels. Agricultural residues with polymeric sugars like corn stover and straw are used as input material. Abengoa´s ABNT biorefinery process fractionates biomass into major constituents, hydrolyzes the carbohydrates to sugars for ethanol fermentation. In bench-scale R&D biorefinery technologies are completed for feasibility testing and optimised processes. In the next step the operation unit is scaled up to a commercial demonstration plant. The construction of a 70 metric t/d biorefinery pilot plant is in completion at Abengoa´s research facility in York, NE, U.S.. A 4,000 t/a bio-ethanol plant in Salamanca, Spain, is under construction. In the area of biomass gasification to biofuels, Abengoa synthesises the gasified product gas to either FT diesel or gasoline or the product gas is synthesised into methanol, dimethylether (DME) or other alcohols. A demonstration plant for optimising the alcohol synthesis is under construction.	

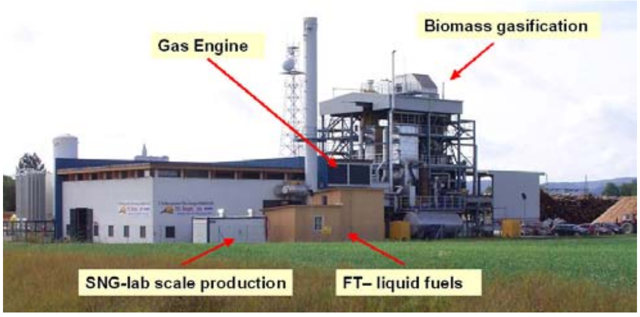
Company Name	**BASF**	
Contact Details	67056 Ludwigshafen Germany phone: +49 621 60-0 fax : +49 621 60-92693 e-mail: presse.kontakt@basf.com web: www.basf.de	
Core Competences	BASF is technology leader in catalyst development and production in various applications with about 800 employees in this field. It produces catalysts for cruel oil preparation, production of polymers and synthetics and thereby investigates in optimised catalyst technology for the production of Fischer Tropsch fuels. This aims at the successful development of Fischer Tropsch synthesis, which can be an alternative to the existing cracker technology. With BASF´s special organic salts, the “Ionic Liquids”, cellulose can be easily extracted from hydrogen compounds. The solved cellulose can thereby be broken up by enzymes. This makes the monomer sugar components applicable for fermentative use in bio-ethanol production. Further BASF provides rare earth / nickel oxide based catalysts for methanation (conversion of carbon oxides to methanol). [5]	

Company Name **Contact Details**	**CHOREN Industries GmbH** Frauensteiner Strasse 59 09599 Freiberg Germany phone: +49 (0)3731 26 62-0 fax: +49 (0)3731 26 62-25 e-mail: info@choren.com web: www.choren.com	
Core Competences	The core technology of Choren´s biomass to energy division is the Carbo-V process, which converts biomass into electrical power, heat or synthetic automotive fuel, SunDiesel®. The Carbo-V Process is a three-stage gasification process with the following sub-processes: • low temperature gasification, • high temperature gasification and • endothermic entrained bed gasification. During the first stage of the process, the biomass (with a water content of 15 – 20 %) is continually carbonized through partial oxidation (low temperature pyrolysis) with air or oxygen at temperatures between 400 and 500 °C, i.e. it is broken down into a gas containing tar (volatile parts) and solid carbon (char). In the 2nd process stage the gas containing tar is post-oxidized using air and/or oxygen in a combustion chamber operating above melting point of the fuel's ash to get a hot gasification medium. During the third stage of the process, the char is ground down into pulverized fuel and is blown into the hot gasification medium. The pulverized fuel and the gasification medium react endothermically in the gasification reactor and are converted into a raw synthesis gas. Once the product gas has been treated, it can be used as a combustible gas for generating electricity, steam and heat or as a synthesis gas for producing SunDiesel. The industrial production of FT diesel is planned to start in 2012 and is expected to have an output of 270 mio l/a biosynthetic fuel.	
Figure	 **Choren Beta Plant in Freiberg (Germany)[6]**	

Company Name	**Haldor-Topsøe AS**	
Contact Data	P.O. Box 213 Nymøllevej 55 2800 Lyngby Denmark phone: + 45-45 27 20 00 fax: + 45-45 27 29 99 e-mail: topsoe@topsoe.dk web: www.haldortopsoe.com **HALDOR TOPSOE, INC. (USA)** 17629 El Camino Real Houston, Texas 77058 phone: +1-281-228-5000 fax: +1-281-228-5109	
Core Competences	Halor-Topsøe is an internationally operating company with core competences in catalysts. In frame with Topsøe´s ammonia processes it provides methanation features, which convert any traces of carbondioxide and unconverted carbonmonoxide (CO) up to few ppm from the shift section into methane (CH_4) for SNG production. To counter problems of carbon monoxide and carbondioxide leakage, Topsoe has developed a methanation catalyst, PK-7R, which operates at inlet temperatures down to 190ºC/375ºF while ensuring that CO and CO2 are fully converted at inlet temperatures down to 190ºC/375ºF. The superior activity and stability of the PK-7R catalyst enables operating at low temperatures which provides the client with long cycle length and significant energy savings. With its ring shape, the PK-7R catalyst achieves a 50% reduction in pressure drop relative to the conventional spherical or cylindrical shaped methanation catalysts. Furthermore, Haldor-Topsøe provides DME catalysts and technology, i.e. for a number of plants in in Asia and the Middle East with capacities up to 800,000 mio t/a. Topsøe's highly active, prereduced methanation catalyst PK-7R is a nickel type catalyst based on an alumina carrier. It was developed to operate at inlet temperatures down to 190°C/375°F, a performance which has been proven in the industry since its introduction in 1994.	

Company Name **Contact Data**	**Inbicon (subsidiary of DONG Energy)** Kraftværksvej 53 7000 Fredericia Denmark phone: +45 76 22 20 00 e-mail: info@Inbicon.com miper@dongenergy.com web: www.inbicon.com www.dongenergy.com	
Core Competences	The core technology of Inbicon is a three-stage process: mechanical, hydrothermal, and enzymatic treatment of biomass. It releases the building blocks of the plant material (cellulose, hemicellulose, and lignin) and converts them to useful purposes. Inbicon reaches high pre-treatment yields of sugar, which results in high alcohol concentrations in cellulosic ethanol processing. Each batch has a lot less water and a lot more ethanol, further increasing yield and efficiency. After hydrothermal pre-treatment, Inbicon further proceeds with two biomass fractions: • The fiber fraction, which consists of 50-60 % cellulose and 2-10 % hemicelluloses, which can be enzymatically liquefied and fermented with yeast. • The liquid fraction contains high levels of C5 sugars, salts, and inhibitors. In Inbicon´s first biorefinery demo plant currently built up in Kalundborg (Denmark), this fraction was used as molasses feed for livestock, which comes to commercial maturity. Other possibilities to use C5 organisms in liquid fermentation are being investigated at the moment. With Inbicon´s IBUS process ligno-celluloses like straw, corn stover, grasses, bagasse, and household waste are converted to 2nd generation bio-ethanol. The process has been fully demonstrated at Inbicon´s pilot plants with 100 kg/h and 1 t/h ligno-cellulosic material input with 4,500 t/a ethanol output at Inbicon´s R&D unit in Skaerbaek (Fredericia), Denmark.	

Company Name	**Lurgi AG**	
Contact Data	Lurgiallee 5 60295 Frankfurt/ Main Germany phone: +49 69 5808 -0 fax: +49 69 5808 – 3888 e-mail: kommunikation@lurgi.com web: www.lurgi.com	
Core Competences	Together with the research partner Forschungszentrum Karlsruhe (see below) Lurgi operates the pilot plant bioliq for the production of BtL fuels. The first stage is implemented, in which ligno-cellulosic biomass is converted into an intermediate transportable liquid product with high energy density (bioliqSynCrude) by high-speed pyrolysis in a double snake mixing reactor. In a second stage the process will be now extended to synthetic and motor gas production. The conversion to syngas takes place at temperatures above 1400 degrees centigrade and at a pressure of 80 bar. In a third stage, the syngas produced at high pressure is purified in several process steps and routed to the downstream synthesis stage. After fuel synthesis a filling pump will be connected. The price of one litre of high-tech motor fuel is expected to be less than one euro. [7]	
References	**BtL plant bioliq, Karlsruhe (Germany) [7]** **Input:** 500 kg biomass/h (agricultural and forest residues); target input: 50 t/h **Initial operation:** 06/2007 **Output:** first stage: bioliqSynCrude, second stage: BtL fuels **Technology:** First stage: high-speed pyrolysis (implemented), second stage: entrained flow gasifier (in launch)	

Company Name **Contact Details**	**Repotec Renewable Power Technologies Umwelttechnik GmbH** Europastrasse 1 7540 Güssing Austria phone: +43 (0)3322 9010 863 0 fax: +43 (0)1 2161895 15 e-mail: repotec@aon.at web: www.repotec.at	repotec renewable power technologies
Core Competences	Repotec operates in the field of power plants and plant engineering & construction with focus on - Biomass-steam-gasification - Wood gas fuel cell - Fuel synthesis from biomass (BTL) - Natural gas synthesis from Biomass (Bio-SNG) - Biomass pressure gasification Aim of the FT pilot plant is to convert the product gas of the Biomass gasification plant with a Fischer-Tropsch (FT) process to liquid fuels, especially to diesel. A FT-PDU (process development unit) is operated, which converts about 7 Nm^3/h PG at 25bar in a Slurry reactor to FT-products. For gas cleaning first a RME-scrubber is used to dry the gas. After compression, chlorine is separated with a sodium aluminate fixed bed. Organic sulphur components are hydrated with a HDS-catalyst and the H_2S is chemically separated with Zinc oxide. Both is realised in fixed bed reactors. As catalyst in the slurry reactor, iron and cobalt based catalyst are used. The obtained diesel from the Cobalt catalyst has cetan-numbers of about 80 and is free of sulphur and aromatics. The plant is jointly operated with Technical University of Vienna and with scientific support of Paul Scherrer Institute in Switzerland.	
References	 **Wood gasification plant in Güssing (Austria) [8]** **Initial operation:** 2005 **Input:** 7 Nm3/h **Output:** 4 t/a; 0.0005 t/h	

Company Name	**Süd-Chemie AG**	
Contact Details	Lenbachplatz 6 80333 München Germany phone: +49-89-5110-322 fax: +49-89-5110-444 e-mail: Ralf.Weishaupt@sud-chemie.com web: www.sud-chemie.com	
Core Competence	Süd-Chemie is a worldwide operating chemical company with a strong focus in catalysts and adsorbents for oil refining. Beside the catalyst required in the crude oil processing, starting from 2006 the company produces in Doha / Qatar Gas-to-Liquid (GtL) catalysts. These catalysts are used in the diesel production from natural gas. In 2008 Südchemie AG and Linde AG joined forces to focus on the ligno-cellulosic ethanol plant research and marketing. This activity builds on the competences for both partners in the fields of catalysts, biotechnology and plant construction. Therefore ligno-cellulosic material like wheat and maize straw, grasses and wood are used. Thus the cooperation of Südchemie and Linde AG offers worldwide the planning and build-up of ligno-cellulosic ethanol plants. [9]	

3.2 Other technology providers for 2nd generation biofuel plants

Company Name **Contact Details**	**Genencor (Danisco A/S)** Langebrogade 1 1001 Copenhagen Denmark phone: +45 3266 2000 e-mail: customer_relations@genencor.com info@danisco.com web: www.genencor.com	GENENCOR® A Danisco Division
Core Competences	Genencor is a worldwide leading biotechnology company, which develops innovative enzymes and other bio-products. Genencor develops low-cost cellulases and other enzymes for the production of ethanol from biomass - unused crop and other plant material. With the launch of Accellerase 1500 in March 2009, Genencor has expanded and enhanced its Accellerase product line. Accellerase 1500 is a new lower-cost, more effective product available in bulk for pilot, demo, and commercial-scale cellulosic ethanol use. Acellerase® accessory products for process developers Accellerase® XY, XC, and BG are accessory enzyme products for small-scale process development. Through the enzymes´ high-performance, feedstock flexible technologies we are fast-tracking cellulosic ethanol to commercialization. Accellerase® XY and XC enzymes are designed for blending with whole cellulases, such as Accellerase® 1500. Accellerase® BG enzyme can be used to supplement enzyme complexes for improved beta-glucosidase activity for improved hydrolysis outcomes. The products are commercially available and increase process performance, flexibility and versatility in a variety of applications.	
References	In October 2008, DuPont Danisco Cellulosic Ethanol LLC broke ground on its first demo-scale biorefinery and research facility, in collaboration with the University of Tennessee (UT) Research Foundation and Genera Energy, LLC. Genencor is supplying enzymes to DONG Energy's cellulosic ethanol pilot plant in Denmark. Genencor is working with POET, the largest ethanol producer in the U.S., on its cellulosic ethanol technology.	

Company Name	**NESTE Oil Oyj**	
Contact Details	Keilaranta P.O. Box 95 00095 NESTE OIL Finland phone: +358 50 458 4885 fax: +358 10 458 4442 e-mail: osmo.kammonen@nesteoil.com web: www.nesteoil.com	
Core Competence	Neste Oil has developed a renewable diesel component NExBTL (Next Generation Biomass to Liquid) utilizing a proprietary conversion process for vegetable oils and animal fats. It is produced by direct catalytic hydrogenation of plant oil into the corresponding alkane. NExBTL Renewable Diesel is a hydrocarbon and offers better product characteristics and engine performance than first-generation biodiesels. NExBTL Renewable diesel properties are similar to the best existing diesels such as GTL. NExBTL is sulfur-, oxygen-, nitrogen- and aromatic free and has very high cetane number. Product meets the requirements set by EN590. Cold properties (cloud point) of NExBTL can be adjusted in the production from -5 to -30 ºC to meet the needs of various climatic conditions. Heating value is similar to the EN590 hydrocarbon fuel, storage stability is good and water solubility low. NExBTL diesel is compatible with existing vehicle fleet as well as diesel fuel logistic system and is technically easy to blend in conventional diesels. Beside the operating plant in Finland, three more NExBTL plants are under construction in Finland and Singapore.	
References	**NExBtL production unit in Porvoo (Finland) [10]** **Input material:** Vegetable oil, animal fats **Initial operation:** 2007 **Output:** 170,000 t/a **Technology:** Vegetable oil refining 	

Company Name **Contact Details**	**Novozymes A/S (World headquarter)** Krogshoejvej 36 2880 Bagsvaerd Denmark phone: +45 44 46 00 00 fax: +45 44 46 99 99 web: www.novozymes.com	
Core Competences	Novozymes produces a wide range of enzymes that optimize the conversion of grains such as corn, barley, wheat and rye into fuel ethanol. Thereby higher ethanol yields, faster throughput and lower overall processing costs can be achieved. Novozymes develops state-of-the-art enzyme solutions that convert cellulose into simple sugars, which in turn can be fermented into fuel ethanol. The approved enzymes by Novozymes are used for • Liquefaction by alpha-amylase for use in breaking down gelatinized starch into dextrins • Saccharification of liquefied starch by broken down dextrins to glucose • Viscosity reduction by use of enzymes that can degrade the cereal-specific components that cause the high viscosity and thereby flexible raw material use, quality choice, increased production capacity etc. Various ligno-cellulosic ethanol plants have been provided with Novozymes´cellulosic enzymes.	

3.4 Biogas through fermentation of wet biomass

3.4.1 Biogas plant manufacturers with upgrading to natural gas quality

Company Name **Contact Details**	**agri.capital GmbH** Hafenweg 15 48155 Münster Germany phone: 0251-27601-100 fax: 0251-27601-900 e-mail: info@agri-capital.de web: www.agri-capital.de	
Core Competences	The standardised product of Agri Capital are 500 kW_{el} biogas plants with inputs of 9,000 t raw material and about 5,000 m^3 slurry. A new business area is the refining of biogas to biomethane (natural gas) for feed in into the natural gas grid. In 2008 the initial operation of such biomethane refinery has been realised in Könnern near Halle as the biggest biomethane conditioning plant in Germany. There 6 Mio m^3/a of biomethane should be produced and fed into the network of the Mitteldeutsche Gasversorgung GmbH (MITGAS) for supply of about 350,000 households in the Halle-Leipzig region. Four further plants of this type are already in the planning stage.	
Reference	**Biomethane Refinery in Könnern (Germany) with upgrading technology by Malmberg [11]** **Biogas Conditioning** **Conditioning:** through pressure swing adsorption by company Malmberg **Input:** Raw biogas with nominal load of 8.65 mio Nm^3/a (47,6 Mio kWh/a) **Max. throughput capacity**: 10,4 Mio. Nm^3/a (57,2 mio kWh/a) **Output biomethane**: 5,73 Mio. Nm^3/a **Methane losses:** < 1 %, gross calorific value: ca. 10,75 kWh/Nm^3 **Biomethane Feed-in** **Distance to natural gas grid:** 200 m **Pressure Stage:** PN 16 **Type of gas:** Natural gas H **Increase of gross calorific value:** Addition of liquefied gas **Increase of Pressure:** Compression up to PN 16 **Average gross calorific value gas grid:** 11,45 kWh/Nm^3	

Company Name **Contact Details**	**BD AgroRenewables GmbH & Co. KG** Auf der Lage 2 49377 Vechta-Calveslage Germany phone: +49 (0) 4447-801-4300 fax: +49 (0) 4447-801-237 e-mail: info@bd-agro.de web: www.bd-agro.de	BD AGRO RENEWABLES
Core Competences	The plant type MegaFerm is implemented together with the associated company Krieg & Fischer Ingenieure GmbH. It usually has capacities from 500 kWel to 1.5 MWel and is suitable for feed-in into natural and micro gas grids. MegaTerm plants have a very good self-insulation, which allows their implementation in regions with extremely high or low surrounding temperatures.	
Reference	**MegaFerm Biogas plant, Hage (Germany)** **Input:** maize silage, grass silage, WCS, cattle manure **Output:** heat for municipal use, feed-in into natural gas grid **Initial operation:** 2008 / 2009	

Company Name **Contact Details**	**BioConstruct GmbH** Head quarter Niedersachsen Wellingstr. 54 49328 Melle Germany phone: +49 5226 / 5932 - 0 fax: +49 5226 / 5932 - 11 web: www.bioconstruct.de	
Core Competences	The core competence of Bioconstruct is the construction of turnkey biogas plants, development of biogas projects and the operation of biogas plants. Besides conventional use of biogas in CHP plants, Bioconstruct also installs systems for biogas refining to biomethane.	
References	**Biogas and Biomethane plant Neukammer 2, Nauen (Germany)** **Input:** 85,600 t/a manure, maize silage, rye **Initial operation:** III. Quarter 2009 (under construction) **Output:** 6.27 mio kWh_{el}, 9.05 mio kWh_{therm}; 8.43 mio m^3 methane (905,000 l fuel oil equiv.) **Technology:** Wet fermentation in single-stage flow-through process, 3 gas processors à 600 m^3/h biogas **Biogas and Biomethane plant Friedersdorf, Heidesee (Germany)** **Input:** Grass silage, rye, cattle manure, maize silage **Initial operation:** I. quarter 2009 (under construction) **Output:** 1.52 mio kWh_{el}; 1.52 kW_{therm}; 1.69 mio m^3 biomethane in natural gas quality **Technology:** Wet fermentation; 1 gas processor à 400 m^3/h biogas	

Company Name **Contact Details**	**Carbotech Engineering GmbH** Am Technologiepark 1 45307 Essen Germany phone: +49 (201) 1 72 - 19 15 fax: +49 (201) 1 72 - 13 82 e-mail: mail@carbotech.info web: www.carbotech.info	CARBOTECH
Core Competences	Carbotech has it's origin in mining research and works for over 40 years in the area of development, engineering and construction of plants for gas generation and upgrading. Today, Carbotech is part of the Schmack group and therefore offers overall solutions in energy conversation. The generation of bio-methane from biogas by Carbotech works through a pressure swing adsorption technology (PSA). Contrary to washing and membrane processes beside carbon dioxide also water, siloxane, hydrogen sulphide etc. are removed. The bio-natural gas flow is 5 to 3,000 Nm^3/h; the bio-natural gas quality reaches > 96 % methane according to DVGW-, ÖVGW-, SVGW- guidelines as well as ISO 15403.	
Reference	**Biogas Upgrading Plant, Fredrikstad Biogass AS (Norway)** **Capacity:** 150 Nm^3/h	

Company Name **Contact Details**	**Greenlane Biogas** Tullgårdsgatan 8 116 68 Stockholm Sweden e-mail: info@greenlanebiogas.com web: www.greenlanebiogas.com	
Core Competences	Greenlane is part of the world-wide operating Flotech group. Greenlane biogas upgrading systems are proprietary-designed solutions that deliver 97+% pure methane for use as vehicle fuel, or for supplementing pipeline gas. The Greenlane system uses a Ro-Flo vane type compressor to supply a packed column scrubber with raw gas, which removes unwanted components. This is followed by a (patented) adsorber process, providing pure and bone dry gas as end product. Greenlane upgrading technology has been implemented in one of the first upgrading plants in Marquette/ Lille (France) in 1995. It has provided the technology for the largest methane production plant in the world in Güstrow (Germany) with a processing capacity of 10,000 nm^3/h.	
Reference	**Biogas Upgrading Plant Marquette/ Lille (France)** **Client:** Municipality of Lille/ SOLAGRO **Initial operation:** 1995 **Output:** 100 m^3/h biogas; 80 Nm^3 vehicle fuel with calorific value of 10,7 kWh/Nm^3 (H_2 content > 97 %; CO_2 content 1,6 %) **Technology:** Water scrubbing	

Company Name	**Haase Energietechnik GmbH**	
Contact Details	Gadelander Straße 172 24531 Neumünster Germany phone: +49 4321 878-0 fax: +49 4321 878-29 e-mail: info@haase-energietechnik.de web: www.haase-energietechnik.de	
Core Competences	HAASE Energietechnik is expert in environmental technology and plant construction with focus on biogas technology, mechanical-biological waste treatment, disposal process technology and energy technology. The BiogasUpgrader technology by HAASE upgrades biogas to biomethane. The technology works with an organic cleaning dilution. The procedure increases the methane percentage inside the gas to 90-98 Vol% (adjustable values) and eliminates at the same time sulphur and water vapour. This is used for feed-in into the municipal natural gas grid and for use as vehicle fuel. Four upgrading plants has already been realised in Germany.	
References	**Biogas Upgrading plant in Ronnenberg (Germany)** **Clients:** 5 regional farmer cooperatives, municipal energy supplier Hannover **Initial operation:** 2008 **Output:** 650m³/h of biomethane (feed-in capacity of 28 mio kWh/a) fed-in into natural gas grid **Technology:** Organic physical scrubbing **Biogas Upgrader plant in Jameln (Germany)** **Client:** Raiffeisen-Genossenschaft Jameln **Initial operation:** 2006 **Output:** 650m³/h (2,4 mio m³/a) biomethane for vehicle fuel **Technology:** Organic physical washing by absorption	

Company **Contact Details**	**Kompogas AG** Flughofstrasse 54 8152 Glattbrugg Switzerland phone:+41 44 809 77 77 fax:+41 44 809 77 00 e-mail : info@kompogas.ch web: www.kompogas.ch
Core Competences	Kompogas offers biogas plant systems along the whole biogas value added chain with specialisation on green waste fermentation. Besides the standard product portfolio Kompogas offers biogas upgrading facilities for refining up to natural gas quality. The upgrading process involves removing CO_2, sulphur and water from the biogas to raise the proportion of methane it contains. Once the treated biogas has been compressed to 250 bar, it can be used as Kompogas, a vehicle fuel equivalent to natural gas. Kompogas has been used as a fuel for years in Switzerland, for instance in a mixture of Kompogas and natural gas marketed by Erdgas Zurich AG.
References	**Biogas and Upgrading Plant Utzenstorf (Switzerland)** **Input:** 12,000 t/a biowaste **Initial operation:** 2007 **Output:** 105 to 130 m³ biogas per ton raw material (70 – 90 l petrol) **Technology:** 2 concrete construction fermenter **Biogas and Refinery plant Engelhölzi / Jona (Switzerland)** **Client:** Municipality Jona, contractor : R.O.M. AG **Input:** 5,000 t/a municipal organic biowaste **Initial operation:** 2005 **Output:** 505,000 Nm^3/a biogas yield ~ 105 Nm^3/t Input; fed-in gas volume: 302,000 Nm^3/a **Technology:** Concrete fermenter; fuel feed-in into natural gas grid of Erdgas Zürich

Company Name **Contact Details**	**Malmberg Water AB** 296 85 Åhus Sweden phone: +46(0)44-231800, fax: +46(0)44-231880 mail: info@malmberg.se web: www.malmberg.se	
Core Competences	Malmberg has a long tradition in environmental solutions and respective plant construction. It operates in four business areas: - Water treatment - Biogas - Heating/Cooling - Drilling - Environmental services For more than 15 years, Malmberg works on the upgrading of biogas to vehicle fuel or for the natural gas grid. Malmberg Compact™ is a prefabricated plant for upgrading, assembled directly in a specially manufactured, insulated, ventilated sheet steel building. It uses the scrubber technology with water circulation. In line with the Compact series Malmberg filling stations are delivered in prefabricated buildings or are integrated into the gas purification plant.	
References	**Biogas Upgrading and Fuel Station, Stockholm (Sweden)** [12] **Client:** Stockholm Vatten **Initial operation:** 2001 **Input:** 1x 400 m^3/h raw biogas, 1x 600 m^3/h raw biogas **Output:** 6 mio Nm^3/a gas **Technology:** Water scrubber More references see Ökobit (plant in Darmstadt) and Schmack (plant in Könnern)	

Company Name **Contact Details**	**ÖKOBiT GmbH** Jean-Monnet-Straße 12 D-54343 Föhren Germany phone: +49-(0) 65 02 /93859-0 fax: +49-(0) 65 02 /93859-29 e-mail: info(at)oekobit.com web: www.oekobit.com	
Core Competences	Besides plant engineering and construction of biogas plants, Ökobit offers biogas upgrading through pressurised swing adsorption for feed-in into natural gas grids.	
Reference	**Biogas Refinery Plant Darmstadt (Germany)** **Client:** HEAG Südhessische Energie AG (HSE) Input: 2,600 t/a pig manure, 10,800 t/a whole crop and maize silage, rye **Initial operation:** 2008 **Output:** 2.5 mio m^3 biogas; 300 Nm^3/h crude gas **Technology:** Pressure swing adsorption by Malmberg; natural gas in quality H	

Company Name	**Schmack Biogas AG**	
Contact Details	Bayernwerk 8 D-92421 Schwandorf Germany phone: +49 (0) 94 31/ 751 - 0 fax: +49 (0) 94 31/ 751 - 204 e-Mail: info@schmack-biogas.com web: www.schmack-biogas.com	
Core Competences	Since 1995 Schmack Biogas works on the planning and construction of biogas plants and has its own accredited biotechnology laboratory for biogas and environmental analyses. Schmack offers plant solutions for upgrading of biogas to natural gas quality through pressure swing adsorption. Together with the biogas upgrading expert CarboTech Engineering GmbH it has realised the first biomethane plant in Germany, in Pliening near Munich.	
Reference	**Biogas upgrading plant Mühlacker (Germany)** **Client:** Municipal energy supplier Mühlacker **Input:** 37,000 t/a maize, cereals, grass **Initial operation:** 2007 **Output:** 2 MW_{el}; 5 MW_{therm}; 500 Nm^3/h biomethane; upgrading capacity: 4,4 Mio Nm^3/a biomethane in natural gas quality; feed-in of ca. 48 mio kWh in natural gas grid **Technology:** Biogas upgrading by CarboTech GmbH	

3.4.2 Biogas plant manufacturers providing standard turnkey biogas plants

Company	**AAT - Abwasser- und Abfalltechnik GmbH**
Contact Details	Konrad-Doppelmayr-Str. 17 6960 Wolfurt Austria phone : +43/5574/65190-0 fax : +43/5574/65185-6 e-mail: office@aat-biogas.at web: www.aat-biogas.at
Core Competences	AAT offers plant design, process engineering and equipment supply for sorting and anaerobic treatment of organic residue and highly polluted organic waste water including biogas handling and utilization. AAT core business is pre-treatment and anaerobic digestion of solid and wet biomass. AAT offers the following digester systems are offered: - Hydraulically mixed digester - Energy crops digester - Prefabricated digester - Compact digester Key components offered are fermenter agitators, safety devices, gas holders, biogas handling equipment, desulphurization plants, flares and off-gas biofilters.
References	**Organic waste disposal plant Roding (Germany)** **Client:** ERC Energie Recycling Landkreis Cham **Input:** bio-waste, kitchen residues, float from fat flotation units **Initial operation:** 1996 **Ouput:** 400 kW_{el} **Technology:** hydraulic mixing with special design for sediment withdrawal, 650 m^3 digester volume **Municipal plant ARA Meiningen (Austria)** **Client:** ARA Meiningen **Input:** sewage sludge **Initial operation:** 2001 **Output:** 630 kW_{el} CHP **Technology:** Sewage sludge digestion 4,000 m^3

Company Name **Contact Details**	**Biogest Energie- und Wassertechnik GmbH** Büropark Donau Inkustraße 1–7/5/2 3400 Klosterneuburg Austria phone: + 43 2243 20840 10 E fax: + 43 2243 20840 40 e-mail: office@biogest.at web: www.biogest.at	BIOGEST®
Core Competences	**Single processing fermenter (SPF)** for easily degradable substrates (maize silage, sunflower silage or slurry). This single-stage process optimises fermenter volume and volumetric loading and has an outstanding price/performance ratio. **Biogest PowerRing Technology** o for unrestricted biodegradable material use o minimised heat losses through thermally-insulated fermenter cover o up to 99 % of design full load elapsed hours o mesophilic light load fermenter for stable and effective biological degradation process	

References

Project / Location	Country	Dimension	Initial operation
Szeged	Hungary	1,000 kW	2008
Desov	Czech Republic	500 kW	2008
Bekko – Odessa	Ukraine	1,000 kW	2008
GAV Krems I	Austria	125 kW	2005

Company **Contact Details**	**Enbasys Biotechnological Energy Plants** Parkring 18 8074 Grambach/ Graz Austria phone: +43 (0) 316 4009-5600 fax: +43 (0) 316 4009-5605 e-mail: office@enbasys.com web: www.enbasys.com www.vtu.com	
Core Competences	Enbasys is a subsidiary of the internationally active VTU Holding. Its core competence is anaerobic digestion technology, but also the know-how in plant engineering combining qualifications in various industry segments, such as substrate management, waste water treatment with low chemical input, biodiesel production, power generation and biotechnology. Enbasys´ innovative system "High Load Hybrid Reactor" produces biogas ➢ from various substrates, like side products of biofuel production or organic residues with high COD content ➢ with large volume-streams (loading rate of 15 kg chemical oxygen demand/m³ fermenter volume) ➢ with high performance digesters (UASB) for waste water (e.g. exhaust vapours, rinsing water) of low organic concentration	
Reference	**North Italy I Biogas plant** **Input:** 350,000 t/a organic municipal and food industry waste; liquid phase: 120,000 t/a **Initial operation:** 2007 **Output:** 3 MW_{el} CHP **Technology:** 2 x 2,900 m³ digester; loading rate: 11,6 kg chemical oxygen demand/m³·d	

Company Contact Details	**Thöni Industriebetriebe GmbH** **Division of Environmental and Energy Engineering** Obermarktstraße 48 6410 Telfs Austria phone: +43 5262 6903-502 fax: +43 5262 6903-510 e-mail: umwelt@thoeni.com web: www.thoeni.com	
Core Competences	Since 1990, Thöni has been involved in developing innovative technologies and modern systems engineering for treating waste and generating biogas from organic waste and raw materials. The fermentation plants are jointly designed with the partner Kompogas. Besides classical fermentation the wet conditioning process for biowaste (co-fermentation) is part of Thöni´s standard portfolio.	
References	Thöni in licensed partnership with Kompogas **Biogas Power Plant Flörsheim-Wicker / Frankfurt (Germany)** **Client:** Rhein-Main Deponie GmbH **Input:** 45,000 t/a of source-segregated biowaste **Initial operation:** Spring 2008 **Technology:** EMSR Technology / Fermenter Thöni in licensed partnership with Kompogas **Biogas Power Plant PASSAU / HELLERSBERG (Germany)** **Client**: AWG DONAU-WALD MBH **Input:** 39,000 t/a of source-segregated biowaste **Initial operation:** November 2004 **Output:** 2 x 836 kW_{el} **Technology:** 3 Thöni - Kompogas – Fermenter; Conditioning fermentation residues/ screw presses	

3.5 Selection of research institutes in the field of 2nd generation biofuels

Institutes Name **Contact Data**	**Aston University** **Bio-Energy Research Group** **Chemical Engineering & Applied Chemistry** Aston Triangle Birmingham, B4 7ET United Kingdom phone: +44 121 204 3381 fax: +44 121 204 3680 e-mail: a.v.bridgwater@aston.ac.uk web: www.aston-berg.co.uk	
Core Competences	BERG - the **B**io**E**nergy **R**esearch **G**roup at Aston University is one of the largest university based research groups in thermal biomass conversion in the world. BERG focuses its efforts on thermal processing and particularly fast pyrolysis for production of liquids that can be used as fuels for power and/or heat production; for production of transport fuels; or as a source of chemicals. The research fields consist of: Thermal processing • Pyrolysis for production of liquid (bio-oil), gas and charcoal • Gasification for production of gas for use as fuel, for production of hydrogen, or for synthesis of transport fuels and chemical • Combustion for production of heat that can be used for heat and/or power production Biological processing • Fermentation to alcohol, including bio-ethanol and biobutanol that is used as a transport fuel or is added to gasoline • Digestion (anaerobic digestion) to bio-gas - a mixture of methane and carbon dioxide - that can be used for heat and/or power Mechanical processing • Production of vegetable oils that can be upgraded to bio-diesel (RME - rape methylester), which can be added to diesel	

Institutes Name Contact Data	**Bioenergy 2020+ GmbH** Inffeldgasse 21b 8010 Graz Austria phone: +43 316 873-9201 fax: +43 316 873-9202 e-mail: centre@bioenergy2020.eu web: www.bioenergy2020.eu	bioenergy2020+
Core Competences	Biomass gasification and fermentation (biogas) as well as liquid biofuels for transport are key research fields of Bioenergy 2020+ (BE2020). The area of thermal gasification is dealing with i.e.: ➢ Development of advanced gasification (FICFB, pressurised gasification, slagging gasifier) and gas cleaning systems for advanced CHP (combined cycles: engine/ORC, fuel cells). ➢ Research and development of polygeneration plants with production of heat, power, and synthetic biofuels (Bio-SNG, BtL) for vehicles and/or feed-in into natural gas grid. ➢ Utilisation of the producer gas in various industrial applications (e.g. steel industry). ➢ Studies and fundamental research on raw materials from biomass for chemicals. In the area of fermentation (biogas) BE2020 works on i.e. following research topics: ➢ Industrial high rate digestion process technology development capable of using diversified raw materials ("energy crops") and substrate mixtures from industrial by-products. ➢ Improvement of the biogas quality, through pre-separation of NH_3, H_2S and CO_2. ➢ Alternative use of biogas (i.e. upgrading to fuel quality, reforming of CH_4). Beside this BE2020 provides engineering services mainly in the field of 1st generation biofuels as well as consultancy services for various technological and economical biomass related projects.	

Institutes Name Contact Data	Cutec Clausthaler Umwelttechnik Institut GmbH Leibnizstraße 21+23 38678 Clausthal-Zellerfeld Germany phone: +49 5323 933-0 fax: +49 5323 933-100 e-mail: cutec@cutec.de web: www.cutec.de	
Core Competences	Cutec works in the research fields of development and optimisation of biofuels and chemical raw materials. With the 0,4 MW_{th} BtL demonstration plant Artfuel launched in 2005, which is operated in support of the automobile industry MAN DWE reactors, a technology will be developed for the central production of FT biodiesel. The plant consists of gasification in an atmospheric circulating fluidised bed with oxygen and steam and the FT synthesis. For FT synthesis a low temperature fixed bed reactor is applied. First BtL products have been produced in the demonstration plant. [13] Furthermore, Cutec works on the optimisation of methanol synthesis technologies.	

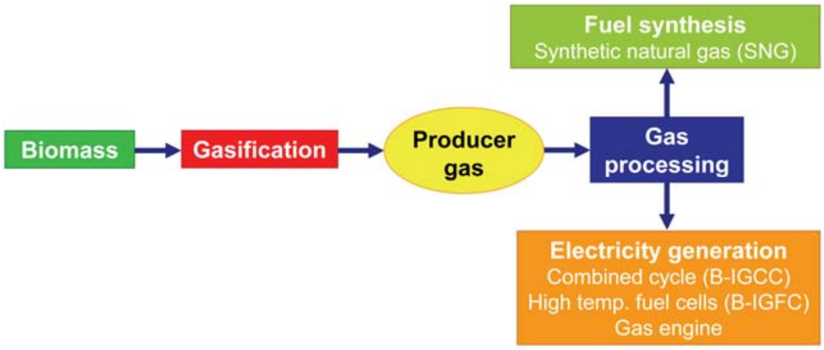
Institutes Name Contact Data	**Energy Research Centre of the Netherlands** P.O. Box 1 1755 ZG Petten Netherlands phone: +31 224 56 4949 fax: +31-224-568487 e-mail: vanderdrift@ecn.nl reith@ecn.nl web: www.ecn.nl	ECN Energy research Centre of the Netherlands
Core Competences	The current status of ECN development of Bio-SNG technologies is that a lab-scale system from biomass to raw SNG is available consisting of a 5 kg/h MILENA indirect gasifier, OLGA tar removal, various dry cleaning reactors for the removal of other contaminants such as sulphur and chlorine, catalytic conversion of olefins, and catalytic methanation reactors. This lab-scale test facility is used to support the selection of conditions and materials. Furthermore, a 160 kg/h MILENA gasifier has been realized in May 2008. It is connected to gas cooler and OLGA tar removal. Further gas cleaning and methanation will be added in 2008/2009, based on lab-scale results.	

Institutes Name **Contact Data**	**Forschungszentrum Karlsruhe** **Karlsruhe Institute of Technology (KIT)** Hermann-von-Helmholtz-Platz 1 76344 Eggenstein-Leopoldshafen Germany phone: +49 724782-0 fax: +49 7247 82-5070 e-mail: kfz@umwelt.fzk.de web: www.fzk.de	Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft
Core Competences	The research area Renewable Energies of KIT is active in R&D for biomass use as chemical energy source in kind of gaseous or liquid biofuels. For the conversion of ligno-cellulosic biomass KIT operates the bioliq®-pilot plant, in which the input material is converted into a tough liquid (slurry) with 10-15 times higher energy density, known as bioliqSyncrude®. In a second step BioSyncrude is further converted into synthesis gas and methanol through a high temperature gasification process. For the generation of biofuels methanol passes through another synthesis step. The plant scale for commercial application of this technology is enhanced step by step. Currently the phase for synthetic gas generation is realised and the stage for the production of biofuels has now be launched. Therefore the synthesis via Fischer Tropsch process and the synthesis via methanation with central conversion of methanol to BtL fuels is planned.	

Institutes Name Contact Data	**German Biomass Research Centre gGmbH (DBFZ)** Torgauer Str. 116 04347 Leipzig Germany phone: +49 (0)341 2434-112 fax: +49 (0)341 2434-133 e-mail: info@dbfz.de web: www.dbfz.de	
Core Competences	DBFZ is a non-profit company owned by the Federal Republic of Germany. The core activity of DBFZ is practical and industry driven research and development in technical, ecological and economic issues of energetic use of solid, liquid and gaseous biofuels. The activities are carried out in the following departments: ➢ Bioenergy Systems ➢ Biogas technology ➢ Biofuels ➢ Thermo-chemical process engineering ➢ Biomass combustion ➢ International affaires	

Institutes Name **Contact Data**	**Joanneum Research** **Institute of Energy Research** Elisabethstrasse 5 8010 Graz Austria phone: +43 316 876 1336 fax: +43 316 876 1320 e-mail: max.lauer@joanneum.at web: www.joanneum.at/en/fb1/ief.html	
Core Competences	The Institute of Energy Research works on the improvement of current and the development of new technologies. With solutions for efficient and environmentally friendly energy planning the institute provides support to companies, local authorities and regions that have opted for responsible energy policy - not least in response to changing legislation. It participates in numerous national and international boards and platforms. The Institute focuses on the following research fields: Renewable Energy Technologies • Development of combustion and control technologies for biomass-based generation of combined heat and power, process heat and space heating • Development of cooling systems using RE sources • Biological gasification of biomass in biogas plants for heat and power generation Energy Systems and Strategies • Information platform for “hydrogen” and “fuels of the future” • Knowledge database supporting technology transfer in the energy and environment sector • Energetic analysis and optimisation of industrial production processes • Assessment of future transport systems from an energy and environmental engineering perspective Energy, Land Use and Climate Change • Assessment of environmental impacts of energy use based on life cycle analyses including carbon sources and sinks • Method development and consulting in emissions trading and project mechanisms of the Kyoto Protocol	

Institutes Name Contact Data	**Lund University** **Department of Chemical Engineering** Center for Chemistry and Chemical Engineering P.O. Box 124 221 00 Lund Sweden phone: +46 46 2228297 fax: +46 46 222 45 26 e-mail: guido.zacchi@kat.lth.se web: www.chemeng.lth.se	LUND UNIVERSITY
Core Competences	The main part of the research within the department falls within the areas of environmental and energy engineering, and product and process development. A great research challenge for the department is to create energy-efficient processes. This comprises: • catalysis • energy saving in separation processes, e.g drying and membrane processes • industrial energy conservation in the process industry • development of gasification processes • development of biomass-based motor fuels Besides, the department works in the fields of development of production systems for products and alternative fuels from renewable raw materials, chemical products and processes as well as industrial biotechnological applications.	

Institutes Name **Contact Data**	**Paul Scherrer Institute** **Thermal Process Engineering Group (TPE)** 5232 Villingen Switzerland phone: +41 56 310 29 32 fax: +41 56 310 21 99 e-mail: serge.biollaz@psi.ch web: http://tpe.web.psi.ch	
Core Competences	Since 2002 TPE has been focussing its activities on the conversion of abundant or waste biomass (woody and dry herbaceous biomass) via conventional gasification process either into 2nd generation bio-fuels (synthetic natural gas SNG) or electricity via high temperature fuel cells and gas turbines. System integration of gasification, gas processing and the final conversion process is one key for a successful implementation of such technologies in the market. New technologies have to compete with established biomass-based technologies. Techno-economic requirements for new technologies are therefore well known and dictate in which directions technology development has to go. More or less independent of the conversion route, the following unit operations are important: ➢ Removal of particles and heavy metals ➢ Treatment and/or removal of hydrocarbons, especially tars ➢ Treatment and/or removal of sulphur species	
Figure	 **Scope of TPE research fields**	

Institutes Name Contact Data	**Technical University Bergakademie Freiberg** **Institute of Energy Process Engineering and Chemical Engineering** Reiche Zeche Fuchsmühlenweg 9 IEC-Haus 1 Freiberg Germany phone: +49 39-4533 fax: +49 39-4555 e-mail: thomas.kuchling@iec.tu-freiberg.de web: http://tu-freiberg.de/fakult4/iec/forschungsgebiete.en.html?int_fav=en	
Core Competences	The Institute is currently building up a pilot plant with a 10 MWth single-stage pressurised circulating bed gasifier with Power High Temperature Winkler technology (PHTW) as well as methanol synthesis with 15 kg/t input via central conversion of methanol to BtL fuels. As input 2,4 t/h straw and energy wood is used.	

Institutes Name **Contact Data**	**University College Cork** **Department of Civil &** **Environmental Engineering** **Sustainable Energy Research Group** Ireland phone: +353 21 4902286 fax: +353 21 4276648 e-mail: jerry.murphy@ucc.ie web: http://www.ucc.ie/en/civileng/Contact/	UCC Coláiste na hOllscoile Corcaigh, Éire University College Cork, Ireland
Core Competences	The principle research areas of the Sustainable Energy Research Group are sustainable energy systems analysis, energy modelling, energy trends analysis, sustainable energy policy research, wind energy prediction and resource analysis, hydrogen production and fuel cells. The expertise within the Group is recognised at national level and SERG staff have been called on to provide key input to a number of energy and environmental policy initiatives, including the Ministerial Renewable Energy Strategy Group, National Climate Change Inventory Data Users Group and the Steering Group on the Grid Upgrade Development Programme. External Strategic advice to Sustainable Energy Ireland was provided in establishing its Renewable Energy Information Office and is currently being provided in the establishment of its Energy Policy Statistical Support Unit.	

Institutes Name **Contact Data**	**University of Copenhagen Forest & Landscape Denmark** Hørsholm Kongevej 11 2970 Hørsholm Denmark phone: +45 3533 1704 fax: +45 3029 8468 e-mail: hnj@life.ku.dk web: www.ucc.ie/en/civileng/Contact/	
Core Competences	Forest & Landscape Denmark is an independent centre at the University of Copenhagen (UC) and undertakes research, education, extension and consultancy services in the area of forest, landscape and planning. It researches into the production and use of wood for fuel, both for heating, production of electricity and as a liquid biomass. Furthermore it works on the whole spectre of "the wood chain", from planting the most useful tree species for timber and other purposes, to their treatment for obtaining the correct quality, and in this way ensuring the future supply of strong wood for construction, beautiful wood for floors and furniture, light wood fibres for paper and fuel for energy and other uses.	

<table>
<tr>
<td>Institutes Name
Contact Data</td>
<td>University Hamburg-Harburg
von Thünen Institutes (vTI) for Wood Chemistry
Leuschnerstrasse 91
21031 Hamburg-Bergedorf
Germany

phone: +49 40 739 62 517
fax: +49 40 739 62 502
e-mail: d.meier@holz.uni-hamburg.de
web:
www.holzwirtschaft.org/content.php?main=international&nav=index
www.vti.bund.de/en/institutes/htb/</td>
<td></td>
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<tr>
<td>Core Competences</td>
<td colspan="2">The vTI works on increased eco-efficiency for chemical wood engineering, particularly for reduction of harmful emissions and residues and increase of energetic and material exploitation of wood. Therefore novel, environmentally friendly technologies are developed with focus on optimisation of the paper and chemical fibres production including thermo-chemical and biotechnological processes like use of catalysts and alternative utilisations for renewable sources.
The following research fields are covered by the institutes:
<table>
<tr><td colspan="2">University Hamburg
Centre for Wood Sciences</td><td>Johann Heinrich von Thünen Institutes</td></tr>
<tr><td>Department for Forest and Wood Management</td><td>Global Forest Management</td><td>Institute for Global Forest Management</td></tr>
<tr><td></td><td>Economy</td><td>Institute for Forest and Wood Economics</td></tr>
<tr><td></td><td>Work sciences</td><td></td></tr>
<tr><td>Department for Wood Technology</td><td>Chemical Wood Engineering</td><td>Institute for Wood Technology and Wood Biology</td></tr>
<tr><td></td><td>Mechanical Wood Engineering</td><td></td></tr>
<tr><td colspan="2">Department for Wood Biology</td><td></td></tr>
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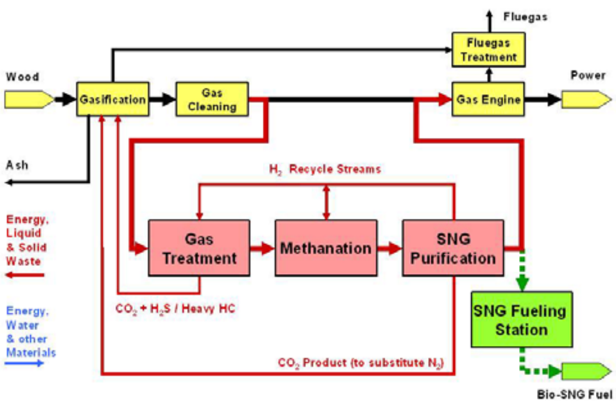
<table>
<tr><td>Institutes Name
Contact Data</td><td>Vienna University of Technology
Institute of Chemical Engineering
Getreidemarkt 9/159
1060 Wien
Austria

phone: +43 1 58801 15970
fax: +43 1 58801 10001
e-mail:
hhofba@mail.zserv.tuwien.ac.at
web: http://www.vt.tuwien.ac.at/</td><td>TU WIEN</td></tr>
<tr><td>Core Competences</td><td colspan="2">The Technical University of Vienna with technical support of Repotec and the European Renewable Energy Centre operates the FT pilot plant in Güssing and as well builds up a Bio-SNG plant. The following achievements can be outlined:
Biomass CHP Güssing is now for 6 years in operation and reaches availabilities over 90 %
2^{nd} biomass CHP based on dual fluidised steam gasification is under commissioning
At lab scale a successful 1,000 hours test was already done to prove the concept
Research on Fischer Tropsch diesel is ongoing and first results are very promising
Concept for polygeneration has been developed to bring also small scale 2^{nd} generation biofuels (~ 50 MW fuel input) on the market
Efficiencies of 2^{nd} generation fuel are high (for Bio-SNG over 60 % and for FT liquids up to 50 %)
For polygeneration an overall efficiency of about 80 % can be reached (biofuel, electricity and district heat)</td></tr>
<tr><td>Figure</td><td colspan="2">

Schematic example for the Bio-SNG fuel production plant in Güssing [14]</td></tr>
</table>

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Core Competences	VTT develops novel fuel conversion methods for production of liquid biofuels for boiler, engine and turbine use. VTT particularly focuses on the development of fast pyrolysis in laboratory and bench-scale facilities and in close cooperation with industry. In the area of transportation fuels VTT´s expertise covers both thermochemical and biotechnical processing of ligno-cellulosic materials and process optimisation. In particular, VTT covers the following research topics: • Pyrolysis • Process assessments of thermochemical conversion (e.g. IEA-TEA project) • Production of transportation fuels • Use of liquid biofuels in engines and vehicles	

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