Technologies relevant for gasification and methanation in Denmark

Project:
Detailed analysis of bio-SNG technologies and other RE-gases

ForskNG 10689

Work Package 3: Environmental aspects and analysis

Milestone 3.1-1:
Report on inventory of relevant bio-SNG technologies

Project report
September 2012
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Report on inventory of relevant bio-SNG technologies

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1 Introduction

1.1 This project

This project is funded by the Forsk-NG program. This report is a Milestone report for Task 3.1 of the project “Detailed analysis of bio-SNG technologies and other RE-gases”, Forsk-NG 10689. It is a report on inventory of relevant bio-SNG technologies. In this report a list of technologies relevant for production of bio-SNG from gasification of biomass is presented.

1.2 Danish gasification plants

During a long period of time a range of gasification technologies has been developed in Denmark. This has been possible due to funds such as UVE, PSO, EFP, EUDP, ForskEL, ForskVE.

All Danish gasification technologies are characterised by the fact that the producer gases – immediately after gasification – are used in a boiler or an engine. This use is initially the most effective because after purification and without modification the gases can be used directly in a boiler or an engine.

1.3 Possible solutions

However, a gasifier plant is rather expensive, which means that in order to be cost-effective the gasifier must operate as base load. In the future, an expectably larger production of producer gases will, therefore, cause a need for storage of the energy – because there won’t be correspondence between production and utilisation. This storage is possible by producing bio-SNG by methanation and then adding it to the natural gas grid and storages.

There are two ways of making gasification plants more cost effective: “Saving by size” and “Saving by number”. Large plants of course have the advantage of smaller specific price for the installation. On the other hand a great number of equal plants scattered across the country would also reduce the specific cost of installations and the expenses for transport would reduce as well.

Even a third possibility is to install at a plant several parallel units for gasification technologies that have maximum unit size and attaching one com-
mon methanation unit. This increases the operational reliability of the plant and save installation costs where possible.

In Denmark, as an example, a plant of 60 MW (output) might be considered, corresponding to approx. 75 MW input. It could correspond to 5-6 unit lines in parallel with very high operation reliability (10-12 MW as unit size). It would be a possibility to install a common (relatively cheaper) methanation unit (e.g. TREMP) after the gasifiers. This methanation unit could also supply steam to the gasification process itself achieving a synergy effect and increasing efficiency.
2 Bio-SNG gasification technologies

Within EU and globally a wide range of SNG production technologies are at hand. The most important ones are described in this report.

Figure 2.1 shows a diagram of the processes included in the conversion of biomass to SNG.

![Diagram showing the processes from biomass to bio-SNG](image)

2.1 The Lurgi process

The Lurgi process was developed in Germany in the 1930s for production of SNG from coal. Through the 60s and 70s a couple of pilot and demonstration plants were built. So far, the only commercial plant for production of SNG is Great Plains Synfuels Plant in North Dakota, US. This plant is based on the LURGI processes for gasification and methanation. The methanation part is in some ways similar to the Haldor Topsoe TREMP process (or perhaps the other way around).

The plant in North Dakota began operating in 1984 and has since 1999 produced CO$_2$ to EOR (Enhanced Oil Recovery) to a nearby oil field. Using Lurgi gasifiers, the Synfuels Plant gasifies lignite coal to produce valuable gases, liquids and metals.
2.2 The Güssing gasifier

The most enhanced indirect gasification system for biomass seems to be Güssing gasification system, which is based on fluid bed technology and steam. It was primarily developed at VUT (Vienna University of Technology).

Figure 2.3 shows schematically the indirect gasification method. The reactors consist of two fluid beds (dual fluid bed) – one for gasification and one for combustion.

Gasification is to the left where steam is fed from the bottom and biomass from the left. The heat for this process is added in form of hot particles such
as (sand, dolomite etc.) and then heated in the combustion section. The product gases exit from the top of the gasifier to the left and in the bottom sand and degasified char particles are transported to the combustion reactor.

In the combustion reactor air is fed at the bottom and char particles burn in the fluid bed and heats the sand, which is led to the gasifier. Often the circulating mass flow rate of this heat carrier is much larger than that of the biomass. Based on the lower calorific value of the biomass this method can achieve an efficiency up to 70% from biomass to SNG.

When the producer gas is cleaned for particles, tar and other components it can be converted into bio-SNG.

In Güssing an 8 MW gasifier plant is in operation. It has been connected to a 1 MW methanation unit, which has demonstrated production of synthetic natural gas (SNG). The project was financed by EU, FP6 Project BIO-SNG, where 9 different European countries participated. Figure 2.4 shows a diagram of the Güssing gasifier.

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**Figure 2.4** Dual fluid bed system of the Güssing gasifier [3]
The gasifier in this system is a bubbling fluid bed, while the combustion reactor is a circulation fluid bed with a riser where the char particles and bed material are lifted by means of a high upward gas velocity. The product gas from this process has a relatively low content of tar. The process is called FICFB (Fast Internally Circulating Fluidised Bed).

The concept was primarily developed at VUT (Vienna University of Technology). The gasification products are used in boilers, for CHP and for demonstration of fuel production (incl. bio-SNG). For demonstration purposes a compressor unit was installed and natural gas vehicles have been fuelled with bio-SNG from wood gasification.

### 2.3 The Chalmers gasifier

At Chalmers University of Technology (Sweden) a pilot project is installed in order to gain experience with gasifiers and as a preparation for the GoBiGas project. It is a circulating fluid bed and it produces 2-4 MW producer gas which is used in a boiler. The gasifier is built as an add-on and retrofitted to a larger fluid bed reactor (10-12 MW) where biomass is combusted and which supplies heat to the university. Figure 2.5 shows a diagram of the Chalmers gasifier.

Part of the circulating fluid bed material can be led to the gasifier where the hot sand circulating in the bed transfers heat to the gasification. Chalmers is using sand only in the gasifier because it is a very durable material, which is well known as bed material.

It is one of Europe’s (except from the Güssing gasifier) largest pilot plants for gasification of biomass. On this gasification plant a number of smaller subdevices can be tested and sub streams extracted from different places. In this way the subprocesses can be analysed.

This is part of the preparation for the GoBiGas project and other Swedish gasification projects. The GoBiGas project uses the principles from the Chalmers gasifier on the first 20 MW plant in Gothenburg.
2.4 MILENA and OLGA processes

Another interesting technology is the MILENA technology that ECN (Energy research Centre of the Netherlands) has developed. It is similar to the Güssing technology, but was developed specially for bio-SNG production and is intended to be used in combination with another process developed by ECN - the OLGA process. The OLGA process is a method to efficiently remove tar from the producer gas. The combination MILENA-OLGA is reported to give 70 % biomass -> bio-SNG conversion.

An 800 kW plant is in operation at ECN in Petten, The Netherlands. The next phase includes a 10 MW plant, which, however, will not be located at ECN. It will be built together with the Dutch HVC Group at Alkmaar in the Netherlands.

The OLGA process is a gas cleaning process to remove tar from producer gases. The energy of the gas cleaning process is utilised in the gasification
process. The Dutch company Dahlman (www.dahlman.nl) holds the rights to the process. The OLGA technology was demonstrated at a 4 MW plant in Moisannes, France.

ECN’s gasification process is an indirect fluid bed process. Steam and air is added to the gasification process, and the bed material is then heated in a combustion process. The char and part of the tar is used in the combustion process. Figure 2.6 compares the Güssing gasifier with the MILENA gasifier.

Both gasification processes shown in Figure 2.6 are indirect processes, i.e. heat is added externally and not from the gasification process itself. In MILENA gasification takes place in the circulating fluid bed (“the riser”), while the combustion takes place in a bubbling fluid bed. It is opposite in the Güssing gasifier. According to ECN this is an advantage for the MILENA concept resulting in approx. 5% better conversion efficiency from biomass to bio-SNG.

2.5 The SilvaGas plant

The technology in the SilvaGas gasifier is originally from a patent developed by Batelle in 1992. It consists of a double fluid bed system where one
is gasifying the biomass and the other is combusting the char residue and thereby heating the bed material. This material releases the heat in the gasifier. This principle is analogous with other indirect gasifiers e.g. the Güssing gasifier.

The previous owners of the IPRs to the process went bankrupt in 2002 and the IPRs now belong to Rentech. A new plant based on this principle is scheduled to be put into service in 2012 in California. Here the producer gas will be converted to liquid fuel. The producer gas from the process is analogous with gases from other indirect gasifiers and they could just as well be used for production of bio-SNG.

![The SilvaGas-process](image)

*Figure 2.7 The SilvaGas-process [6]*

### 2.6 GreatPoint Energy

GreatPoint Energy is an American company with a gasifying technology where SNG is produced directly in the process – the so-called Hydromethanation. In this process the feedstock material (such as coal or biomass) is ground to less than the size of sand particles.
The first step in the hydromethanation process is to disperse the catalyst throughout the matrix of a carbon-rich feedstock under specific conditions so as to ensure effective reactivity. The catalyst/feedstock material is then loaded into the hydromethanation reactor. Inside the reactor, pressurized steam is injected to "fluidize" the mixture and ensure constant contact between the catalyst and the carbon particles. In this environment, the catalyst facilitates multiple chemical reactions between the carbon and the steam on the surface of the particles. These reactions, catalyzed in a single reactor and at the same low temperature, generate a mixture predominately composed of methane and CO₂ [7].

After CO₂-removal the result is SNG, which can be injected into the natural gas grid. CO₂ can be used in oil fields for EOR.

The technology looks promising but is not yet to be found in Europe. Figure 2.8 shows the Hydromethanation technology from GreatPoint Energy. The company has a research plant at Mayflower Clean Energy Center in Somerset, Massachusetts.

![HydroMethanation™ Process](image)

*Figure 2.8 The Hydromethanation-technology, GreatPoint Energy, [7]*)
2.7 Absorption Enhanced Reforming at ZSW

Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW), Germany has developed the AER technology which is used in gasification (Absorption Enhanced Reforming). It is an enhancement of the indirect gasification technology with chemical looping including CaO (burnt lime). CaO is used as bed material in the fluid bed gasification process. CaO contains energy for the gasification process in the form of chemically latent heat which is released when CaO absorbs CO₂ and turns into CaCO₃ (lime). The bed material supplies heat into the gasifier – both as chemically latent heat and by the thermal heat capacity.

CaO absorbs CO₂ and the result of the gasification process is a producer gas with a high content of hydrogen and which then again is directly convertible to CH₄, and the gas is prepared for SNG. In addition CaO absorbs other impurities which then are not going to be extracted from the producer gas. The absorbed materials in CaO can be used directly with the generated lime on the farming fields from where the biomass came. This means manuring the fields.

Furthermore, CaO works as a catalyst for conversion of tar and the gas then has a concentration below 500 mg/m³ of tar. If the pressure is increased, both gasification temperature and combustion temperature rise equally, which facilitates the conversion of tar, while the other advantages of CaO are maintained.

There is only one drawback (yet discovered). Used as bed material CaO is eroded. This material is found as dust together with the ashes from the combustion of the biomass. If the level of erosion is too high it can lead to high costs. The preliminary results show that the quantity is less than the usual amount added to fields by cultivation.

In order to keep the grain size of the bed material consistent it is sorted to a size of approx. 0.7-2 mm.
The AER technology has successfully been tested on the Güssing plant. The share of hydrogen in the producer gas was enhanced from 37 % to approx. 50 % at the expense of CO₂. At a pilot plant especially set up for the AER technology, 65 % hydrogen was achieved in a producer gas that could be used without a shift reaction (chemical conversion/shift from CO to hydrogen in the gas) directly for production of SNG with up to 90 % methane.

2.8 The Blue Tower concept

The German company Blue Tower GmbH owns the rights to a gasification technology that relates to other gasification technologies, but is also different from all other technologies. The technology could be called “Falling Bed” technology, see Figure 2.10.
Figure 2.10  Diagram of the Blue Tower concept [9]

It is a three-stage gasification concept: Pyrolysis, gasification and reforming. Depending on the biomass, a drying unit is placed at the front.

The Blue Tower concept is very interesting. Ceramic pellets (alumina, Al₂O₃) are used as heat carriers. The gasifier consists of three levels: At the top level the pellets are heated to approx. 1050 °C by the flue gas from combustion of char. Pellets enter at the top of the reformer (after heating) and move downwards by gravity, providing heat, first to reforming of the pyrolysis gas with an ensuing low tar content and high hydrogen content, next down to the pyrolysis unit where the biomass is added and pyrolysed in conjunction with addition of steam. The char then moves with the pellets down to separation (approx. 550 °C) where char is separated and combusted. Pellets are transported and returned mechanically to the top of the upper level at a temperature of approx. 550 °C where they are again heated by the flue gases from the char combustion. The gas is moving in counter flow with the heat carrier, while char is moving downwards together with the
heat carrier. The residence time in the pyrolysis unit is approx. one hour [10].

A project (H2Herten) is planned in Herten, Germany. It is a 13 MW demonstration plant. More plants are being built in India and Japan, including a 30 MW plant in India meant for hydrogen production.

An interesting feature of the concept is that the product gases could be used directly for production of SNG. The product gases have the following composition (dry vol.):

- \( \text{H}_2 \): 50 %
- \( \text{CO} \): 15 %
- \( \text{CO}_2 \): 25 %
- \( \text{CH}_4, \text{C}_2\text{H}_4, \text{C}_6\text{H}_6 \): 10 % (mainly \( \text{CH}_4 \))
- \( \text{H}_2\text{O} \) before drying ~20%

This leads to an \( \text{H}_2/\text{CO} \) ratio above 3. Thus all hydrogen can be converted to \( \text{CH}_4 \) by methanation without a preceding shift reaction. Most other concepts need such a shift reaction, but this concept includes automatic shift reaction in the reformer. The gas leaves the reformer at a temperature of approx. 950 °C.

The concept aims at a water content of 20 % (vol.) out of the reformer, which will pose no problem for an ensuing methanation. It is this relatively high water content in the reformer that results in a shift reaction and tar reduction. The tar content from the reformer is very low.

Presently, this concept seems to be one of the most suitable concepts for production of producer gas for bio-SNG production. After particle separation and tar and trace element removal the gas can directly enter the methanation process for SNG production (e.g. TREMP). According to the company the price per producer gas unit is lower in this concept than in other concepts. It would be possible to achieve a very high efficiency (probably around 80 %), as the waste heat from the methanation process can be used in the gasification process. Presently the concept has not yet been demonstrated with SNG production.
The only weakness of the concept seems to be the fact that each production line can only have a fuel input of approx. 15 MW (the present limit). A 30 MW plant in India, therefore, has three lines in parallel, each of 10 MW, which furthermore leads to larger operation reliability.

### 2.9 CORTUS-WoodRoll three-stage gasification

The CORTUS-WoodRoll technology has three stages: drying, pyrolysis and gasification. The technology has been demonstrated with woodchips, waste wood and sludge from the paper industry.

CORTUS has signed a 12-year contract for supply of a 5 MW facility to a Swedish lime burning plant. The plan is to expand the facility to 25 MW.

Figure 2.11 shows a diagram of the technology.

![Figure 2.11 The CORTUS three step gasification [11]](image)

A part of the technology is indirect gasification, where heat is transferred by means of heat pipes in the gasification section. The composition of the pro-
ducer gases is very suitable for methanation as it has a very large content of 
H₂. The composition of the producer gas is approx:

- H₂: 60 %
- CO: 15 %
- CO₂: 23 %
- CH₄, C₂H₄, C₆H₆: 1-2 % (mainly CH₄)

The important thing here is that the ratio H₂/CO is larger than 3, which 
means that methanation may take place without preceding shift reaction. At 
the same time there is a large content of CO₂ in the gas, which makes it pos-
sible to methanize hydrogen completely and to optimally utilise the energy. 
Therefore, the technology is very suitable for biomass gasification for bio-
SNG production. However, bio-SNG is not the primary focus of CORTUS.

In the autumn of 2011 a 500 kW demonstration project was successfully 
carried out. The earlier pilot project was a successful 150 kW facility. The 
efficiency from biomass to syngas was measured at 80 %.

2.10 Heat Pipe technology

In the heat pipe technology heat is transferred inside pipes from exothermic 
areas to endothermic areas, i.e. from combustion regions to gasification and 
reforming regions. This technology is like the previous an indirect gasifica-
tion technology.

The concept is illustrated in the below figure from agnion [12]. The research 
and development has been carried out by agnion Highterm Research GmbH 
and the technology has been commercialized by agnion Technologies 
GmbH in Pfaffenhofen a.d. Ilm, Germany [13]
The heat is transferred from the combustion chamber to the reformer/gasification via the so called Heatpipes. Heat pipes are enclosed metal pipes containing an alkali metal working fluid (e.g. Na or K). This working fluid evaporates in the region of the exothermic combustion chamber fluid bed (~900°C) whereby it consumes energy, which is then released in the region of endothermic gasification fluid bed (~800°C) by condensation [12]. The two regions on the outside of the pipes consist of bubbling fluid beds.

Below is an illustration of the two bubbling beds and the heat transfer between. [13]

A 500 kWth pilot plant has been in operation for some years. A commercial plant was constructed and put into operation in May 2012 in Grassau.
Also other applications of this technology can be found [14]

The advantages of this technology are like other indirect gasifiers that the syngas is nitrogen free. On the other hand the scale up advantages are limited due to a maximum unit size.
3 Bio-SNG related technologies

3.1 Other gasification technologies

During a long period of time a range of gasification technologies has been developed in Denmark. This has been possible due to funds such as UVE, PSO, EFP, EUDP, ForskEL, ForskVE.

However, none of these technologies is directly suited for production of bio-SNG because air is used for the gasification, which results in N₂ in the producer gas. This component then has to be removed later in the process in order to manufacture bio-SNG and with subsequent costs.

If, however, steam and oxygen or pure steam were used these technologies could be used to produce syngas (primarily H₂, CO and CO₂) which then can be methanized into bio-SNG.

3.1.1 Pyroneer

Pyroneer is especially interesting in this connection because the technology is using a double fluid bed system, which gives relatively low temperatures in the system. In this way e.g. the alkali metals can be preserved in solid state that does not agglomerate on surfaces. Therefore almost all types of biomasses can be utilised. This makes the process very flexible.

Pyroneer is a product of cooperation between Danish Fluid Bed Technology ApS (DFBT) and DONG Energy. DONG Energy acquired IPR of the technology.

The technology is based on LT-CFB (Low Temperature Circulating Fluidised Bed) for production of producer gases used for co-firing the boiler at the power plant Asnæsværket.

At the moment the plant is adding up to 10 % straw directly to the coal to be fired into the boiler. With this new technology the straw is gasified and then only the gases are added. Thus the amount of biomass could be increased. Figure 3.1 shows a diagram of the LT-CFB plant.
3.1.2 Carbona - Skive

Carbona (owned by Andritz) is a supplier of gasification plants that originally are not suitable for production of producer gas for bio-SNG. The reason for including the technology here is that the Skive facility has a Carbona gasifier followed by an advanced tar reformer. Such a tar reformer, in this case a catalyst from Haldor Topsoe, would also be very relevant for a facility producing producer gas for SNG production [16].
The Skive facility has a bubbling/circulating fluid bed with dolomite as bed material. Extra dolomite is continuously fed in order to replace the loss leaving the plant together with the ash.

The plant is fired with pellets that have other characteristics than wood chips. Pellets are dry and “explode” in the heat, thus developing large amounts of dust leading to problems in the facility in the dust cleaning due to the large amounts. The facility was prepared for wood chips, but is only fired with pellets.

The catalytic tar reformer converts the tar to combustible gases. The reformer is operating at 850-920 °C. There is a gas filter operating at 200 °C and a scrubber at 40 °C.

The Skive facility is in operation, but there have been frequent stops for repair and modifications. In particular the tar reformer has created problems. The plant supplies gas to a gas engine (5.5 MW_e) that supplies heat and electricity to Skive District Heating.
By using steam and oxygen for gasification instead of air the Carbona technology can be adapted for bio-SNG production. E.ON is contemplating this technology for their future 200 MW facility in the south of Sweden.

3.1.3 Weiss, Viking gasifier

Boiler manufacturer Weiss has further developed the DTU multistep gasifier “Vikingforgasseren”. In Hadsund a facility with this technology has been established. First in this technology the biomass is dried, then pyrolyzed (degassed) and finally the coke residue is gasified in combination with cracking of tars, which thereby are eliminated. The system produces a highly pure gas to be used in gas engines.

![Diagram of the Viking gasifier from Weiss](image)

The gasification part works with a very high efficiency and the drying and pyrolysis methods could be of interest in combination with other gasification methods to make a producer gas for bio-SNG.

3.1.4 Firgas Alternating Gasifier, Ammongas and Vølund

The Firgas concept by Ammongas and B&W Vølund is a new concept unlike any other gasification technology. The gasification process is alternat-
ing, which means that the two gasification reactors are in operation for a short period (10-20 minutes) and the gas is stored. Then the gasification is stopped and one of the catalysts is heated with a part of the produced gas (10-20 minutes). Then the gasification is started again in the opposite direction for the same period of time while the heat in the just heated catalyst is utilized for the gasification. In the last of the four operations the second catalyst is heated and then the four operations start over again. Figure 3.4 shows a diagram of the concept.

![Diagram of the concept](image)

**Figure 3.4. The Firgas Alternating Gasifier by Ammongas and Babcock & Wilcox Vølund [19]**

The concept has several advantages and also disadvantages. The advantages are:

- Recirculation of producer gases, which are heated and used for gasification of biomass
The disadvantages of the technology are:

- The production of the producer gases is discontinuous necessitating a gas storage
- The quality of the producer gas is varying due to varying temperature levels of gasification

The producer gas is meant for direct utilization in an engine for electricity production. The technology is however very interesting and parts of the technology might be used for bio-SNG gasification plants.

### 3.1.5 BioSynergi

The company BioSynergi has a demonstration plant at Græsted heating plant. The technology is the so-called Open Core technique in which the gasification takes place by the addition of air co-currently with biomass at the top of the reactor. The biomass may be wood chips or other relatively dry biomass. The exhaust from the connected gas engine is used for direct drying of the biomass before it enters into the gasification reactor.

Plant size is somewhat smaller here than in previous systems, and the focus is on plants in size 300-1000 kW_{el}. There is one commercial plant [20].

The technology cannot be used for bio-SNG production. However, the drying technique may be used in connection with other technologies for bio-SNG production.

### 3.2 Gas cleaning and conditioning

Gas cleaning is necessary between the gasification unit and the methanation unit, which in most cases needs a clean and conditioned gas not to damage the catalysts and other components.
There are a number of different gas cleaning concepts and techniques but common for them all is the removal of substances that may compromise the function (e.g. catalyst deactivation or poisoning) and the life time of the components used downstream of the gasifier and to ensure the required quality of the final product.

Many concepts are based on advanced and extensive gas cleaning while others are based on development of components that are more durable and robust. [21].

The different technologies are:

- Dust cleaning
- Tar conversion/separation
- Sulphur and Chlorine removal
- Reforming and shift processes

In SGC report “Gasification – Status and technology” [21] a short but thorough description of different technologies are presented and it will not be repeated here.

Dust cleaning is obviously necessary to avoid blocking of catalyst and other mechanical components.

Tar conversion/separation is necessary for the same reasons but at the same time the energy content in the tar may be high depending on the gasification technology. To increase the overall efficiency conversion is needed.

Sulphur and chlorine removal is obviously necessary to avoid destruction of catalysts and to avoid corrosion of mechanical parts in the plant.

Reforming and shift are chemical processes that are necessary to condition the syngas, i.e. to adjust the concentration of chemical components before the entrance to the methanation process. In some gasification technologies, however, these processes are included in the gasification and no further reforming or shift is needed.
3.3 Methanation technologies

Bio-SNG from gasification of biomass is only possible if a methanation unit is installed after the unit which produced syngas.

In the methanation unit hydrogen, carbon monoxide and carbon dioxide in the syngas are converted to methane and water according to following reactions:

\[
\begin{align*}
\text{CO} + 3\text{H}_2 & \rightarrow \text{CH}_4 + \text{H}_2\text{O} \\
\text{CO}_2 + 4\text{H}_2 & \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}
\end{align*}
\]

Methanation normally takes place over a nickel based catalyst at a temperature of approx. 250 – 450 °C. Both the above methanation processes are strongly exothermic and the methanation reactor is usually cooled by internally recycled gas and heat exchangers. The strong heat release is an important reason to choose a gasification technique and process conditions that favour methane formation already in the gasification step.

3.3.1 Haldor Topsoe’s TREMP process

Haldor Topsoe A/S (HTAS) has developed the TREMP process which can convert H\(_2\) and CO in the ratio 3/1 into methane. The result is SNG. The premise is that the gasification products are conditioned to the TREMP process (pure syngas).

In the TREMP process approx. 80 % of the energy in the feed gas is converted into methane in a gas with up to 98 % methane. The rest of the energy (heat released during the process) can e.g. be delivered in the form of pressurized steam, which can be used for power production, or otherwise used in the gasification process (the production of the syngas).

Figure 3.5 shows HTAS’ TREMP technology. Figure 3.6 shows a diagram of the process.
Figure 3.5  The TREMP technology of Haldor Topsøe [22]

Figure 3.6  Graphical illustration of the TREMP-process [22]
3.3.2 Methanation at PSI

The combined shift and methanation reactor developed at Paul Sherrer Institute (PSI) is based on fluid bed technology and works at low temperatures of around 350°C. It has shown to work at hydrogen/carbon monoxide ratios within as broad interval as 1 to 5 [21].

In the PSI methanation process the carbon dioxide is separated after the methanation using conventional technology. This technology was used at the Güssing gasification plant for demonstrating SNG production from gasification of wood chips. See Figure 3.7.
3.3.3 Methanation at ZSW

Another activity at Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW), which was mentioned earlier in connection with the AER-process, is testing of a methanation unit. This is a unit which was tested with 50 kW production of SNG in a one tube process. This process consists of one long tube containing catalyst material. The temperature is kept at the right level with a heat exchanger with melted salt at different temperature levels. See Figure 3.8.

![Figure 3.8 The methanation unit at Zentrum für Sonnenenergie- und Wasserstoff-Forschung [8]](image)

3.3.4 Bio-methanation

The idea of biomethanation of gasification gas has developed as a result of the studies in this project.

In an existing project supported by EUDP the company Electrochaea is demonstrating a concept for biological methanation of CO₂ and H₂ to form
CH₄. The CO₂ here comes from a biogas plant and the H₂ from electrolysis of water using wind power.

This technology, however, could be used as the second part of a methanation unit for gasification gas (producer gas). Producer gas consists of a mixture of H₂, CO₂, CH₄ and CO. In existing chemical methanation plants a part of the CO of this mixture is first shifted to H₂ in a “Shift”-reaction to convert the energy in CO to H₂. When sufficient CO is shifted the mixture of H₂, CO and CO₂ is converted to CH₄, CO₂ and H₂O. The CO₂ and water are removed and the remaining CH₄ is bio-SNG.

These processes could be done by biological processes instead of chemical/thermal processes. A study of fermentation processes show that some microbes are able to convert CO and water to a mixture of H₂ and CO₂ [23]. This process is exothermal and the microbes use a part of the excess energy for reproduction purpose. This biological process could be called a “biological shift” reaction.

A combination of the above two biological reactions could form a full biological methanation process for converting producer gases from thermal gasification to bio-SNG. Below in Figure 3.9 is a diagram showing the method of bio-methanation.

After a first cleaning of producer gas from a thermal gasifier the gas consist of a mixture of CO₂, CO, CH₄ and H₂.

Next the gas is brought to the first reactor in which CO is converted into any mixture of CO₂, H₂ and CH₄ by any of the microbes (hydrogenogens and/or methanogens), which can do this work as fast as possible and at any desired temperature in the range of 35-100°C.

From here the gases (without CO) is then brought to the next reactor where the H₂ and a part of the CO₂ is converted into CH₄ by hydrogenotrophic methanogens (as in the Electrochaea process).
The final result is a well-known biogas (like biogas from fermentation) with only CH$_4$ and CO$_2$, which can be upgraded into bio-methane by conventional methods.

![Diagram of a bio-methanation method for producing bio-SNG from thermal gasification gas (syngas)](image)

Figure 3.9  Diagram of a bio-methanation method for producing bio-SNG from thermal gasification gas (syngas)

The question is if this method would be more or less costly compared to conventional chemical methanation processes. However the biological processes are known to be very fast and the reactors can be made very concentrated (small volume per production unit).

The resulting gas would be conventional biogas and by that subject to subsidies in parallel to conventional biogas plants. The gasification plant would
act as a “thermal pre-treatment” of the biomass before the fermentation in the bio-shift and bio-methanation reactors.

This method would have several advantages:

- The methanation unit is less sensitive to changes in syngas concentrations
- Easy shut down and start up (the microbes just sleep and wait dormant for a new start up)
- The unit could be made both small and medium scale (perhaps large scale)
- Conventional biogas is the output
- Small footprint for the methanation unit
- Cheap??

No plants of this kind have yet been built but the technologies exist and seem promising. Plants like these for ethanol production have been built in USA (see [24, 25]). Hence, the idea is not new, only the purpose of bio-SNG is new.
# Abbreviations and glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Allothermal</td>
<td>Indirect heating in the gasification process</td>
</tr>
<tr>
<td>Anaerobic</td>
<td>With no addition of oxygen</td>
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<tr>
<td>Biogas</td>
<td>Gas product from biological low-temperature conversion of biomass by anaerobic digestion process</td>
</tr>
<tr>
<td>Bio-SNG</td>
<td>Substitute (or Synthetic) Natural Gas from biomass</td>
</tr>
<tr>
<td>Chalmers</td>
<td>Chalmers University of Technology</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>ECN</td>
<td>Energy research Centre of the Netherlands</td>
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<tr>
<td>EOR</td>
<td>Enhanced Oil Recovery</td>
</tr>
<tr>
<td>EUDP</td>
<td>Energiteknologiske Udviklings- og DemonstrationsProjekter (Energy Technology D&amp;D projects)</td>
</tr>
<tr>
<td>Firgas</td>
<td>Gasification concept by Ammongas and B&amp;W Vølund</td>
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<tr>
<td>Gasification</td>
<td>Thermal/chemical conversion of biomass into gas at high temperature</td>
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<tr>
<td>GOBIGAS</td>
<td>Gasification project in Gothenburg with the goal of producing up to 100 MW bio-SNG</td>
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<tr>
<td>H₂</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>HTAS</td>
<td>Haldor Topsøe A/S</td>
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<tr>
<td>Hydromethanation</td>
<td>Methanation by means of water and/or hydrogen</td>
</tr>
<tr>
<td>kWh</td>
<td>Unit of energy = 3.6 MJ = 3.6·10⁶ Joule</td>
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<tr>
<td>LT-CFB</td>
<td>Low Temperature - Circulating Fluid Bed</td>
</tr>
<tr>
<td>Methanation</td>
<td>Chemical conversion of gasification gases to a gas predominantly consisting of methane</td>
</tr>
<tr>
<td>MILENA</td>
<td>Gasification process developed at ECN in the Netherlands</td>
</tr>
<tr>
<td>OLGA</td>
<td>Process developed in the Netherlands for removing tar from gasification gases</td>
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<tr>
<td>ORC</td>
<td>Organic Rankine Cycle</td>
</tr>
<tr>
<td>PJ</td>
<td>Unit of energy = 10¹⁵ Joule</td>
</tr>
<tr>
<td>RME</td>
<td>Bio-oil, bio-diesel</td>
</tr>
<tr>
<td>SNG</td>
<td>Substitute (or Synthetic) Natural Gas</td>
</tr>
<tr>
<td>Syngas</td>
<td>A mixture of H₂, CO and CO₂ (+possibly CH₄)</td>
</tr>
<tr>
<td>TREMP</td>
<td>Methanation process developed at Haldor Topsøe A/S</td>
</tr>
</tbody>
</table>
Viking gasifier:  Multi step gasification concept offered by Weiss
VUT: Vienna University of Technology
ZSW: Zentrum für Sonnenenergie- und Wasserstoff-Forschung
5 References

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