Global screening of projects and technologies for Power-to-Gas and Bio-SNG

A reference report

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Appendix

Appendix 1  Project description
1 Summary

At the request of Energinet.dk Danish Gas Technology Centre (DGC) has updated the previous (December 2011) global screening of projects where gas is produced for the grid and projects integrating electricity and gas. As the screening did not include projects with ordinary biogas plants with upgrading to natural gas quality the identified relevant projects are divided into two main groups: Bio-SNG plants and plants with electrolysis.

1.1 Bio-SNG

Only gasification plants for production of bio-SNG will be relevant for the integrated planning of electricity and gas systems in Denmark. Gasification plants for CHP may be relevant for electricity and heating systems, but not for electricity/gas. State-of-the-art for bio-SNG from gasification is the indirect gasification method (allothermal), where combustion takes place outside the gasification reactor and with steam-blown gasification.

The direct gasification methods, where combustion takes place in the gasification reactor, are mostly air-blown. This means that $\text{N}_2$ is present in the producer gas, which is undesired for bio-SNG. It is possible, though, to use the direct methods with oxygen-/steam-blown gasification, but the efficiency will be lower, and it is necessary to establish on-site oxygen production.

The indirect (allothermal) gasification methods seem to be best developed in Austria, the Netherlands and Sweden. The Güssing plant in Austria and the plant at Chalmers in Sweden will be used as reference for the GOBIGAS project in Sweden, the first commercial bio-SNG plant world-wide.

The MILENA plant at ECN in the Netherlands is used as reference for the first Dutch bio-SNG plant, which is planned to be built in cooperation with the Dutch HVC-Group in Alkmaar.

GreatPoint Energy in the USA uses a technology that seems to be very suited for bio-SNG. However, the company is now cooperating with a large coal producer and is now focussing on coal-based SNG in the USA and China.
The direct gasification methods are used all over the world, but especially Finnish Carbona and Danish Pyroneer seem to be technologies that, over time, may become relevant for bio-SNG. The Carbona technology is used in Skive achieving experience with tar cleaning in collaboration with Haldor Topsøe. Pyroneer is owned by DONG Energy, and like the Carbona technology Pyroneer can be modified for oxygen-/steam-blown technologies for the purpose of bio-SNG.

E.ON in Sweden is contemplating to use the Carbona technology for a 200 MW plant in the south of Sweden for production of bio-SNG.

### 1.2 Electrolysis

As the screening did not include industrial utilisation of electrolysis plants and plants for refuelling of hydrogen vehicles, most of the plants in connection with energy supply are stand-alone plants. I.e. hydrogen acts as storage for a fluctuating electricity supply based on solar and wind. Demonstration plants of this type are found all over the world. The typical plant size is 5-100 kWe.

Electrolysis plants used in systems connecting the electricity and natural gas systems have only been realised as demonstration plants in Germany and France during the last couple of years. More are on their way, though, in Denmark, Germany, France, The Netherlands and Italy. The main principles of this kind of plants are that surplus electricity is converted to hydrogen via an electrolyser, and

*either*

a) that hydrogen from an electrolyser with a CO\textsubscript{2} source (typically from a biogas plant) is fed to a methanation unit prior to feeding the gas to the gas grid. The report describes several varieties.

*or*

b) that hydrogen from an electrolyser is fed directly to the natural gas grid. In some countries 5 % vol. hydrogen is already permitted in the gas grid, and some say that e.g. 15 % vol. could be permitted without considerable modifications of the gas consuming appliances. (DGC is not of this opinion – especially as it is evident that electrolysis plants will be given the task of
acting as “peak shaving” resulting in very fluctuating hydrogen content in the grid.)

or

c) that hydrogen from an electrolyser is stored and converted to electricity/heat via a CHP unit (fuel cell plant or gas engine), when electricity is needed. Biogas via storage may be included in a variable share.

The reason that Denmark and Germany are following this path is that in these countries a heavy expansion of renewable energy plants is on the agenda. This requires increased balancing of the system, and the interest in energy storage is thus sky-high.
2 Introduction

2.1 Objective

According to Energinet.dk’s project description (Appendix 1) and supplementary conversations the objective is to acquire an up-to-date overview over completed and on-going projects (test, development, demonstration) that integrate electricity and gas.

2.2 Emphasis

a) Projects including e.g. electrolysis, where gas is going to be stored in the natural gas grid, either immediately or in the long run.

b) Projects including thermal gasification and methanation to achieve gas grid quality (SNG plants).

c) Combined projects with several different technologies, such as electrolysis, CHP, biogas. The crucial issue is that gas (grid) storage is included.

2.3 Implementation and sorting

The screening is carried out country by country.
For countries not mentioned no relevant projects was identified.

The following template has been used, if possible:

a) Description of principles
b) Diagram
c) Main data
d) Status and progress
e) Contact data for key persons

“Gas cleaning and conditioning” as well as “Methanation” have been added as separate chapters in the report.
3 Austria

3.1 The Güssing gasifier

The most enhanced indirect gasification system for biomass seems to be the Güssing gasification system, which is based on fluid bed technology and steam. It was primarily developed at VUT (Vienna University of Technology). It is called the FICFB-technology (Fast Internal Circulating Fluid Bed).

Figure 3.1 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 the form of hot particles, such as sand, dolomite etc. and then heated in the combustion section. The producer gases exit from the top of the gasifier to the left, and at 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 heat 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 3.2 shows a diagram of the Güssing gasifier.

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 producer gas from this process has a relatively low content of tar.

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.

Contact

www.repotec.at
3.2 The Oberwart plant

The CHP plant in Oberwart produces gasification gas to be used directly in an engine for the production of electricity and heat. The fuel input is approx. 8.7 MW. In the summer, where the need for heat is small, an ORC process (Organic Rankine Cycle) is used to increase electricity production. The electrical efficiency is approx. 27 % and the overall efficiency is approx. 64 %.

![Diagram of the Oberwart plant](image_url)

Figure 3.3 Schematic view of the Oberwart plant /9/

The Austrian plants (Güssing and Oberwart) are semi-commercial: They receive continuous subsidies for participation in research projects in addition to the revenue of electricity and heat production.

Repotec is an Austrian company with only few employees (< 10). The company performs basic engineering for plants for biomass gasification. Repotec was in charge of the Güssing plant and performed basic engineering of the Oberwart plant, which was basically a copy of the Güssing plant.

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4 The Netherlands

4.1 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 4.1 compares the Güssing gasifier with the MILENA gasifier.

Both gasification processes shown in Figure 4.1 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.
Figure 4.1 Comparison between MILENA (left) and FICFB at Güssing (right) /19/ 

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4.2 The Ameland project
The project includes a small, well-defined residential area in Ameland, where 5-20% hydrogen was added to the natural gas.
The reported results show:

- No problems relating to operation safety
- No problems relating to materials regarding plastic or steel pipes (a number of laboratory tests support this)
- No problems relating to gas meters or fittings (a number of laboratory tests support this)
- Normal leak test is still ok. One boiler did leak initially, though
- Emission conditions ok.

**Project Start-Stop:** 2007-2011.

**Project state:** Finalised.

**Project partners**
Joulz og Kiwa Gas Technology.

**Contact**
M.J. Kippers, Kiwa Gas Technology.
4.3 P2G project in Rozenburg

In a residential area of the Rozenburg municipality, a small P2G project is being demonstrated during 2012-14. The test phase is scheduled to finish at the end of 2013 and operation will be maintained through 2014.

Hydrogen from a PEM electrolyser and CO₂ from an unknown source are used in a methanation stage to get SNG, which is injected in the local gas network in a residential area.

![The Rozenburg P2G demonstration set-up](image)

The electrolyser input power is 7 kWₑ, and the SNG output is around 2 Nm³/h.

**Project start-stop:** 2012-2014  
**Project state:** Test phase

**Project partners**
- DNV Kema
- Stedin.net
- Resort Wonen
- Gemeente Rozenburg

**Contact**
Lukas Grond, DNV Kema
5 Denmark

5.1 The Vestenskov project

In connection with the development of micro CHP plants in Denmark, Vestenskov at the island of Lolland was chosen as the demonstration site in the eastern part of Denmark. The Vestenskov demonstration project has reached phase 3 and the size of the plants has gone down and the efficiency has increased. In the long run, it is planned that CHP plants will supply the electricity grid which will be controlled by the amount of wind power, for example /17/.

An electrolyser produces hydrogen; the hydrogen is pressurised and stored in a pressure vessel.

![Figure 5.1 Electrolyser and hydrogen storage vessel for the Vestenskov plant](image)

SEAS-NVE is in charge of project management of the east part of Denmark and is also in charge of the overall project management.

The objective of the project is to contribute to the development of CHP plants based on LT-PEM fuel cells for single-family houses in order to make the CHP plants commercially available.

35 households in Vestenskov (5 km from Nakskov) have been selected for installation of a pilot plant. Five households had a plant installed in phase 2.
5.1.1 The plants

The pilot plants in the eastern part of Denmark comprise a fuel-cell CHP unit (produced by IRD) and a 200 l heat storage vessel. In order to get the best result from the measurements in the households data collection equipment is installed that ensures correct energy data from each household. The Vestenskov plants will be supplied with hydrogen via an underground distribution network analogous to the natural gas network.

The status and targets for the plants in the different development phases of the project were and are as follows:

Energy utilisation is expected to increase from approx. 40 % to 50 % electricity efficiency from phase 1 to phase 3. Overall efficiency, including heating, must increase from approx. 75 % to 90 % with an additional 10 % at condensing operation.

Electric output to the grid must be 1.3 kW per unit. The development target for lifetime after 2012 is 40,000 operating hours. The uptime must increase from 85 % to 95 % from phase 2 to phase 3. The start-up time must be around 1 minute. The efficiency of the inverters must be 94-95 %.

An optimised heating system and heat storage facility are planned in order to optimise overall efficiency. In phase 3 the system will be optimised regarding peak load, and this is an important element for the overall efficiency of the system.

**Project start-stop:** 2004-2014

**Project state (Nov. 2013):** Operation phase 3

**Project partners**

- Danfoss
- DONG Energy
- SEAS-NVVEN
- Dantherm
- Haldor Topsøe
- COWI
- Lolland Municipality
• IRD A/S

Contact
SEAS-NVE, Kristina Fløche-Juelsgaard

5.2 Region Midtjylland (The Central Denmark Region), project “Towards the Methane Society”

This project integrates electrolysis, biogas upgrading and the natural gas grid as follows:

• Electrolysis generates hydrogen and heat based on wind
• CO2 in biogas reacts with hydrogen from the electrolysis to form CH4 and high-grade steam, when biogas reacts directly with hydrogen in a catalyst
• The natural gas grid is used for distribution and storage for the generated methane.

Figure 5.2 Schematic diagram showing the synergy between different energy systems /4/
The processes and perspectives of symbiotic methane generation from biogas and hydrogen are shown in the figure above. Biogas consists of methane and CO₂. Wind power is used for hydrogen generation via electrolysis (blue/red). Hydrogen reacts with the biogas’s content of CO₂ that is converted to methane in the Sabatier reactor. Thus the biogas is upgraded to methane to be injected into the natural gas grid. This concept will increase methane generation from biomass by at least 50%. At the same time, wind power is “stored” in the natural gas grid in the form of methane.

The largest immediate challenge is to clean the biogas sufficiently to optimise the lifetime of the Sabatier reactor, which requires preliminary laboratory tests.

**Project start-stop:** 2011-2012
**Project state (Nov. 2013):** Finalised. See final report /55/.

**Project partners**
- HIRC (Hydrogen Innovation & Research Centre) (project manager)
- Planenergi
- Haldor Topsøe
- GreenHydrogen
- HMN Naturgas
- Strandmøllen
- Lemvig Biogas
- DTU, DJF – Århus University
- Innovation Network for Biomass from the Agro Business Park.

### 5.3 Electrochaea

The US company Electrochaea is commercialising a disruptive, scalable technology to convert electric power into methane, the principal component of natural gas. Using CO₂ as a feedstock gas, power can be efficiently converted to renewable natural gas for power storage, for transportation fuels, or for transmission via a natural gas network.
This technology was conceived by Dr. Laurens Mets at the University of Chicago as a reuse for waste CO$_2$ and as a power storage medium by converting CO$_2$, electrical power and water into methane and oxygen. When using renewable sources of electrical power, the technology provides a scalable source of renewable natural gas /3/.

Electrochaea’s intellectual property from the University of Chicago covers methods and compositions for the conversion of CO$_2$ and power to methane using Archaea, microorganisms that serve as efficient biological catalysts. Electrochaea is currently developing an innovative and scalable electrolysis unit, in which power and carbon dioxide are combined with unprecedented volumetric productivity (> 1kW/l) to minimise spatial footprint and costs. Archaea enable a highly specific reaction with a separated stream of oxygen as the only significant by-product. Archaea are self-maintaining catalysts with culture stability of years. The reactor produces methane continuously and can cycle on/off to match the power available from wind or other renewable sources. Figure 5.3 below shows the concept.
The benefits of the technology are as follows:

- There is a quick up- and down-regulation of power (bacteria are just dormant until start-up).
- CO₂ dissolved in water is used, which can be taken from biogas upgrading with water scrubber.
- The process is a low-temperature process <100°C.

Electrochaea has formed a Danish company, Electrochaea.DK ApS, which together with other Danish parties have obtained funding from the EUDP-2011-II to demonstrate the technology in Denmark in the range 10-100 kW at Foulum research centre.

The Foulum project is expected to conclude by November 2013. The test results will be used to develop a detailed design for a MW-scale project anticipated to start in 2014.

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5.4 Biogas upgraded using surplus electricity

The project objectives are

- to design, construct and operate a pilot plant for methanation of CO₂ in biogas by means of hydrogen produced from steam in a Solid Oxide Electrolyser (SOEC) at a scale of approximately 10 Nm³/h corresponding to 40 kW SOEC capacity.
- to monitor the efficiency and durability of the process steps and estimate costs of a full-scale plant that can compete with traditional upgrading of biogas and elaborate a plan for market introduction and market development.
- to analyse the value of the technology for the Danish electricity and gas infrastructure.

Methanation of biogas will at the same time offer storage possibilities for wind produced electricity (and thus reduce the need for power transmission), upgrading of biogas and extend the biogas resource by 50-80 % (and
thus reduce natural gas supply uncertainties and CO₂ emissions). Previous projects have indicated that a conversion efficiency from electrical power input to lower heating value of methane of 74-76 % can be achieved. In addition, the efficiency of waste heat for district heating will be 14 %.

These high efficiencies are obtainable due to the inherent high efficiency of the SOEC technology and the synergy with advanced methanation technology capable of producing the steam used in the SOEC unit.

*The project partners* cover the complete value chain from agricultural raw materials and electrical power to the utilization of the upgraded biogas.

- Haldor Topsøe A/S will be the project coordinator and perform the design of the demonstration unit and the full-scale commercial plant. Topsøe will also supply the SOEC module and cleaning masses for the biogas and catalyst for the methanation step.
- Aarhus University (AU) will supply biogas feedstock from their existing biogas reactor in Foulum. AU will be responsible for day-to-day operation and advanced sulfur analyses. Based on pilot plant data, a feasibility study will be done for a full-scale plant.
- PlanEnergi together with Ea Energy Analyses will optimise the full-scale plant design based on dynamic models of the predicted, future price structure for electricity.
- HMN Naturgas and Naturgas Fyn will do the engineering work for pipelines and will also contribute with their knowledge the quality demand from the natural gas system.
- Energi Midt will install electricity connections.
- Xergi have built the existing test plant at Foulum and will participate with their knowledge of biogas plant design and catalyst for the methanation step.
- DGC will perform certified analysis of biogas and product gases.
- Cemtec will look into certifications of components and permits.

*Contact*
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**Project start-stop:** 2013-2016.

**Project state (Nov. 2013):** The activities are planning and design.

### 5.5 MeGa-stoRE – storage of biogas and wind power on the gas network

The project focus is development and test of new methods for gas cleaning and design of a Sabatier reactor. The principle setup is shown in Figure gk. In the test phase a simplified test cycle will be used and at a local biogas plant. Bottled hydrogen delivery will replace the electrolyser due to budget limitations.

![Figure 5.4 Schematic arrangement /72/](image)

**Project partners**

- Aarhus University (AU)
- GreenHydrogen.dk
- ElPlatek
- DTU Mekanik
- Lemvig Biogas
**Contact**
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**Project start-stop:** 2013-2014.
**Project state (Nov. 2013):** Component testing

### 5.6 DTU, biogas: Hydrogen directly to a biogas plant

DTU has tested direct injection of hydrogen to a biogas plant. Perhaps the biogas plants will prove to be a shortcut to integrating hydrogen in the energy supply. Recent tests at DTU Environment show that hydrogen can be converted to methane gas in a biogas plant, and subsequently the gas can be distributed via the existing natural gas network.

The experience from DTU demonstrates that when hydrogen is injected into a biogas plant it can be converted to methane at an efficiency of more than 90%. During the tests 40-60% of the biogas’s CO$_2$ content was converted, but new tests indicate that it is possible to remove virtually all the CO$_2$ from the biogas by converting it to CH$_4$.

The system is brilliant, since not only is the hydrogen converted into methane gas, containing three times as much energy per volume as hydrogen. Injecting the hydrogen into a biogas plant will also upgrade the biogas making it easier to distribute via the natural gas network, as CO$_2$ is converted to methane, thus avoiding the costs of the conventional upgrading system /7/.

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5.7 Green Natural Gas

The purpose of the project is to demonstrate the feasibility of integrating the gas and electricity systems by generating Green Natural Gas by the use of efficient Solid Oxide electrolysis. This integration is considered a critical element in the future integration of large amounts of wind power in the Danish energy system /5/. The project has obtained funding from the EUDP-2011-II.

The conceptual outline of a dual-mode SOEC/SOFC system

*Figure 5.5 Illustration of the idea behind the Green Natural Gas project /5/*

By Green-NG is understood ‘green’ methane (CH₄) based gas, which is compatible with the existing natural gas grid. Solid Oxide Electrolysis (SOEC) is chosen as electrolysis technology because it is the potentially the most energy- and cost-efficient electrolysis technology, and because very promising technical results have been demonstrated recently. The project
will include a cost-analysis for Green-NG systems which will be used to provide a roadmap for the technology. This cost-analysis and roadmap will be important elements in the future decisions on how to cost-effectively integrate large amounts of fluctuating wind power in the Danish energy system.

The SOEC technology is a key element in this project and is expected to enable Green-NG systems, which are about 33% more cost-effective than possible with other electrolysis technologies. In the project, an integrated SOEC submodule (FuelCore) is developed and tested as a first critical step towards a future commercialisation of the SOEC system technology.

The project is seen as an essential first step towards developing cost-effective Green-NG systems; however, this project will only be one of several projects towards commercial Green-NG. This project will demonstrate an SOEC electrolyser capacity of 35-40 kW and will provide qualified roadmap for the next development and demonstration phases /5/.

**Project start-stop:** 2011 – 2014

**Project state (Nov. 2013):** In progress

**Project partners**

- Haldor Topsoe A/S
- Dong Energy
- Danish Gastechnology Centre A/S
- Ea Energy Analysis
- DTU

**Contact**

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5.8 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 Topsøe, would also be very relevant for a facility producing producer gas for SNG production /2/.

![SKIVE PROCESS DIAGRAM](image)

*Figure 5.6 Diagram of the Carbona plant in Skive /1/*

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) 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.

Contact
Kari Salo, CARBONA or Skive Fjernvarme I/S (Skive District Heating).

5.9 The Pyroneer gasifier

Pyroneer is especially interesting for multifuel conversion 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.

![Diagram of the LT-CFB technology in Pyroneer](image)

*Figure 5.7 Illustration of the LT-CFB technology in Pyroneer /6/*

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.

If steam and oxygen or pure steam were used, the Pyroneer technology could produce syngas (primarily H₂, CO and CO₂), which then could be methanised into bio-SNG.

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5.10 Viking gasifier, Weiss

Boiler manufacturer Weiss has further developed the DTU multistep gasifier “Viking-forgasseren”. 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 in this way are eliminated. The system produces a highly pure gas to be used in gas engines. Figure 5.8 shows a diagram of the Viking gasifier.
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 with high efficiency.

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5.11 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 alternating, 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 utilised for the gasification. In the last of the four operations, the second catalyst is heated and then the four operations start over again. Figure 5.9 shows a diagram of the concept.
The concept has several advantages and also disadvantages. The advantages are:

- Recirculation of producer gases, which are heated and used for gasification of biomass
- No movement of heat storage material
- Tar cracking and reforming in high-temperature catalysts
- Absorption Enhanced Reforming (AER) technology by chemical looping included

The disadvantages of the technology are:

- The production of the producer gases is discontinuous, necessitating a gas storage facility
- The quality of the producer gas is varying due to varying temperature levels of gasification
The producer gas is meant for direct utilisation in an engine for electricity production. The technology, however, is very interesting, and parts of the technology might be used for bio-SNG gasification plants, e.g. the recirculation of producer gases and the AER technology.

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6 Sweden

6.1 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 GoBi-Gas 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 6.1 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 for the Güssing gasifier) largest pilot plants for gasification of biomass. On this gasification plant a number of smaller sub-devices can be tested and substreams 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.
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6.2 The GOBIGAS project

The Swedish Energy Agency has granted 222 million SEK to the GOBIGAS project in Gothenburg. First, the project will use the Güssing technology and the Chalmers technology for production of 20 MW SNG. Later, an 80 MW SNG plant is to be built using a technology that has not yet been decided. EU ratified the grant in December 2010, where it was not considered state aid with a negative market influence.
The GOBIGAS project is the world’s first large-scale commercial plant for generation of SNG from biomass via gasification. The plants in Austria (Güssing and Oberwart) are semi-commercial, as they receive continuous subsidies for participation in research projects in addition to the revenue of electricity and heat production.

The GOBIGAS project is part of Göteborg Energi’s vision of becoming independent of natural gas over a period of years. This can be achieved by replacing natural gas by RE gases that are upgraded to natural gas quality and injected into the grid.

In Sweden, natural gas is not considered as environmentally friendly as in many other countries. The argument being that it is a fossil fuel to be imported. The attitude towards biogas, on the other hand, is very positive. Today, Sweden uses as much biogas as does Denmark, but quite a lot of the biogas in Sweden is upgraded for use in vehicles as well as in the natural gas grid.

The potential for RE gas in Sweden has been calculated to 14 TWh/year from digestion and 59 TWh/year from gasification. The gasification plant in Gothenburg is a first actual step to meet this.

The idea of GOBIGAS is to convert wood, wood chips and other types of biomass to a gasification gas that will be upgraded and conditioned for the natural gas grid. Very large amounts are planned. In the first phase, a gasification plant in the size of 20 MW will be built. This plant is expected to be commissioned at the end of 2013. A couple of years later, 80 MW will be added to reach a total output of 100 MW, corresponding to a small power plant in 2016-2018.

The GOBIGAS plant is built in Ryahamnen/Rya Harbour in Gothenburg. This will offer the opportunity of having biomass supplied by sea and by land. The supply of the large amounts of biomass for generating 100 MW SNG requires a well-developed infrastructure in the local area. The location in Ryahamnen ensures the supply of biomass by vessel, by rail and by road.
The target is a methane output of approx. 65% of the amount of energy in the biomass with an expected overall efficiency of approx. 90%. The difference will be in the form of district heating to be supplied to the local community. Approx. 8,000 operating hours per year are expected.

For the gasification part the contractor is Metso Power AB in cooperation with Repotec. Haldor Topsøe A/S has the contract on the methanation unit.

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Figure 6.1 Process diagram for the GOBIGAS project /73/
6.3 The E.ON project, Bio2G

E.ON has similar plans of an even larger gasification plant in Scania (Skåne), probably in Trelleborg or in Malmö. This plant is planned to have an output of 200 MW natural-gas quality gas and to be commissioned before 2020. No decision on exact location has been taken, yet, but the prerequisites are connection to natural gas grid, a district heating grid for removal of heat and a harbour for transport of the biomass.

Nor has the technology been decided, yet, but it is contemplated to use the Carbona technology, even though it is not directly suited for the SNG production. The Carbona technology is a direct gasifier, but by using oxygen together with steam or CO₂ it is possible to achieve a producer gas that can be used for SNG. The advantage is a producer gas with high content of methane.

For the moment (end of 2013) the project is on hold and awaits solid political support with firm policies on subsidies etc. [54/].

Figure 6.3  Schematic process diagram showing E.ON’s Bio2G project [54/].
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6.4 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 6.4 shows a diagram of the technology.

1.2 Gasification of biomass - WoodRoll

A part of the technology is the indirect gasification, where heat is transferred by means of heat pipes in the gasification section. The composition of the producer gases is very suitable for methanation, as it has a very large content of H₂. The composition of the producer gas is approx:
- H\(_2\): 60 \%
- CO: 15 \%
- CO\(_2\): 23 \%
- CH\(_4\), C\(_2\)H\(_4\), C\(_6\)H\(_6\): 1-2 \% (mainly CH\(_4\))

The important thing here is that the ratio H\(_2\)/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 CO\(_2\) in the gas, which makes it possible to methanise 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 \%.

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7.1 Power to Gas (P2G), Werlte biogas plant

The Werlte biogas plant was built in 2002, and a part of the gas is upgraded to natural gas quality and is injected into the natural gas grid. The biogas is upgraded via traditional PSA (Pressure Swing Absorption). The capacity is approx. 3.6 MW injected into the natural gas grid.

In 2011 there were two different demonstrations of P2G at the plant. In one demonstration they used the separated CO$_2$ component from the upgrading, added hydrogen via electrolysis and then carried out methanation of the mixture. In the other demonstration they mixed hydrogen directly with biogas from the plant and then carried out methanation of the mixture. In the latter case the methane from the biogas plant is led passively through the methanation plant, which has certain advantages at temperature stabilisation. Figure 7.1 shows the two principles.

![Figure 7.1 Schematic diagram for the Power to Gas (P2G) project at Werlte biogas plant](image)
Both demonstrations resulted in approx. 92 % methane, 4 % CO₂ and 4 % hydrogen in the SNG.

The demonstration described above is a part of a bigger plan for demonstration of P2G in Germany.

- The α plant is a 25 kW container based plant commissioned in 2009. It has demonstrated upgrading of CO₂ + H₂ to CH₄. The Werlte demonstration was part of this.
- The α-plus plant is a 250 kW plant that was put into operation in 2012.
- The β plant is a 6 MW plant that was put into operation in 2013 in cooperation with Audi and others, see Chapter 7.2 below.
- The γ plant is expected to be a commercial product of more than 6 MW and is expected to be introduced in 2015 /10/.

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7.2 Audi project e-gas

In spring 2012 Audi (VW group) started the building of a plant in Werlte in the northwest part of Germany. This plant is to generate bio-SNG based on electricity from their own wind power plants in the North Sea and CO₂ from local biogas plants. The idea is that part of Audi’s future production of natural gas and electric vehicles is to be considered CO₂ neutral.
The methanation is done by means of the Sabatier principle, i.e. CO$_2$ and hydrogen are injected into a reactor for methanation. After a treatment level the gas is ready for injection into the natural gas grid.

7.2.1 Main data /22/

Wind turbines: 4 x 3.6 MW$_e$ with a total annual production of 53 GWh, corresponding to 3,700 full-load operating hours per year.

Bio-SNG plant output: 6.3 MW bio-SNG.

Bio-SNG plant annual production: 1,000 t bio-SNG. This would be sufficient for fuelling 1,500 of the new CNG version of the AUDI A3 for approx. 15,000 km/year.

7.2.2 Time schedule /22/


Start of building work: Spring 2012.

Commissioning: Autumn 2013.
7.2.3 Project partners

- Solarfuel
- Fraunhofer IWES
- ZSW
- EWE

7.3 Kombikraftwerk 1

This is a virtual power plant with limited storage facilities and export opportunities. The concept is solely based on renewable energy sources, such as solar cells, wind turbines, biogas based gas engine and gas turbine plants, as well as pumped storage in high altitude (e.g. mountain lake). The basic target is 1/10,000 of the German electricity need. Plants all over Germany have been included, and in combination the included plants cover the desired 1/10,000 of the German electricity need in 2007. Both the included storage capacity and the included export capacity correspond exactly to the 1/10,000 of Germany’s total storage capacity (including gas grids with caverns) and export capacity in 2007.

Biogas based electricity production provides short-term balancing of fluctuations in wind and solar. Long-term fluctuations are balanced by injecting bio methane into the natural gas grid.

Figure 7.3 Schematic diagram of Kombikraftwerk 1
The objective of the project was to demonstrate that with 100% renewable energy it is, in fact, possible to cover the German electricity need. Long-term tests in the project period 2007 showed that this is possible. It was shown that

- renewable energy can be controlled at any time
- renewable energy units can inter-operate and cover the German electricity need
- renewable energy can be outbalanced across the grid

7.3.1 Project partners

7.4 Kombikraftwerk 2

As a follow up on “Kombikraftwerk 1” (2007) the German federal government has decided to start-up the project “Kombikraftwerk 2”.

This project will test how to handle grid stability with an energy supply that is based on 100% renewable energy. The project will investigate how to optimise system services. First, the project will develop and via simulation test how to optimise system services. In the last phase, the project will connect energy plants all over Germany for test under realistic conditions.

The budget is EUR 1.8 million, and the project has a time frame of three years. The project partners are:

- Cube Engineering GmbH
- Deutcher Wetterdienst
- Enercon GmbH
- Frauenhofer IWES
- ÖKOBiT GmbH
7.5 **Enertrag Hybridkraftwerk**

In October 2011, Enertrag and project partners Total, Vattenfall and Deutsche Bahn started up a so-called hybrid power plant located at Prenzlau in northeast Germany. The plant comprises:

- 3 x 2 MW wind turbines
- 1 x 500 kW$_e$ atmospheric alkaline electrolyser
- Biogas plant with 2 x 350 kW$_e$ biogas/hydrogen engines and biogas storage facility
- 1 hydrogen compressor
- Hydrogen storage facility with 1,350 kg hydrogen at 30 bar

*Figure 7.4 Schematic diagram of hybrid plant /24/**
The objective of the plant is to demonstrate that stable energy supply based on RE in the form of wind and biogas is possible. The electricity surplus from wind is converted via electrolysis to hydrogen. In case of electricity shortage, biogas/hydrogen fuelled gas engines will supply the power. A smart detail is that the gas mixing ratio of the engines can be varied according to the availability of hydrogen and biogas, so that the hydrogen content varies between 0 and 70%.

The plant also supplies filling stations at Berlin Airport and in Hamburg with hydrogen.

The price of the plant was approx. DKK 150 million.

### 7.6 Solarfuel and Juwi project P2G Morbach

In March 2011 (in the presence of the German Minister of the Interior), Solarfuel and Juwi commissioned a small demonstration plant at Morbach. This area already accommodates a number of energy plants, including wind turbines, solar cell plants and biogas plants. This plant is a further development of a laboratory plant that was in operation at ZSW in Stuttgart in 2010.

![Figure 7.5 Location of demonstration plant in the existing network of energy plants at Morbach /25/](image)

The container plant converts surplus electricity from solar and wind plants to bio-SNG. The plant comprises a 25 kW_e electrolysis plant and a succeed-
ing methanation plant of the Sabatier type. CO₂ is supplied from a nearby biogas plant.

![Schematic diagram of the plant](image_url)

*Figure 7.6 Schematic diagram of the plant /25/

### 7.6.1 Time schedule

The plant is being optimised from 2011 to 2013. Market maturing and corresponding know-how regarding scaling up are expected to be achieved in 2014.

### 7.7 Project RH2-WKA

The project is one of the larger examples in Germany of storing surplus electricity from wind power via electrolysis, of storing hydrogen and of regenerating electricity via CHP plants. The project entered the project planning phase over the spring of 2011. The first turf was cut July 2011.

The project’s main components are:

- 1 MWₑ electrolyser (Hydrogenics)
- Hydrogen compressor
- Hydrogen storage facility 27 MWh
- 0.25 MWₑ CHP unit (gas engine based)

The plant is located close to a natural gas pipe, and the hydrogen produced will partly be injected into the natural gas grid and partly used as transport fuel.
The German Gas Regulations allow up to 5% hydrogen content, which allows a considerable hydrogen injection – if the gas flow conditions are stable.

![Schematic diagram of the RH2-WKA plant](image)

*Figure 7.7  Schematic diagram of the RH2-WKA plant /26/*

The plant is located in Mecklenburg-Vorpommern in the northern part of Germany, where wind conditions are favourable. The plant is placed at a 170 MW_e wind farm, where the unit sizes vary from 5 MW_e and upwards.

The company Wind-Wasserstoff-projekt GmbH has built the plant. Electrolyser etc. are sponsored by NIP (a national innovation program for hydrogen and fuel cells).

### 7.8 E.ON Falkenhagen electrolysis and hydrogen in gas grids

In 2013 E.ON installed a pilot plant for production and injection of hydrogen in the local Ontras gas network in Falkenhagen in the northwest part of Germany. Hydrogen is generated via electrolysis from surplus electricity from local wind turbines /27/. The plant capacity is 360 Nm³/h.
The plant comprises 6 electrolysis modules; each with 6 electrolysis stacks of 10 Nm$^3$/h each, totally 360 Nm$^3$/h corresponding to electrical input of 2 MW$_e$. The plant also comprises compressor unit, buffer storage and a power and control electronics unit.

The DVGW standard G262 today allows up to 5% vol. hydrogen content in the natural gas grid.

The purpose of the project is
- Demonstration of process chain
- Optimisation of operation concept at different wind power levels and levels of hydrogen injection
- Improved wind power utilisation
- Experience regarding: new technical equipment, actual costs, energy trading

**Project Start-stop:** 2011-2015
**Project state (Nov. 2013):** Operation
Project partners

- E.ON
- ONTRAS-VNG Gastransport
- Hydrogenics

Contact
E.ON

7.9 Power-to-gas plant Hamburg, Reitbrook

The project is similar to the Falkenhagen project, apart from the electrolyser technology, which is PEM based. This technology enables a much more compact design and the 1 MWₑ size PEM electrolyser is contained in only one container. The similar power in Falkenhagen, which is based on the traditional technology Alkaline electrolyser, occupies 3 containers. In this project, for the first time the PEM electrolyser technology is scaled up 3 times from what has been demonstrated elsewhere (ITM has recently supplied a 320 kWₑ PEM based unit for the Thüga project group in Frankfurt).

The main goals of the project are

- Development of PEM technology
- Field trial via injection into E.ON energy infrastructure
- Development of business models
**Project start-stop:** 2012-2015

**Project state (Nov. 2013):** In progress

**Project partners**
- E.ON Hanse AG (field trial)
- Research centre Jülich
- Hydrogenics (electrolyser system builder and packer)
- Solvicore GmbH (PEM stack supplier)
- Fraunhofer ISE
- DLR

### 7.10 RWE demo, Ibbenbüren

This P2G demonstration plant is based on a 100 kW<sub>e</sub> PEM electrolyser unit from the French company CERAM HYD. The produced hydrogen will be injected in the local RWE gas network. The hydrogen production is 20 Nm<sup>3</sup>/h.

The project goals are:
- Design and field test of a PEM based P2G unit.
- Development of operation concepts to handle dynamic loads in the electricity market.
- Optimisation of plant design and operation.
- Evaluation of P2G storage of electricity in an energy system based on renewable energy.

**Project start-stop:** 2013-

**Project state (Nov. 2013):** Construction. Operation is scheduled to take place later in 2013.

**Project partners**
RWE and CERAM HYD.

**Contact**
RWE
7.11 P2G demo Thüga Group

The P2G demonstration plant is based on a 320 kWₐ PEM electrolyser unit from the English company ITM Power.

![Diagram of the Thüga P2G demonstration plant](image)

*Figure 7.10 Principle of the Thüga P2G demonstration plant /63/

Figure 7.10 indicates that the output of the electrolyser is 60 Nm³/h. This means that stack efficiency is $60 \times 3 / 320 = 0.56$. Total plant efficiency is somewhat lower due to consumption from blowers, pumps, standby heating and power electronics.

The plant was delivered at the end of September 2013 at the site in Frankfurt am Main. A test phase is scheduled to run for the next three months, before injection into the gas distribution network starts up.

The project goals are:

- Demonstration of PEM electrolyser in P2G setup.
- Investigation of the ability to handle variable and very dynamic loads.
- Injection of hydrogen in the local gas distribution network at 3.5 bar.

*Partners*

- badenova AG & Co. KG
- Energieversorgung Mittelrhein GmbH
- Erdgas Mittelsachsen GmbH
- erdgas schwaben GmbH
- e-rp GmbH
- ESWE Versorgungs AG
- Gasversorgung Westerwald GmbH
- Mainova AG
- Stadtwerke Ansbach GmbH
- Stadtwerke Bad Hersfeld GmbH
- Thüga Aktiengesellschaft (Projektkoordinatorin)
- Thüga Energienetze GmbH
- WEMAG AG

**Project start-stop:** 2013-

**Project state (Nov. 2013):** Test phase. After 3 months, the operation phase is expected to begin.

### 7.12 P2G by Microbenergy: Eucolino at Schwandorf

The Viessmann owned company Microbenergy has installed a P2G plant in Schwandorf. The system is based on an electrolyser of a capacity of 120 kWₑ and a 100 m³ biological reactor with the trade name “Eucolino”. The biogas plant generates 10 Nm³/h biogas consisting of 52 % methane and 48 % carbon dioxide. In order to ensure complete transformation of the carbon dioxide the electrolyser has a capacity of 20 Nm³/h hydrogen. The hydrogen is directly injected and the methane content is increased from 52 to around 75 % during the slow mixing process involving mechanical stirring.

The principle of the system is shown in Figure 7.11. The figure shows data for a much larger system which is scheduled to be demonstrated in 2014 /64/.

![Figure 7.11 Schematic diagram of the biologically based methanation](image)
The 120 kW\textsubscript{e} R&D plant has been in operation since November 2011.

**Partners**
Microbenergy GmbH (a subsidiary of Viessmann)

### 7.13 DVGW-EBI research project: Storage of electrical energy from regenerative energy sources in the natural gas grid – H\textsubscript{2}O electrolysis and synthesis of gas components

The objective of the project is to develop relatively rapidly achievable concepts for producing SNG from surplus electricity from solar and wind plants.

Figure 7.12 shows the main components of the process flow to be investigated. A crucial element is the CO\textsubscript{2} source – here the project investigates supply via biogas or chemical industry.

![Figure 7.12 Schematic diagram of the process flow investigated](image)

The German potential for storage in the gas grid is considerable. At the moment there is a storage capacity of 23 GNm\textsuperscript{3}, and an additional 7 GNm\textsuperscript{3} is planned. A total of 330 TWh\textsubscript{e} energy can be stored in these storage caverns. In comparison, the pumped storage facilities hold 0.04 TWh\textsubscript{e}.

**Project start-stop:** 2011-
**Project state (Nov. 2013):** In progress

#### 7.13.1 Project partners

- H-tec (builds PEM electrolyser)
- Fraunhofer ISE (system optimising)
- DVGW (project coordinator og three-stage methanation)
- IOLITEC (synthesis of ionic fluid)
- Outotec (alternative methanation in Horden reactor)
- Engler-Bunte-Institut (calorific val adaptation)
- EnBW Energie (feasibility and identification of possible sites)

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7.14  DVGW-GUT research project: Development of modular concepts for generation, storage and injection of hydrogen into the natural gas grid

The project started in 2010 and is based on the large five-year EU project Naturalhy that was finalised around 2009 with 39 European partners. The objective of Naturalhy was to investigate possibilities and consequences of hydrogen injection into the gas grid.

As previously mentioned, DVGW G 262 already today allows a hydrogen content in the gas grid of up to 5 % vol. Preliminary calculations with the tool “Gascalc” in this project indicate that up to 15 % vol. hydrogen may be allowable. 15 % hydrogen means that the gas mixture is still inside the quality band (Wobbe calorific value) that was established in DVGW G 260.

The project has now been finalised and a comprehensive report is freely available for download /62/.

Project start-stop: 2010-2013
Project state (Nov. 2013): Finalised.

7.14.1  Project partners
- DVGW-GUT
- Fraunhofer IWES
- Verbundnetz Gas AG
- EON Ruhrgas
- Engler-Bunte-Institut EBI

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7.15 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 CO$_2$ and turns into CaCO$_3$ (lime). The bed material supplies heat into the gasifier – both as chemically latent heat and by the thermal heat capacity /29/. See Figure 7.13.

CaO absorbs CO$_2$, and the result of the gasification process is a producer gas with a high content of hydrogen, which then again is directly convertible to CH$_4$, 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, where the biomass originated from. This means manuring the fields.

Furthermore, CaO works as a catalyst for conversion of tar. The gas then has a concentration below 500 mg/m$^3$ 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). When used as bed material, CaO erodes. 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.

![Principle of AER: Dual Fluidised Bed (DFB) Gasifier with in situ CO2 Removal](image)

**Figure 7.13** Schematic diagram of the AER-process at ZSW /29/

The AER technology has successfully been tested on the Güssing plant. The share of hydrogen in the producer gas was improved 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.

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7.16 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 7.14.

![Diagram of the Blue Tower concept](image)

*Figure 7.14 Diagram of the Blue Tower concept /14/

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 /37/. 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 producer gases could be used directly for production of SNG. The producer gases have the following composition (dry vol.):

- H₂: 50 %
- CO: 15 %
- CO₂: 25 %
- CH₄, C₂H₄, C₆H₆: 10 % (mainly CH₄)
- H₂O before drying ~20%

This leads to an H₂/CO ratio above 3. Thus all hydrogen can be converted to CH₄ 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.

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7.17 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, like the previous one, is an indirect gasification technology.

The concept is illustrated in the below figure from agnion /38/. The research and development has been carried out by agnion Highterm Research GmbH, and the technology has been commercialised by agnion Technologies GmbH in Pfaffenhofen a.d. Ilm, Germany /39/. 
The heat is transferred from the combustion chamber to the reformer/gasification via the so-called heat pipes. 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 /38/. 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 them /39/.

![Illustration of the Heat Pipe heat transfer](image)

**Figure 7.15** Illustration of the Heat Pipe heat transfer

![The two fluid bed regions in the Heat Pipe reformer](image)

**Figure 7.16** The two fluid bed regions in the Heat Pipe reformer /38, 39/
A 500 kW\textsubscript{th} 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 /40/.

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.

For the purpose of bio-SNG, agnion has developed a low cost methanation unit, AMR (agnion methanation reactor), suited for the HPR (Heat Pipe Reformer) of agnion. It is based on replacement of catalysts every 1-2 years of operation. This means that the CAPEX cost is low, but the OPEX higher for this methanation unit /41/.

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7.18 Super critical gasification of wet organic waste at the Karlsruhe Institute of Technology (KIT)

KIT is an institution, like the Danish RISØ, that has been a development centre for nuclear research, but is now doing research in RE. At the institute in question they do research in gasification technologies with up to super critical conditions of water, i.e. up to 500 bar and 600 °C.

KIT has succeeded in gasifying biomass at super critical conditions – so-called hydrothermal gasification. The focus is on production of bio oil, but the process may also be changed to production of gases, \(H_2\), CO, CO\textsubscript{2} and CH\textsubscript{4}. These gases may then be converted directly to SNG, via a catalyst, which makes this technology very interesting.
KIT does not recommend hydrothermal gasification for “dry” biomass, as this material is difficult to access for the process, as the water is not “inside” the material.

However, hydrothermal gasification can be used for all “wet” types of biomass. For example slurry, products (sludge) from waste water treatment plants, “wet” energy crops, residual products from biogas plants.

One of the advantages of the method is that the biomass is completely converted at a relatively low temperature. Another advantage is that an in-situ gas cleaning is carried out due to water’s properties in supercritical conditions.

If the method is used as an “add on” for a biogas plant the residual product from the biogas plant (often containing half of the energy) can be utilised, and the total amount of gas products from both the biogas plant and the gasification plant can be upgraded to CH₄ at the same time. Of course, this needs to be compared to a plant operating at 100 % hydrothermal gasification.
At the moment, KIT is cooperating with PSI (Paul Scherrer Institute) in Switzerland about gasification of residual products from biogas plants. KIT is also cooperating with PNNL (Pacific North West National Laboratory) in the USA, Douglas Elliott. PSI is working with processes just above the critical point of water, whereas PNNL is working with processes just below this. Both methods have their advantages and disadvantages. Both result in producer gases that can be methanised to SNG.

The pilot plant at KIT can convert up to 100 kg wet biomass per hour, corresponding to approx. 10 kg dry matter per hour. The future plant at PSI (in cooperation with KIT) is planned to reach 200 kg/h, corresponding to 20 kg dry matter/hour. This corresponds to approx. 100 kW.

A number of other institutions are working with supercritical gasification of wet organic waste, but they are not included here.

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8.1 Paul Scherrer Institut

For many years, Paul Scherrer Institut (PSI) has been working with technologies for gasification and bio-SNG, but apparently there are only plants with direct utilisation of the producer gas for CHP in Switzerland, at the moment.

PSI did participate in the Güssing project and supplied the technology for methanation (1 MW bio-SNG).

PSI carries out a lot of fundamental research in gasification, combustion, methanation and upgrading. Figure 8.1 shows a PSI overview of the application range of key technologies for bio-SNG /51/.

![Application range of key technologies for bioSNG](image)

*Figure 8.1 Application range of key technologies for bio-SNG /51/*

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9.1 GAYA project

With GDF-SUEZ as coordinator, the GAYA project was started in 2010 with support from the French government. The project is in collaboration with a number of European players and companies, mainly from France, though.

The project will run from 2010 to 2017, and the total budget is EUR 47 million. The project covers gasification of dry biomass, first of all wood. The FICFB process has been chosen for gasification, i.e. the same as in the Güssing project. Repotec from Austria is technology supplier.

A gradual development from CHP over industrial utilisation to methanation to bio-SNG has been chosen. See the figure below.

Figure 9.1 Stages of the GAYA project, coordinated by GDF-SUEZ /56/

The site for GAYA’s R&D platform is close to Lyon. First, gasification as a kind of copy of the Güssing plant is going to be demonstrated, where the gas is used in engines for production of CHP. Then, utilisation of the syngas directly for industrial purposes will be demonstrated, e.g. glass works and
tile works, where the syngas will replace fossil fuels. Finally, methanation will be demonstrated, where the gas is to be injected into the natural gas grid and replace fossil natural gas /16/.

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9.2 Cyrano-1-project: Wind farms connected to hydrogen grid

In the years 2009-2011 a feasibility study was carried out. For an area in Brittany (France) with approx. 0.5 million inhabitants (Brest and Quimper) and neighbouring wind farms (270 MW$_e$) on the basis of
- Mean electricity need on an hourly basis for the last 10 years
- Mean wind/electricity production on an hourly basis for the last 10 years

the costs were calculated for a system consisting of
- Wind turbines
- Electrolysis plant
- Hydrogen network
- Hydrogen storage buffer
- Fuel cell plant.

Figure 9.2 Schematic diagram of Cyrano-1-project /20/

The system was planned to balance differences in electricity production and consumption.
Calculations were made on the system, both with and without connections to the remaining French electricity grid. Furthermore, examples were calculated with limitations in the wind/electricity production. In all cases it was found that the costs of electricity production were very high. As the separate hydrogen network alone constituted 50% of the installation costs, it was suggested to use the natural gas grid for hydrogen transport – which, on the other hand, entails a number of unsolved problems and costs.

9.2.1 Project partners

- GDF-Suez
- CEA
- Helion
- Ineris.

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9.3 GRHYD project

The GRHYD project includes two pilot projects that will be carried out in Dunkerque. Both pilot projects include injection of wind/electricity based hydrogen into the natural gas grid in the amount of 6-20% vol. In one case, the site is a well-defined residential area with 200 households in Capelle-la-Grande in Dunkerque, and the other project will supply fuel for gas buses in Dunkerque.

Project start-stop: 2013-2020
Project state: Study and preparation phase
9.3.1 Project partners

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9.4 Myrte (Corsica)

Solar electricity is feeding electrolysis supplying hydrogen to buffer storage. Electricity is produced as needed by a fuel cell system for the electricity grid of the island.

The project aims to test and optimise the system and control strategy in order to minimise the constraints on the electricity grid caused by the intermittence of the solar electricity. In other words, to optimise peak shaving and load balancing.
The project is divided into three phases. In phase 1 the full solar array was installed with a capacity of 560 kW\textsubscript{e} together with an electrolyser capacity of 10 Nm\textsuperscript{3}/h and a fuel cell capacity of 100 kW\textsubscript{e}. In phase 2, the capacity of the electrolyser and fuel cell system was increased to reach an electrolyser input/output capacity of around 110 kW\textsubscript{e}/23 Nm\textsuperscript{3}/h and a fuel cell capacity of 200 kW\textsubscript{e}. Phase 3 focuses on optimisation and reliability.

**Figure 9.4  **Myrte Site arrangement

**Project start-stop:** 2009-2015  
**Project state (Nov. 2013):** Operation, phase 3

**Project Partners**
- University of Corsica (Project Manager)
- Areva Renewables
- CEA

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### 9.5 Minerve

Minerve is an R&D project with the focus on flexible storage of CO\textsubscript{2}-free electricity (based on renewables or nuclear) by converting CO\textsubscript{2} emission from industry into methane/bio-SNG or synthetic liquid fuels, such as meth-
anol and DME. The concept is based on high-temperature co-electrolysing of water/steam and CO₂ plus methanation.

The main advantage of the system, compared to systems equipped with the usual low-temperature electrolyser, is that system efficiency in theory can be higher. Such high-temperature electrolysis-based systems are not commercially available now. The Danish company Haldor Topsoe is working on similar systems based on the high-temperature SOEC (solid oxide electrolyser cells).

Figure 9.5 Principle diagram /69/

**Project start-stop:** ?
**Project state:** ?

**Project partners**
- GdF-Suez (project manager)
- CEA
- KIT
- AGH
- Solvay

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9.6 ElectroHgena

ElectroHgena is a demonstration project based on the electro-hydrogenation technology, which enables conversion of surplus electricity, CO₂ and water to methane and oxygen in just one step. The conversion efficiency is expected to be above 75% or at the same level as systems based on high-temperature co-electrolysis of water and CO₂.

![ElectroHydrogenation Diagram]

Figure 9.6 The electroHgena project /70/

Project start-stop: ?
Project state: ?

Project partners
- Gdf-Suez
- Areva
- Rhodia

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10.1 Ingrid, FCH JU project

Surplus of wind electricity is converted via electrolysis into hydrogen that is stored in metal hydrides. Hydrogen is used for transport, industry, grid balancing and injection into gas network. The principle of the project is shown in Figure 10.1.

The project was started in 2012 with a planning and preparation period. According to the project manager, the construction phase is expected to begin December 2013. Project duration will be 4 years. The budget is 24 million Euro, of which 14 million Euro is funded by the EU 7th framework for research.

Figure 10.1 Schematic layout of the project /65/

The project goals are /65/:

- To maximise utilisation of fluctuating renewable energy sources by increasing the efficiency of integration without compromising grid reliability and security.
- To design and make available advanced ICT monitoring and control tools aimed at simulating, managing, monitoring, controlling power dispatching in compliance with the power request of the grid, allowing a correct balance between variable energy supply and demand.
To demonstrate the usage of an innovative hydrogen solid-state storage technology as safe and high-density energy storage systems, to be integrated in a closed loop coupled with water electrolyzers and fuel cell systems with the objective of achieving a high-efficiency regenerative loop (larger than 50-60 %) at a reasonable cost.

To demonstrate the use of hydrogen for transport, industry, grid balancing and injection in the local gas network.

**Project start-stop:** 2012-2017

**Project state:** Planning. Construction will begin December 2013.

**Project partners**

- Engineering Group
- Enel Distribuzione
- ARTI Puglia
- RSE Italy
- Hydrogenics
- McPhy Energy
- Tecnalia

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11.1 Sotavento

Surplus of wind electricity is converted via electrolysis into hydrogen that is stored in tanks (5 MWh), and via a gas engine based ICE unit it is converted to electricity as needed.

\[\text{Figure 11.1 Schematic layout of plant /66/}\]

The objectives of the project are

- Maximising the utilisation of wind power
- Production and storage of hydrogen from a wind farm that features 24 wind turbines of 5 different technologies
- Using the H\(_2\) in an internal combustion engine to produce electricity.
11.1.1 Results of the project

The system control strategy was not optimised to handle fluctuating renewable energy. It showed difficult to model the various components.

**Project start-stop:** 2007-
**Project state:** Operation

**Project partners**
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- Cener

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12 Great Britain

There are a number of gasification projects in Great Britain, but no on-going projects regarding bio-SNG have been identified.

Nor have any relevant projects for bio-SNG opportunities been identified, apart from a couple of feasibility projects /30, 31/.
13 Finland

13.1 VTT Technical Research Centre of Finland

Finland has a number of institutions with a wide expertise in gasification and a number of gasification projects have been identified. However, no active projects regarding bio-SNG have been identified. Most projects based on biomass are utilising CHP directly or aim at BtL (bio-to-liquids) for production of liquid fuels. Finnish Carbona was technology supplier for Skive District Heating that utilise the gasification for CHP.

The Technical Research Centre of Finland, VTT, has carried out research in gasification and bio-to-fuel for several decades. In a recent project, “Woody biomass based gasification process development for SNG or hydrogen synthesis” (VETAANI), tar production and tar reduction in gasification were thoroughly researched /52, 53/.

Figure 12.1 VTT concept for Syngas Route to Biofuels /53/

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14.1 Electrolysis projects based on RE

No large demonstration projects have been implemented, but research and development have been going on for quite some years. However, no projects with the objective of natural gas grid injection in the form of RE-SNG or hydrogen have been identified.

One laboratory should be mentioned: NREL – National Renewable Energy Laboratory. NREL is a national laboratory under US Department of Energy’s office for energy efficiency and renewable energy and it is led by “Alliance for Sustainable Energy, LLC”. Their special expertise is within system engineering, integration, modelling, test and analysis. A major part of their recent projects can be seen at their website /33/.

14.2 The Lurgi process – the Great Plains Synfuels Plant

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. Figure 13.1 shows a process flow diagram of the plant /32/. The methanation part is in some ways similar to the Haldor Topsøe TREMP process (or perhaps the other way around).

Figure 13.1 Process flow diagram of SNG-plant at Great Plain Synfuel based on the Lurgi process /32/
The plant in North Dakota began operating in 1984 and since 1999 it has produced \( \text{CO}_2 \) for 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. Figure 13.2 shows the plant schematically.

![Figure 13.2 The Great Plain Synfuel plant](http://www.dakotagas.com/index.html)

Contact

http://www.dakotagas.com/index.html

### 14.3 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 system is gasifying the biomass, and the other system 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 IPR of the process went bankrupt in 2002 and the IPR now belong to Rentech. A new plant based on this principle was scheduled to be put into service in 2012 in California. Here the producer gas was planned to be converted to liquid fuel. The producer gas from the pro-
cess is analogous with gases from other indirect gasifiers and they could just as well be used for production of bio-SNG.

Figure 13.3 The SilvaGas-process /15/

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14.4 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, pressurised steam is injected to "fluidise" 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, catalysed in a single reactor and at the same low temperature, generate a mixture predominately composed of methane and CO$_2$ /34/.

After CO$_2$-removal the result is SNG, which can be injected into the natural gas grid. CO$_2$ can be used in oil fields for EOR.

The technology looks promising, but is not yet to be found in Europe. Figure 13.4 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 13.4 The Hydromethanation technology, GreatPoint Energy /34/*

*Contact*

14.5 Rentech-ClearFuels Biomass Gasification Process

The Rentech-ClearFuels biomass gasification technology produces hydrogen as well as syngas from cellulosic feedstocks through the use of a High Efficiency Hydrothermal Reformer (HEHTR). The syngas can be used to produce renewable power or be processed through Rentech's technology or other third-party fuel conversion technology to produce renewable drop-in fuels. The Rentech-ClearFuels technology has operated at pilot scale in excess of 10,000 hours and multiple third parties, including Idaho National Laboratory and Hawaii Natural Energy Institute, have independently validated the results of the pilot scale data. The Rentech-ClearFuels technology has been proven at demonstration scale at Rentech's Energy Technology Center in Commerce City, CO through a $23 million grant received from the U.S. Department of Energy under the American Recovery and Reinvestment Act /59/.

Unlike other gasifiers or pyrolysis processes, ClearFuels HEHTR is a one-step rapid steam reforming process that converts biomass to syngas with minimal char, ash and tar yields. The technology has operational controls for tuning the hydrogen to carbon monoxide ratio in the syngas product from 1.0 up to 3.5 as shown in Figure 13.6, which presents syngas composition as a function of residence time in the ClearFuels gasifier. The tuning of syngas composition provides flexibility for various downstream processing and conversion options.
Wood waste from wood product facilities like sawdust or wood scrap and sugar mill waste like bagasse and cane trash are two examples of many inexpensive and readily available feedstocks for the process /58/.

![Figure 13.6 Tuning of the Hydrogen to CO ratio in the syngas](image)

Unfortunately the test facility has now been shut down and the staff reduced from 75 to a core group of 10, which is focusing on selling the technology, the Production Demonstration Unit and the site in Commerce City /60/.

Apperently the process would, however, be very suitable for bio-SNG production as the H₂/CO ratio is easily adjusted to the desired 3.0 for methanation.
15 Japan

At the moment, no relevant projects have been identified.

Japan has initiated a large number of projects related to a possible future, where hydrogen might be a significant energy carrier. One example of these projects is the “Hydrogen Town demonstration project”, which is implemented in Fukuoka Prefecture, Kita-Kyushu-shi. As usual in Japan, the hydrogen generation is either industrial waste product or reformer based. The project is demonstrating operation of fuel cell plants in households and vehicles.

Figure 14.1 Schematic diagram of the Japanese town demonstration project /35/
16 Argentina

16.1 Hychico

In the IEAHIA task 24 final report /66/, this project is described as follows: "The project objective is to maximise wind utilization by producing hydrogen, which is admixed to natural gas and used as fuel in a genset. High-pressure oxygen will be supplied to the local market.

The P2G and G2P plant has been into operation since 2008.

The project has two phases:
Phase 1 was the “Large Scale Clean Hydrogen Production in Patagonia Argentina” pilot project.

In Phase 1, two 325 kW electrolysers produce a total flow of 120 Nm³/h of hydrogen and 60 m³/h of oxygen at max. 10 bar. For re-electrification, the hydrogen is mixed with natural gas from an oil field. The 1.4 MW genset supplies the oil field with power. Oxygen is compressed to 200 bar and stored.

The genset has an ICE designed to operate with gases from biomass, pyrolysis, etc., and has been specially adapted to operate with rich and/or poor gas – hydrogen mixtures. It is worth mentioning that gases used are raw gases extracted from the field with no previous treatment. The rich gas has a 90%
methane content and the poor gas has a ~40 % CO$_2$ content. It is planned to use 3 years’ wind resource data as input signal to the electrolyzers, in order to simulate wind park behaviour.

Phase 2 is to be the start-up of a 6.3 MW wind park, which feed 0.6 MW to the hydrogen plant, the remaining output being sold to the national interconnected electric system. “

*Partners*

- Hydrogenics
- Hychico
17 New Zealand

17.1 University of Canterbury

University of Canterbury (UOC) in Christchurch and CRL Energy Ltd in Lower Hutt are the only two institutes in New Zealand to conduct research and development on thermal gasification. UOC is focusing on biomass gasification and collaborating with CRL for co-gasification of biomass and coal /57/.

Biomass gasification projects have been established and run since 2004 in the Department of Chemical and Process Engineering (CAPE). A 100 kW (biomass in) dual fluidised bed (DFB) gasifier has been designed, constructed, commissioned and improved during 7 years. The concept of the DFB gasifier was similar to the Güssing gasifier and the gasifier developed at Vienna University of Technology (VUT). Collaboration has been established between UOC and VUT. Modification of the gasifier has been conducted for testing of New Zealand feedstocks /57/.

The current research programme conducted at the University of Canterbury is Biomass to Syngas and Liquid Fuel (BTSL). The programme is funded by the Ministry of Business, Innovation and Employment (MBIE) for six years from 2008 to 2014. The programme is to adapt and develop the most advanced thermo-chemical conversion technologies to suit the New Zealand biomass resources. These technologies include using gasification to convert biomass into hydrogen-rich syngas followed by Fischer-Tropsch (F-T) synthesis to produce biodiesel for transport.

Flexibility of the DFB gasifier has been demonstrated in producing producer gases with a wide range ratio of $H_2$ to CO from 0.9 to 4.4. This means that the DFB gasifier developed can be used for generation of energy using the producer gas of low ratio of $H_2$ to CO, for generation of Fischer-Tropsch syngas using the optimum $H_2$ to CO ratio of 2, or for hydrogen production using the high ratio of $H_2$ to CO /57/.

This flexibility makes it very suitable for the production of bio-SNG as well.
18 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 so as not to damage the catalysts and other components.

There are a number of different gas cleaning concepts and techniques, but common for all of them is the removal of substances that may compromise the function (e.g. catalyst deactivation or poisoning) and the lifetime 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 /45/.

The different technologies are:
- Dust cleaning
- Tar conversion/separation
- Sulphur and chlorine removal
- Reforming and shift processes

In the SGC report “Gasification – Status and technology” /45/ a short, but thorough description of different technologies is 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 entering into the methanation process. In some gasification technologies, however, these processes are included in the gasification and no further reforming or shift is needed.
19 Methanation technologies

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

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

\[ \text{CO} + 3\text{H}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O} \]
\[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]

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.

19.1 Haldor Topsoe’s TREMP process

Haldor Topsoe A/S (HTAS) has developed the TREMP process which can convert H\textsubscript{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 be delivered e.g. in the form of pressurised steam, which can be used for power production, or otherwise used in the gasification process (the production of the syngas).

Figure 15.1 shows HTAS’ TREMP technology. Figure 15.2 shows a diagram of the process.
Figure 15.1  The TREMP technology of Haldor Topsøe [22]

Figure 15.2  Graphical illustration of the TREMP-process /46/
19.2 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 an interval as 1 to 5 /45/.

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 15.3.

Figure 15.3 The methanation unit at the Güssing plant /32/
19.3 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 15.4.

![Figure 15.4 The methanation unit at Zentrum für Sonnenenergie- und Wasserstoff-Forschung /29/](image)

19.4 The agnion methanation reactor (AMR)

For the purpose of bio-SNG the company agnion has developed a low-cost methanation unit, AMR (agnion methanation reactor), suited for the HPR (Heat Pipe Reformer) of agnion. It is based on replacement of catalysts every 1-2 years of operation. This means that the CAPEX cost is low, but the OPEX higher for this methanation unit /41/.
The AMR could be applied for several different small-scale gasification technologies with indirect gasification and suitable syngas composition, e.g. CortusWoodroll, Blue Tower, MILENA, FICFB.

19.5 Bio-methanation

The idea of bio-methanation of gasification gas has developed as a result of the studies in an earlier project at DGC /50/.

In an existing project supported by EUDP the company Electrochaea is demonstrating a concept for biological methanation of CO$_2$ and H$_2$ to form CH$_4$. The CO$_2$ here comes from a biogas plant and the H$_2$ 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 H$_2$, CO$_2$, CH$_4$ and CO. In existing chemical methanation plants a part of the CO of this mixture is first shifted to H$_2$ in a “Shift”-reaction to convert the energy in CO to H$_2$. When sufficient CO is shifted, the mixture of H$_2$, CO and CO$_2$ is converted to CH$_4$, CO$_2$ and H$_2$O. The CO$_2$ and water are removed, and the remaining CH$_4$ is bio-SNG.

These processes could be done by biological processes instead of chemical/thermal processes. A study of fermentation processes shows that some microbes are able to convert CO and water to a mixture of H$_2$ and CO$_2$ /47/. 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. Figure 15.5 shows in a diagram the method of bio-methanation.

After a first cleaning of producer gas from a thermal gasifier, the gas consists of a mixture of CO$_2$, CO, CH$_4$ and H$_2$. 
Next, the gas is brought to the first reactor, in which CO is converted into any mixture of CO\(_2\), H\(_2\) and CH\(_4\) 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) are led to the next reactor, where the H\(_2\) and a part of the CO\(_2\) are converted into CH\(_4\) 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 15.5 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 pro-
cesses 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)
- The output is conventional biogas
- Small footprint for the methanation unit
- Low-priced??

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 /48, 49/. Hence, the idea is not new, only the purpose of bio-SNG is new.
20 Possible small-scale demonstration projects

20.1 Demonstration project for gasification in Denmark

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.

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 storage facilities.

There are two ways of making gasification plants more cost-effective: “Economy of scale” and “Economy of number”. Large plants, of course, have the advantage of lower specific price for the installation. On the other hand, a great number of similar plants scattered across the country would also reduce the specific cost of installations and the expenses for transport would be reduced, as well.

A third possibility is to install at a plant several parallel units for gasification technologies that have maximum unit size and attaching one common methanation unit. This would increase 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.
There are several small- to medium-scale technologies well suited for bio-SNG production, e.g. Cortus WoodRoll, Blue Tower (Concord Blue), agnion, MILENA and others.

Even the Danish gasification technologies Viking and Firgas in combination would theoretically be a high-efficient small- to medium-scale unit for bio-SNG production combined with e.g. the AMR methanation from agnion or perhaps future bio-methanation technology /50/.

Small-scale demonstration projects with these technologies should be supported.

20.2 Demonstration of DTU’s hydrogen injection into biogas plants

Hydrogen injection directly into biogas plants seems to be an elegant method of using surplus electricity for methane production. The bacteria in a biogas plant are already converting hydrogen and CO$_2$ to methane so that approx. ¼ of the methane from a biogas plant is generated in this way.

When additional hydrogen is added, the bacteria are slowly becoming used to a higher amount of hydrogen and will convert this with surplus CO$_2$ to additional methane. By storing hydrogen locally, it is possible to balance the peak load of wind energy and to use the hydrogen continuously in the biogas plant. This will result in an alternative upgrading process that at the same time increases the total methane generation from the biogas plant.

Demonstration of this process needs to be supported.
21 Abbreviations and glossary

AER: Absorption Enhanced Reforming
Allothermal: Indirect heating in the gasification process
AMR: anion methanation reactor
Anaerobic: With no addition of oxygen
Biogas: Gas product from biological low-temperature conversion of biomass by anaerobic digestion process
Bio-SNG: Substitute (or Synthetic) Natural Gas from biomass
Chalmers: Chalmers University of Technology
CH₄: Methane
CO: Carbon monoxide
CO₂: Carbon dioxide
DFB: Dual Fluidised Bed
DTU: The Technical University of Denmark
ECN: Energy research Centre of the Netherlands
EOR: Enhanced Oil Recovery
EUDP: Energiteknologiske Udviklings- og DemonstrationsProjekter (Energy Technology D&D projects)
FICFB: Fast Internally Circulating Fluidized Bed
Firgas: Gasification concept by Ammongas and B&W Vølund
Gasification: Thermal/chemical conversion of biomass into gas at high temperature
GOBIGAS: Gasification project in Gothenburg with the goal of producing up to 100 MW bio-SNG
H₂: Hydrogen
HHV: Higher heating value
HPR: Heat Pipe Reformer
HTAS: Haldor Topsøe A/S
Hydromethanation: Methanation by means of water and/or hydrogen
kWh: Unit of energy = 3,6 MJ = 3,6·10⁶ Joule
LHV: Lower heating value
LT-CFB: Low Temperature - Circulating Fluid Bed
Methanation: Chemical conversion of gasification gases to a gas predominantly consisting of methane
MILENA: Gasification process developed at ECN in the Netherlands
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<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>
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<tr>
<td>PJ:</td>
<td>Unit of energy = $10^{15}$ Joule</td>
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<tr>
<td>RME:</td>
<td>Bio-oil, bio-diesel</td>
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<td>SNG:</td>
<td>Substitute (or Synthetic) Natural Gas</td>
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<td>Syngas:</td>
<td>A mixture of $\text{H}_2$, CO and $\text{CO}_2$ (+possibly $\text{CH}_4$)</td>
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<td>TREMP:</td>
<td>Methanation process developed at Haldor Topsøe A/S</td>
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<tr>
<td>Viking gasifier:</td>
<td>Multi step gasification concept offered by Weiss</td>
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<td>VUT:</td>
<td>Vienna University of Technology</td>
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<td>VTT:</td>
<td>Technical Research Centre of Finland (Valtion Teknillinen Tutkimuskeskus)</td>
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<tr>
<td>ZSW:</td>
<td>Zentrum für Sonnenenergie- und Wasserstoff-Forschung</td>
</tr>
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22 References


5. Green Natural Gas, 2011. Edited from application to EUDP.

6. DONG Energy, 2011. Edited from application to ForskEL.


23. www.kombikraftwerk.de

24. www.enertrag.de


28. www.fona.de. Speicherung elektrischer Energie aus regenerativen 
Quellen im Erdgasnetz – H₂O-Elektrolyse und -Synthese von Gaskompen-
ten.


30. The potential for bio-SNG production in the UK. Final report E4Tech. 
NNFCC project 10/005. April 2010.

31. Bio-SNG. Feasibility Study. Establishment of a regional project. 10 No-
vember 2010. Progressive Energy & CNG Service for NEPIC.


www.greatpointenergy.com/ourtechnology.php

35. Japan country update. Presentation at IEAHIA Task 28 workshop, Sep-
ember 2011, Berlin.

36. Henrik Thunman, International Seminar on Gasification, Göteborg 
2010.

37. Blue Tower GmbH, private communication.


41. agnion, private communication


44. FIRgas, internal presentation, Vølund, Ammongas, 2012.


48: http://www.coskata.com/process/


50. Niels Bjarne Rasmussen, *Technologies relevant for gasification and methanation in Denmark*, DGC, September 2012


52. Jörgen Held, Feedback report on VETAANI project, SGC 2013


56. GAYA project, 2nd Generation biomethane through gasification Biomass Valorisation for Energy Production - Turin - 06/02/2013.

58. IEA Bioenergy Task 33, United States Country Report, 2011


61. Innovation Energiespeicherung – Fokus Power to Gas. EON presentation 18.06.13 at DENA annual P2G meeting

62. www.dvgw-innovation.de/die-projekte/archiv/energiespeicherkonzepte/

63. www.energi-und-wende.de


65. www.ingridproject.eu


70. http://atee.fr/sites/default/files/presentationateeouest9avril2013v0.pdf

72. Personal communication with Lars Yde, AU. Nov. 2013.

Appendix 1: Project description from Energinet.dk

European and global projects integrating electricity and gas

Purpose: The purpose of the project is to update and to extend the survey: Screening of European and global projects integrating electricity and gas (in Danish) that DGC prepared for Energinet.dk, December 2011.

Background: DGC prepare the above report for Energinet.dk at the end of 2011. Since then, there has been an increasing focus on the subject, globally and in Denmark. Therefore, it is necessary to update the survey, as it is now the impression that a number of new projects have been initiated. Also, some of the projects described in the 2011 report have developed quite a bit.

In addition, the EU Commission and other international stakeholders have shown interest in the previous survey, so there is also a need for an English version.

Execution: The project is expected to be executed as a literature study and via telephone interviews. The extent of the project and its execution will be coordinated with Energinet.dk on a regular basis.

Scope: As in the previous survey the scope is limited to a survey of projects generating RE gases for the gas grid by means of

- thermal gasification
- electrolysis

Biogas produced via anaerobic decomposition of organic material is not part of the scope. Nor is conventional upgrading of biogas part of the scope, whereas projects where biogas is upgraded by means of methanation of the CO₂ in the biogas are part of the scope.

The survey must include projects generating hydrogen for the gas grid or in mixtures with more than 50% methane.

Steen Vestervang / 13 August 2013