# SYNTHETIC NATURAL GAS (SNG)
# STATE-OF-THE-ART TECHNOLOGY AND APPLICATION REVIEW

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ABSTRACT: Synthetic natural gas (SNG) can be produced by thermochemical or hydrothermal conversion of carbon containing fuels like biomass or coal with subsequent cleaning, methanation and upgrading. In contrast to fossil natural gas, the biomass-derived SNG (Bio-SNG) has a neutral or even negative $CO_2$ balance due to $CO_2$ capture and storage.

Although the SNG production process is not a "new" technology, there is still no commercial break-through of the technology for biomass. So far concepts for SNG plants range from small applications around few $MW_{th}$ (> $1MW_{th}$) up to several 100 $MW_{th}$. Whereas small size has the advantages of easy, local supply of biomass and local heat sinks, big industrial scale plants have the inherent higher efficiency due to scale up effects. Furthermore, various biomass gasification technologies are available but not all of them are suitable for a subsequent SNG production. The allothermal gasification has some advantages regarding the gas composition (low $N_2$ content in the product gas).

In general, all SNG processes from synthesis gas contain a gas cleaning, a methanation and a subsequent upgrading/conditioning of the raw SNG. However, in detail, there are some different concepts for the conversion and lots of elaborate challenges to solve, for example the tar problematic. One critical point is the methanation, which may be conducted in a fluidized or a fixed bed catalytic reactor with intermediate cooling or recirculation of product gas but as well can be done in liquid phase (slurry reactor). The critical parameter is the removal of reaction heat and so far no final design is established.

In Europe there are some prominent SNG example facilities mainly in the pilot plant stage. An overview of SNG projects and operating plants and their technical specifications are shown. Today the most prominent Bio-SNG plants are located in Austria (Güssing), the Netherlands and Sweden.

For the final grid injection SNG has to fulfill the respective legal conditions, as for example in Germany specified in the G260 worksheet. Economic considerations as well as legal boundary conditions are outlined.

**Keywords**: Synthetic natural gas (SNG), allothermal gasification, gas cleaning, product gas, polygeneration

## 1 INTRODUCTION

The urgent demand for greenhouse gas reduction and safe, reliable as well as sustainable energy supply promotes renewable energy technologies. In this context, the utilization of biomass for heat and power generation is an option which not only lowers the dependency on fossil fuels but also reduces $CO_2$ emissions.

A particularly promising option for future renewable energy systems is the production of synthetic natural gas (SNG) from biomass. By using the existing natural gas grid, energy from biomass can be stored and distributed in a very efficient way. The production of electricity is independent from direct utilization of biomass and can be adapted to the present power demand. Therefore, SNG is considered as a perfect complement to balance fluctuating electricity production from other renewable sources like solar or wind.

Furthermore, the SNG route resolves some of the problems often caused by direct biomass utilization like the limited efficiency of localized heat generation and its emissions.

SNG can be produced by thermochemical conversion of biomass with subsequent cleaning, methanation and upgrading of the gas. While fixed and fluidized bed gasification and combustion became the state-of-the-art of science and technology for biomass applications in small and medium scale facilities, the technology of SNG production is still in its research stage [1].

This paper is meant to give a brief overview of various issues connected to the field of SNG: from history to prospects, from technology to application, from research to industry and from small scale pilot plants to industrial scale units. Furthermore different production pathways, different conceptual designs (e.g. for the methanation) and different overall concepts are shown.

## 2 HISTORICAL DEVELOPMENT

First SNG activities started in the USA around the 1960s due to serious concerns regarding possible natural gas shortage. At that time, natural gas had a share of 30% in primary energy consumption in the US. Hence, several investigations financed by the DOE (Department of Energy, US) were published on the early Synthetic Pipeline Gas Symposia in Chicago. Germany had some research as well due to similar concerns and at the latest from the oil crisis in the 1970s, numerous countries were involved in SNG research and development.

However, the interest faded away during times of prosperity and cheap and easy supply of fossil natural gas and crude oil. SNG was no longer profitable and the technology was buried for a long time, only to show up again in times of increasing oil and gas prices and the urgent demand to decrease $CO_2$ emissions [1].

Unsurprisingly, today SNG is considered again as a promising approach, this time even with some major additional arguments like the neutral or even negative $CO_2$ balance. Moreover, political decisions as well as the public opinion are increasingly gaining influence, promoting "green", non-fossil, non-nuclear renewable energy sources. In this context, the European Council for example stated a 20% share of renewable energies in EU energy consumption by 2020 [2].

Biomass in general and particularly the SNG technology are expected to play an important role in future renewable energy mix.

## 3 TECHNOLOGY REVIEW

### 3.1 General aspects

SNG can be produced by thermochemical gasification of biomass and subsequent gas cleaning and methanation. In case of wet biomass, the decomposition (e.g. in supercritical water or $CO_2$) or the fermentation of biomass and a subsequent upgrading of the biogas to SNG are an option.

This paper focuses on gasification-derived SNG as a very promising technology for dry biomass. Figure 1 shows the main process steps from biomass to SNG via gasification.

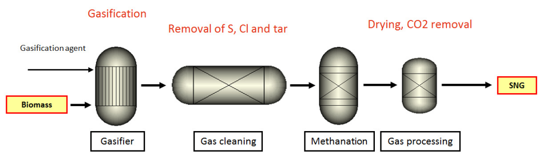


**Figure 1:** General process steps from biomass to SNG

From a technical point of view, the gasification process and the synthesis gas production process respectively, has a huge influence on the following SNG production. Allothermal gasification with no dilution of the synthesis gas with $N_2$ has the best potential for a subsequent methanation and conditioning to SNG [3]. There are also concepts using oxygen blown entrained flow gasifier. Although there is no dilution with $N_2$ too, the corresponding gas composition is normally not that favorable compared to allothermal fluidized bed gasifiers (only small amount of methane and lower $H_2/CO$ ratio).

Table I shows an overview over possible processes and chemical conversion steps involved in the biomass-to-SNG process chain.

**Table I:** Possible process steps for SNG production

| Gasification | Gas cleaning | Methanation | Conditioning |
|---|---|---|---|
| - Allothermal or autothermal<br>- Fluidized bed or entrained flow | - Particle removal<br>- Tar removal/conversion<br>- Sulfur and chloride removal<br>- Removal of other impurities | - Fixed bed<br>- Fluidized bed<br>- Other concept (e.g. liquid phase methanation LPM in a so-called slurry) | - CO shift<br>- Water separation<br>- $CO_2$ separation<br>- Pressurization |

After the gasifier, the product gas has to be cleaned from particles, dust, ash and any other kind of substances or chemicals, which for example could cause damage to downstream units. Particle removal is mostly done by a cyclone and a filter system (hot gas candle filter, bag house filter, etc.), which is state of the art in various related fields. Also wet scrubber systems are commercially available and have proven their reliability but are mostly used to separate not only particles but other impurities like tars, too. The recovered, separated particles are mostly recycled either to a combustion section or the gasifier itself.

The removal of tars or their conversion to gaseous components is far more problematic. Tars cause depositions and plugging in downstream pipes and process units like heat exchangers. Thus, it is crucial to remove tars before decreasing the synthesis gas temperature below the tar dew point. The dew point depends on the tars present in the producer gas and can be higher than 300°C.

Sulfur compounds such as $H_2S$, COS and organic thiophenes are another group of compounds, which must be removed from the gas prior to further gas processing steps. Nickel-based catalysts used for methanation or tar conversion are very sensitive to catalysts deactivation and poisoning with sulfur. Regarding long time catalyst stability and reliability of the whole process, very small traces of sulfur can already have a devastating result. Thus, these components have to be removed to a very low level of usually lower than 1 ppm. This is normally done by adsorption for example on activated carbon beds or ZnO adsorber. Chemical absorption (e.g. wet absorption sodium hydroxide washing) is hardly applied anymore but is a theoretical option too. Similar to sulfur components, impurities like chlorine compounds are removed either in the same adsorption step or an extra one using similar principles.

The most important process step of the SNG production is the actual conversion of $H_2$ and $CO/CO_2$ to $CH_4$. The following two reactions are the most important ones taking place in the methanation reactor:

$$CO + 3\,H_2 \rightarrow CH_4 + H_2O \qquad \Delta H_R = -\,206\ kJ/mol$$
$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O \qquad \Delta H_R = -\,165\ kJ/mol$$

The critical aspect of the methanation reaction is the heat removal of the very exothermic reaction. Therefore different concept have been investigated and developed. For example Haldor Topsoe's process called TREMP™ uses three fixed bed methanation reactors with an internal recycle and intermediate cooling [4,5]. Also there are concepts using salts as cooling agent (ZSW with MAN) [6]. Furthermore there are different concepts concerning the general reactor design and the temperature operation range. Today fixed bed and fluidized bed methanation concepts seem most promising.

After the methanation of the synthesis gas, the raw-SNG has to be further conditioned to meet end-use requirements and grid injection regulations, respectively. This always includes a drying step, either through condensation of the vapor fraction or chemical drying for example with TEG (triethylene glycol). Both processes are state of the art and available for a broad range of process scales.

In most cases, surplus $CO_2$ has to be separated as no complete conversion of the less reactive $CO_2$ is reached. This process step can be conducted via membrane separation or scrubber systems like amine scrubber. Another approach to the problem is the concept developed for example by ZSW Stuttgart which already separates the $CO_2$ in-situ in the gasifier ("AER"), thus saving one process step.

At the end, the temperature and pressure requirements for grid injection have to be met by means of compression and cooling (usually to a pressure of 16 bar and a temperature of 25°C).

From a technology point of view, there are still some obstacles and challenges, which are not yet fully answered. Most important, there is no broad agreement whether hot gas cleaning can become competitive to existing cold gas cleaning systems like RME scrubber, selexol washer etc. Depending on the concept, hot gas cleaning is suggested to have some serious advantages due to losses during cooling and reheating. From a thermodynamic point of view, the cool down and heat up process wastes big amounts of exergy which results in lower overall efficiencies. However, the high temperature cleaning systems are still challenging from a material point of view as well as for example regarding corrosion.

3.2 Exemplary concepts

Some prominent process concepts from biomass to SNG are shown in the following figures, in order to get an overview over the state-of-the-art of science and technology. Figures 2-5 show the examples of current process concepts in Europe.

Concept 1:

**Small scale allothermal gasification "HPR" (Heatpipe reformer) coupled with hot gas cleaning and fixed bed methanation**

Country: Germany

Scale: 1-10 $MW_{th}$

Partner:
- TU München/LES
- hse

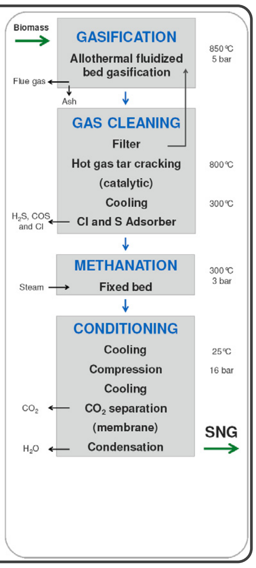


**Figure 2: Concept 1 "Bio-HPR-SNG"**

Concept 2:

**"BioSNG" Dual fluidized circulating allothermal biomass gasifier with subsequent gas cleaning and methanation (fluidized bed/PSI)**

Country: Austria

Scale: 10-100 $MW_{th}$

Partner:
- TU Wien
- PSI
- Repotec/CTU

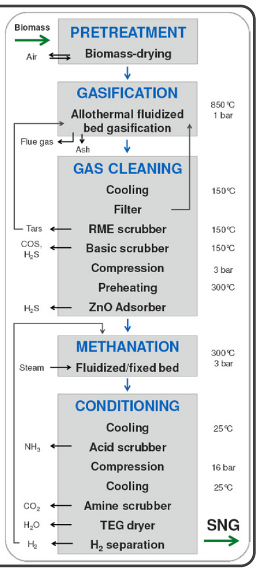


**Figure 3: Concept 2 "Güssing"**

Concept 3:

**Dual circulating fluidized bed gasifier with AER technology, modified gas cleaning and fixed bed methanation in "MAN/ZSW" methanation reactor**

Country: Germany/Austria

Scale: 10-100 $MW_{th}$

Partner:
- TU Wien/PSI
- ZSW
- Repotec/CTU

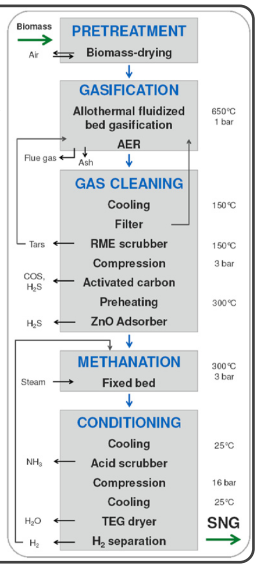


**Figure 4: Concept 3 "Güssing + AER"**

Concept 4:

**Allothermal biomass gasifier "Milena" with OLGA tar removal system and cold gas cleaning/upgrading and methanation designed for scale up to >100 $MW_{th}$**

Country: Netherlands

Scale: 10-100+ $MW_{th}$

Partner:
- ECN

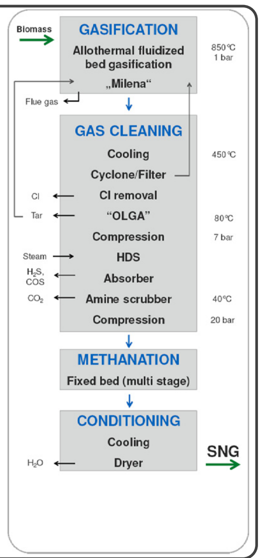


**Figure 5: Concept 4 "ECN"**

Concepts are built on the background of literature data and publications [7-15], but are not meant to exactly represent the actual underlying projects but highlight in a simple manner the most important process parameters.

All concepts are in different stages of development or (pilot) plant operation. Focus - however - is on the general concept and basic conditions, like applied temperature and pressure levels and the sequence of process steps. Even if there is a general agreement for some process steps, each concept usually favors a different sequence and different process units.

Although heat integration is a very critical concern especially when it comes to overall efficiency and economics, the visual presentation of concepts shown above, lack the corresponding heat streams. This is due to the high complexity, to enable a fast and easy visual comparability with focus on process steps. Heat concepts are always elaborate. Besides usual steam production e.g. for process steam or additional district heating systems, the concepts often include ORC (organic rankine cycles) in order to use the great amount of low temperature heat produced during the single process steps.

The latest and maybe most up-to-date activity regarding SNG research and development is the GoBiGas (Göteborg Biomass Gasification) project in Schweden, initiated by Göteborg Energy and E.ON (first phase: 20 $MW_{th}$ BioSNG plant to be operational in 2012, second phase: 80 $MW_{th}$ SNG plant, scheduled to be operational by 2016). Also there is a lot of research going on at ECN in the Netherlands including an advanced SNG pilot facility in Alkmaar [19]. Austrian research and development activities focused in Güssing and Oberwart are improving and investigations on the SNG option are forced in detail. Altogether, SNG is increasingly considered as a promising option in the future energy supply.

## 4 ECONOMICS AND BASIC CONDITIONS

Besides $CO_2$ reduction potential compared to fossil natural gas and $CO_2$ abatement costs, SNG production costs provide a reliable basis, for example for a comparison of SNG to biogas or natural gas.

In order to get an impression concerning economic considerations of SNG, the gas generation costs proposed by the different projects are a good basis to compare the projects among each other and place them in context with current natural gas prices. Figure 6 shows an overview of exemplary gas production costs proposed by the projects or independent studies. Values are taken from literature references [16-18].

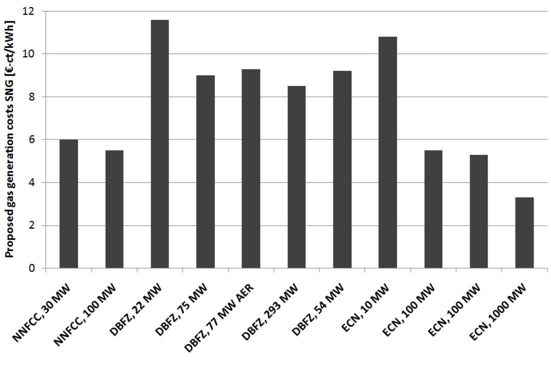


**Figure 6:** General process steps from biomass to SNG

In general, literature values expect a strong influence of scale on the generation costs. As expected, costs are predicted to go down with increasing plant size. However, the absolute values differ in the range of about 10 €-ct/kWh, which makes a general statements difficult. It is widely agreed though, that SNG can be economically competitive to natural gas in the future. Furthermore it is crucial to aim for optimal heat utilization as this factor very strongly influences the overall economics.

Boundary conditions like the respective injection directives have to be considered for each country. In Germany, for example, there is the gas injection regulation specified in the G260 and G262 worksheets. Also, there are for example different pressure levels at different injection locations and as the pressurization influences the overall efficiency and the internal energy consumption, this has to be considered, too.

From a financial point of view, a very challenging obstacle for many biomass projects is the handling of fluctuating increasing feedstock market prices, which can very sensitively influence the overall economics.

## 5 CONCLUSION AND OUTLOOK

SNG has many advantages as for example the high conversion efficiency, the already existing gas distribution infrastructure and high efficient as well as established end use technologies.

However, there are a couple of technical obstacles like for example the tar problematic or sulfur poisoning of methanation catalyst. Furthermore, there is still no clear technical break-through regarding process options like hot or cold gas cleaning, fixed or fluidized bed methanation (multi or single stage), reactor designs and intermediate cooling or recycle. Research is still required in terms of gasification concepts as well as catalyst investigation regarding long time stability and reliability.

As the theoretical potential of biomass is sufficient for a broad substitution of EU's natural gas imports by SNG and Biogas, the corresponding technology has to be established now.

New technologies, a steep learning curve and worldwide increasing prices for natural gas suggest SNG options to become profitable in the future. If this hurdle is past and the gas production costs are in a comparable level to NG prices, the SNG will contribute to a reliable renewable future energy system.

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