COMPARISON OF SNG (SYNTHETIC NATURAL GAS) PRODUCTION PATHWAYS FOR THE STORAGE OF RENEWABLE ENERGY - A GERMAN CASE STUDY

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ABSTRACT: In the course of energy system transformation towards sustainability, SNG concepts using the existing natural gas grid as storage system for renewable energy have significantly gained importance in recent years. To evaluate the performance of SNG technology based on renewable energies, the three most advanced and relevant concepts called Biogas-to-SNG (biochemical), Syngas-to-SNG (thermochemical) and Power-to-SNG (electrochemical) are analyzed and compared in terms of development status, efficiencies, technical potential, production costs and ecological impacts. Finally, a brief survey among political organizations and energy companies is linked to the findings, to examine the future prospects of the three emerging SNG concepts.

As a result, the Syngas-to-SNG concept seems considerably superior to the Biogas-to-SNG concept, especially in terms of technical potential and ecological impacts. Mean SNG-production costs of the Syngas-to-SNG concept range between 4.7 – 16.5 €ct/kWh$_{SNG}$ (average: 7.8) and are therefore in the same range as the production costs of the biogas-based SNG concept (5.6 – 11.6 €ct/kWh$_{SNG}$ (average: 8.8)). However, the gasification and methanation technology required for the Syngas-to-SNG concept is still at an early stage of development. Additionally, the lack of political support is going to hinder the further development of the Syngas-to-SNG concept. Due to the enormous storage potential of the German natural gas grid, the conversion of power into SNG by the Power-to-SNG concept is an attractive solution to store excess electricity from fluctuating power generation of renewable energies. Though, with an overall efficiency of the extended Power-to-SNG-to-Power process chain in the range of 28-45% and average SNG production costs of 8.2 €ct/kWh$_{SNG}$, actually, the Power-to-SNG concept cannot compete with state-of-the-art power storage systems like pumped storage power plants. Nevertheless, the Power-to-SNG concept currently attracts a great deal of political attention and will therefore very likely gain considerable importance in the years to come. However, the discrepancy between recent natural gas costs and SNG costs are so significant that a sustainable development of all SNG concepts is highly dependent on subsidies and strong political support.

Keywords: Synthetic natural gas (SNG), biomass, renewable energies, efficiency, costs

1 INTRODUCTION

The future energy supply is one of the greatest challenges we face today. Together with the urgent demand for greenhouse gas reduction, sustainable energy supply has become more and more important around the world. Furthermore, energy policy attracts a great deal of public interest and recent developments cause a continuing reevaluation of our energy policy today.

Emission of greenhouse gases from fossil sources leads to a significant rise in temperature in the atmosphere with nearly unpredictable consequences [1]. Furthermore, reserves of fossil fuels are declining highlighting the finite nature of all fossil energy [2]. In addition, the remaining sources are lying in politically unstable countries in the Middle East which use their energy sources as political weapons drawing industrial countries further into strong dependencies [3]. This inherent vulnerability of Europe's energy supply can only be decreased by finding alternatives to our fossil based energy system.

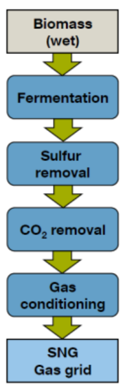
A particularly promising option for future energy systems might be the production of synthetic natural gas (SNG). SNG – or bio-methane - can be produced by thermochemical conversion of biomass and subsequent conversion of the synthesis gas to SNG (thermochemical), by fermentation and subsequent gas upgrading (biochemical) and by using excess power in an electrolysis unit and a subsequent methanation with CO_2. Thus, by using the existing natural gas grid, energy from biomass as well as excess power from renewable sources like wind and solar can be stored and distributed in a very efficient way.

This paper is meant to give a brief overview of these three most relevant production routes for SNG, comparing the concepts by means of efficiencies, technical potentials, costs, status of the development and political as well as public acceptance and future prospects.

2 CONCEPT DESCRIPTIONS

A detailed analysis of each SNG concept in terms of the current status, the performance evaluated by means of energetic potential, SNG costs and ecological impacts is carried out.

2.1 Biogas-to-SNG



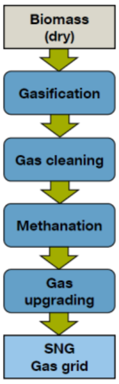
The Biogas-to-SNG concept consists of the main process steps fermentation (biogas production), sulfur removal, CO_2 removal and gas conditioning and injection. Feedstock for the fermentation process can be any organic material with low lignin content, but also sewage gas or landfill gas can theoretically be used as raw gas for the process [4]. The most common treatment methods for CO_2 removal in Germany are pressure swing adsorption (PSA), chemical scrubbing with amines and pressurized water scrubbing

(DWW) [5].

The main energy losses arise in the fermentation and gas upgrading process. Thereby, the conversion efficiency highly depends on the applied feedstock in the fermenter as well as the required biogas treatment process due to grid injection [6].

The technology of the Biogas-to-SNG concept can be considered as state-of-the-art and scientifically well researched with the exceptions of gas cleaning and purification processes. At the moment, about 100 biogas plants with grid injection are operated in Germany [7].

2.2 Syngas-to-SNG



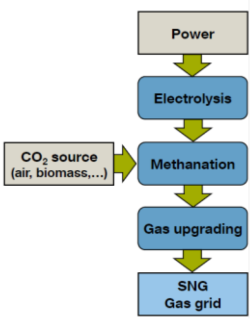
Dry, high lignin containing biomass like wood (chips or pellets) can be used in a gasification process to supply the feedstock for higher, universally applicable valorization.

The main process steps are biomass drying, gasification (allothermal), gas cleaning and methanation followed by the final gas upgrading [8].

Design and adjustment of the gasification process with the subsequent gas cleaning and methanation unit is the most challenging part of the (Bio-) Syngas-to-SNG concept. Depending on the plant capacity, fixed bed, fluidized bed or entrained flow gasifier could theoretically be used for gasification, whereas fluidized bed gasification seems to be most adventurous for biomass conversion [9].

The main losses in efficiency occur during the gasification, methanation and CO_2 removal. Due to the complex implementation, the whole process chain is still in its research and technical demonstration phase.

2.3 Power-to-SNG



The Power-to-SNG concept is a relative new approach to use the huge storage capacity of the German natural gas grid (about 220 TWh_{th}) to counterbalance fluctuating power production of renewable energies.

The concept consists of two main process steps: electrolysis and methanation. Common electrolyzers are polymer electrolyte membranes (PEM), solid oxide fuel cells (SOFC) or alkaline electrolyzers [10]. For the methanation reaction according to the Sabatier process, external carbon dioxide is required, which can be provided from any kind of carbon source, CO_2 producing industries (power plants, cement industry) or an air separation unit. Due to the relative pure raw gas, an elaborate final gas upgrading is not necessarily required.

The efficiency of the process chain is strongly influenced by the applied carbon source and by the performance of the electrolysis and methanation unit.

The first Power-to-SNG demonstration plant has started operation in March 2011 in Germany [11]. Further plants are planned or currently under construction.

3 CONCEPT COMPARISON RESULTS

Based on the concept evaluation described above, a comparison of the Biogas-to-SNG, Syngas-to-SNG and Power-to-SNG concept is made in the following to relate the single SNG concepts to each other and to put the overall performance of SNG technology into an expedient energy political context.

3.1 Status quo of concepts

The development status of the three SNG concepts varies significantly. While biogas production and cleaning technologies can be considered state-of-the-art, part of the technology required for the Power-to-SNG concept as well as the gas cleaning and methanation process of the Syngas-to-SNG concept and especially, the quite complex technical adjustments of these two process steps have not yet been developed to marked maturity. Accordingly, the number of current projects differs extremely among the concepts. While commercial SNG plants based on the Biogas-to-SNG concepts have already been operating for several years in a few European countries, the Power-to-SNG concept is in a first demonstration phase (by means of operating demonstration plants and first building projects), whereas currently no demonstration plant for the whole process chain of the Syngas-to-SNG concept is in operation yet.

The public focus of political parties, NGOs and energy related companies is on the Biogas-to-SNG and to some extend on the Power-to-SNG concept. The Syngas-to-SNG concept has currently very small relevance for the recent energy/business policies as will be explained later in more detail.

3.2 Performance in terms of efficiencies

Table 1 summarizes the performance in terms of efficiencies.

- The conversion efficiency relates the energy content of the SNG ($E_{SNG,}$ without LPG addition) to the energy content of the used raw material input (E_{SUB}) [12].
- The overall efficiency relates the energy content of the final SNG product ($E_{SUM,\ output}$, i.e. including by-products) to the summed up energy inputs ($E_{SUM,\ input}$, i.e. energy content of raw materials, parasitic energy, LPG, etc.). However, the utilization of waste heat is not considered in the calculation of the overall efficiencies.

As the Power-to-SNG concept has primarily been designed for power storage purposes, also the energetic performance by considering the reconversion of SNG into electricity is stated for this concept.

Table 1: Comparison of concepts by efficiencies

Name of concept	Overall efficiency [%]	Conversion efficiency [%]
Biogas-to-SNG	43	52 – 54
Syngas-to-SNG	41.1-50.3	54 – 66
Power-to-SNG	46 – 75	N/A
Power-to-SNG-to-Power	*28 – 45*	*N/A*

The energetic performance differs considerably among the SNG concepts and also estimations by various authors or research groups differ substantially. If the Biogas-to-SNG and Syngas-to-SNG concepts are compared, the last mentioned is significantly superior to the biogas-based concepts in terms of conversion efficiency and to a smaller amount also in terms of overall efficiency.

Although the Power-to-SNG concept has an apparently high overall efficiency, the results are not directly comparable to the biomass-based concepts due to the substantially different character of the Power-to-SNG concept, primarily determined by the applied energy source (electrical power instead of biomass). However, the SNG production by the Power-to-SNG concept with an overall efficiency in the range of 46 - 75% is a quite attractive solution to use excess power from fluctuating renewable energy sources.

3.3 Comparison of technical potential

The energetic technical potential differs substantially between the concepts. Though, the technical potential of the Power-to-SNG concept is not readily comparable with biomass-based SNG concepts due to the explicit different structure of concept. Therefore, the technical potential of the Power-to-SNG concept is analyzed separately.

Table 2 summarizes the current and future technical potential of the Biogas-to-SNG and Syngas-to-SNG concepts.

Table 2: Comparison of technical potential of SNG concepts

Concept	Current energetic potential [PJ/a]		Future development potential [PJ/a]	
	excl. energy crops	incl. energy crops	min	max
Biogas-to-SNG	~130/160*	191-260	~450	~650
Syngas-to-SNG	~530/742*	N/A**	830	1542

* With and without nature protection restrictions

** No relevance

A distinction is made between potential calculations including energy crops and calculations without consideration of energy crops, as these two concepts are in direct competition for agricultural raw materials.

Whether energy crops are considered or not, the Syngas-to-SNG concept has by far a higher technical potential than the Biogas-to-SNG concept, not only today, but also if the future development potential is taken into account. In contrast to the Biogas-to-SNG concept, the vast amount of dry biomass originates from forestry and agricultural waste. Thus, nature protection restrictions (e.g. forest conservation) have a great impact on the technical potential of the Syngas-to-SNG concept, which is also apparent from Table 2. However, as the development potential of non-cultivated raw materials is stagnating for both concepts the Syngas-to-SNG concept can be considered superior.

Although the technical potential of power generation by wind and solar power plants is enormous, the share of the technical potential utilizable for the Power-to-SNG concept is not that high, as only the usage of excess power is sensible from an ecological and financial point of view (e.g. only 0.4572 PJ electricity was wasted due to fluctuating renewable energy sources and power network restrictions in 2010). Furthermore, the potential renewable CO_2 sources which could be used for the supply of the required CO_2 feed are limited as well (e.g. CO_2 from biogas upgrading plants). Nevertheless, the expectations of political organizations and energy companies, considering the development potential of the Power-to-SNG concept, are relative high.

In 2010 the primary energy and gross power consumption in Germany was approximately 14057 PJ and 2174 PJ respectively [13]. Relating these values to the average technical potential of each SNG concept, it is obvious that SNG concepts can only contribute modestly to the future primary energy and power supply.

3.4 Economic considerations

The future prospects of all SNG concepts is predominately determined by the final SNG production costs, as only attractive financial terms lead to an intensified investment in SNG technology. Since the majority of SNG concepts, with exception of the Biogas-to-SNG concept, are at an early stage of development, the price calculation of SNG production is based on some assumptions. Furthermore, reliable data for the cost calculation does only exist for the Biogas-to-SNG concept. However, following relevant costs are collected from literature: consumption costs (e.g. fuel, raw materials, parasitic energy, etc.), operation costs for the plant (e.g. human resources, maintenance), capital costs (e.g. interest rates, deprecations, investments) and other costs (e.g. insurances).

Table 3 summarizes the results of the cost calculations. The average prices for SNG production were determined based on detailed analysis of literature values.

Table 3: SNG production costs

Name of concept	Biogas-to-SNG	Syngas-to-SNG	Power-to-SNG
Range of prices [€ct/kWh]	4.7 – 16.5	5.6 – 11.6*	7.0* - <20*
Average price [€ct/kWh]	≈ 8.8	≈ 7.8	≈ 8.2

*Without consideration of compression and grid injection

Although the ranges of SNG prices vary considerably between the concepts, the average SNG production costs presented in this paper are in the same order of magnitude. However, only SNG costs for the Biogas-to-SNG concept are validated by real experience with existing commercial SNG plants. Whether the other two concepts can meet the expected SNG prices, cannot be foreseen today.

Comparing the average SNG production cost with the current price level of natural gas, it is unequivocal that SNG cannot compete with fossil natural gas without extensive financial subsidies.

3.5 Ecological impact

The analysis of SNG concepts shows that, in general, the GHG emission balances of all SNG concepts can be considered as superior to fossil fuel based systems. However, with avoided GHG emissions of around 49 to 56 kg CO_2(eq)/GJ in relation to fossil reference systems, the Syngas-to-SNG concept has a significant better performance as the Biogas-to-SNG concept with avoided GHG emissions of around 38 to 48 kg CO_2(eq)/GJ. Although reliable data for the GHG balance of the Power-to-SNG concept is not available, it can be expected that this concept has a much higher GHG emission reduction potential compared with biomass-based SNG concept due to avoided emissions for cultivation, harvesting and transportation of biomass.

The formation of monocultures as well as acidification and eutrophication of arable land due to increasing cultivation of energy crops like corn for biogas production leads to serious ecological problems within the ecosystem. These environmental impacts are partly so severe that a further development of energy crop cultivating is not recommended by some experts. The rising resistance of citizens' initiatives and NGOs towards intensified cultivation of energy crops can lead to a significant shrinkage of the technical potential of the Biogas-to-SNG concept. Though, the Syngas-to-SNG concept can be affected as well, if ligneous energy crops are used as raw material.

3.6 Political interest and public notice

The feasibility of SNG concepts depends to a high degree on political decisions and the legal framework in the examined country. For this reason, a survey among political parties, NGOs and energy related companies in Germany was conducted in the course of the case study. As a result, it can be stated that the Biogas-to-SNG and Power-to-SNG concept are most relevant for current business and energy strategies, both in terms of expected energetic potential and technical feasibility. In contrast, the acceptance and recognition of the Syngas-to-SNG concept seems to be rather low.

The role of SNG concepts for the future energy supply is assed quite differently by the participants. Ecological impacts (monocultures etc.) and competition to food production due to intensified energy crop cultivation is seen as a limiting factor for biomass based SNG concepts.

Additionally, the relative high SNG production costs are assessed critically for sustainable economic growth in Germany. However, power storage through the Power-to-SNG concept is expected to significantly gain in importance in the years to come.

4 CONCLUSION AND OUTLOOK

As a result, the Syngas-to-SNG concept seems superior to the Biogas-to-SNG concept in terms of technical potential and ecological impacts. Mean SNG production costs of the Syngas-to-SNG and Power-to-SNG concept are in the same range, but have a significant higher cost reduction potential compared to the biogas-based SNG concept. However, the gasification and methanation technology required for the Syngas-to-SNG concept is still at an early stage of development and the technical feasibility of the whole process chain remains unproved. Additionally, the lack of political support is going to hinder the further development of the Syngas-to-SNG concept.

Due to the enormous storage potential of the German natural gas grid, the conversion of power into SNG by the Power-to-SNG concept is an attractive option to store excess electricity from fluctuating power generation of renewable energies. Though, with an overall efficiency of the extended Power-to-SNG-to-Power process chain in the range of 28-45% and average SNG production costs of 8.2 €ct/kWh$_{SNG}$, the Power-to-SNG concept cannot compete with state-of-the-art power storage systems like pumped hydro storage. Nevertheless, the Power-to-SNG concept currently attracts a great deal of political attention and will therefore very likely gain importance in the years to come.

From a political point of view, it can be stated that there is still much uncertainty amongst decision makers. In quite some cases, expected performances of political organizations and energy companies differ significantly from scientific results, an intensified work in public relations by research institutions is required, to promote and enable a sustainable development of SNG concepts.

However, the discrepancy between recent natural gas costs and SNG costs are so significant that a sustainable development of all SNG concepts is highly depending on subsidies and strong political support. As increasing energy prices can considerably reduce the economic growth and in addition, put financial pressure on private households as well as public budgets, it is uncertain to which extend subsidies and further investment in SNG technology are accepted by the public.

Though, in the course of pressing environmental problems, dwindling resources and increasing energy prices, SNG concepts can contribute to a future more sustainable energy supply and it is very likely that SNG technology will gain importance in the years to come.

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