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Life cycle assessment of SNG from wood for heating, electricity, and transportation

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ABSTRACT

The conversion of wood to synthetic natural gas (SNG) via gasification and catalytic methanation is a renewable close to commercialization technology that could substitute fossil fuels and alleviate global warming. In order to assure that it is beneficial from the environmental perspective, a cradle to grave life cycle assessment (LCA) of SNG from a first-of-its-kind polygeneration unit for heating, electricity generation, and transportation was conducted. These SNG systems were compared to fossil and conventional wood reference systems and environmental benefits from their substitution evaluated. Finally, we conduct sensitivity analysis for expected technological improvements and factors that could decrease environmental performance.

It is shown that substituting fossil technologies with SNG systems is environmentally beneficial with regard to global warming and for selected technologies also with regard to aggregated environmental impacts. On the condition that process heat is used efficiently, technological improvements such as increased efficiency and denitrification could further increase this advantage. On the other hand, lower GHG emissions and aggregated impacts are partly compensated by other environmental effects, e.g. eutrophication, ecotoxicity, and respiratory disease caused by inorganics. Since more efficient alternatives exist for the generation of heat and electricity from wood, it is argued that SNG is best used for transportation. In the light of a growing demand for renewable transportation fuels and commercial scale technological development being only in its initial stage, the production of SNG from wood seems to be a promising technology for the near future.

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1. Introduction

Even though second-generation biofuels are not produced on a commercial scale yet, a number of pilot and demonstration units have been set up in recent years [1]. Among these is the production of SNG (synthetic natural gas) from lignocellulosic biomass via gasification and catalytic methanation, which is currently developed at the Paul Scherrer Institut (PSI) and other research institutes [2]. Serious technological progress has been achieved in Güssing (Austria) during tests of a 10 kW SNG pilot plant in 2004 and a 1 MW process development unit in 2009 [2,3]. Recent evaluations to build a 7.5 MW polygeneration SNG plant in Baden, Switzerland [4] and a 20 MW/80 MW SNG plant (in two stages) in Gothenburg, Sweden [5] are indications that the wood-to-SNG technology is coming closer to the commercialization stage.

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Arguments in favour of the production of SNG are potentially higher conversion efficiencies than other conversion routes such as BTL or lignocellulosic ethanol [1], economic robustness with regard to different levels of fuel and electricity prices [6], a broad usability of SNG, and the already existing natural gas supply infrastructure.

Several studies have recently raised attention to the fact that assessing the full environmental impacts over the whole life cycle of the production and use of biofuels is crucial to assure that these are truly more sustainable than fossil alternatives [7,8]. Even though a previous assessment of the environmental impacts of PSI's wood-to-SNG technology showed that the production and use of SNG in heating and transportation is beneficial from the environmental perspective [9], a renewed assessment seemed appropriate for two reasons: first, new engineering data for the potential first-of-its-kind 7.5 MW Baden plant was available [10] providing thus a better basis for the calculation of the environmental performance than the 10 kW Güssing pilot (which was used in the previous study). Second, the foreseen plant in Baden is a polygeneration plant producing heat, electricity, and SNG and therefore its design is fundamentally different from the pure SNG pilot in Güssing.

The aim of this study was to evaluate the environmental performance of the production and use of wood-derived SNG based on the Baden project plans. We used life cycle assessment (LCA) to analyze the environmental impacts generated during the life cycle stages of the production and use of SNG from cradle to grave. We compare the life cycle impacts of heating, generating electricity, and driving with SNG to fossil and wood-based reference systems. We then evaluate which of the potential uses of SNG is ecologically preferable. Finally, sensitivity analysis is presented for potential technological improvements and critical factors that could worsen the ecological performance.

2. Scope definition

2.1. *Compared systems*

The analyzed polygeneration plant produces SNG, heat, and electricity from wood. The SNG can be used in a natural gas boiler for domestic heating, in a large combined cycle natural gas plant (SNG CC), in a small combined heat and power unit (SNG CHP) or in a natural gas car for transportation (Fig. 1). The process heat that is recovered during the SNG production is used in a district heating system and a hospital, which require heat throughout the year. This heat would otherwise be produced with a natural gas boiler. The electricity is used to cover the plant's own demand.

The fossil reference systems include a light fuel oil boiler, a natural gas boiler, and a heat pump operated with electricity from natural gas for home heating. Since Switzerland's energy demand is still growing, we assume that electricity from SNG substitutes power from otherwise newly built combined cycle natural gas (NGCC) or nuclear power plants [11]. Petrol, diesel, and natural gas passenger cars are used as reference systems for the use of SNG in transportation. For a comparison with wood-based reference systems we also include a wood chip district heating.

2.2. *Function and functional unit*

The function of the analyzed polygeneration plant is a) to produce SNG, which is then used for heating, generating electricity or driving, and b) to generate (process) heat, which substitutes heat from the natural gas boiler of the district heating network. We account for the latter by using system expansion (see Section 2.3) and focus on the comparison of the use of SNG to different reference systems. There is no need to account for the generated electricity as it is produced and used exclusively within the SNG production process.

Since heating, electricity, and transportation are measured in different units (e.g. MJ, kWh and passenger kilometres (pkm)), we define the functional unit as the use of 1 m^3 of SNG in either one of these applications. The quantity of a service (heat, electricity or transportation) that is delivered by 1 m^3 of SNG is shown in Fig. 1. These values are the basis for the calculation of the net environmental benefit, which is used to compare the environmental advantages resulting from the substitution of different reference systems by SNG systems. It is calculated therefore as the difference between the impacts generated by SNG and reference systems.

2.3. *System delimitation*

The life cycle phases of the SNG production system are considered from cradle to grave, i.e. the wood production chain (growth and harvest), the transport of wood to the SNG plant, the conversion of wood-to-SNG as well as the pipeline transport, and the use of SNG for heating or transportation. Similarly, the entire life cycle from resource extraction to fuel use is considered in the reference systems.

ISO 14044 provides several methods for dealing with systems that generate multiple products, which include physical allocation (e.g. by energy or exergy), economic allocation, and system expansion. For dealing with the co-product heat during SNG production, system expansion was applied as the preferable option compared to allocation in the foreground system [12,13]. System expansion can either be realized by system enlargement or by accounting for the avoided burdens [14]. The avoided burdens approach which is used in this study can be explained as follows: the environmental impacts, which would have been generated from the alternative production of heat (for the district heating system and the hospital) using a natural gas boiler, are subtracted from the life cycle impacts of the SNG system. Alternatively the comparison could have been done by adding these impacts to all reference systems (system enlargement).

2.4. *Used LCIA methods*

For impact assessment, relevant impact categories were assessed with midpoint indicators from the CML [15] and Ecoindicator '99 [16] methods, as well as the cumulated energy demand (CED) [17] and the global warming potential (GWP) [18] (Table 1). For aggregated impact assessment the Ecoindicator '99 (H/A) [16] and Ecological Scarcity 2006 [19] methods are used, the latter especially since it applies to the Swiss context. We assume that wood is a CO_2-neutral energy source (i.e. the uptake of CO_2 by trees is equal to its subsequent release during

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