Value chains for integrated production of liquefied bio-SNG at sawmill sites – Techno-economic and carbon footprint evaluation

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HIGHLIGHTS

• Investigation of value chains for production of liquefied bio-SNG from gasification.
• Integration opportunities with a generic Nordic sawmill host site were investigated.
• Focus is on the interaction between plant capacity and efficient heat integration.
• Efficient heat integration is necessary to achieve low production cost.
• Transportation costs are a critical parameter for production costs for large plants.

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ABSTRACT

Industry’s increasing demand for liquefied natural gas could be met in the future by liquefied methane produced from biomass feedstock (LBG - liquefied biogas). This study presents results from an investigation of value chains for integrated production of LBG at a generic sawmill site, based on gasification of sawmill waste streams and forest residues. The objective was to investigate the cost for, as well as the carbon footprint reduction associated with, production and use of LBG as a fuel. Five different LBG plant sizes were investigated in combination with three different sawmill sizes. The resulting cases differ regarding biomass feedstock composition, biomass transportation distances, LBG plant sizes, how efficiently the excess heat from the LBG plant is used, and LBG distribution distances. Pinch technology was used to quantify the heat integration opportunities and to design the process steam network. The results show that efficient use of energy within the integrated process has the largest impact on the performance of the value chain in terms of carbon footprint. The fuel production cost are mainly determined by the investment cost of the plant, as well as feedstock transportation costs, which mainly affects larger plants. Production costs are shown to range from 68 to 156 EUR/MW hfuel and the carbon footprint ranges from 175 to 250 kg GHG-eq/MW hnet biomass assuming that the product is used to substitute fossil LNG fuel. The results indicate that process integration of an indirect biomass gasifier for LBG production is an effective way for a sawmill to utilize its by-products. Integration of this type of biorefinery can be done in such a way that the plant can still cover its heating needs whilst expanding its product portfolio in a competitive way, both from a carbon footprint and cost perspective. The results also indicate that the gains associated with efficient heat integration are important to achieve an efficient value chain.

1. Introduction

Many countries have established targets to achieve a transition from fossil to renewable fuels within the transport sector. Sweden has adopted a target of a fossil-independent transport sector by 2030 [1]. Demand for biofuels produced from lignocellulosic feedstock is thus projected to increase significantly in the future [1].

Extensive work has been put into estimating the carbon footprint and economic performance of producing synthetic natural gas (SNG) from biomass feedstock (hereafter referred to as bio-SNG). A process design and evaluation study of a direct, steam blown, biomass gasifier for bio-SNG production was performed by Gröbl et al. [2]. The study focused on small-scale gasifiers for decentralized bio-SNG production and indicated that a total process cold gas efficiency of 68% could be
achieved if wood pellets (19.55% moisture content by weight) are used as feedstock. Through sensitivity analysis, it was concluded that gasification performance and temperature air pre-heating temperature have a large impact on the performance of the gasifier. Gassner and Maréchal [3] performed a thermo-economic optimization of a polygeneration plant producing bio-SNG, power and heat from gasified lignocellulosic biomass. Their results indicate that a systematically optimized process flow sheet could achieve conversion efficiencies of 66–75% from wood (50% m.c. by weight) to bio-SNG (LHV basis), for concepts that include simultaneous production of heat and electricity. Alamia et al. [4] performed a well-to-wheel study of production of bio-SNG for use as fuel for heavy duty vehicles within the transport sector of the European Union. Their results indicate a GHG emissions reduction potential of up to 67%, depending on engine type, compared with fossil diesel. The study was based on data from the GoBiGas demonstration bio-SNG plant in Gothenburg, Sweden. GoBiGas is the world’s largest biomass gasification plant with a full downstream synthesis process and has a production capacity of 20 MW bio-SNG. The plant uses wood pellets with an 8% moist content (by weight) as feedstock. The total biomass-to-methane efficiency of the plant is 65% (LHV basis) and the overall system energy efficiency, which includes delivery of excess heat to a district heating network, is above 90% (LHV basis) [5].

Pettersson et al. [6] investigated opportunities for future cost-efficient production of biofuels in Sweden, considering different possible plant locations. The results indicate that bio-SNG, especially integrated production at sawmill sites, is an interesting fuel due to high conversion efficiency and good opportunities for both heat and feedstock integration with the host plant. The energy, greenhouse gas (GHG) and cost performance of value chains for production of bio-SNG as a vehicle fuel were evaluated in an well-to-wheel analysis by Börjesson et al. [7]. Their results indicate that using renewable methane as a vehicle fuel result in reduction of WTW GHG emissions of 80% or higher compared to vehicles operated with fossil diesel or gasoline. Furthermore, the WTW costs for bio-SNG are similar to those of comparable fossil fuels, applying current (2016) prices for fossil fuels.

Börjesson et al. [8] and Ekbohm et al. [9] investigated the perspectives for bio-SNG production from gasified biomass in terms of reduction of GHG emissions (7.5–8.5 tonnes CO₂eq/ha land use) and production costs (5.5–7 SEK/t of gasoline equivalent). Both studies concluded that bio-SNG is an attractive fuel compared to other biofuel alternatives, mainly due to low production costs. However, both studies emphasize the potential risk for expensive distribution costs due to low energy density of the fuel. Calderón et al. [10] investigated supply chains for bio-SNG production in the United Kingdom. Their results indicate that the UK could cover 21.4% of its total gas demand using domestic biomass feedstock resources, considering a planning horizon of 20 years. The results indicate operating costs of bio-SNG production facilities as the main cost in the supply chain, followed by the required investments in new bio-SNG production sites.

There are also a number of published studies investigating process integration opportunities for gasification-based biofuel production. Previous studies of gasification-based biofuel production, comparing process integrated facilities to stand-alone production, suggest that co-locating and integrating biorefineries with existing industrial plants is beneficial from an energy perspective and results in lower fuel production costs. Heyne et al. [11] showed how production of electricity as a by-product from a bio-SNG plant can be increased by a factor 2.5–10 if the plant is integrated with a CHP plant, depending on the type of biomass dryer that is used. Andersson et al. [12] showed how the total energy efficiency of a biorefinery plant based on an entrained flow gasifier can be increased by 7 percentage points if the unit is heat integrated with an existing chemical pulp and paper mill. Aziz et al. [13] investigated process integration of empty fruit bunch (a by-product from palm oil production) drying with gasification and combined cycle systems. The idea is to use excess heat from a combined cycle to dry the fruit bunch gasifier feedstock. The gasifier syngas product is then cleaned and used as fuel in the combined cycle. The results show that integrating the dryer reduces the primary energy usage of the drying plant by 30% compared to stand-alone drying. The plant’s electric power generation efficiency reaches 44% for a gasification temperature of 1000 °C. These increases in efficiency are primarily due to co-location of the plants which allows heat to be cascaded between the processes, thus decreasing the need for primary energy.

Bio-SNG production processes perform comparably well from both an economic and a GHG emissions reduction perspective because they have high biomass-to-SNG conversion efficiencies and there are significant amounts of excess heat available at high temperature from the SNG process which can be harnessed by heat integrating a steam cycle with the process. The steam can be used to cover the process heating needs, while co-generating electricity, resulting in an increased combined energy output in relation to the energy input in biomass. Use of bio-SNG as an energy carrier has the disadvantage that it has a low energy density compared to liquid energy carriers and DME (dimethyl ether). This makes distribution of the product relatively inefficient and expensive for all cases where it cannot be transported in pipelines. It also makes SNG less attractive as a fuel, since the volume of the fuel storage needs to be significantly larger than for more energy dense fuels, unless very high pressure tanks are used. An alternative way to increase the energy density of the product is to liquefy the bio-SNG (liquefied bio-SNG is hereafter denoted LBG - liquefied biogas). The energy density of LBG is then approximately 600 times higher than that of bio-SNG, which results in significantly decreased distribution costs [14].

Kumar et al. [15] state that the market for fossil LNG is expected to increase during coming years. High energy density and efficient low-cost production are presented as key reasons to expect that LNG could become a significant fuel for heavy duty vehicles in the future. Due to the positive fuel characteristics of liquefied natural gas (LNG), there are a number of ongoing political initiatives to increase the demand for this fuel. The EU-co-financed Northern European LNG Infrastructure project was initiated in 2015. This project aims at developing pathways for an expansion of the LNG infrastructure required to implement LNG as a ship bunker fuel in the Baltic Sea [16]. An increased demand for LNG as a fuel can also be observed from shipping companies and ship
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