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The competitiveness of synthetic natural gas as a propellant in the Swedish fuel market

Farzad Mohseni, Martin Görling*, Per Alvfors

Royal Institute of Technology—KTH School of Chemical Science and Engineering, Chemical Engineering and Technology, Division of Energy Processes, Stockholm, Sweden

HIGHLIGHTS

- ► The production cost for synthetic natural gas corresponds to the current biogas price.
- ► High return on capital if the synthetic natural gas could be sold for the same price as petrol.
- ► Production can cost-effectively be run off-peak hence electricity is the major cost.
- ► This study is based on Swedish prerequisites but is applicable on other regions.

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ABSTRACT

The road transport sector today is almost exclusively dependent on fossil fuels. Consequently, it will need to face a radical change if it aims to switch from a fossil-based system to a renewable-based system. Even though there are many promising technologies under development, they must also be economically viable to be implemented. This paper studies the economic feasibility of synthesizing natural gas through methanation of carbon dioxide and hydrogen from water electrolysis. It is shown that the main influences for profitability are electricity prices, synthetic natural gas (SNG) selling prices and that the by-products from the process are sold. The base scenario generates a 16% annual return on investment assuming that SNG can be sold at the same price as petrol. A general number based on set conditions was that the SNG must be sold at a price about 2.6 times higher per kWh than when bought in form of electricity. The sensitivity analysis indicates that the running costs weigh more heavily than the yearly investment cost and off-peak production can therefore still be economically profitable with only a moderate reduction of electricity price. The calculations and prices are based on Swedish prerequisites but are applicable to other countries and regions.

1. Introduction

The road transport sector today is almost exclusively dependent on fossil fuels. Consequently, the transport energy system is facing a radical change if it aims to switch from a fossil-based system to renewable-based system. This will be a massive challenge and many renewable alternatives to address it are under development.

Currently, there does not seem to exist an alternative that can alone replace fossil fuels in the transport sector, mainly because the amount of energy from a single renewable source is not enough to cover the total energy demand. Hence, various technologies and propellants from different sources will have to be combined in order to obtain enough energy to replace a fossil-based transport sector's needs with entirely renewable alternatives (Lindfeldt et al., 2010).

One alternative fuel that has received more attention lately is biogas[1] . It is normally produced in anaerobic digestion of organic matter and is often implemented in waste handling. In digestion processes, crude biogas is formed which in addition to methane also contains carbon dioxide, sulphur compounds and other impurities depending on what substrate is used. The crude biogas can be upgraded to reach different qualities, i.e., varying methane content, for different purposes. When crude biogas is upgraded it can be used in, for example, vehicles, power production or as town gas in households. In vehicle applications, it must contain a high purity of methane and some few per cent of carbon dioxide. Natural gas[2] is also used in vehicle applications and often blends

* Corresponding author. Tel.: +46 8 790 6713; fax: +46 8 723 0858.
E-mail address: gorling@kth.se (M. Görling).

[1] Biogas in this paper refers to gas produced from non-fossil organic matter through, e.g., digestion containing mainly methane when upgraded.

[2] Natural gas is a fossil resource which contains mainly methane, but also higher alkanes. Natural gas and biogas have similar properties in terms of energy content and combustion properties and can therefore be used in same applications, e.g., in vehicles.

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of these are sold at gas refilling stations, commonly labelled as vehicle gas[3] . However, there is a limitation to organic matter that is useful for anaerobic digestion (further discussed in Section 1.3). An option which could improve the potential of renewable alternatives is to synthesize natural gas, where the process and its applications have been studied by, for example, Mohseni et al. (2012).

One must keep in mind that there are many aspects to consider when trying to develop and introduce a new technology to a market, especially when the product is so well anchored in the lifestyle of people. Personal transport is one example. Renewable-based substitutes for today's fossil-driven vehicles should not only be able to perform as well as conventional cars, but they must also maintain competitive prices in order for people to be interested in buying such vehicles. In this case, biogas would be a good alternative; it can be used in conventional Otto engines, it is competitively priced and today's biogas cars have almost the same range as their conventional equivalents.

1.1. Aim and scope

This paper is based on research done with Swedish prerequisites and conditions; however, the methodology and calculations of the stated examples are also applicable to foreign regions with different conditions. The main focus of this paper is to study and analyse the economic perspectives of synthetic natural gas (SNG), which resembles biogas (more thoroughly explained in Section 2), and its possibilities to be competitive with other propellants; both fossil- and bio-based alternatives. The paper will also present and discuss different drivers for developing biofuel production lines which may possibly lead to moving away from fossil usage.

Even though the assessment is based on Swedish market prerequisites, all prices are given in Euro (€) to increase readability and comparability with other markets. The exchange rates used throughout the report are SEK/Euro = 9 and USD/Euro = 1.37.

The energy calculations are presented in units of kWh since most of these refer to electricity and is normally measured with such units. However, to increase comparability, the corresponding value for 1kWh equals to 3.6 MJ.

1.2. EU and Swedish goals for renewable energy

In 2007, to turn Europe into a highly energy efficient and carbon-lean economy, the EU's heads of state and government put forward a series of challenging targets to be attained by 2020. These are known as the "20–20–20" targets and, briefly explained, they entail a 20% reduction of greenhouse gases compared to 1990 levels, 20% energy from renewable sources, and 20% lower primary energy usage compared to anticipated levels. Additionally, it includes a goal of using 10% biofuels in the transport sector. In the case of Sweden, 10% fossil free energy in transport would mean a reduction of about 4% carbon dioxide. This is because transport constitutes about 40% of the total greenhouse gas emission in Sweden (Lindfeldt et al., 2010).

The targets comprise an average of the whole EU combined. All countries have national goals dependent on their prerequisites, e.g., the targets in Sweden are to reach a 40% reduction of greenhouse gases compared to 1990 and additionally (as a national goal) it has been decided that at least 50% of the energy should come from renewable sources (Swedish Energy Agency, 2010).

[3] "Vehicle gas" is the common term (in Sweden) for methane-rich gas used as a propellant regardless of origin, i.e., biogas, natural gas or any blend between the two.

In 2010, the total energy usage in the road transport sector was about 90 TWh, of which almost 6% was from renewable sources, mainly depending on the low-blend additive of ethanol and FAME in petrol and diesel, respectively (Swedish Energy Agency, 2011a). The target set for the Swedish transport sector is to increase the share to about 10% by 2020 (Swedish Energy Agency, 2010). Hence, about 5 TWh of fossil energy needs to be replaced with renewable alternatives. As stated earlier, biogas is gaining increasing attention and will probably be a key substitute for fossil fuels in the future, some of the reasons being that a distribution network (for natural gas) already exists and it uses a conventional technology. The demand for and usage of vehicle gas in Sweden has increased dramatically from 0.15 TWh to about 1 TWh over the last decade (Energy Gas Sweden, 2011).

1.3. Biogas potential

There is a great interest on the part of some industries and authorities in Sweden to determine the national biogas potential. Many assessments have been made which show that it can be extracted from a wide range of different industries/areas. Today, however, biogas is mainly produced in water treatment plants (Värmeforsk, 2006). Additional sources include, for example, agriculture, food waste from households and restaurants, industrial waste and garden waste, which combined could increase the relative amount of biogas. Together these sources are assessed to yield about 10.6 TWh (and still be economically viable) (Linné et al., 2008), which would represent about 9–10% of the total energy amount used in the road transport sector (where most of the biogas is presumed to be used). To increase the yields even more, another option that has been investigated is gasification of forest residues. Many assessment reports have been reviewed by (Linné et al. 2008) and based on the input data a potential of 59 TWh/year is presented, which is a very substantial amount.

However, to identify how much of the wood biomass could contribute as a source in biogas production is highly uncertain. There are many sectors in society that are interested in the forest. Established actors such as the pulp and paper industries, for example, will be biogas competitors. Additionally, methanol and ethanol production from wood biomass are also upcoming industries which have or are planned to have industrial scale production within a short period of time. Moreover, various environmental associations are often in favour of keeping natural habitats for rare wildlife and people see the forest as a recreational environment. It is therefore likely that new actors will face difficult challenges before any significant production will be possible from forest biomass. The sectors, together with the commodity prices of, for example, biomass and energy, will in time probably fall and reach an equilibrium which will decide how much of the biomass can be used for biogas production.

2. Synthetic natural gas

As alternative to conventional biogas, SNG could be produced through synthesis by various chemical paths; in this paper, the Sabatier reaction is suggested. The reaction needs CO_2 and H_2 as reactants to form CH_4. Water is also produced as a by-product of the reaction. Principally CO_2 from any emission source could be used and the H_2 could be produced from water electrolysis. To keep the product free from fossil constituents, the reactants should be based on renewable sources, i.e., CO_2 should originate from biomass and renewable electricity should be used for H_2 production.

As in regular biogas, synthetic natural gas will mainly contain methane, diluted with a few per cent of CO_2 when used in vehicle