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Electrofuels for the transport sector: A review of production costs

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ABSTRACT

Electrofuels (also called power-to-gas/liquids/fuels or synthetic fuels) are potential future carbon-based fuels produced from carbon dioxide (CO_2) and water using electricity as the primary source of energy. This article assesses the production cost of electrofuels through: (i) a literature review, focusing on which steps that have the largest impact as well as the greatest uncertainty; (ii) a more comprehensive review, including the costs and efficiencies for the separate production steps, and (iii) calculations to compare the production costs of the different fuel options in a harmonized way, including a sensitivity analysis of the parameters with the greatest impact on the total electrofuel production cost. The assessment covers: methane, methanol, dimethyl ether, diesel, and gasoline. The literature review showed large differences among the studies and a broad range of production cost estimates (10–3500 €$_{2015}$/MWh$_{fuel}$), which is first and foremost as a result of how authors have handled technology matureness, installation costs, and external factors. Our calculations result in productions costs in the range of 200–280 €$_{2015}$/MWh$_{fuel}$ in 2015 and 160–210 €$_{2015}$/MWh$_{fuel}$ in 2030 using base cost assumptions from the literature review. Compared to biofuels, these estimates are in the upper range or above. Our results also show that the choice of energy carrier is not as critical for the electrofuels production cost as technological choices and external factors. Instead the two most important factors affecting the production cost of all electrofuels are the capital cost of the electrolyser and the electricity price, i.e., the hydrogen production cost. The capacity factor of the unit and the life span of the electrolyser are also important parameters affecting that production cost. In order to determine if electrofuels are a cost-effective future transport fuel relative to alternatives other than biofuels, the costs for distribution, propulsion, and storage systems need to be considered.

1. Introduction

The transport sector, including road, air, and waterborne transport, contributes to slightly more than 20% of the global emissions of greenhouse gases (GHG) [1,2]. The European Union aims to reduce GHG emissions from transport by 60% by 2050, compared to 1990 [3]. However, in the absence of vital measures, emissions are expected to continue to increase due to the increasing demand for transport [1]. Reducing GHG emissions and increasing energy security will pose considerable challenges for the transport sector in the coming decades [1,3].

GHG emissions from transport can be reduced by decreasing the total energy demand, the emission intensity of that energy, or both. This paper focuses on reduced fossil carbon intensity by the introduction of low-fossil-carbon fuels [1,4]. Potential energy carriers for the transport sector include liquid and gaseous carbon-based fuels, hydrogen, and electricity (Fig. 1). However, producing low-fossil-carbon energy carriers require using renewable energy sources such as biomass, solar, and wind energy.

There is a substantial potential to increase the use of biofuels, electricity, and hydrogen in the transport sector. For the latter two, there is uncertainty to what extent batteries and fuel cells are appropriate solutions in, for example, aviation, shipping, and long-distance road transport. These new energy carriers also require new infrastructure [5]. Large-scale use of biofuels produced from biomass faces sustainability challenges as well. The future contribution of biofuels seems limited in relation to expected global transport demand [6–8].

Electrofuels are carbon-based fuels produced from carbon dioxide (CO_2) and water, with electricity as the primary source of energy [9,10]. Electrofuels are also known as power-to-gas/liquids/fuels, e-fuels, or synthetic fuels.[1] They are potentially of interest for all transport modes; some can be used in combustion engines and may not require significant investments in new infrastructure. In addition to represent-

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[1] This study only considers fuels that include a carbon atom, although the literature on power-to-gas fuels typically also includes hydrogen.

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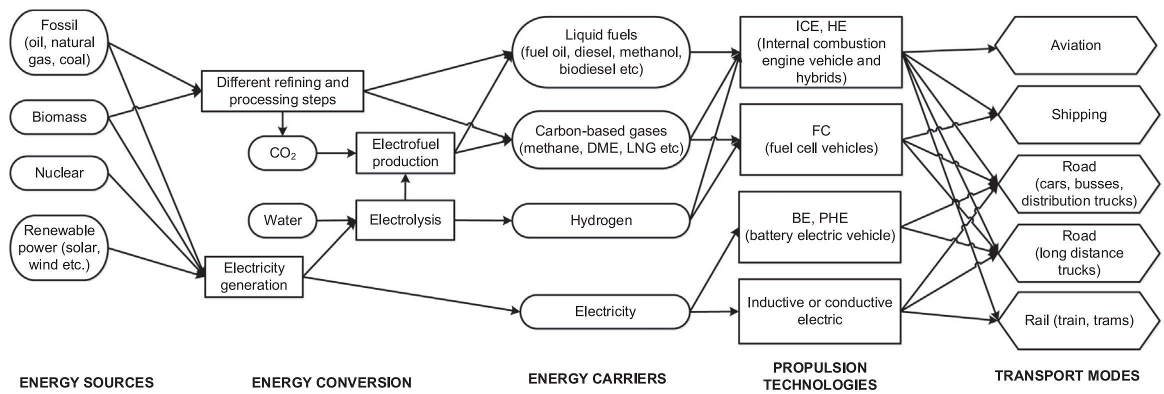

Fig. 1. Simplified schematic of primary energy sources, energy conversion technologies, and energy carriers for different transport modes. DME = dimethyl ether, LNG = liquefied natural gas, ICE = internal combustion engines, HE = hybrid electric propulsion, FC = fuel cells, BE = battery electric propulsion, PHE = plug-in hybrid electric propulsion.

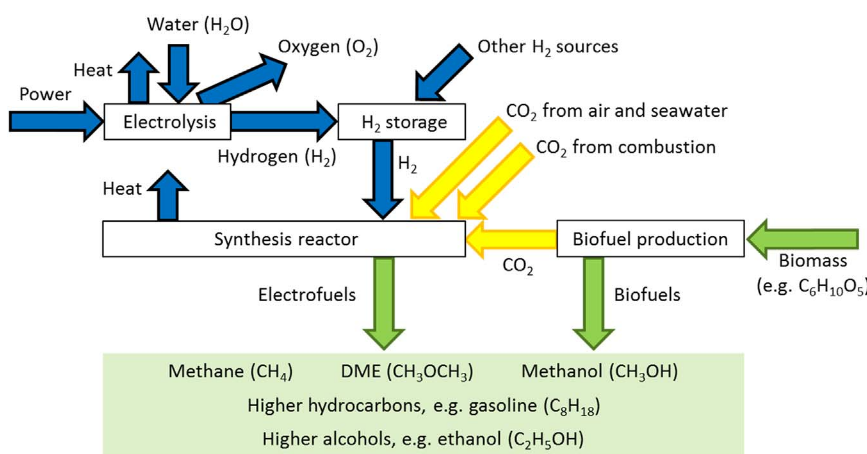

Fig. 2. Process steps in the production of electrofuels, modified from Urakawa and Sá [29], Graves et al. [30], Ganesh [31], and Grahn et al. [18].

ing a possible future option for transport fuels, electrofuels may allow for increased biofuel production by using the associated excess CO_2 [11] and may contribute to balancing intermittent electricity production. Electrofuels are produced by mixing hydrogen and CO_2 in a reactor to form energy carriers such as methane and diesel, see Fig. 2. A range of liquid and gaseous fuels, including gasoline and diesel, can be produced. The production process also generates marketable by-products, namely high-purity oxygen and heat.

Several demonstration-scale facilities have been developed in Europe in the last decade [12]. For example, Carbon Recycling International (CRI) in Iceland produces methanol by using geothermal energy and CO_2 from the same source. CRI has operated a commercial plant since 2011, with the capacity to produce 5 million liters of methanol per year [13]. Audi AG's ETOGAS has invested in a 6 MW plant in Germany that uses renewable electricity from wind power and CO_2 from a biogas processing plant to produce methane [14]. In Germany, a test facility producing diesel from renewable electricity and CO_2 captured from the air has shown that it is possible to produce high-quality drop-in electrofuels [15].

In addition to the new pilot and demonstration plants, a slew of papers assessing different aspects of electrofuels have been published in recent years: electrofuels as a way to balance the increasing share of intermittent renewable electricity in the energy system (e.g. [16,17]), as a transport fuel (e.g. [18–23]), and as a way to increase carbon utilization in biofuel production (e.g. [11,24–26]). However, many aspects need to be clarified in order to understand the potential role of electrofuels in a future transport sector with low CO_2 emissions, including the costs of producing electrofuels compared to other energy carriers. Methodologies and data used for assessments of electrofuel production costs vary greatly in the literature, as do the resulting cost estimates. For methane, for instance, one study estimates the cost at 10–100 $€_{2015}/MWh_{fuel}$ [27], while another reports 340–640 $€_{2015}/MWh_{fuel}$ [28].

The main purpose of this study is to assess the production costs of electrofuels. We perform (i) a literature review of the total cost of electrofuel production focusing on which steps that have the largest impact as well as the greatest uncertainty (Section 2); (ii) a comprehensive complementary review of costs and efficiencies for the separate production steps (Section 3); and (iii) own calculations to compare the production costs of the different fuel options in a harmonized way (Section 4). The review in Section 2 identifies key parameters and reveals large differences in assumptions and methodologies. This literature review shows the need for a more comprehensive review of the literature on the costs and efficiencies of the individual production steps, see Section 3. Section 4 assesses the key parameters identified in Section 2 and includes a sensitivity analysis using the costs and efficiencies for electrolysers, carbon capture, and fuel synthesis compiled in Section 3. The environmental performance (e.g. life cycle assessment) and environmental costs of the different electrofuels are not included in the scope of this study but briefly discussed in Section 5.3.

2. Literature review of electrofuel production cost assessments

This section includes a systematic review of electrofuels based on primarily peer-reviewed literature (> 75%) published between 2010 and February 2016, in English or Swedish. A search of online databases such as Web of Science and Scopus was done, using different combinations of search terms including *power-to-gas (PtG), power-*