"Can electrofuels in combustion engines be cost-competitive to hydrogen in fuel cells?"

M. Grahn*
Chalmers University of Technology, Department of Space, Earth and Environment, Division of Physical Resource Theory, 412 96 Gothenburg, Sweden. Tel +46-31 772 3104.

Tailor-made synthetic fuels, here called electrofuels, are fuels produced from hydrogen and carbon dioxide, using electricity as the major source of energy. This study analyzes under what circumstances electrofuels used in combustion engines may be cost-competitive to hydrogen used in fuel cells, for cars, trucks and shipping. Results show that electro-diesel can be competitive when vehicles and vessels operate only part time of the year, whereas hydrogen has advantages when vehicles and vessels are used for longer distances more days over the year. Cars is the category showing the most positive results on electro-diesel.

* Corresponding author: maria.grahn@chalmers.se

Introduction

Tailor-made synthetic fuels, here called electrofuels (elsewhere also called e.g. sunfuels or power-to-gas/liquids/fuels), are fuels produced from hydrogen and carbon dioxide (CO_2), using electricity as the major source of energy [1-8]. Electrofuels is one potential group of fuels that could contribute to reduce the climate impact from transport depending on type of CO_2 and electricity mix (preferable non-fossil). When forming the electrofuels it is possible to choose among a range of different final fuel molecules, such as methane, methanol, dimethyl ether, or longer hydrocarbons (gasoline/diesel) [3]. If a fuel can be blended, in high concentrations, with fossil gasoline and diesel, within the conventional fuel standards, it is called a drop-in fuel. Drop-in fuels have the potential to, in a short time perspective, substitute fossil transport fuels without changing the fuel infrastructure or drivetrain technology. That is, drop-in fuels can be used in existing vehicle fleets and reduce the need for more advanced, and relatively costly, vehicle technologies. 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 [9].

Hydrogen, if used as a fuel itself and not as feedstock for an electrofuel, obviously has a lower production cost compared to electrofuels (since investing in an additional synthesis reactor will add costs to the total production cost of electrofuels) [3]. Hydrogen is preferably used in fuel cells, which have a higher conversion efficiency but also a higher cost compared to combustion engines [10-11].

This study tries to shed some light on under what circumstances electrofuels (the more expensive fuel option) used in combustion engines (the less costly drivetrain technology) may be cost-competitive to hydrogen (the less costly fuel option) used in fuel cells (the more expensive drivetrain technology). The cost comparisons are made for a generalized passenger car, heavy truck and three types of vessels (short sea, deep sea and container).

Approach

Brynolf et al [3] have carried out a comprehensive literature review of costs and efficiencies for the steps when producing electrofuels followed by calculations to compare the production costs of the different fuel options in a harmonized way. Results from their base case scenario, assuming values representing year 2030, have been used for this study comparing electro-diesel (via a Fischer-Tropsch synthesis) with hydrogen (produced via alkaline electrolyzers). To be able to compare costs for the five different generalized categories of vehicles and vessels, run on either electro-diesel or hydrogen, the fuel production costs are combined with propulsion and storage costs taken from Taljegård et al [11]. Cost-calculations are made depending on how much each vehicle/vessel category is used per year expressed in days per year for the vessels and km per year for the vehicles. For vehicles/vessels run on hydrogen, the fuel stack need to be replaced if its life time ends before the vehicle/vessel's life time. Stack replacements are assumed to cost half of the fuel cell investment. Tables 1-3 present assumptions used in this study and Table 4 lists the calculated amount of stack replacement for vessels (no replacements are needed for cars and trucks).

Table 1. Assumptions on currency, fuel production costs, life time and engine efficiency.

Interest rate [%]	5
Currency USD/EUR [12]	0.89
Production cost electro-diesel [€/MWh] [3]	180
Production cost H_2 (Alkaline electrolyzer) [€/MWh] [3]	113
Additional cost H_2 liquefaction [€/MWh] [3]	3
Tot production cost H_2 (liquid) [€/MWh] [3]	116
Life time fuel cell stack [hours] [3]	65000
Average vessel engine load (factor of max capacity) [11]	0.75
Engine efficiency Diesel-IC [11]	0.40
Engine (fuel cell) efficiency H_2-FC [11]	0.45
Fuel consumption heavy truck [lit/10 km]	3
Fuel consumption pass. car [lit/10 km]	0.5

Table 2. Assumptions made for vehicles and vessels using electro-diesel in Diesel combustion engines [10-11].

	Container vessel	Deep sea vessel	Short sea vessel	Heavy truck	Pass. car
A	23000	11000	2400	250	80
B	113574	69163	15638	71	18
C	7388	4499	1017	9	2
D	30	30	30	10	15

A= Engine power [kW] [11]
B= Investment cost [1000 € per vehicle/vessel] [11]
C= Annuitized investment cost [1000 € per vehicle/vessel per year] [11]
D= Life time [years per vehicle/vessel] [11]

Table 3. Assumptions made for liquefied hydrogen used in fuel cells [10-11].

	Container vessel	Deep sea vessel	Short sea vessel	Heavy truck	Pass. car
A	23000	11000	2400	250	80
B	201948	118309	23769	120	33
C	13137	7696	1546	15	4
D	30	30	30	10	15
E	2874	1599	264		

A= Engine power [kW]
B= Investment cost [1000 € per vehicle/vessel]
C= Annuitized investment cost [1000 € per vehicle/vessel per year]
D= Life time [years per vehicle/vessel]
E= Cost per fuel cell stack replacement [1000 €/replacement]

Table 4. No of stack replacement during vessel life time

Days/yr	50	100	150	200	250	300
Replacements	0	1	1	2	2	3

Results

Annual cost per vehicle/vessel is calculated depending on how much they are used, and results are presented for the five categories in Fig 1.

Results show that the electro-diesel option is slightly less costly than the hydrogen option for vessels that operate less than 100 days per year, for all three ship categories. The hydrogen option becomes more and more cost-competitive the more days per year the ship is operated, i.e., if the vessels are operated more than 100 days per year it is more beneficial to install the relatively costly fuel cell technologies onboard, see Fig 1a-c.

For the truck category, results are presented assuming a driving distance of 30,000-180,000 km per year, where it is common that a heavy truck is running around 150,000 km/yr. For the analyzed range, the electro-diesel option is not shown to be cost-competitive, although very similar to the hydrogen option at 30,000 km/yr, see Fig 1d.

For the car category, however, the electro-diesel option is shown to be the least costly option, compared to hydrogen, for all analyzed driving distances (5,000-30,000 km/yr), see Fig 1e.

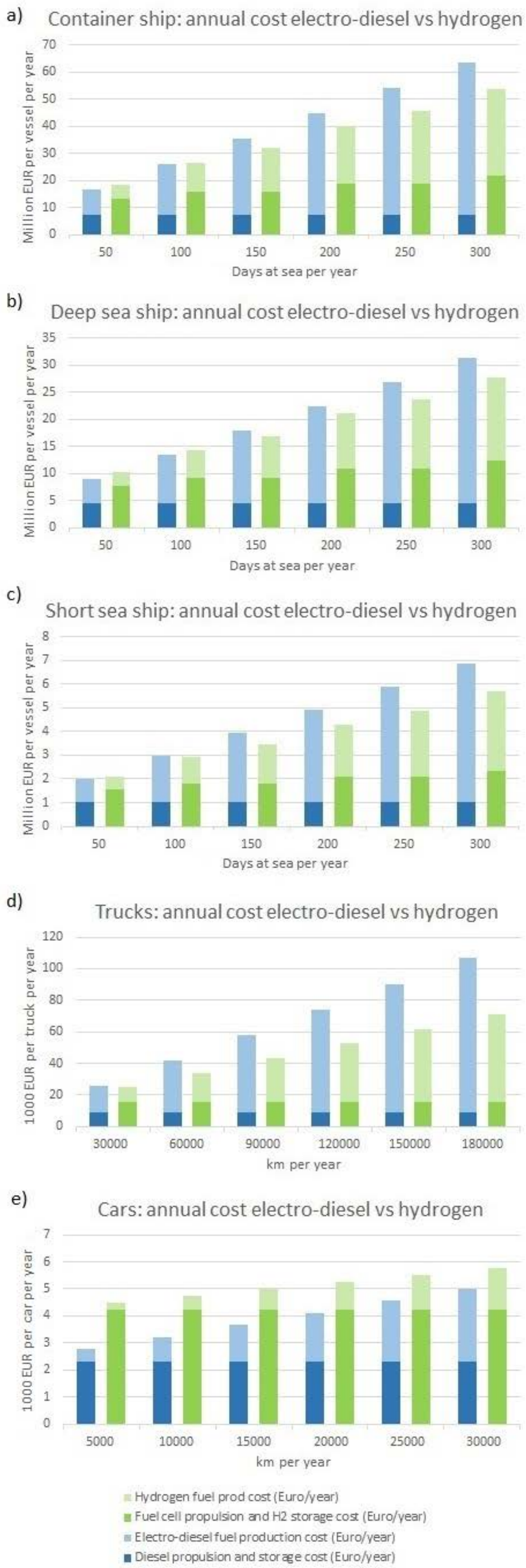

Fig. 1: Cost-comparison tailor-made electro-diesel in combustion engines versus hydrogen in fuel cells for five different types of vessels/vehicles, depending on how much they are used per year.

Discussion and Conclusions

Results show that there may be circumstances where electrofuels in combustion engines are cost-competitive to hydrogen in fuel cells. This study especially points out that the option electro-diesel in diesel engines seems to be beneficial for vehicles and vessels only used part time of the year, whereas the option of hydrogen in fuels cells seems beneficial for commercial vehicles and vessels that is used for longer distances and/or more days during the year. This can be understood from that if costs from relatively expensive investments, such as fuel cells, can be spread out over a large amount of operating hours (or km), the cost is less dominated by the investment, but more of the cost of fuel. When it is the fuel cost that dominates the total cost, hydrogen has a great advantage compared to the more expensive electro-diesel fuel.

All cost assumptions made in this study are chosen to reflect mature technology around 2030 or beyond, and are of course associated with uncertainties. Alternative assumptions has been tested using values taken from Brynolf et al [3] where a range of possible production costs for electrofuels are presented as well as data on, e.g., life time of electrolyzers. Although assuming higher or lower fuel production costs it should be noted that the production cost of hydrogen always will be lower than the production cost of electrofuels meaning that a similar relation remains. Changing the assumed life time of electrolyzers did not significantly affect the results. However, if for some reason the engine efficiency would be higher for the combustion engines than for fuel cells the results are affected.

Uncertainties related to electricity prices and investment cost of electrolyzers effect both fuel options equally much.

Further sensitivity analyses, e.g. using Monte Carlo simulations for testing combinations of uncertain data would improve the analysis. This is planned as the next step for this study.

Important to note is that if electrofuels are used as drop-in fuels, although they may offer a solution for a fast transition away from fossil fuels, there is a risk that they may contribute to a prolonged era of fossil fuels. Policy measures that continuously encourage increased shares of low-emitting drop-in fuels would reduce this risk.

Regarding effects on human health, such as the local emissions NOx and soot, from combustion engines would also remain in the case where electrofuels are used in conventional internal combustion engines These local emissions would be slightly lower with electrofuels in the form of, e.g., dimethyl ether, methanol or methane, than with gasoline or diesel, however, never as low as with hydrogen in fuel cells. The majority of these local emissions can, on the other hand, be reduced with exhaust after treatment technologies.

For traffic outside cities, local emissions are of less concern for human health, simplifying the use of electrofuels in ships, and long-distance road transport.

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