Methanol as a renewable import energy carrier: Results from the C^3-Mobility project

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Abstract

Currently, two thirds of the European primary energy demand are imported. Although the further extension of renewable energy production and the shift towards more and more electrification in every sector will reduce this dependency, a European energy autarky cannot be assumed under the given short timeframe until 2050. Hence, renewable energy imports will play a vital role within our future energy system. Being directly producible from H_2 and CO_2 on a high TRL, methanol qualifies as an attractive Power-to-X product. Therefore, the research project "Closed Carbon Cycle (C^3)-Mobility" [1] – funded by the German Federal Ministry of Economics and Energy – investigates the methanol production pathway, its further upgrading towards drop-in and alternative fuels and their respective applicability in combustion engines for passenger and heavy-duty vehicles as well as marine engines. This contribution will focus on the economic assessment of the methanol production in different global locations. The results show the costs of methanol synthesis as a function of the respective local hydrogen production costs and CO_2 out of different sources. An energy specific comparison to the alternative of importing liquid hydrogen demonstrates the influence of the distribution costs and CO_2 prices on the total costs at the harbor of energy importing countries for the respective renewable energy carrier.

Main results

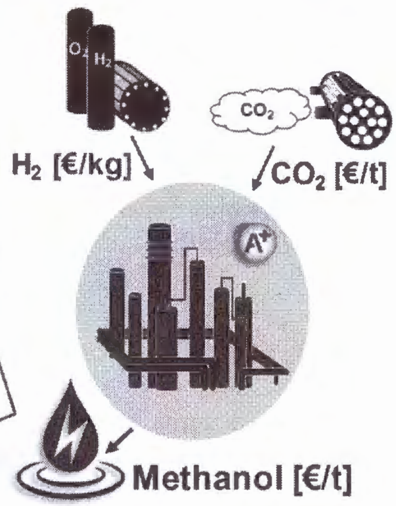
Last year's presentation of the Institute of Electrochemical Process Engineering outlined, that especially hydrogen and carbon dioxide costs determine the final methanol production costs. As an extension, Table 1 visualizes this dependency for a wide range of hydrogen net production costs (NPC) and carbon dioxide prices. Here, the net production costs for methanol are given, using detailed process engineering modeling of a 300 MW (433 kt/a) methanol production plant. The general methodology is described in Schemme et al. [2].

The resulting net production costs are placed into three defined categories depending on their respective cost competitiveness against methanol market price levels of 2018 of approximately 400 €/t [3]. Since no surcharges for the emission of greenhouse gases from fossil energy carriers are presently added to the current market price, it is assumed, that a renewable methanol with net production costs of up to 150% of the current market price can be economically competitive. In order to achieve production costs within this category, given in green in Table 1, renewable hydrogen would have to be accessible for 2.50 €/kg or less. As the timeline in Table 1 shows, those costs are predicted for the year 2030 at the latest [4]. With decreasing hydrogen production costs, the window for possible CO_2-prices and hence different CO_2-sequestration technologies expands. The second category given in orange represents production costs of 150-300% of the current market price. A competitiveness against current fossil methanol would either require strong legislative actions towards renewable energy carriers or a customer willingness to pay a surcharge for a renewable product. As can be seen from Table 1, renewable methanol production costs in this category can already be achieved with current NPC of hydrogen (2020) and CO_2 prices of up to 200 €/t. The methanol production costs, which exceed the current market price level by 300% are marked red in Table 1 and considered not competitive. The input CO_2 prices are qualitatively classified into the three main CO_2 sources discussed in the literature and investigated within the C^3-Mobility project: biomass, process-related industry emissions and direct air capture (DAC). The price range of CO_2 capture via DAC currently faces the greatest uncertainties. Values of roughly 100-500 €/t_{CO2} can be found in the literature [5, 6], with recently discussed target prices around 100 €/t_{CO2} by the DAC industry [7].

For energy importing regions, the final prices for the renewable energy carriers do not only include the production, but also the distribution costs. Since methanol is a liquid energy carrier, its handling and shipping properties are beneficial compared to alternatives in gaseous state at atmospheric pressure. Hence, the total costs at the harbor of liquid (cryogenic) hydrogen in contrast to methanol will be compared.

Table 1: Methanol production cost in €/t as a function of the net production costs (NPC) of H_2 and CO_2 prices. Values given are valid for the system size of 300 MW and based on the methodology presented in Schemme et al. [2]. Current (fossil, year 2018) methanol market price: 400 €/t [3]

		NPC H_2 [€/kg]							
	time[4]	2050		2030					2020
CO_2 Price [€/t]		1	1.5	2	2.5	3	3.5	4	4.5
biomass	0	254	350	445	578	635	731	826	921
biomass	20	282	377	473	606	663	758	854	949
biomass	40	310	405	500	634	691	786	881	977
industry	60	337	433	528	661	719	814	909	1004
industry	80	365	461	556	689	746	842	937	1032
industry	100	393	488	584	717	774	869	965	1060
DAC	150	462	558	653	786	843	939	1034	1129
DAC	200	532	627	722	856	913	1008	1103	1199
DAC	300	670	766	861	994	1051	1147	1242	1337
DAC	400	809	904	1000	1133	1190	1285	1381	1476
DAC	500	948	1043	1138	1272	1329	1424	1519	1615



NPC range	MeOH production...
<600 €/t	Competitive → Max. 150% of current price level
>600 < 1200 €/t	Possibly competitive → Max. 300% of current price level
>1200 €/t	Not competitive → More than 300% of current price level

For the afore mentioned comparison the input values for the hydrogen production and distribution are taken from a recent study of the Hydrogen Council [8]. For the year 2030, hydrogen production cost between 1.35-2 $/kg for three global production sites are specified with investment cost for electrolysis of 400 $/kW and levelized costs of renewable electricity of 20 $/MWh in average. Those values are in line with comparable recent studies [4, 9, 10]. As a comparison, the respective methanol production and distribution costs were determined with the methodology used to calculate the values in Table 1 and distribution costs after Pfennig et al. [11] for a variety of CO_2 prices. The results are shown in an overview map in Figure 1. For each origin/destination combination an individual graph shows the respective outcomes. To compare the costs for hydrogen and methanol at the destination harbor, the energy specific unit €/GJ based on the lower heating value is used. In each case, the first bar represents the hydrogen production and distribution costs, which are taken from Hydrogen Council [8]. The following four bars show the determined production costs for methanol based on the hydrogen costs at the origin for a range of CO_2-prices from 30-100 €/t_{CO2} plus the respective distribution costs.

As a first observation from all graphs shown in Figure 1, it can be stated, that the distribution costs for methanol are almost negligible compared to the distribution of hydrogen. Consequently, the share of transportation of the renewable energy carrier within the overall costs descents from 41-50% for hydrogen to 1-2% for methanol. In total, the methanol costs are in a range of 18.6-29.7 €/GJ which translates to 370-591 €/t. With the defined categories in Table 1, those methanol production costs would all be marked as "competitive" in the year 2030.

The second observation from the four graphs presented is, that the energy specific costs for methanol and hydrogen at the harbor are comparable for each case within the presented boundary conditions. This shows, that the additional costs for upgrading of hydrogen to methanol are balanced out by the significantly less expensive shipping of liquid methanol versus liquid hydrogen. Methanol is initially less expensive for CO_2 prices of 30 and 50 €/t_{CO2} and becomes more expensive depending on the origin/destination combination after a specific CO_2-price is exceeded. Those critical CO_2-prices lie within 80-100 €/t_{CO2} with the exception of the case Saudi Arabia to Japan, where even at 100 €/t_{CO2} methanol at the harbor is still slightly less expensive.

Comparing the different origin/destination combinations, Chile to USA shows the lowest, Saudi Arabia to Japan the highest respective cost. This is due to the cheapest hydrogen production cost in Chile (ca. 1.35 €/kg [8]) and the longest transportation distance from Saudi Arabia to Japan. For the example of exporting hydrogen or methanol from Saudi Arabia to Germany (Jedda – Hamburg), hydrogen and methanol costs were determined to 3.36 €/kg_{H2} and 0.49-0.6 €/$kg_{Methanol}$ respectively.

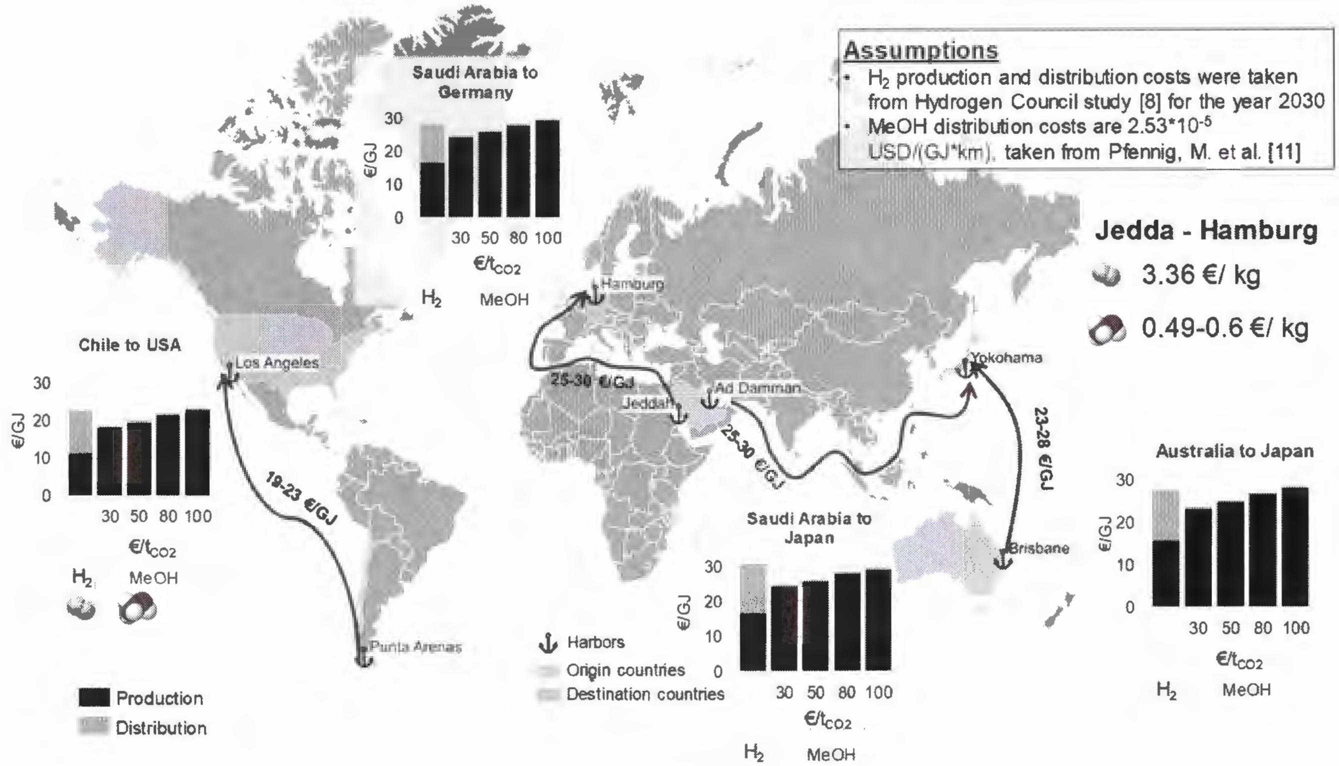


Figure 1: Hydrogen and methanol production and distribution costs for the four investigated origin/destination combinations

Conclusions and Summary

The techno-economic analysis of the CO_2 based methanol synthesis shows, that with the H_2 cost predicted for 2030, the possible renewable energy carrier methanol could be produced for 370-600 €/t in global regions with favored conditions for renewable electricity generation. This could enable a price competitive production compared to fossil based methanol.

If the necessary CO_2 is available in sufficient capacities and at 100 €/t or below at the origin country, a local upgrading of hydrogen to methanol is comparable with or even less expensive than the production and the shipping of liquid hydrogen. One main reason for this is that in contrast to cryogenic hydrogen, the transport costs of methanol only play a minor role within the total cost at the port of the energy importing country.

Therefore, methanol qualifies as an attractive Power-to-X import product, which provides a basis for multiple applications. For the transport sector, the C^3-Mobility project [1] investigates the production and the usage of gasoline, DME, OME (polyoxymethylene dimethyl ethers) and the higher alcohols butanol and octanol in passenger and light and heavy duty vehicles in addition to the direct usage of methanol.

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