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The feasibility of synthetic fuels in renewable energy systems

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ABSTRACT

The transport sector is the only sector in which there have been no significant renewable energy penetrations, it is heavily dependent on oil with rapid growth in the last decades. Moreover, it is challenging to obviate the oil dependence due to the wide variety of modes and needs in the sector. Nowadays, biofuels along with electricity are proposed as one of the main options for replacing fossil fuels in the transport sector. The main reasons for avoiding the direct usage of biomass, i.e. producing biomass derived fuels, are land use shortage, limited biomass availability, interference with food supplies, and other impacts on environment and biosphere. Hence, it is essential to make a detailed analysis of this sector in order to match the demand and to meet the criteria of a 100% renewable energy system in 2050. The purpose of this article is to identify potential pathways for producing synthetic fuels, with a specific focus on solid oxide electrolyser cells combined with the recycling of CO_2.

KEYWORDS

Synthetic fuels; 100% renewable energy system; transport sector; feasibility study; biofuels.

INTRODUCTION

Shifting from oil to other fuels is not just desirable, it is necessary for a number of reasons: resources are limited, geographic distributions are uneven and the greenhouse gas emissions must be reduced. The transport sector is one of the most important sectors of our time, as well as a significant carrier and the backbone of the economic and social development of each country. With a rapidly growing demand in the last decades, the infrastructure relied on liquid fuels and different kinds of modes and needs the transport sector represent a challenge for

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implementing renewable energy sources. At the moment, oil and oil products cover more than 96% of energy needs in transportation. The transport sector accounts for about 19% of global energy use and for 23% of energy-related carbon dioxide emissions. Given current trends, transport energy use and CO_2 emissions are projected to increase by nearly 50% by 2030 and more than 80% by 2050 [1]. The reduction of oil consumption in this sector is one of the key steps towards zero carbon society. While most sectors have been taking measures to reduce CO_2 emissions and shifting to renewable energy sources, the emission share for transportation has been steadily increasing. At present, oil is the only fuel that can meet the demand. Reducing reliance on oil and oil products in the transport sector is a daunting challenge. Encouraging the strong decarbonisation of transport could lead to energy security which is an important goal for sustainability.

Biomass is a preferred alternative to fossil fuels in many energy sectors. It is considered that biomass along with wind, is a pillar for a non-fossil energy system. However it is really important to carefully distribute biomass use, taking into account the fact that biomass resources and land area are limited. Along with electricity, biofuels are proposed as the main option for replacing fossil fuels in the transport sector. The problem lies in biomass potential and land use issues, as well as their correlation with the demand for biofuels. Biomass may be a severe bottleneck of the fossil free society, and replacing fossil fuels in the transport sector with biomass liquid fuels may not be the best solution from a long term perspective. Even if the electricity based energy carriers partially replaced liquid fossil fuels, there would still be a great need for hydrocarbon fuels.

The motive to focus on synthetic fuels lies in the advantages of their production process. The term ”synthetic fuel” relates to fuel made by using electrolysis as a base process and a source of carbon to produce liquid hydrocarbon. Even though biomass is not a direct fuel source, by using carbon capture and recycling at a biomass power plant, carbon source is provided for electrolysis. Using this kind of fuels could be a solution not just for lowering the CO_2 emissions, but for providing geographical independence and solving supply related issues of conventional fuels and biofuels. The implementation of electrolysers in the transport sector does not only provide synthetic fuels for transportation, it also provides an option for regulating the energy system. Therefore, electrolysers possibly represent a good solution for balancing a system with high shares of renewable sources, which is important due to their intermittency. With captured CO_2 from the atmosphere, the proposed production process of synthetic fuels could enable a closed-loop carbon-neutral fuel cycle.

METHODOLOGY

The methodology for analysing synthetic fuel implementation and for assessing the technical and socio-economic consequences can be divided into three steps. The data collecting, technology and fuel review, the energy system analysis, and finally the feasibility study.

Input data for the analysis has been gathered by literature review and by interviewing relevant people for this matter. There is very little literature relating to the energy system in this particular area, given that it mostly focuses on materials, performance, and durability of the electrolysis cells as well as the modelling of SOEC stacks. After collecting all the necessary data, possible scenarios were proposed as well as comparable ones. This was followed by reviewing individual stages of the production cycle of synthetic fuels. Mass and energy balances are formed based on chemical reactions of fuel production. A separate energy/mass flow diagram is formed for each pathway outlining the electricity, biomass, CO_2 and water needed for producing 100 PJ of the primary fuel. The overall energy system analysis and the feasibility studies were performed using the freeware model EnergyPLAN. The feasibility study is divided into two analyses – technical and socioeconomic, both conducted from the perspective of the whole energy system. Fuel consumption is evaluated, the wind capacity integrated in the system in comparison to electrolyser's capacity is determined, as well as the biomass consumption. CO_2 emissions are negligible because the system is 100% renewable and this is proven through analysis. The socio-economic feasibility of implementing synthetic fuels in the transport sector is done by calculating socio-economic costs including costs of fuel, operation and maintenance costs and investment costs.

The EnergyPLAN energy system analysis model

The EnergyPLAN model is a deterministic mathematical model for national or regional energy system analyses according to inputs defined by the user. The model has an input/output user-friendly interface with a wide-range of inputs, such as energy demands, production capacities, renewable energy sources and efficiency of systems. Outputs include energy balances and resulting annual productions, fuel consumption, import/export of electricity, and total costs including income from the exchange of electricity. Model can be used for three types of energy system analysis: technical analysis, market exchange analysis and feasibility study. The advantage of this model is that it is based on an hourly approach for a one-year period as opposed to scenario models that analyse a series of years. This approach enables precise modelling of hourly fluctuations in demand and supply as well as the influence of the intermittency of renewable energy sources on the system. The EnergyPLAN model has been used and applied for various energy system analyses [2]. The modelling of the transport sector in EnergyPLAN is outlined in the following flow chart [Fig 1]

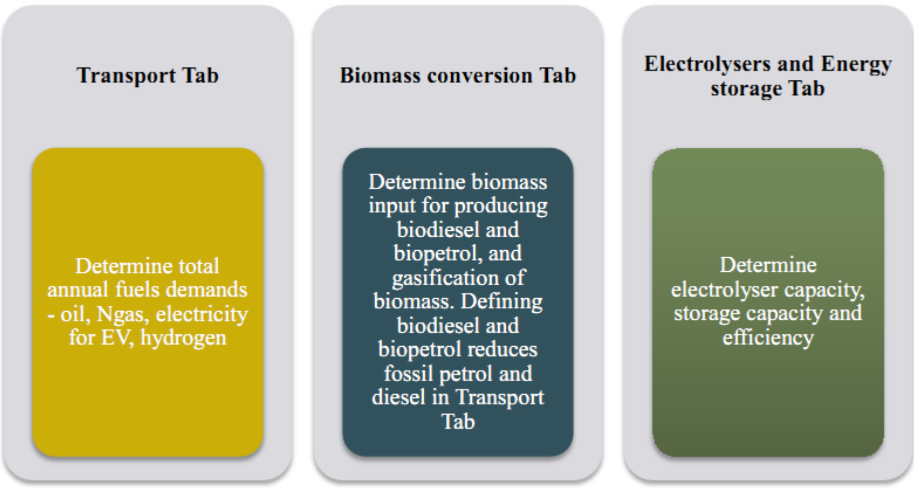

Fig 1. Transport balancing methodology

The reference energy system

Analysis is carried out for the transport sector in the Danish 100% renewable energy system for 2050, one of the most coherent and well analysed national energy systems, projected as a part of ―Coherent Energy and Environmental System Analysis known as CEESA project [3]. The chosen reference system is Recommendable scenario CEESA 2050. In the 100% renewable energy scenario used in the analyses here, the aim has been to minimise the biomass consumption in transport sector in order to preserve it for other sectors. The main priority in the reference scenario, as in all the scenarios analysed in the thesis, is the direct electrification of the transport sector.

SOLID OXIDE ELECTROLYSER CELLS (SOEC)

Solid oxide cells can operate reversibly as a fuel cell or as an electrolyser. The difference between the two modes of operation is that in a fuel cell mode, cell converts the chemical energy from a fuel into electricity through a chemical reaction and in electrolysis mode cell produces fuels such as H_2 and CO. The topic of interest for this analysis is the electrolysis mode. The advantage of solid oxide electrolyte is that it conducts oxide ions, so it can oxidize CO and reduce CO_2 in addition to H_2/H_2O. This cannot be done with other types of cells, like proton exchange membrane (PEM) or alkaline cells, because their electrolytes conduct protons (H^+) and hydroxide ions (OH^-) respectively.

Solid oxide electrolysis cell operates at high temperatures (around 850°C). High temperature electrolysis has both a thermodynamic advantage and an advantage in reaction rates. One of the benefits of the high temperature electrolysis is that part of the energy required for splitting reactants is obtained in the form of high temperature heat enabling the electrolysis to occur with lower electricity consumption. The electrolysis process is endothermic i.e. it consumes heat. High temperature electrolysis thus produces almost no waste heat, resulting in very high efficiency, significantly higher than that of low-temperature electrolysis. High temperature results in faster reaction kinetics, which reduces the need for expensive catalyst materials. In comparison with low temperature electrolysis, which uses precious materials, high temperature electrolysis enables relatively cheap electrode and electrolyte materials.

There are several current research and development projects on SOEC in Europe, and the main research centres for SOEC are located in Denmark [4, 5]. While water electrolysis was highly investigated, electrolysis of CO_2 was reported on a smaller scale [6].

If steam and CO_2 electrolyses are combined in a process called co-electrolysis, the produced synthetic gas, or shortly syngas which contains varying amounts of carbon monoxide and hydrogen, can be catalyzed into various types of synthetic fuel. Co-electrolysis is relevant for the production of CO_2 neutral synthetic fuel. High operating temperature and high pressure, which provides further efficiency improvement, enables the integration of catalysis of the synthetic gas to synthetic fuel. The heat generated in the catalysis reaction can be utilized for steam generation, making the heat reservoir more or less superfluous [7]. The advantages of solid oxide electrolyser cells are the potential for great fuel production rates at high efficiency, low material costs and the possibility of co-electrolysis of H_2O and CO_2. The main disadvantage of SOECs is the durability of the cell - durable performances at high current densities remain to be proven.

FUEL PRIORITISATION IN TRANSPORT SECTOR MODELLING

Different energy carriers for transportation require different primary energy consumption and have diverse technology requirements for their implementation. Fuels have been prioritised according to the above characteristics. Direct electrification is the most energy efficient form of transport. Electrification can provide energy security, as it can be generated by a wide variety of means. The high efficiency of the electrification, therefore, results in a higher net energy balance and lower life-cycle GHG emissions than the other energy carriers for the transport sector. An electrical engine is also quieter than internal combustion engine and, thus, the noises in the transport sector could be reduced. Unfortunately, many transport subsectors are not suitable for electrification and will continue to rely on liquid fuels as a result of limited energy storage, power and weight issues, e.g. long distance transportation, such as trucks, aviation and maritime transport [8].

Apart from electrification, the only other proposed solution for achieving a 100% renewable transport sector has so far been the use of biofuels that can cover subsectors that are not suitable for electrification. Biofuels production represents a great concern in renewable energy systems, mainly due to the land use problem. Even though this problem is obvious, many biofuels technologies are well established on the market, primarily because they can be used directly or with slight changes in the existing combustion engines that are available on the market. Many fuels are subsidized in order to achieve the goal of 10% of biofuels in the transport sector by 2020 in the European Union. All EU members have either quota obligation and/or tax exemption for implementing biofuels [9]. Moreover, related NO_x and NH_3 emissions of biofuels are not lower for all types of biofuels in comparison to those of reference fossil fuels.

The conversion of electricity into form of synthetic fuels could be beneficial in the future transport sector. The main advantage of electrolysis in the production of synthetic fuels lies in the fact that output gas can be catalyzed into various types of fuels. Synthetic fuels overcome land-use problems and are not interfering with food supply issues. Moreover, in their production there is no direct usage of biomass at all. The production of synthetic fuels relies on electricity for driving the electrolysis process in electrolysers that can be used to balance intermittent energy production from renewable sources. Methanol and DME are chosen as the most promising types of fuels, primarily due to well know chemical synthesis for producing these kinds of fuels and the possibility of their almost direct application into existing internal combustion engines. Although methane is often considered as an easiest fuel to convert from syngas, it is not included in the analysis, because it is assumed that the application of methane is too expensive as a result of the fact that the existing infrastructure is utilised for liquid fuels [3].

PRODUCTION CYCLE OF SYNTETIC FUELS

Production cycle of synthetic fuels is divided into three steps as shown in Fig 2: carbon and energy source, dissociation of oxides and fuel synthesis. The concept of carbon capturing and recycling is important not just because of the issue of global warming, but also in order to achieve 100% renewable system. This concept enables the production of sustainable fuels that can be used in transport sector.

Two carbon sources are proposed – Carbon Capture and Recycling (CCR) from energy sector and Air capturing as a promising future technology. The analysis with CCR was conducted with post-combustion process, due to the fact that this method is more established for CO_2 capture than the others [10]. An important difference between air capture and CCR is that this process enables a CO_2 closed loop. Air capturing is not connected to any specific carbon source and is, thus, more flexible than CCR technologies. In addition, air capturing can be used to collect emissions from mobile sources like airplanes and vehicles. This technology could play an important role in 100% renewable energy systems because air capture can keep up with the entire world emissions, and could even be used to reduce the CO_2 content of the atmosphere. The electricity which enables the electrolysis process is provided by wind turbines. This option is chosen not only because wind energy is a renewable source, but also due to the fact that the integration of electrolysers in the transport sector enables the integration of wind turbines and the balancing of the system. Moreover, Denmark is a leader in modern wind energy, with 19% of electricity produced from wind in 2009 [11].

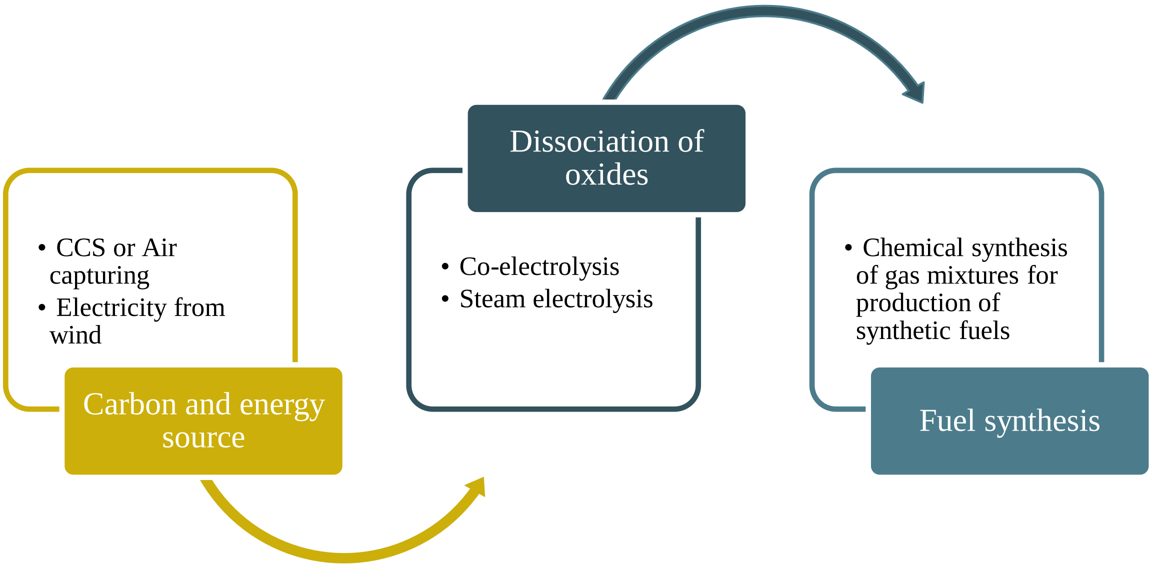

Fig 2. Production cycle of synthetic fuels

The main step in production cycle is dissociation of oxides – H_2O or a mixture of H_2O and CO_2, can be conducted with steam electrolysis or co-electrolysis. These processes use electricity to drive dissociation and have the largest energy conversion, because this is where electricity is converted to fuel or fuel precursors. Electrolysis performs the dissociation in a single step. The production cycle finishes with fuel synthesis – chemical synthesis of produced gas mixtures from electrolysis process.

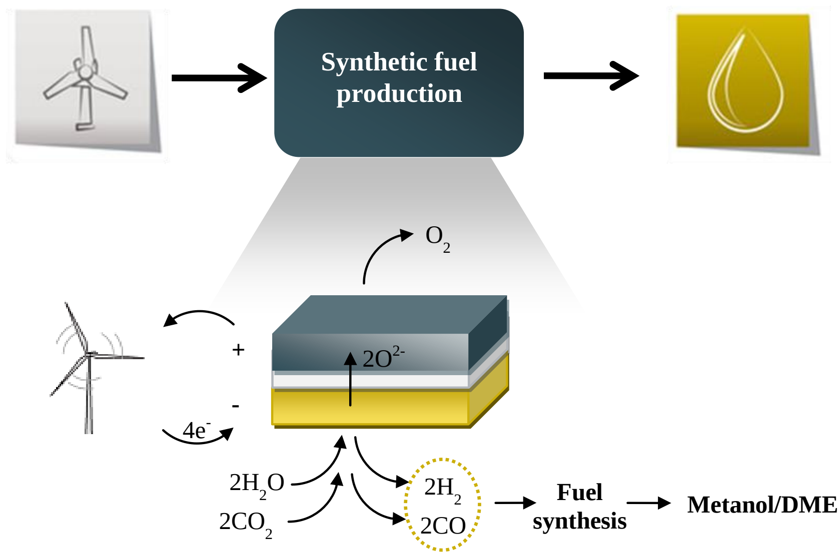

Fig 3. Synthetic fuel production

SYNTHETIC FUEL PATHWAYS

After identifying cycle steps needed for the production of synthetic fuels, two pathways are proposed with four variations as illustrated in Fig 4. The first pathway is *co-electrolysis of steam and CO_2* and the second one is *hydrogenation of CO_2*. Co-electrolysis is a combined process of steam and CO_2 electrolysis. Hydrogenation of CO_2 involves steam electrolysis and then a reaction of hydrogen with recycled CO_2. Gas mixtures as products of these processes can be catalyzed into synthetic fuel.

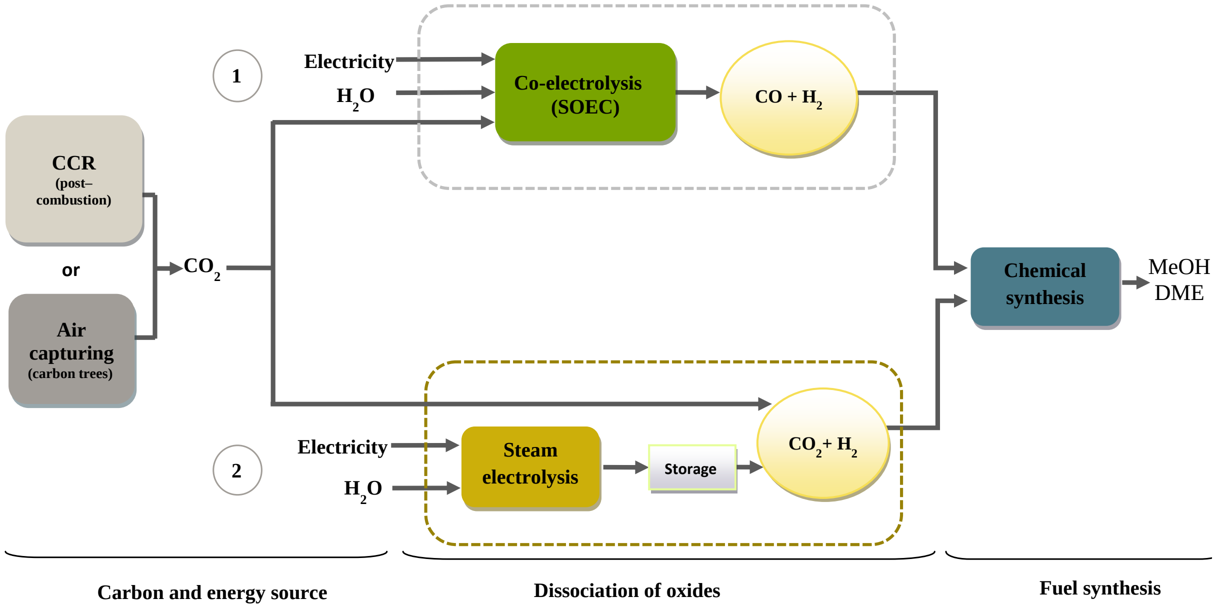

Fig 4. Pathways for production of synthetic methanol or DME; 1 - co-electrolysis, 2 - CO_2 hydrogenation

In order to complete the analysis in the EnergyPLAN it was important to construct mass and energy balances for methanol/DME production. This was made in [13] by forming chemical reactions of production process. In order to simplify the calculations, methanol and DME are treated the same. As DME is produced from methanol, the efficiency lost when comparing with methanol is gained through higher efficiency of diesel engines suitable for DME compared to petrol engines suitable for methanol.

Both pathways for producing synthetic fuels exclude direct biomass input for fuel production. However, these pathways are in strong connection with power and heat generation sector that uses biomass. As it can be seen from flow charts [Fig 5, Fig 6] the same amount of carbon dioxide for the production of fuel is needed resulting with the same amount of electricity needed for the carbon capturing and recycling system. Air capturing was excluded from the analysis because it would require approximately 5% more electricity which would not cause significant variation in the results of the whole system. In the case of air capturing, all sectors are not connected and there is not even indirect biomass input. Assumed electrolyser efficiencies are reduced by 5% accounting for storage and chemical synthesis losses. In the hydrogenation of CO_2 pathway, synthesis of methanol produces excess water which can be recycled. Calculations for both pathways were carried out with dry willow biomass fired power plant with assumed electricity generation efficiency of 40%.

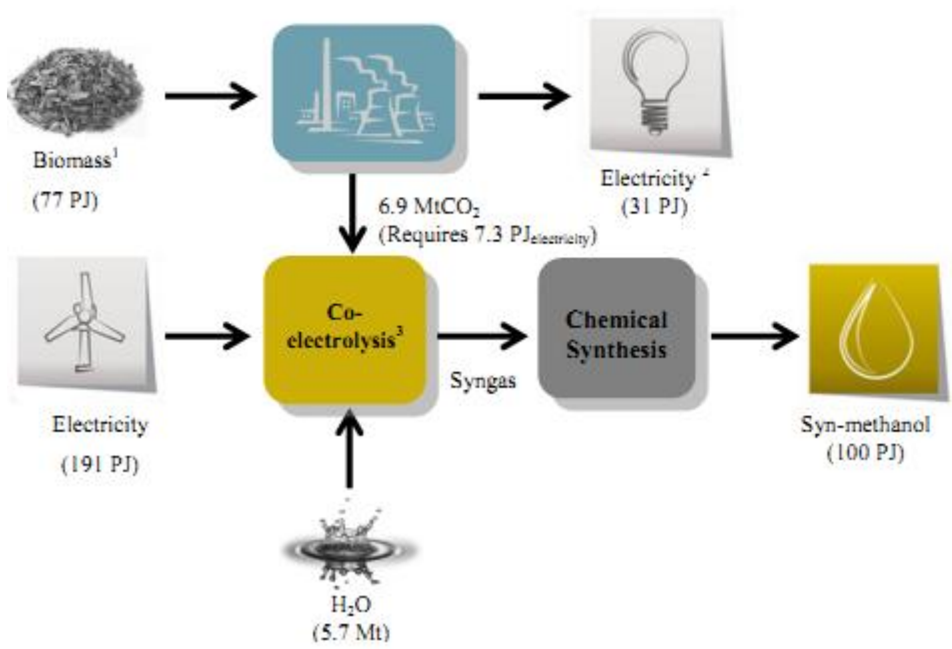

Fig 5. Co-electrolysis scenario. [1]Based on dry willow biomass. [2]Assumed an electricity generation efficiency of 40%. [3]Assumed an electrolyser efficiency of 78% [12], minus 5% accounts for storage and chemical synthesis losses.

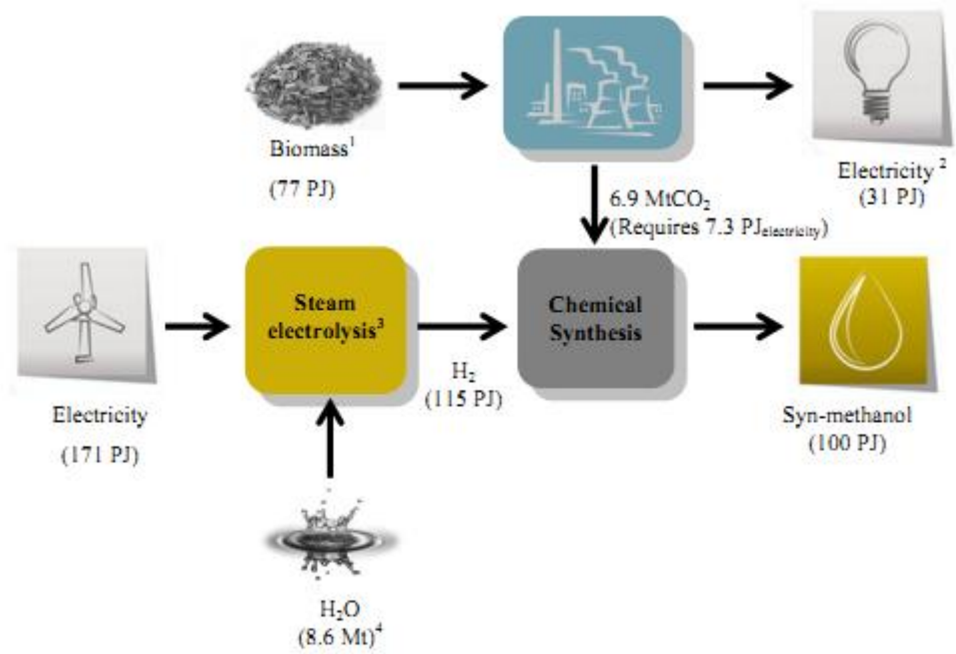

Fig 6. Hydrogenation of CO_2. [1]Based on dry willow biomass. [2]Assumed an electricity generation efficiency of 40%. [3]Assumed an electrolyser efficiency of 73% [14], minus 5% accounts for storage and chemical synthesis losses. [4]This does not include the excess water which can be recycled from the hydrogenation process.

ALTERNATIVES TO SYNTHETIC FUELS

Two biofuels scenarios that have direct usage of biomass for producing liquid fuels are included in the analysis: *Hydrogenation of biomass* and *Conventional biodiesel*. Conventional biodiesel production is the only scenario that does not include electrolysers in the production process.

Hydrogenation of biomass

Hydrogenation of biomass is a well-known process of upgrading the energy content and energy density of biomass with hydrogen. Hydrogenation of biomass involves gasifying the biomass into a syngas which subsequently reacts with hydrogen. Biomass gasification is a high-temperature process (500 to 1400°C) for converting complex hydrocarbons of biomass into a combustible gas mixture primarily consisting of hydrogen and carbon monoxide, known as syngas. However, in reality, some carbon dioxide, water and other hydrocarbons can be formed as well. The gasification of biomass breaks biomass into combustible gas mixture in the presence of gasification agents such as oxygen, air, steam or a combination of them [15]. The hydrogenation of biomass is a path for producing liquid fuels that involves direct input of biomass [see Fig 7]. It is more preferable than the conventional production of biofuels due to the fact that it consumes less biomass and allows the integration of more wind in the system.

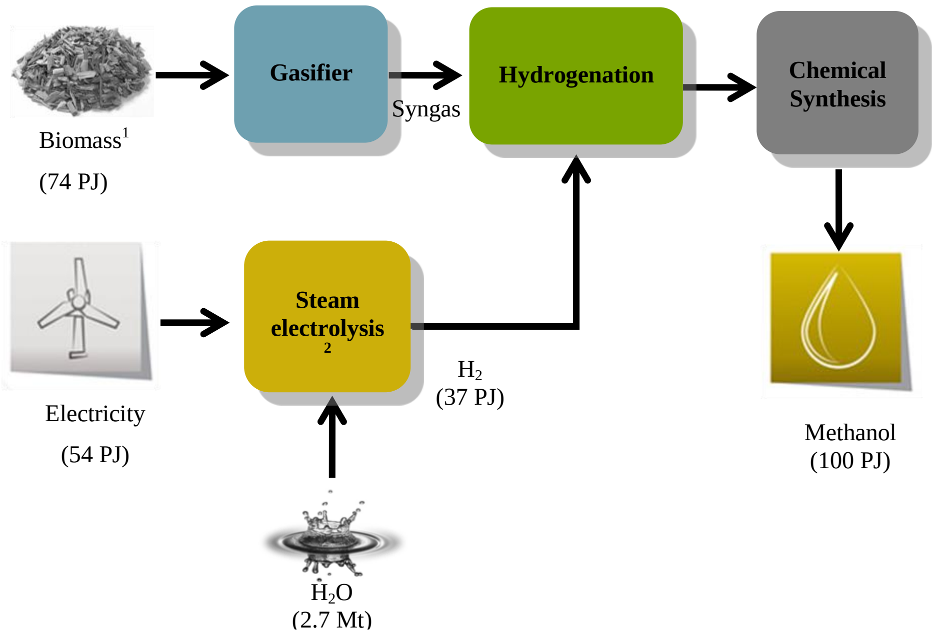

Fig 7. Hydrogenation of biomass. [1]Based on straw/wood chips. [2]Assumed an electrolyser efficiency of 73% [14], minus 5% account for storage and chemical synthesis losses.

Conventional Biodiesel

This pathway is a response to Technology Roadmap - Biofuels for Transport [16] based on BLUE Map Scenario from the Energy Technology Perspectives 2010 [17], which sets out cost effective strategies for reducing greenhouse-gas emissions by half by 2050. The scenario suggests that a considerable share of the required volume will come from advanced biofuel technologies that are not yet commercially deployed. However, the biodiesel path in our analysis is an extreme case of the conventional production of biodiesel in 2050. Conventional biodiesel production is the only scenario that does not include electrolysers in the production process.

ENERGY SYSTEM ANALYSIS

Pathways modelled for this analysis represent extreme cases of replacing total liquid fuel demand with synthetic fuels, biofuels or bio-diesel. Total predicted fuel demand in 2050 is 138 PJ/year which is equal to 38 TWh/year and it is kept the same in all scenarios while fuel mix is changed [see Fig 8]. Moreover, as only the transport sector is analysed, renewable energy and conversion technologies are not changed except for the wind capacities.

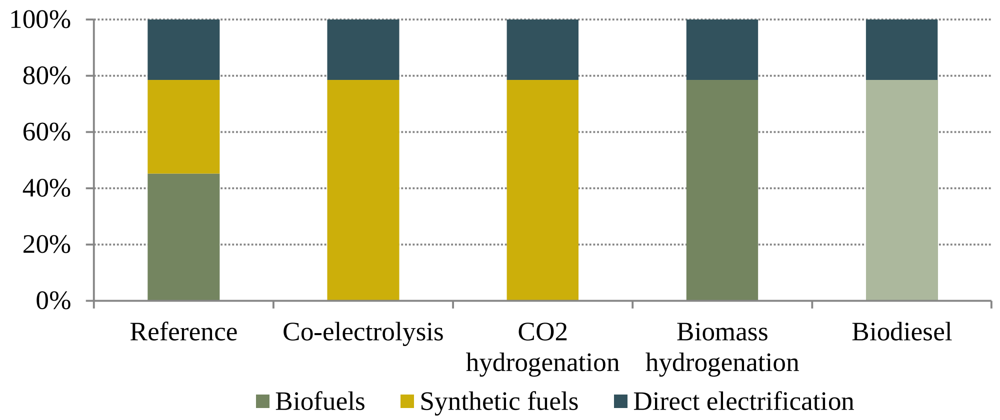

Fig 8. Share of different types of fuels in scenarios

In order to analyse the steps needed for achieving a 100% renewable transport sector in 2050 and to analyse the different key elements for establishing the latter, four scenarios have been created [Table 1]. Two main pathways are focused on synthetic fuels for providing all liquid fuels that cannot be replaced by direct electrification - *Co-electrolysis* and *CO_2 hydrogenation*. Two biofuels scenarios that have direct usage of biomass for producing liquid fuels are included in the analysis: *Hydrogenation of biomass* and *Conventional biodiesel* pathway. While *Reference* scenario includes a liquid fuel mix, all other scenarios have one type of liquid fuels that cover 79%, while the rest of the transport energy demand is met by electrification. In terms of transport demand is even more significant.

Table 1. Pathways for producing liquid fuels in 2050

Pathway	**Description**
Co-electrolysis	Production of liquid fuel by a combined process of steam and CO_2 electrolysis. Carbon source is CCR cycle from biomass power plant. No direct biomass usage.
CO_2 hydrogenation	Hydrogenation of CO_2 involves steam electrolysis and afterwards the reaction of hydrogen with recycled CO_2 from biomass power plant. No direct biomass usage.
Hydrogenation of biomass	Hydrogenation of biomass involves gasifying the biomass into a syngas and which subsequently reacts with hydrogen from steam electrolysis
Conventional Biodiesel	Conventional biodiesel production by transesterification of vegetable oils and fats

All scenarios are 100% renewable scenarios for 2050, without any fossil fuel input. In general, 21% of the consumption is met by the electrification of the transport sector, with different types of electric vehicles and electrically powered trains, while the rest is covered by different kinds of liquid fuels depending on scenarios. The main idea in creating scenarios was to keep biomass consumption as low as possible making it available for other sectors. The priority for liquid fuels is given to methanol/DME. This approach resulted in synthetic fuel scenarios that allow the integration of more wind turbines into the energy system.

RESULTS

Once the scenarios were defined and integrated in EnergyPLAN, the feasibility study was completed with a focus on four criteria:

1) *Fuel consumption*, indicating which scenario represents the most fuel-efficient solution.
2) Balancing wind production as an indicator of the *system flexibility*.
3) Overall *biomass use* regarding the land use issue connected with the production of conventional biofuels and the biomass potential, given that biomass is exploited in energy sectors.
4) *Socio-economic costs* which can provide relevant information in terms of defining which system has advantages in terms of fuel, operation and annual investment costs.

The biomass consumption for the whole energy system is illustrated in Fig 9. The assumed biomass feedstocks used for the production of biofuels in *Biodiesel* scenario are energy crops-willow and straw/wood chips are used in the *Hydrogenation of biomass* scenario. It can be seen that the *Co-electrolysis* scenario uses the least biomass possible - 193.2 PJ while in the *Biodiesel* scenario consumption is almost 280 PJ on a system level. On the transport level, this ratio is even worse at the expense of the *Biodiesel* scenario, due to the fact that *CO_2 Hydrogenation* and *Co-electrolysis* have no direct biomass input in the transport sector.

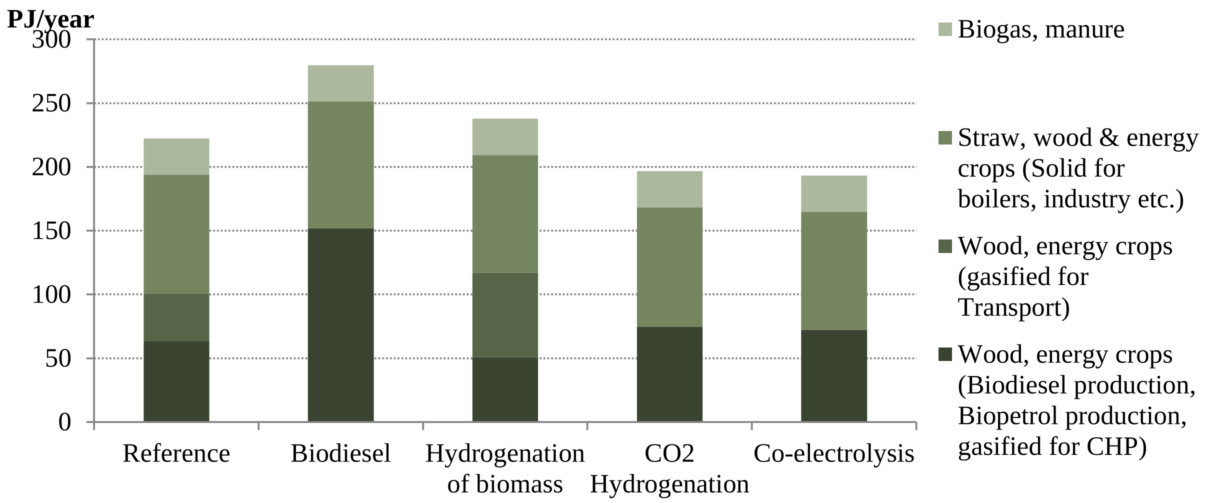

Fig 9. Biomass use in overall energy system

Flexibility of the system was measured by the integration of wind capacities with a focus on offshore capacities, fixing the on shore capacities allowing the comparison of the scenarios. Installed on shore capacities are 4,454 MW. From the energy system perspective, 20-25% of the wind power can be integrated without significant changes to the system, while integration more wind power than this, implies the installation of large storages like heat pumps. To balance the energy system with more than 40-45% of wind power which will probably be indispensable for establishing a 100% renewable system, transport sector will have to implement technologies that could facilitate wind power integration [3].

The Critical Excess Electricity Production (CEEP) diagrams serve as an illustration of the ability of a system to integrate fluctuating RES which differ from one year to another. These kinds of diagrams can be used for comparing radically different systems. A rise in CEEP indicates an existing lack of flexibility in the system. Integrated offshore wind capacities in scenarios are adjusted so the CEEP for all scenarios is 0.5 TWh/year. As it is presented in Fig 10, the contribution of electrolyser capacity is enviable in different systems for further integration of wind energy. It can be seen that, as it was expected, the *Biodiesel* scenario is the least flexible one, followed by the *Hydrogenation of biomass*. The integration of more than calculated wind capacities results in an increase of CEEP. Such increase in the storage capacity, provided by electrolysers, significantly reduces excess production.

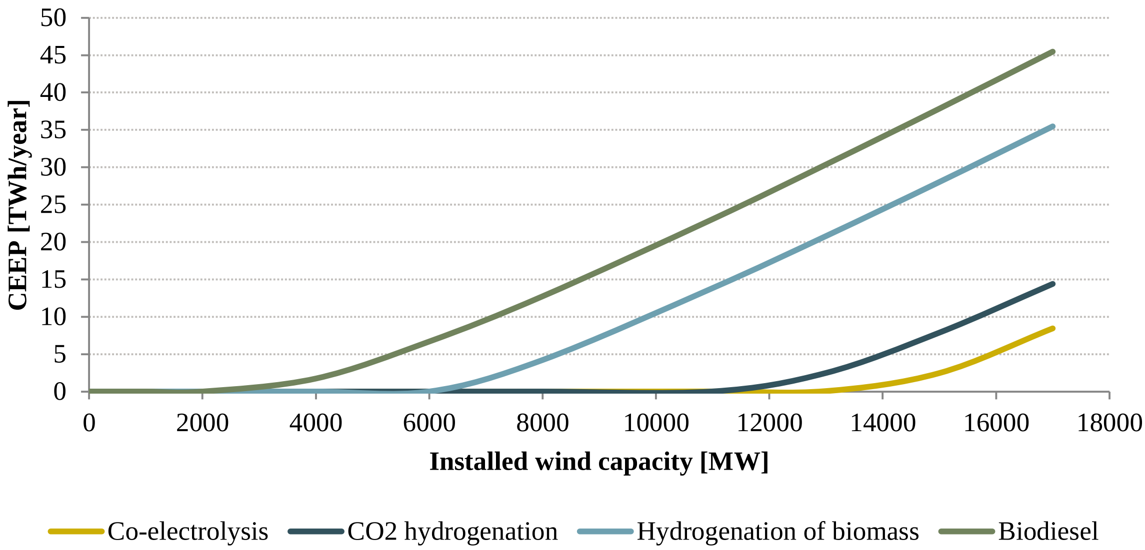

Fig 10. Increasing wind integration by different scenarios

Installed wind capacities are strongly connected with the integrated electrolyser in the system [see Fig 11]. The implementation of electrolysers in the system enables a flexible and efficient integration of larger amounts of renewable energy into the transport sector. As it was expected, the *Co-electrolysis* pathway represents the most flexible scenario with 14,203 MW integrated off-shore wind turbines. It is evident from the results that the *Biodiesel* scenario can utilise small amount of wind energy compared to the rest of the scenarios. In total, the *Biodiesel* scenario has approximately four times less off-shore wind capacities (3,444 MW) than the *Co-electrolysis* scenario. This is due to the much larger electricity demands and energy storage capacities available in the scenarios that include electrolysers.

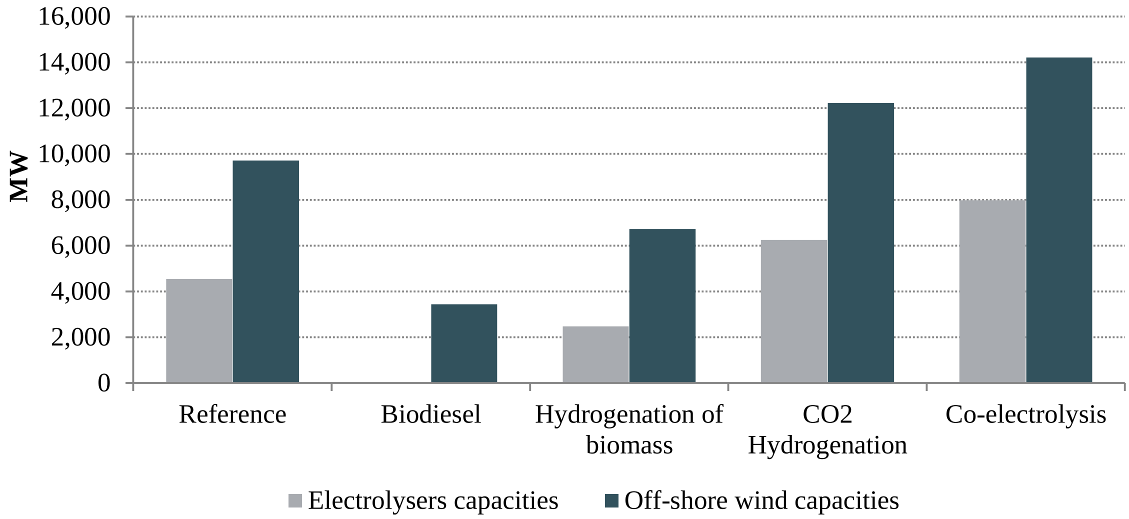

Fig 11. Installed electrolysers and off-shore wind capacities

All scenarios that implemented electrolysers have higher wind shares in primary energy supply (up to 49%) than the *Biodiesel* scenario with 21%. However, as these scenarios are part of a 100% renewable system, significant fraction of electricity is generated from wind power.

The primary energy supply (PES) is outlined in Fig 12. The scenarios differ only in their utilisation of biomass and offshore wind power, while the use of the rest of renewable energy sources is identical. The more wind is integrated in the system, the higher the primary energy supply is. It is obvious that the technologies implemented in different scenarios are crucial for the biomass consumption. Even though the *Biodiesel* scenario overall has the lowest primary energy supply among all analysed scenarios, with 454.5 PJ compared to 526.2 PJ in the *Co-electrolysis* pathway, it has the lowest wind integration and the lowest flexibility while having the highest biomass use. In other scenarios, electricity produced with wind replaces the demand for biomass while electrolysers stabilize the grid.

Fig 13 illustrates the annual primary energy supply excluding renewable energy sources. The advantage of such approach is that it can reveal the ability of the technology to utilise RES, in this case offshore wind power. In our system, this basically represents the biomass fuel consumption. The specified electricity demand for installed electrolysers cannot be met by the capacity of power plants in combination with import on the transmission line resulting in higher primary energy supply in the *Co-electrolysis* and *Hydrogenation of* CO_2 scenarios. After reaching a certain capacity of wind power in the system, in case of *Biodiesel* and *Hydrogenation of biomass*, flexibility of their systems becomes lower than those with larger integration of electrolysers, and systems' biomass fuel consumption stays almost the same while CEEP continues to rise.

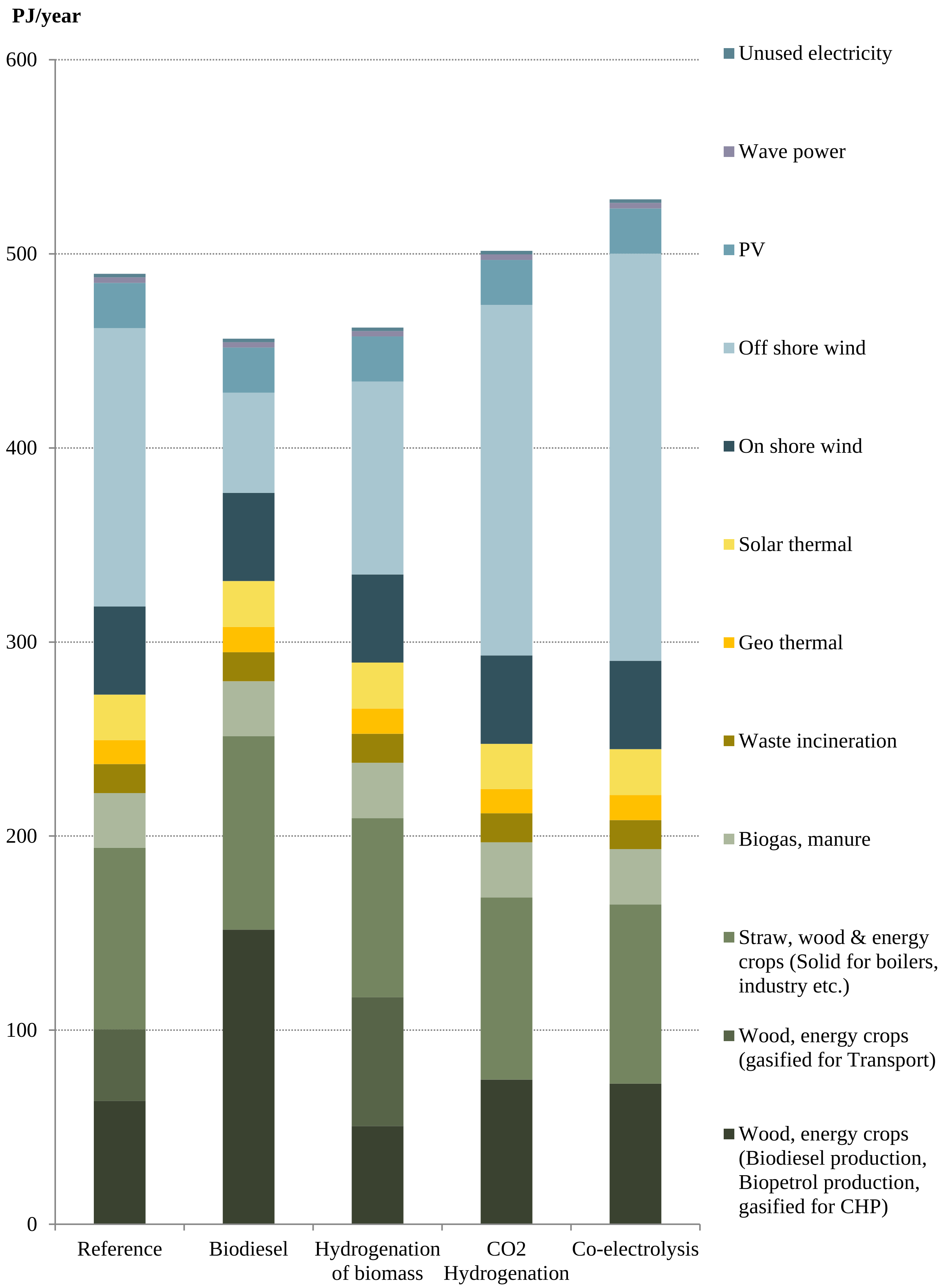

Fig 12. Primary energy supply in the 2050 reference energy system and analysed scenarios

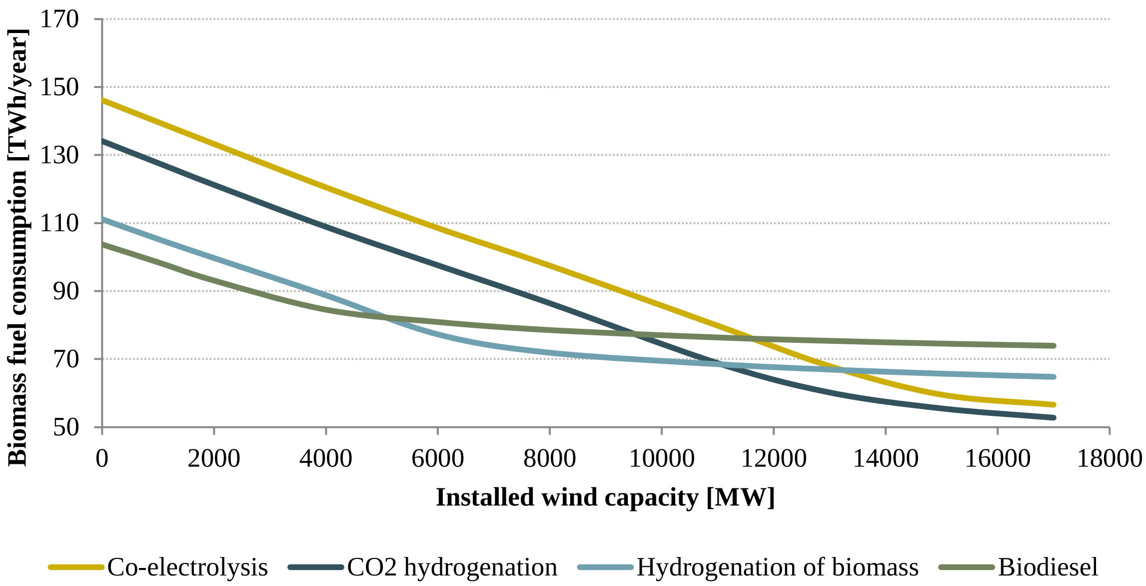

Fig 13. Biomass fuel consumption for all scenarios

Due to uncertainty of fuel prices in a long-term planning three assumptions are used:

1) A low fuel price development corresponding to an oil price of $65/barrel.
2) A medium price level corresponding to an oil price of $85/barrel.
3) A high price level corresponding to an oil price of $125/barrel.

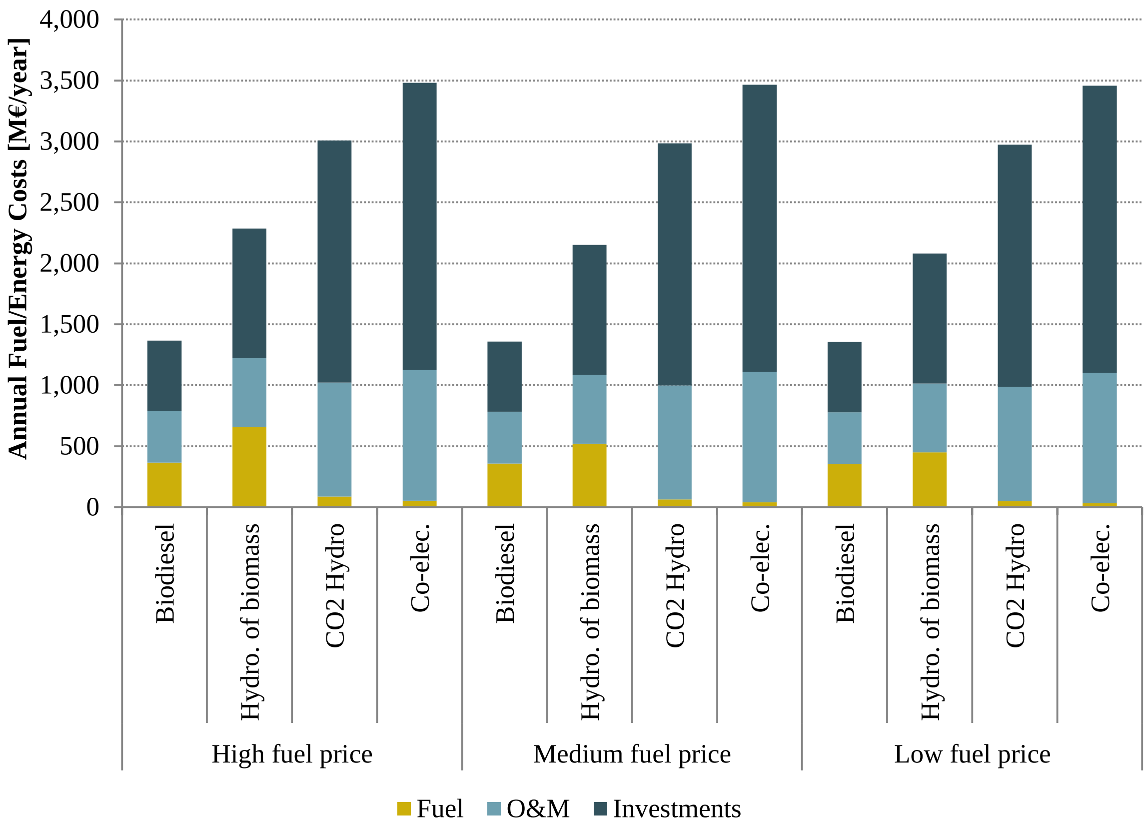

Fig 14. Annual fuel/energy costs for all scenarios for medium price level in the transport demand

The annual fuel/energy costs for all scenarios are shown in Fig 14. The scenarios differ in energy system and fuel costs. Due to the implementation of new technologies, scenarios with electrolysers have higher investment costs followed by lower fuel costs. The investment costs of SOEC are assumed to be 0.25 M€/MW for grid connected electrolysers with a 20 year lifetime and 2% fixed O&M costs [14]. In terms of the overall system, a 100% renewable system is not so fuel price sensitive because the energy system is constructed not to be fuel dependent. However, in terms of the transport sector alone, since the fuel costs are the key difference between scenarios, scenarios were analysed with three different price levels.

CONCLUSION

The production of synthetic fuels has many advantages, it combines the heat and power sector with the transport sector, it uses CO_2 for its production, and by using electrolysers it helps balancing the grid, facilitates wind power integration and represents smart energy system solutions. By combining electricity and electrolysers for transport it becomes possible to relocate the electricity consumption and to replace inefficient technologies. The synthetic fuel scenarios showed improvements of system flexibility and this is essential for making the energy system 100% renewable. Moreover, the advantage of synthetic fuels scenarios is that processes finish with chemical synthesis, meaning the choice of fuel production is very flexible. However, as synthetic fuel scenarios were based on technologies that are still at R&D level, the ultimate decision on which scenario is the best for the future transport system will depend on the technological development and demonstration of proposed facilities on a large scale. Overall, the costs of synthetic fuel scenarios are more expensive, but the associated biomass savings make the additional costs worthwhile due to its scarcity. With feasible technological development and mass production of the Solid Oxide Electrolyser Cells, synthetic fuels could be competitive and have market advantage over biomass derived fuels based on their supply related issues, land use shortage, limited biomass resources, etc.

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