Sustainability of Transport Fuels

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Sustainability of Transport Fuels

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1 Introduction

Given the magnitude of transportation fuels to be provided by renewable energies in the future, a sustainability framework that goes beyond greenhouse gas emissions is essential in order to avoid backlashes in other environmental categories. Major environmental issues include greenhouse gas emissions, air pollutants, biodiversity and protection of natural habitats. Water consumption already goes beyond environmental concerns touching human and geopolitical issues alike. Social and local economic sustainability are further topics that are already vividly discussed in the context of biofuels production (see the 'food vs. fuel' debate).

As a result, the European Union target of 10% renewable energies in transport by 2020 is conditioned by a comprehensive set of sustainability criteria. This is currently under strong political debate as e.g. the assessment of potentially disastrous indirect land use changes clearly falls short when addressing individual bioenergy projects only.

This paper presents the sustainability criteria and approach of the European Union as laid out in the EU Renewables Directive. Furthermore, aspects going beyond the EU Directive are discussed and typical values for selected criteria are presented.

Focus is put on the comparative assessment of primary energy potentials, greenhouse gas emissions, land-use and water intensity of different fuel and power train options including biofuels, electricity and hydrogen.

2 EU Renewable Energy Directive

On 23 April 2009, the European Union has voted on the EU Renewable Energy Directives (EU-RED [1]). The RED includes a comprehensive set of sustainability criteria to apply for EU Member States' mandatory share of 10% of renewable energies in transport fuel by 2020. The Directive will have to be implemented in EU Member States' law by end of 2010. Article 17 stipulates "go/no-go" criteria for greenhouse gas emission reductions, land with high biodiversity and land with high carbon stock. Article 18 stipulates reporting obligations (to be further defined) on soil, water, and air protection; social issues; availability of foodstuffs; land rights; etc. The sustainability criteria apply to geographic origins both from within the EU as well as import from third countries. For the time being, the focus is set on sustainability issues related to the cultivation of biomass for bioenergy. However, paragraph 4 of article 3 states that "all forms of energy" is included to make up for the 10% target. Hydrogen is explicitly mentioned in the 1st paragraph of article 5 to be considered for the calculation of the Member States' share of renewable energies.

It is expected that certified transport fuels will gain a premium in Europe. For the time being, hydrogen energy stakeholders are largely unaware of this novel policy framework. Opportunities for renewable hydrogen in transport have yet to be explored.

3 Energy Potentials

The potentials for producing electric power from renewable energies in Europe noticeably exceeds current consumption (see Figure 1). Distinguishing between direct power production and biomass-based power generation, Figure 1 clearly shows that bioenergy is strongly limited in potential: direct power generation (left) exceeds current consumption by more than a factor of two, while the biomass power generation potential (right) is around 10% of consumption. A similar relationship holds true for transport fuels.

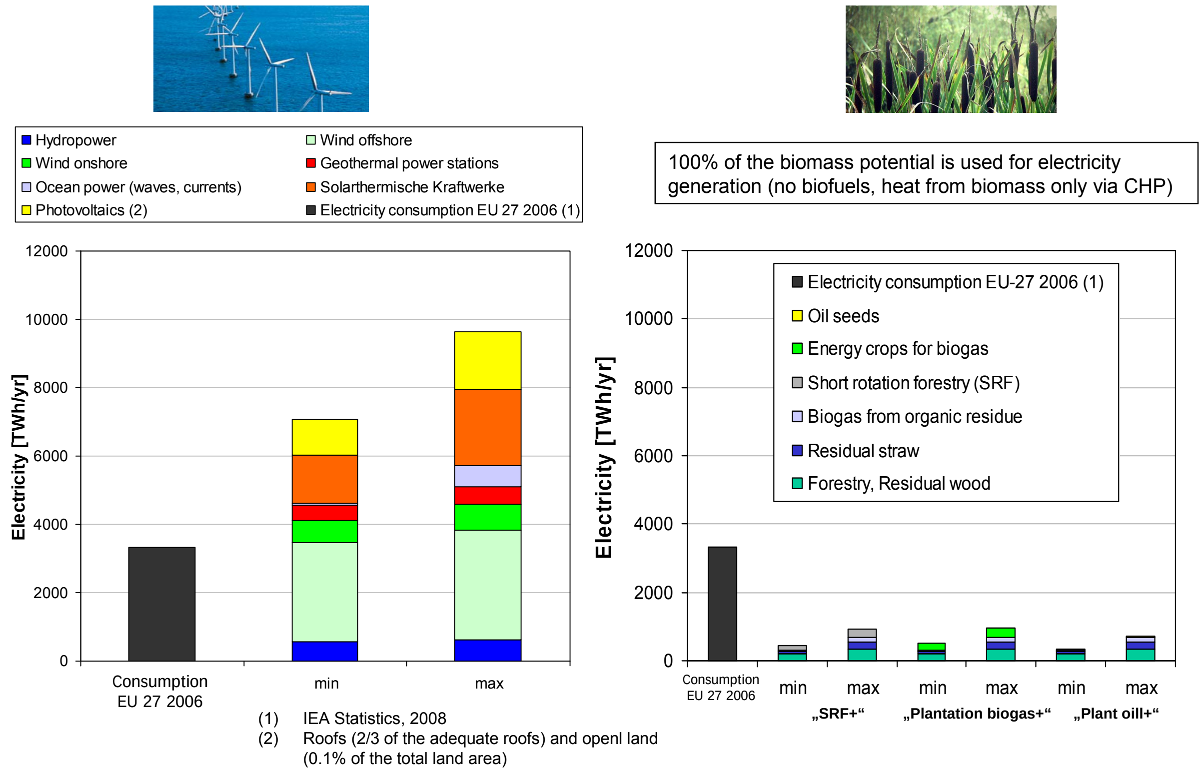

Figure 1: Energy potentials for direct renewable electricity production (left) and bio-based electricity production (right) in Europe.

4 Greenhouse Gas Emissions

Greenhouse gas emission (GHG) reductions of biofuels, hydrogen and electricity compared to conventional transport fuels have large bandwidths. A 100% reduction is feasible if renewable power or suitable biomass pathways are used. Unfavourable biomass pathways provide only insignificant greenhouse gas emission reductions compared to mineral oil-based fuels (see Figure 2 based on analyses by the authors [2]). Including land-use changes can drive up GHG emissions to levels significantly above conventional fuels, e.g. palm oil emissions are up to 25 times the emissions of fossil-based diesel if land use changes are accounted for.

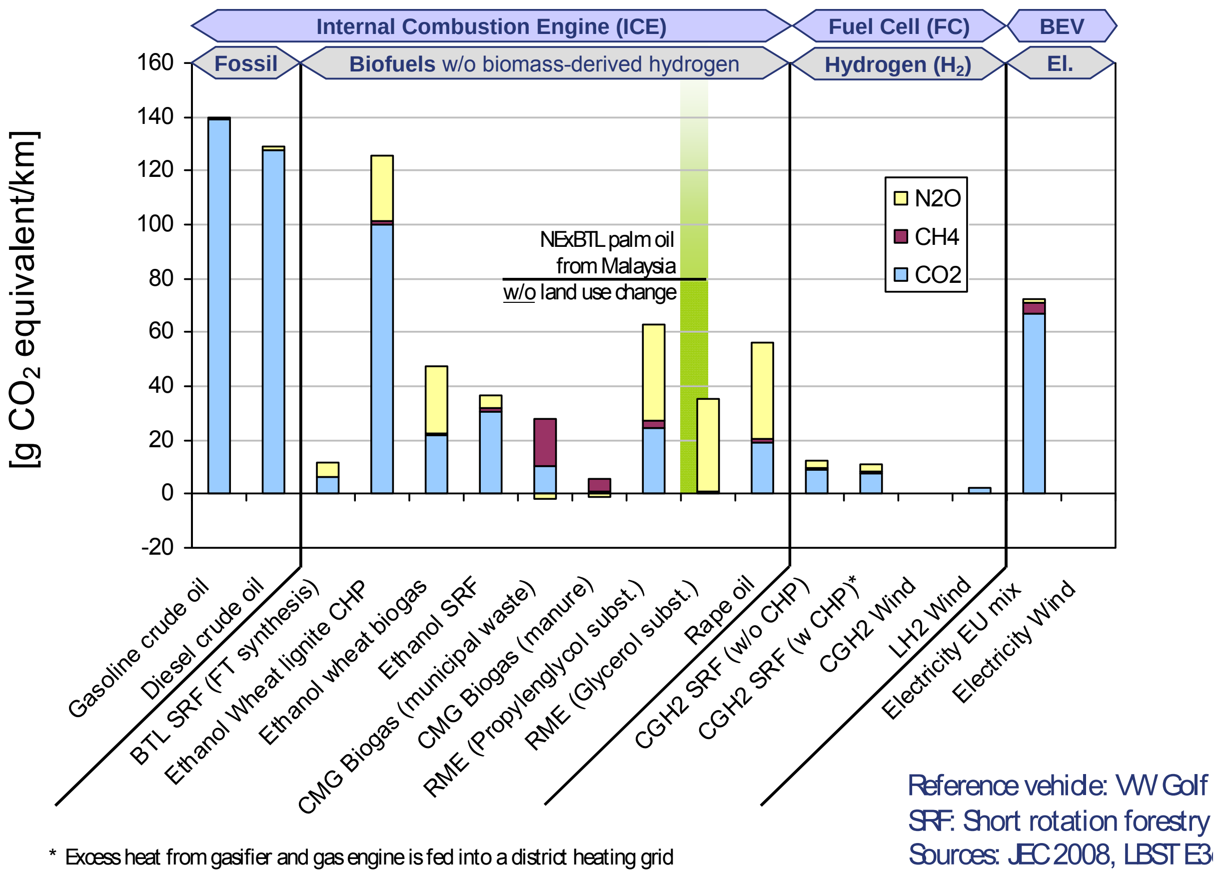

Figure 2: Greenhouse gas emissions "well-to-wheel" (without land use change).

Note that battery electric vehicles do not fulfill all performance requirements, notably cruising range, which gives them a bias towards better GHG emissions.

5 Air Pollutant Emissions

Air pollutants have come more into focus again in recent years with pollutant concentration levels in urban areas not improving, in spite of stricter emission limits for vehicles. Hence, stricter air quality requirements are being enacted in European. The latest move is the EU Directive on Ambient Air Quality and Cleaner Air for Europe [3].

Critical for human health are high pollutant concentrations in urban areas. Figure 3 depicts the nitrogen oxide emissions by place of occurrence for the same fuels as Figure 2 for GHG emissions. As can be seen, emissions are reduced significantly by renewable hydrogen and renewable electricity, while biomass-based fuels do not reduce pollutant emission levels. It has to be noted, that the future EURO6 emission standard (best case for internal combustion engines) has been taken into account for Figure 3. Today, the EURO4 emission standard applies with significantly higher tank-to-wheel (TTW) emissions.

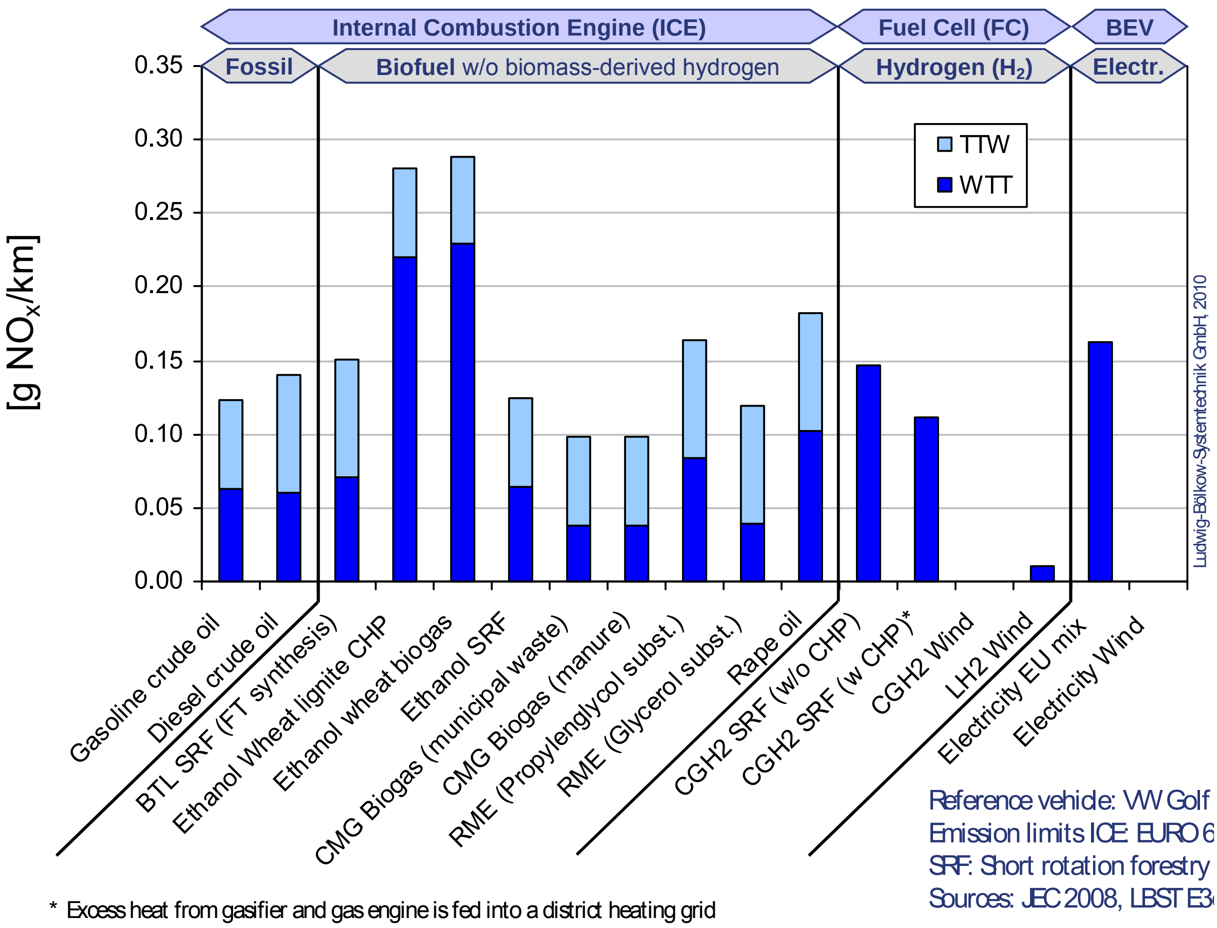

Figure 3: **Nitrogen oxide emissions “well-to-wheel”, based on VW Golf with EURO6 emission standard (applicable from 2014).**

6 Land-use

The European goal of substituting 10% of transport fuel consumption by alternative fuels by the year 2020 is designed to essentially be met by biofuels. Assuming all biofuel crops to be grown in Europe, this would require substantial land areas. Figure 4 relates these to the total arable land available in EU-27. Conventional biofuels would require some 25-35% of arable land, while second generation Biomass-to-Liquids would require 20%. Preliminary values for algae-based fuels indicate that around 5% would be required under very strong irradiation conditions, while under central European conditions this value goes up to 25%. Direct renewable power for hydrogen fuel cell vehicles or battery electric vehicles requires less than 5% of arable land in the EU. It should be noted here that algae can be grown on non-arable lands (similar to photovoltaics) and that wind power still allows for agriculture on the land covered.

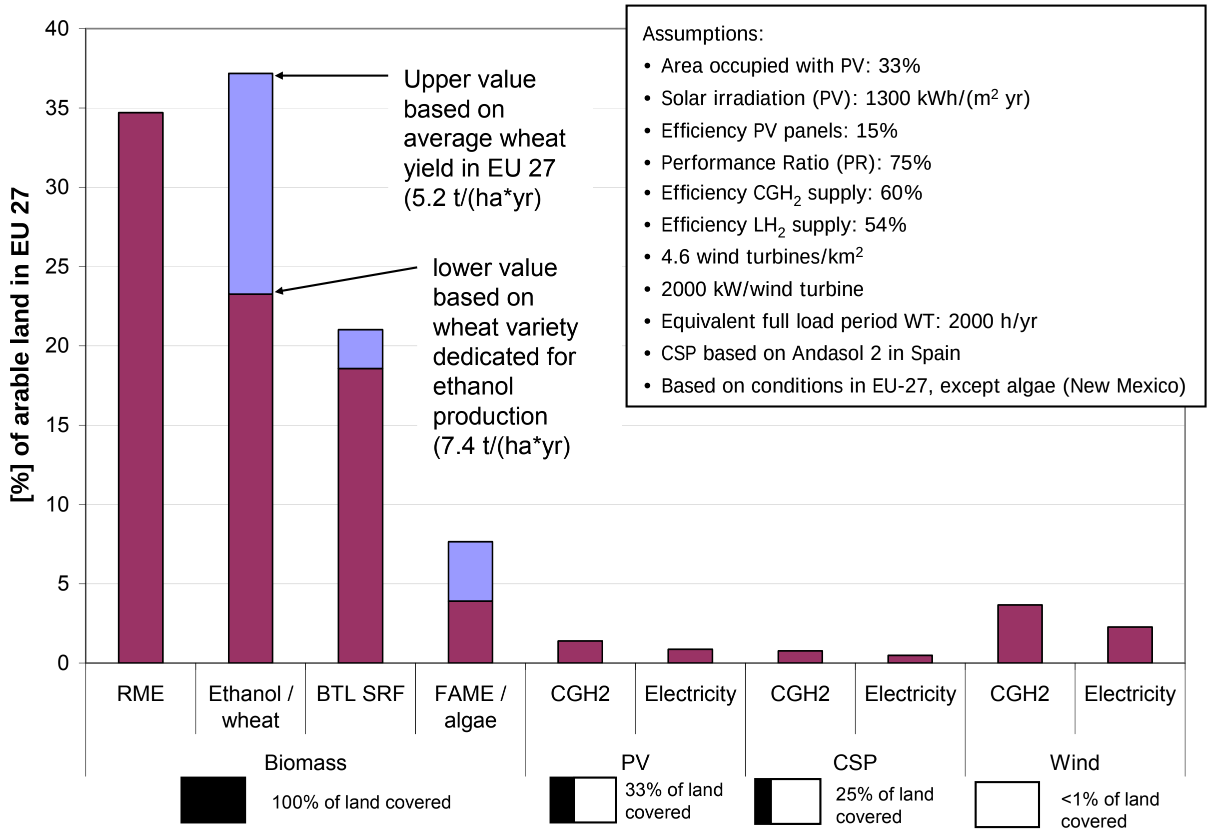

Figure 4: Land-use of various transport fuels in terms of share of arable land required for achieving the EU of a 10% substitution of conventional fuels by 2020.

Figure 5 maps vehicle mileage against fuel yield per hectare. A clear grouping results with liquid biofuels showing lowest yields as well as lowest mileage; hydrogen fuel cells showing medium values; and battery vehicles highest. This is a clear indicator that battery electric vehicles would be the best solution if they achieved the performance levels of conventional or hydrogen fuel cell vehicles.

Fuel cell-electric vehicles have a head start compared to pure battery-electric vehicles in terms of operating performance (range, temperatures, etc.). Demonstration projects are required to validate whether the very high expectations set on battery technology can be delivered under real-world conditions. Despite economic challenges for both technologies, the key question should not be “Which technology’s gonna make it?”, but rather “Which shares between batteries and fuel cells perform best in future hybridised drive-train concepts for the various transport applications and mobility patterns?”.

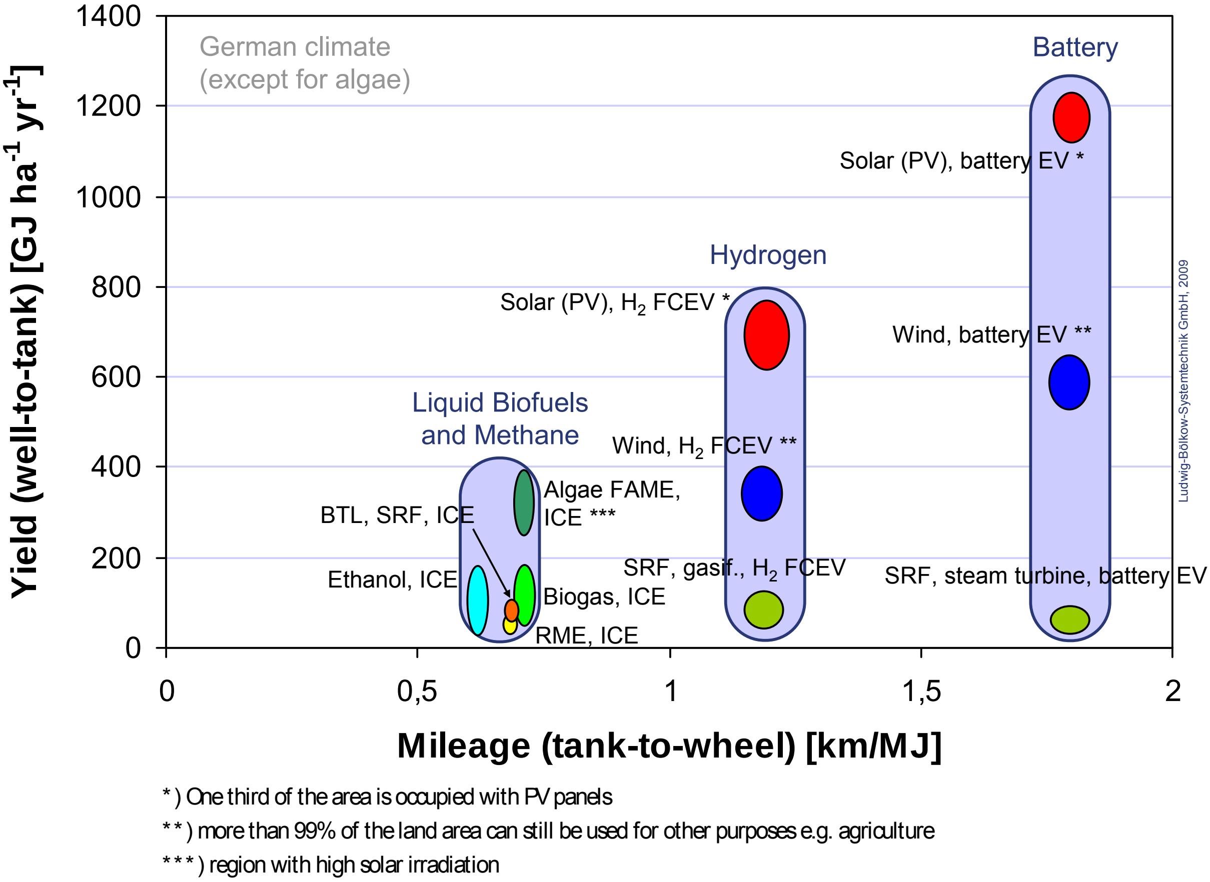

Figure 5: **Mapping of key performance criteria "mileage" versus "yield" for different fuels and drive-train options under German conditions (except for algae).**

7 Water Intensity

Analyses based on average or typical values of water requirements show that biofuels production in general consumes several orders of magnitude more water than electrolytic hydrogen production, or electricity generation from solar thermal power plants (see Figure 6). This is aggravated if inefficient irrigation systems are used for cultivation (flood, spray, furrow, and drip irrigation in increasing order of efficiency). The agricultural sector is responsible for some 60% of world water consumption. Sea water desalination for electrolytic hydrogen production only requires 0.13%-0.16% of the power consumption of the electrolysis process itself [4], [5]. "Grey waters", i.e. water consumed in manufacturing the production machinery and infrastructure have not been taken into account. It is assumed that they are negligible, similar to "grey energies".

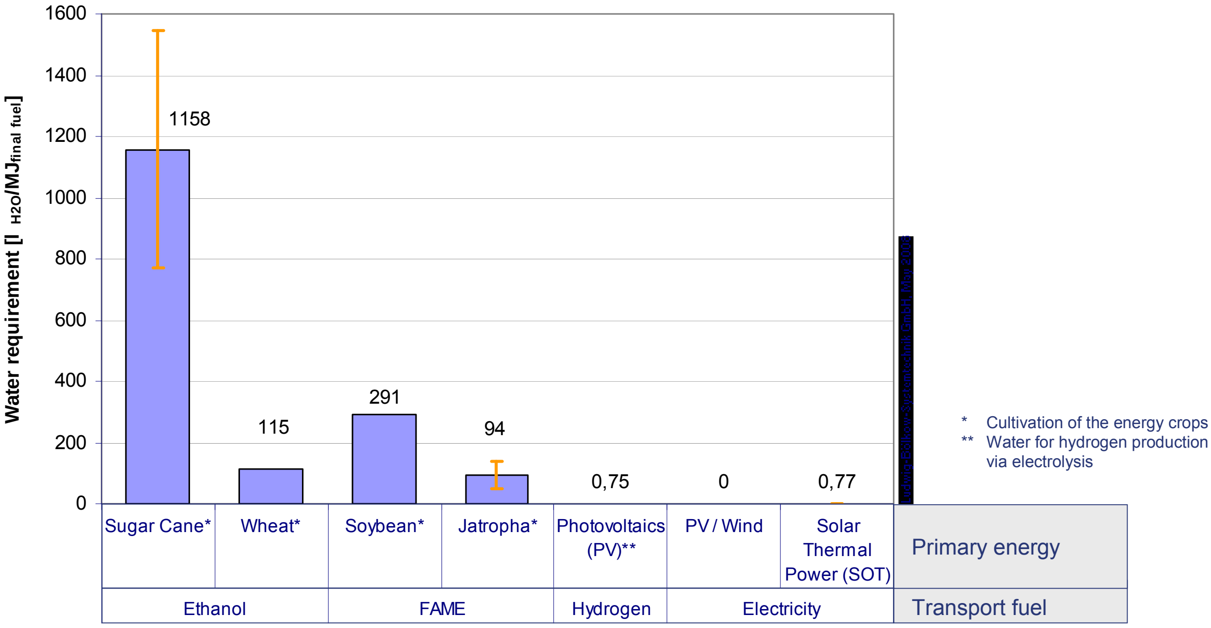

Figure 6: Water requirement for the cultivation of various crops used for biofuels, for electrolytic hydrogen production, and for renewable electricity generation.

8 Conclusions

It is shown that biofuels are most complex, most critical, and provide the lowest potential, but can be used as a ‘drop-in’ substitute not requiring new infrastructures or vehicle propulsion systems. Battery electric cars are most efficient, can rely on abundant renewable electricity potentials, but have a limited operating range (battery swapping to be validated) and require new recharging infrastructure build-up. Hydrogen and fuel cells provide it all – great primary energy potential, high environmental performance based on renewable energies, and a sufficient operating range – but require pro-active infrastructure build-up. Therefore, all solutions are needed at different scales and for different applications while avoiding exaggerated expectations.

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