Prospects for alternative transport fuels in EU-countries up to 2050 from an energetic and economic point-of-view

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Abstract
In recent years alternative fuels and corresponding alternative automotive technologies have been seen as major potential contributors to head towards a sustainable transport system. The core objective of this paper is to investigate the perspectives of different alternative fuels and automotive technologies in a dynamic framework till 2050 in comparison to fossil fuel driven conventional cars from a technical, ecological and economic point-of-view. The technologies considered in this paper are: conventional and hybrid internal combustion engines, compressed natural gas-, flex-fuel-, battery electric- and fuel cell-vehicles.

The most important results and conclusions of this analysis are: (i) there is no single "one size fits all" energy carrier which can be considered to serve all problems alone. All analysed alternative fuels still face major problems in different parts of the over-all energy service providing chain; (ii) The energetic improvements up to 2050 will lead to substantial reduction of energetic losses mainly in the Tank-to-Wheel part of the energy service provision chain; (iii) By 2050 the total driving costs of all analyzed fuels and powertrains could almost even out; (vi) The major uncertainty regarding battery electric- and fuel cell vehicles is how fast technological learning will take place especially for the battery and the fuel cells.

Introduction
In the transport sector Alternative Fuels (AF) based on various categories of renewable energy sources (RES) and corresponding alternative automotive technologies are considered as major environmentally benign alternatives to fossil fuels. However, there are still major barriers for a broad market breakthrough of these new technologies.

In addition, to improve the energy efficiency of passenger cars continuously is one of most important instruments for combating increasing GHG emissions and climate change. Beside the technical improvements of conventional internal combustion engine (ICE), it is also important to improve the efficiency of alternative automotive technologies (AAMT) such as battery electric vehicles (BEV), fuel cell vehicles (FCV), flex-fuel vehicles (FFV) and hybrid cars (HEV). These AAMT allow us also to use new, alternative and more environmental friendly fuels such as biofuels, electricity and hydrogen. Yet, the limited operating range, technical immaturity and particularly high costs are still the most important barriers for a broad market breakthrough of AAMT vehicles.

The core objective of this paper is to provide an appraisal of the prospects of these new alternative fuels and technologies from energetic and economic points-of-view for the average conditions in Europe in a dynamic framework till 2050 in comparison to fossil fuels. Another objective is to investigate the future market prospects of alternative powertrains like BEV, HEV and FCV in a dynamic framework till 2050 in comparison to conventional passenger cars for average conditions of EU-15 countries. This work builds on the work done in the scope of the EU project ALTER-MOTIVE, Ajanovic et al (2012) and Ajanovic/Haas (2012). We also consider different primary energy sources (fossil and hydropower/wind) used for electricity and hydrogen (H_2)

production. This is relevant to identify the energetic and economic performance of mobility with different vehicles and fuels.

Finally, we analyze how improvements of the energetic performance might impact market prospects from an economic point-of-view. As AF we consider: (i) electricity and hydrogen from different RES; (ii) biomethane from biogas and (iii) various categories of 1st (BF-1) and 2nd generation biofuels (BF-2), like biodiesel, bioethanol and Synthetic natural gas. Note, that while the analysis is based on regional parameters, e.g. feedstocks, most of our results are also applicable to other countries.

With respect to the time frame analyzed the following remark is important: It is evident that up to 2050 fundamental changes in the structure of passenger transport may take place with severe impact on shares of different technologies, modal splits as well as organization of living, labour and leisure time. However, these changes are neither subject of this paper nor do they impact our results. The only dimensions where we have to rely on an external scenario are learning rates for BEV and FCV used for the economic analysis.

Dynamic energetic Well-to-Tank assessment

The first issue of interest from an energetic viewpoint is how the well-to-tank performance of fuel production looks. This performance is described for the current situation (2010) in Figure 1 and for the likely development up to 2050 in Figure 2. The starting points for the energetic WTT assessment of the considered conventional fossil fuels, biofuels, hydrogen and electricity is depicted in Figure 1. This figure depicts the WTT-conversion factor f_{conv} for an energetic WTT assessment of conventional fuels and electricity for 2010

For the energetic assessment it is of specific interest to split up the overall energetic performances into renewable (RE) and fossil (FF) energy parts based on a life-cycle assessment approach. As "renewable energy" we consider biofuels, electricity and hydrogen from renewable energy sources. Figure 1 shows the renewable and fossil energy shares in the whole WTW energy service provision chain in 2010 for analysed alternative automotive technologies and alternative fuels in comparison with conventional ICE vehicles powered by fossil fuels. It can be seen that a major problem of BF-1 is the relatively high share of fossil energy – higher than those of BF-2 – while for BF-2 the low conversion efficiency and the corresponding high input of renewable feedstocks is the major problem. The WTT-conversion factor f_{conv} for 2050 is depicted in Figure 2. We can also see that up to 2050 it is expected that the mentioned problems of biofuels will be relieved but only slightly.

The best WTT performance, currently, show BEV powered by electricity from hydropower/wind. In this case reduction of fossil energy used in WTT as well as TTW part is especially high. The share of renewable energy is very high in a chain with FFV powered by bioethanol. With FFV use of fossil energy is significantly reduced in comparison to conventional ICE vehicle. We can see that for biofuels used in FFV large part of the total energy balance is attributed to WTT conversion losses. With the switch from first generation biofuels to more efficient second generation biofuels this figure could improve in the future, see Figure 2. In case of electricity from fossil energy sources used in BEV total fossil energy inputs could be even higher than with conventional gasoline or diesel ICE vehicles.

Finally, we look at the whole WTW energy service provision chain for alternative fuels in comparison with conventional vehicles powered by fossil fuels. To obtain a full WTW-assessment of the energetic performance also the TTW conversion is to consider. In Figure 3 the historical developments of passenger cars' fuel intensities from 2000 to 2010 as well as the

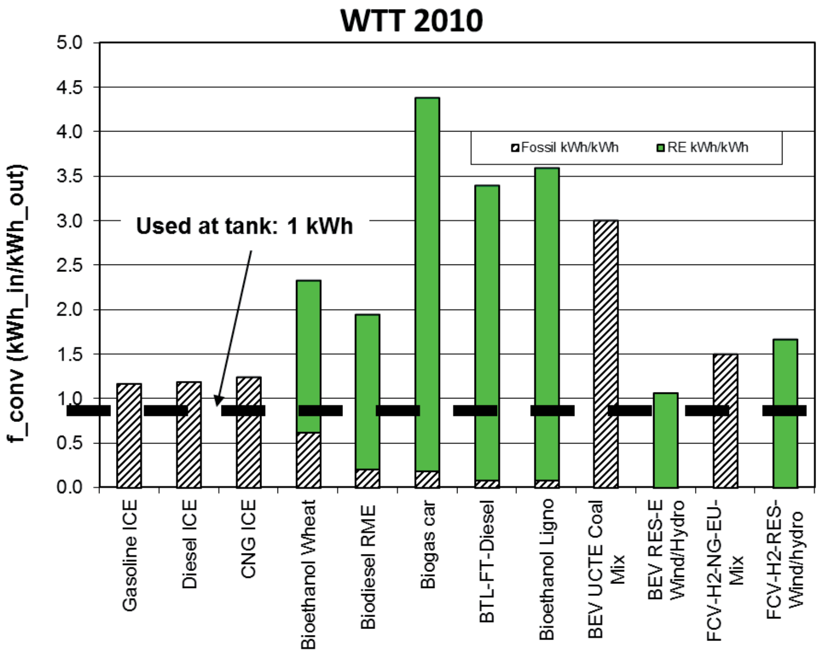

Figure 1. The feedstock/fuel conversion factor f_{conv} for an energetic WTT assessment of conventional and alternative fuels for 2010 (Source: Joanneum Research calculations, documented in Ajanovic et al 2012).

assumptions for development in the scenarios up to 2050 (for average car size of 80 kW) is described. Note, that the steepest decrease in fuel intensities took already place before 2011 as a first result of the EC to improve the efficiency of cars.

The future developments up to 2050 are based on potential technological improvements documented in the literature see Kobayashi (2009), EC (2010), CONCAWE 2008, EUROSTAT (2011)). It is assumed that these developments follow paths in a way that progress (% improvement of efficiency per year) is decreasing up to 2050 and by 2050 the full over-all efficiency improvement is reached.

The renewable and fossil energy shares in the whole WTW energy service provision chain in 2010 respectively 2050 for conventional and alternative vehicles are shown in Figure 4

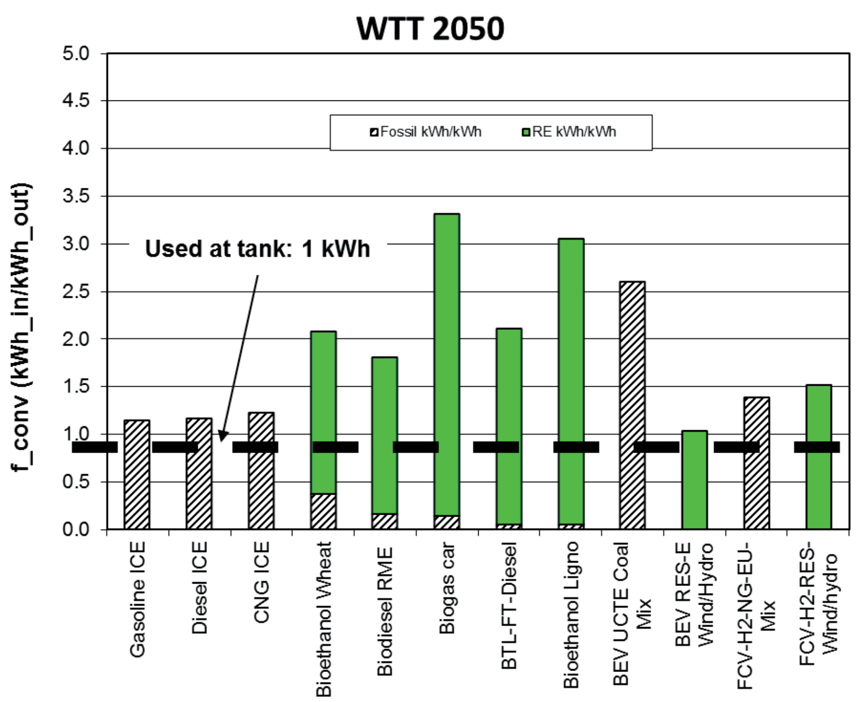

Figure 2. The feedstock/fuel conversion factor f_{conv} for an energetic WTT assessment of conventional and alternative fuels for 2050 (Source: Joanneum Research calculations, documented in Ajanovic et al 2012).

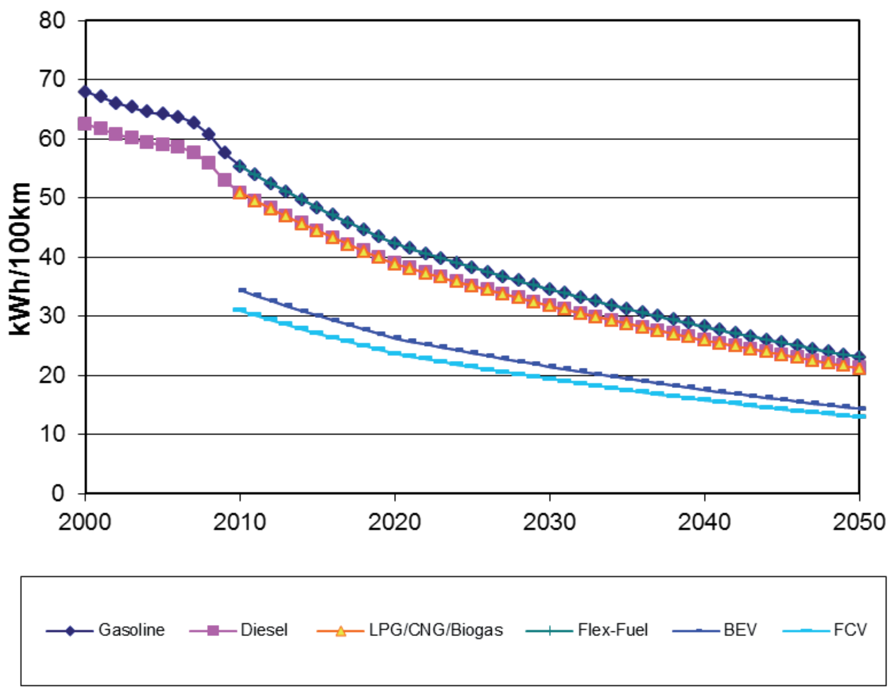

Figure 3. Historical developments of passenger cars' fuel intensities and assumptions for development in the BAU scenarios up to 2050 (for average car size of 80 kW) (Sources: Kobayashi (2009), EC (2010), CONCAWE 2008, EUROSTAT (2011)).

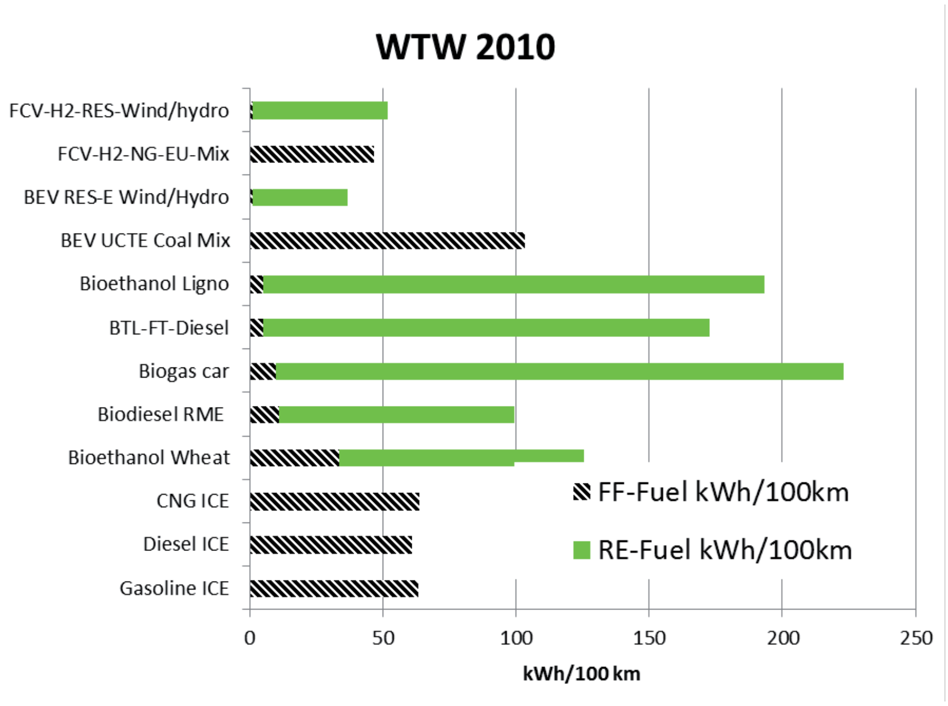

Figure 4. Renewable and fossil energy shares in the whole WTW energy service provision chain in 2010 for AAMT and AF in comparison to conventional vehicles powered by fossil fuels.

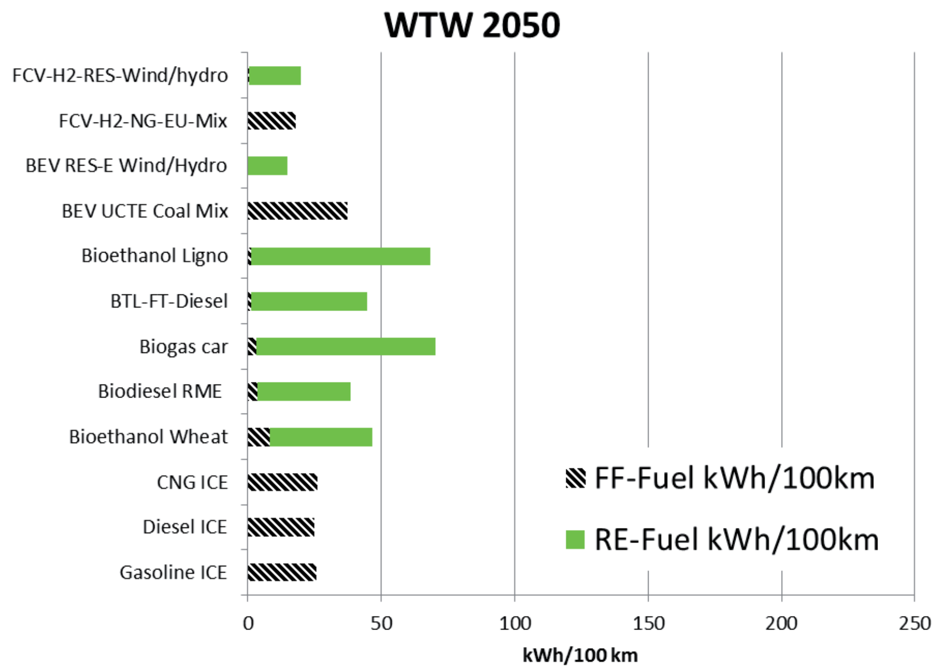

Figure 5. Renewable and fossil energy shares in the whole WTW energy service provision chain in 2050 for AAMT and AF in comparison to conventional ICE vehicles powered by fossil fuels.

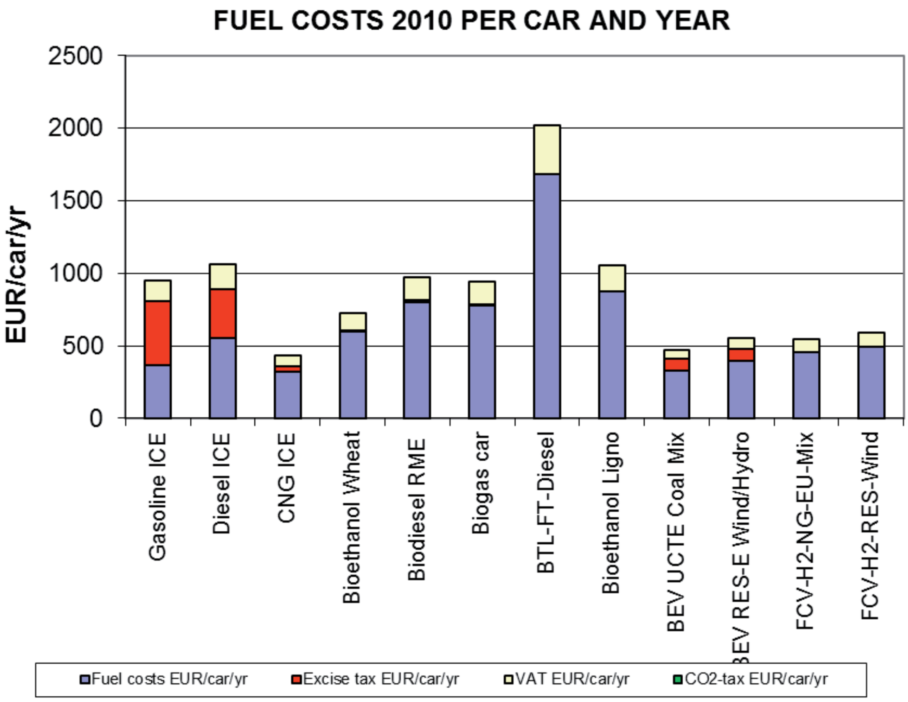

Figure 6. Fuel costs of passenger cars per year in 2010.

and Figure 5. Compared to 2010 due to especially the better fuel intensity, the energy balance is improved for virtually all technologies. The improvements in the WTT-part are most remarkable for chains with biofuels, see Figure 1 and Figure 2.

Economic Assessment

We have documented above that most of the AF have already today a better efficiency and lower CO_2 emissions than fossil fuels. However, the core problem for their wider use of are still high costs. The largest part of the total transport costs are capital costs for vehicles. As Figure 7 depicts the investment costs of BEV and FCV are especially high. Compared to capital costs the impact of fuel costs is low especially with BEV and FCV. Currently, for total transport costs it is not really relevant if hydrogen is produced from RES or from fossil energy.

Of special interest in our analysis is finally how improvements in energetic performance influence economic competitiveness. Figure 6 depicts the fuel costs of the service mobility in 2010. Most expensive are cars driving on BTL, biogas, bioethanol from lignocellulosis because of their high production costs. Next is already a gasoline-powered car mainly due to high excise tax and high fuel intensity. Cheapest fuel cost for driving show cars using CNG.

Next it is analyzed how the fuel costs could change until 2050. The major focus of our analysis is a “Policy Lead Scenario” (PLS). In this scenario CO_2-taxes are replacing excise taxes starting in 2013 and increasing up to 2050 by 1.5 cent/kgCO_2 Further details see next chapter. In this scenario the yearly fuel costs for driving are cheapest for electricity and hydrogen from RES and are remarkably lower than fossil fuels and biofuels, see Figure 7.

Yet, finally the only thing that counts are the total costs C_{Tot}. These are calculated for every year t as follows:

$$C_{Tot\,t} = C_{F_t} + C_{O\&M_t} + IC_t\,CRF$$

with

C_F = fuel costs

$C_{O\&M}$ = operation and maintenance costs

IC = investment costs

CRF = capital recovery factor

In this equation the investment costs are based on effects of Technological Learning (TL), see e.g. Ajanovic 2013. So if we look at the total costs – including the capital costs – the advantages of BEV and FCV regarding lower fuel costs are more than compensated by higher capital costs in 2010, see Figure 8, and also in 2050, see Figure 9. Currently, cheapest total costs for driving show cars using CNG. However, due to their limited acceptance in EU-countries the number of CNG cars is still very low. Moreover, by 2050 costs of most cars will even out, see Figure 9.

Scenarios for potentials of alternative fuels

As is shown in Figure 9, up to 2050 AF can become increasingly competitive. In this context the next major aspect is to identify which AF can achieve a critical mass and relevant potential. In order to provide a sound assessment of the future prospects of AF we derived scenarios up to 2050 to show under which circumstances, to which extent and when specific AF could become economically competitive. The analyses in the scenarios are based on economic competitiveness and Technological Learning (TL) and the available potentials for primary feedstock resources (available areas and waste potentials, e.g from wood industry residues, organic waste, forest wood residues, straw …). This approach is described in detail in Ajanovic et al 2012. Moreover, the analysis is based on the TL effects described above. The results of investment cost reductions due to the TL effects are shown in Figure 9.

Our major scenario is a “Policy Lead Scenario” (PLS) which corresponds to the assumptions of international deployments of biofuels and hydrogen according to IEA [4, 6, 7]. In this scenario priority is given to the production of liquid biofuels over electricity. From these analyses it is derived which market diffusion of the AF is to be expected in a dynamic context and which AF have a special relevance in EU-15 in the long-term.

In the following we present the results of the corresponding quantities of AF that can be possibly produced in EU-15 till 2050. A major focus is put on AF based on “new” biomass resources. Figure 10 depicts the energy production in the PLS scenario in EU-15 countries. The major characteristics of this scenario are additional use of arable land for AF (with max. 30 % arable land in 2010), CO_2 based tax starting from 2013 and priority for biofuels production.

As can be seen in this scenario by 2050 finally about 6,000 PJ of AF will be produced. This is about six times more than in 2010. By about 2020, due to technology maturity, a remarkable increase of the 2nd generation bioethanol can be noticed. The share of 2nd generation biodiesel is increasing starting from 2030. Yet, these developments take place only if it can be managed that these technologies – BTL, FT-Diesel – become mature and if significant learning effects are achieved. Due to the finally better energetic and economic performance of BD-2 it also substitutes BE-2 production ter 2040. However, it must be noticed that energetic as well as economic developments of the different categories of BF-2 are of course not known in detail today. Due to these uncertainties other fractions of BF-2 could also “win”. What can be stated today is that – given that the economic performance of any BF-2 leads to cost-effectiveness under the suggested CO_2-tax policy – there is a significant potential for BF-2 up to 2050 regardless which one will succeed.

Due to the priority for biofuels in this scenario electricity will be produced only from those feedstocks which are not usable for biofuels production such as waste wood. However, an increasing use of biomass in the future could raise two issues: (i) the use of biomass requires large amounts of land which otherwise could be used for other purposes (e.g. food production); (ii) increasing biomass production might be in contradiction with sustainability issues.

The major reasons why in Figure 10 BD-2 and SNG reach so high amounts are: (i) they have highest energy efficiency and hence lowest feedstock costs and (ii) they have lowest CO_2-emissions and hence lowest CO_2-taxes.

In Figure 10 the energy output of AF which can be used in transport sector is shown. In addition Figure 11 depicts total energy output of AF from biomass in EU-15 including also wood products such as pellets, fuel wood and wood chips.

The over-all potential of all AF based on all available RES (incl. fuel wood and electricity from large hydro plants, wind and PV) till 2050 is shown in Figure 12. It can clearly be seen that hydro power, wind and photovoltaics can deliver significantly higher contribution than biomass-based energy carriers.

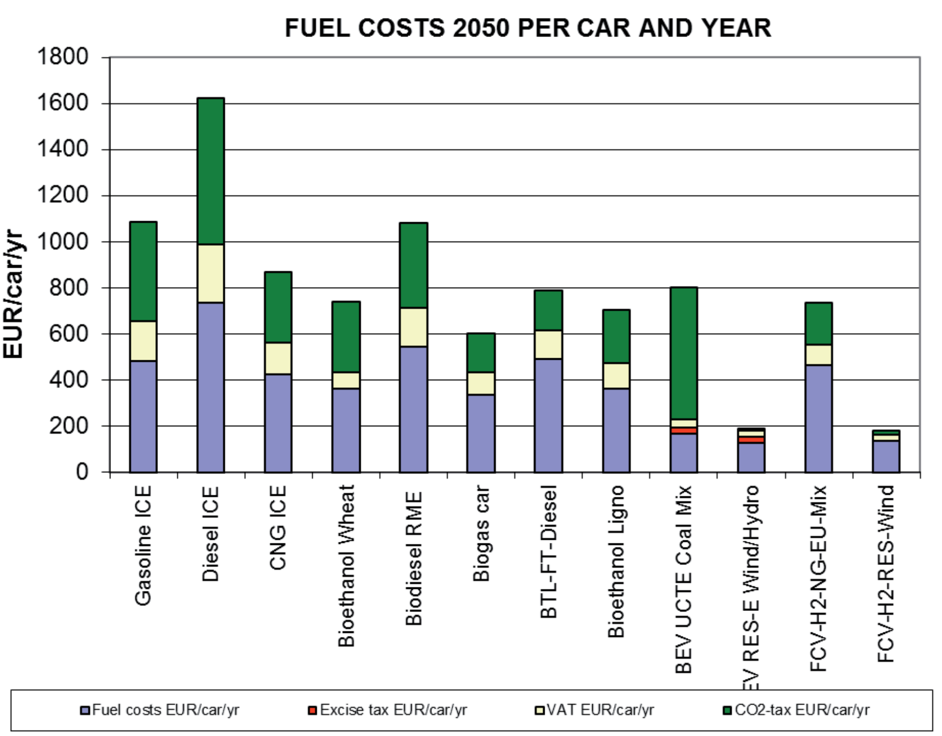

Figure 7. Fuel costs of passenger cars per year in 2050 in a “Policy Lead Scenario” (PLS).

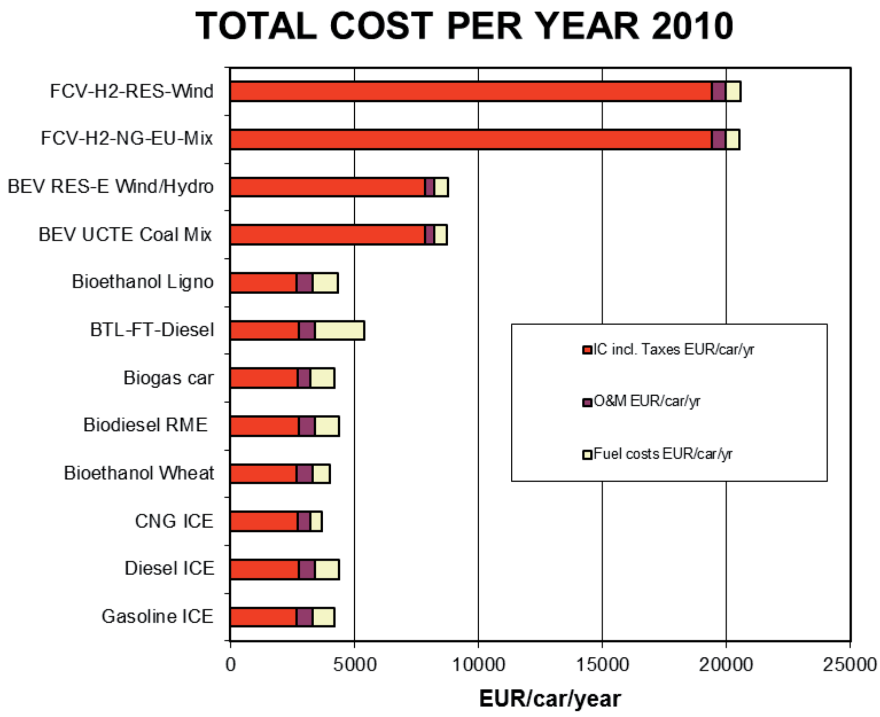

Figure 8. Total costs of service mobility in passenger cars in 2010.

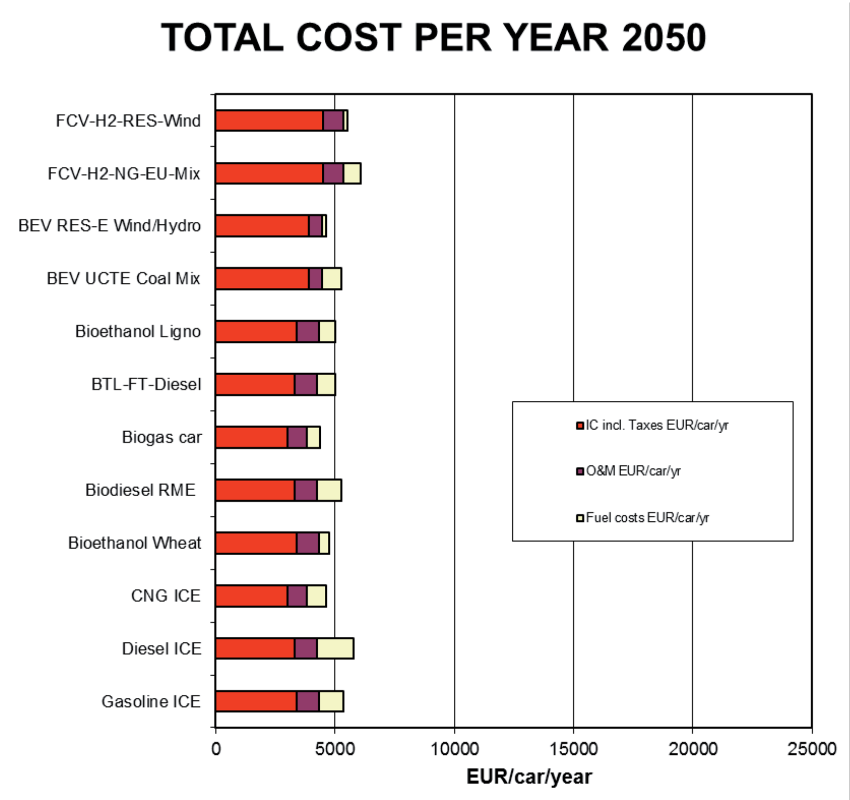

Figure 9. Total costs of service mobility in passenger cars in 2050.

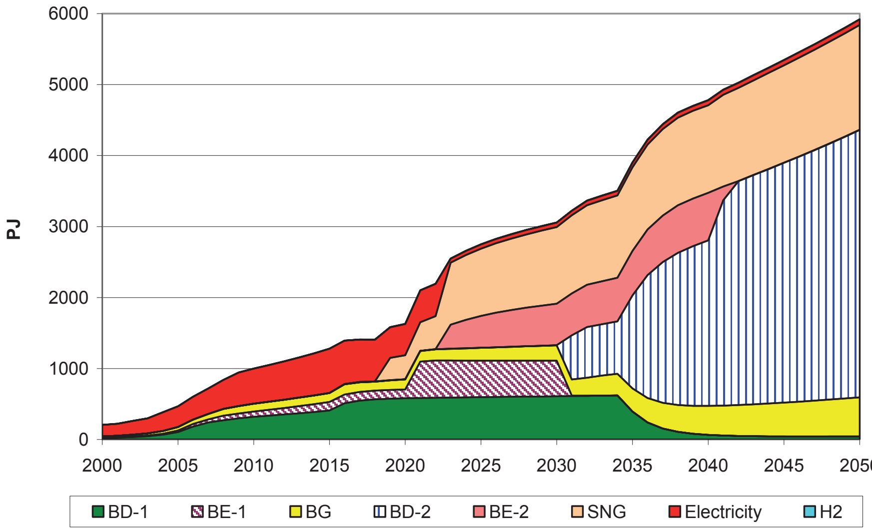

Figure 10. Energy production (final energy) in the Policy Lead Scenario (with max. 30 % arable land in 2010, with CO_2 tax, and with priority for biofuels).

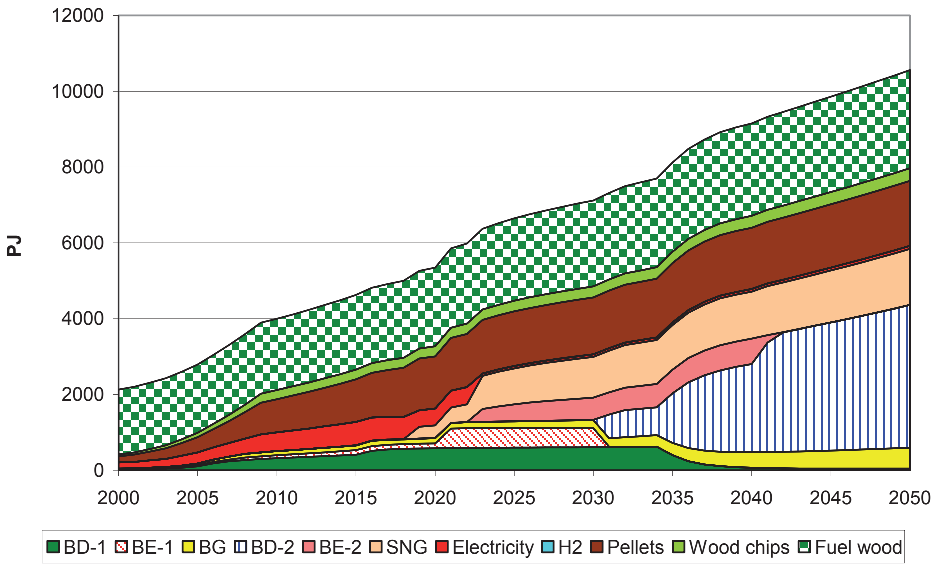

Figure 11. Total energy from AF from biomass only in PLS.

Conclusions

The major conclusions of this analysis are:

- Up to 2050 considerable changes for conventional as well as for AF will take place. Unlike nowadays, by 2050 there will be no big difference in total costs of the different technologies, see Figure 8 and Figure 9. It seems likely that a much broader portfolio of car technologies and fuels will be available at similar total costs in the future;
- Significant technical efficiency improvements are possible and looming but their implementation has to be procured by R&D from car companies as well as governments. These improvements in conversion efficiency can reduce specific fuel consumption – for same size cars – by about 33 % up to 2030 and about 50 % by 2050;
- The introduction of CO_2-based fuel taxes is an important policy measure to foster energy efficiency improvements (for curtailing the rebound) and a signal to consumers to switch to more environmentally friendly fuels and technologies;
- Finally, the highest uncertainty lies in the speed of the market introduction of BEV and FCV. It depends mainly on the technological learning effects that can be achieved with respect to batteries and fuel cells.

With respect to AF it is important to state that there is no single "one size fits all" energy carrier which can be considered to serve all problems alone. All analysed AF and car technologies still face major problems in different parts of the over-all energy service providing chain. It is especially important to point out the following core current weaknesses:

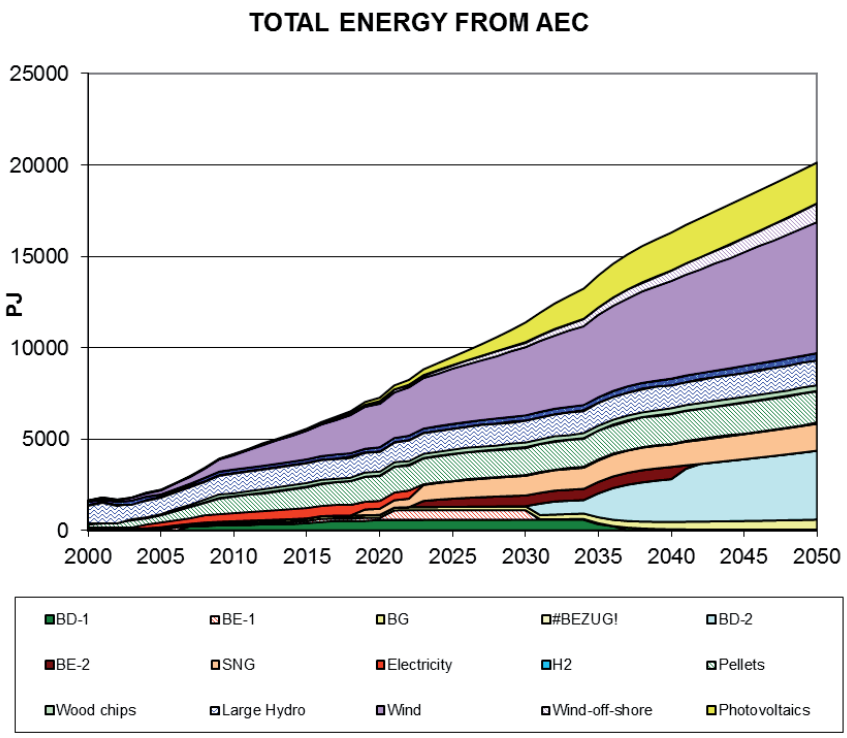

Figure 12. Total energy from all AF in EU-15 countries in a Policy Lead Scenario.

Table 1. Survey on major problems related to the broader use of AF as of 2012.

	Production	Storage	Conversion into services	CO_2 emissions
BD-1 and BE-1	Minor problems of production but social problems of use of agricultural areas (food vs fuel discussion)	No problem	No problem	Problem of still large shares of fossil inputs
Biomethane	Problem of high investment costs & low scaling and learning effects	No problem	No problem	No problem
BD-2, BE-2	Problem of high investment costs. Problem, that the technology is so far not mature.	No problem	No problem	No problem
Electricity	No problem	Storage is still a costly problem	No problem	Depends on source of production (no problem with RES)
H_2	No problem	No problem	A proper reliable and of affordable conversion technology (fuel cells) is not yet available	Depends on source of production (no problem with RES)

- With respect to electricity from volatile RES like PV and wind the prevailing problem is still lack of proper storages;
- Regarding BF-1 the major problems are still high CO_2 emissions due to rather large amounts of fossil fuels use. Another problem is the food vs fuel discussion. For BF-2 immature production processes and corresponding high production costs are the major impediment;
- The major barrier for hydrogen is lack of mature technology for conversion into services (mobility, electricity) – mature fuel cells that work at reasonable prices are not yet available. Moreover, over-all conversion efficiency in the fuel providing chain is still moderate;
- Biomethane (from Biogas) faces the problem of high investment costs and low scaling and low learning effects. Moreover, in many cases the proper use of heat is a problem.

Table 1 summarizes these major performance parameters of AF. The final major conclusion is that only if the portfolio of actions described above – CO_2 tax, ecological monitoring system, and a focussed R&D programme for BF-2 and fuel cells – is implemented in a tuned mix it will be possible to exploit the potential of AF up to 2050 in Europe in an optimal way for society.

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