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Presenter Index

Bridging The Electrification Gap In The Sub Saharan Africa
Advancements in RE Technology: Technology (Ignite) - 5/17/2012 2:30pm - 4:00pm
View Full Paper
View Presentation

.H.L, Deepthi
SJCE, India
INDIA'S BIOMASS POWER SECTOR
Energy Generation, Distribution, & Transportation: Technologies Working Together (Ignite) - 5/17/2012 1:15pm - 2:30pm

A. R., Patel
Indian Institute of Technology Ropar, India
EXERGO-ECONOMIC ANALYSIS OF PERFORMANCE OF A HOT AIR GENERATION SYSTEM USING PRODUCER GAS AS FUEL INSTEAD OF LIGHT DIESEL OIL TO DETERMINE THERMO-ECONOMIC DE-RATING FACTOR (Part II)
WREN: WREN-V (Technical) - 5/17/2012 10:30am - 11:45am
View Full Paper

A.Putrus, Ghanim
Northumbria University, UK
Multi-Objective Optimisation of Hybrid Wind Turbine - PV Systems
Advancements in RE Technology: PV & Wind Applications (Ignite) - 5/14/2012 2:45pm - 4:00pm
View Full Paper
View Presentation

Ahmadu, M. Lawal
Usmanu Dan Fodiyo University, Nigeria
Renewable Energy: Challenges and Prospects of Adopting a New Policy and Legal Paradigm in Nigeria
WREN: WREN-II (Technical) - 5/14/2012 1:15pm-2:30pm
View Full Paper
View Presentation

Aiello, Daniel
Arizona Solar Center, Inc., USA
FORUM - IN HOT WATER - Experiences and Issues - Residential Solar Hot Water and its Implementation -
Advancements in RE Technology: In Hot Water: Solar Hot Water Issues in Utility Programs (Forum) - 5/15/2012 4:15pm - 5:30pm
View Presentation

Ajanovic, Amela
Vienna University of Technology, Austria
Renewable fuels -A comparative assessment from economic, energetic and ecological point-of-view up to 2050 in EU-Countries
Advancements in RE Technology: Biomass and Liquid Fuels 2 (Technical) - 5/14/2012 1:15pm-2:30pm
View Full Paper
View Presentation

RENEWABLE FUELS – A COMPARATIVE ASSESSMENT FROM ECONOMIC, ENERGETIC AND ECOLOGICAL POINT-OF-VIEW UP TO 2050 IN EU-COUNTRIES

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ABSTRACT

Fuels based on renewable energy sources (RES) are considered as an important mean to cope with environmental problems in transport. The core objective of this paper is to investigate the perspectives of "renewable fuels" from economic, energetic and ecological points-of-view in a dynamic framework till 2050. Renewable fuels are various 1st and 2nd generation biofuels as well as electricity and hydrogen from RES. The major results are: All analyzed fuels have lower CO_2-emissions than gasoline. An additional problem for mobility with hydrogen and electricity are very high costs of the corresponding vehicles. By 2050 these costs could be reduced due to technological learning effects and efficient policy measures (e.g. CO_2-based tax). This leads to the final conclusion that "renewable fuels" will play a significant role only if the proper mix of CO_2-taxes, intensified R&D and corresponding riding down the Learning Curve is implemented timely.

1. INTRODUCTION

In the last years the major challenges for EU climate and energy policy are to implement effective policies and measures to mitigate global warming, improve air quality and reduce energy consumption. Since about one quarter of EU greenhouse gas emissions is coming from transport sector a large part of EU-targets are directed to this sector. Fuels based on renewable energy sources (RES) are considered as an important means to contribute to these targets in the transport sector. According to EU "20-20-20 targets" by 2020 at least 10% renewable fuels should be used for transport (1,2).
The most important renewable fuels used nowadays in the EU are 1st generation biofuels – biodiesel and bioethanol. However, due to relatively bad ecological performance and the problem of competition with food production, 1st generation biofuels are often criticized. Currently, there are higher expectations from 2nd generation biofuels, which can be produced using different kind of lignocellulosic materials, as well as from electricity and hydrogen produced from RES.

The core objective of this paper is to investigate the perspectives of "renewable fuels" from economic, energetic and ecological points-of-view in a dynamic framework till 2050 in EU-countries.

2. METHOD OF APPROACH

In this work we investigate the following categories of "renewable" fuels: biofuels, electricity from RES and hydrogen from RES.
Biofuels:
We analyse the following three types of biofuels for 2010:
- biodiesel 1st generation from rapsmethylester (RME);
- bioethanol 1st generation from wheat or corn;
- biogas from organic waste, maize silage or grass.

For 2050 we consider the following three types of 2nd generation biofuels:
- biodiesel 2nd generation, Fischer-Tropsch (FT) diesel;
- bioethanol 2nd generation from different types of lignocellulosic resources;
- Synthetic natural gas (SNG).

Electricity:
Regarding electricity from RES we analyze for 2010 and 2050:
- electricity from wind or hydro: these two sources are treated together because they have virtually the same ecological and economic performance;
- electricity from photovoltaic (PV);
- electricity from biomass in combustion plants.

Hydrogen:
Regarding hydrogen from RES we analyze for 2010 and

2050:
- hydrogen from wind or hydro power by electrolysis: again these two sources are treated together because they have virtually the same ecological and economic performance;
- hydrogen from PV by electrolysis;
- hydrogen from biomass by means of steam reforming.

We use gasoline as a reference fossil fuel for comparison.

The comparison is conducted from economic, energetic and ecological points-of-view for all fuels as well as for total derived energy service (ES) – mobility - provided with these fuels, see Fig. 1.

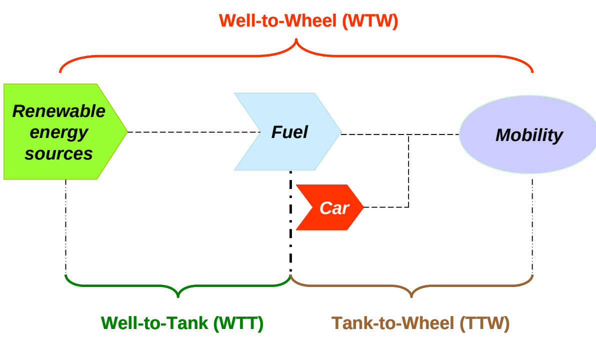

Fig. 1: The energy chain for providing the service mobility based on (3).

The environmental assessment is based on the method of Life Cycle Assessment (LCA). Since the future use of renewable fuels depends on characteristics of the provided energy service, beside WTT-analysis of fuels WTW-analysis of the whole energy chain is also provided. Economic assessment is conducted based on technological learning up to 2050.
This work extends the analysis conducted in Ajanovic et al (3, 4, 5 and 6). With respect to the literature the most important analyses are summarized by Ohlrogge et al (7) and Campbell et al (8).

3. ENVIRONMENTAL ASSESSMENT

In this chapter are presented greenhouse gas (GHG) emissions and cumulated primary energy demand of analyzed renewable fuels.

3.1 Greenhouse gas emissions

Fig. 2 shows the GHG emissions in the life cycle related to the use of different renewable fuels compared to fossil reference system. Conventional mobility chain with gasoline used in an internal combustion engine (ICE) vehicle is chosen as a reference system.

As it can be seen from Fig. 2 all renewable fuels reduce WTW-GHG emissions compared to fossil reference system. However, the results are very different depending on fuel as well as on primary energy sources used for fuels production. The analyzed renewable fuels are divided in three groups – biofuels, electricity and hydrogen.
Biomass-based fuels have mostly negative WTT-GHG emissions, while CO_2-fixation during photosynthesis is accounted as negative CO_2-emissions. Negative WTT-GHG emissions are also related to non-energy co-products of the renewable fuels-system which substitute conventional products and thus avoid related GHG emissions. Another contribution to WTT-GHG emissions are processes providing auxiliary energy and materials in the biofuels production facilities. Relatively high WTT-GHG emissions for bioethanol production from wheat are mainly due to the electricity and process heat required in the ethanol plant and its distillation unit (4).

TTW-GHG emissions include the emissions for production, operation and disposal of the passenger cars.

WTT-GHG emissions of electricity from hydro- and wind-power are very similar. Electricity from PV has higher WTT-GHG emissions due to energy intensive production process of the PV-modules as well as to relatively low number of sunshine hours in Europe. WTT-GHG emissions for electricity from biomass are negative as it is assumed that the co-product is used for heat production in conventional biomass heating plant, avoiding related life cycle GHG emissions. TTW-GHG emissions include the emissions for production, operation and disposal of the battery electric vehicle and are the same for all analyzed chains with electricity.

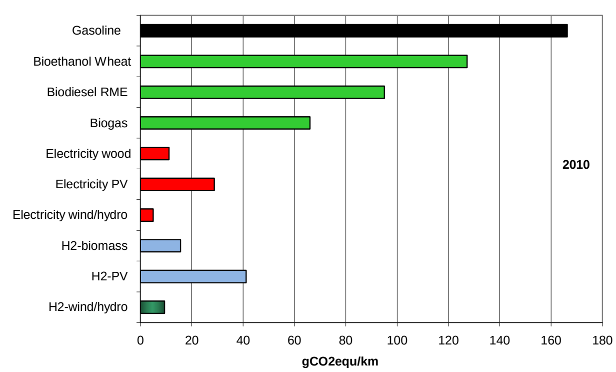

Fig. 2: Comparison of specific WTW CO_2-emissions in 2010.

WTW-GHG emissions of the hydrogen from renewable energy sources are also shown in Fig.2. In this case WTT-GHG emissions include the hydrogen production processes as electrolysis or biomass gasification with hydrogen separation and hydrogen compressing for vehicle fuelling. TTW-GHG

emissions include the emissions for production, operation and disposal of the fuel cell vehicle and are the same for all analyzed hydrogen chains.
As it can be seen in Fig. 2 hydrogen produced by electrolysis with electricity from hydro- or wind-power has the lowest WTW-GHG emissions.

By 2050 WTW-GHG emissions of all analyzed fuels should be lower than in 2010. Biomass and biofuels production processes as well as the passenger cars are assumed to be more efficient in the future. Electricity and process heat as input to biofuels production processes will have a higher share of renewable energy in 2050.
By 2050 2^{nd} generation biofuels should become more competitive on the market and due to better WTW-GHG balances they will almost completely replace 1^{st} generation biofuels, especially bioethanol.
Wood-based FT-Diesel and SNG have the lowest WTW-GHG emissions compared to the other biofuels. These biofuels require relatively low energy and material input for collection of the wood as well as for biofuels production plants and its gasification units (4).

In Fig. 3 are shown WTW- CO_2 emissions of renewable fuels in 2050.

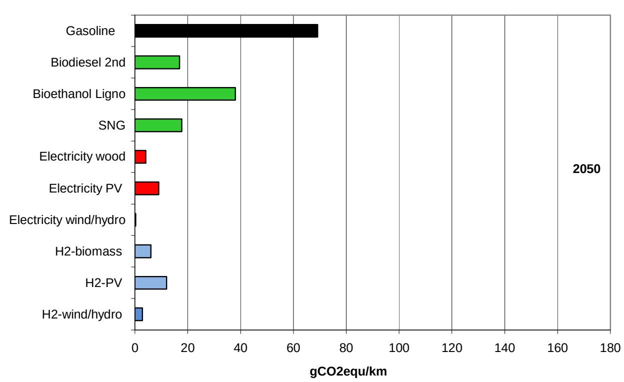

Fig. 3: Comparison of specific WTW CO_2-emissions in 2050.

3.2 Cumulated primary energy demand

The overall energy used per km driven depends on conversion efficiency in the WTT- and the TTW-part of the energy chain.
Fig. 4 shows the cumulated primary energy demand in the life cycle related to the use of different renewable fuels compared to fossil reference systems. All renewable fuels reduce the cumulated fossil primary energy demand, but in most cases total energy demand is higher compared to the fossil reference systems.
However, the results are different depending on kind of renewable fuel as well as on primary energy sources which are used for fuel production.
Among the analyzed fuels those based on biomass have the highest cumulated primary energy demand.
In 2010 bioethanol from wheat has a relatively high WTW fossil cumulated primary energy demand. As already shown for WTW-GHG emissions its production requires a high share of electricity and heat.

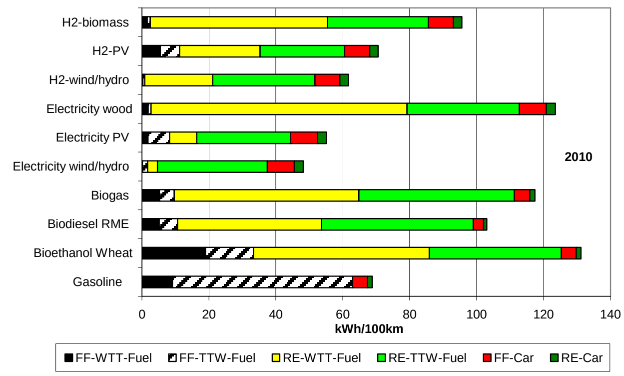

Fig. 4: Renewable (RE) and fossil (FF) energy shares in the whole WTW energy service provision chain in 2010 for gasoline versus renewable fuels.

Fig. 5 depicts the renewable and fossil energy shares in the whole WTW energy service provision chain for conventional fossil fuel (gasoline) versus renewable fuels for 2050. Compared to 2010 the energy balance is improved for all fuels due to better fuel intensity. The improvements in the WTT-part could be significantly increased due to the switch to biofuels 2^{nd} generation.

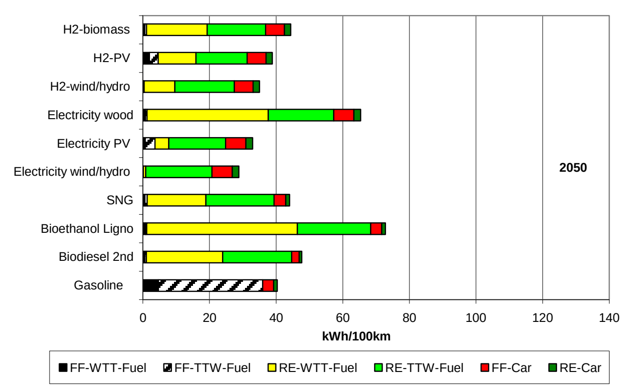

Fig. 5: Renewable (RE) and fossil (FE) energy shares in the whole WTW energy service provision chain in 2050 for gasoline versus renewable fuels.

WTW-cumulated primary energy demand for 2050 is lower than for 2010 for all analyzed fuels; compare Fig. 4 and Fig. 5.

4. ECONOMIC ASSESSMENT

For all analyzed renewable fuels a dynamic economic assessment is conducted based on technological learning up to 2050. The detailed method of approach is documented in Ajanovic et al (4).

Finally, it is of special interest how improvements in energetic performance influence economic competitiveness of these fuels. Fig. 6 depicts the fuel costs of the service mobility in 2010 including taxes (excise tax and value add tax). However, as it can be seen in Fig. 6, biofuels and hydrogen are currently excepted from excise tax, and tax on electricity is much lower comparing to gasoline.

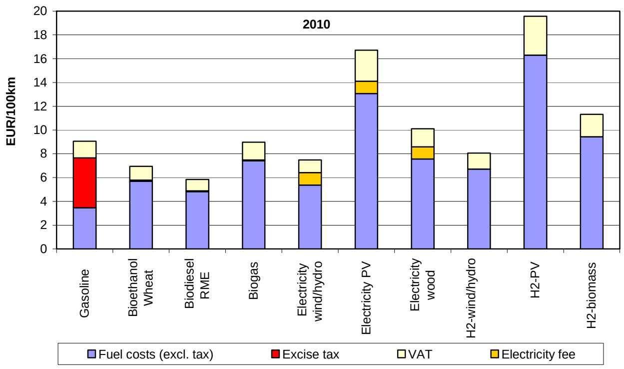

Fig. 6: Transport service fuel costs in 2010 per 100 km.

In 2010 the most expensive fuels per km driven are hydrogen and electricity from photovoltaic.

The future use of renewable fuels depends mainly on their economic performance and on implemented policy measures. This may also affect the aspect which fuels will be finally produced.
In this work it is assumed that current excise tax will be replaced with CO_2-based taxes in the future.
The idea of the suggested tax system is as follows: The highest excise tax in 2010 – which was on gasoline – is converted in CO_2 tax of the same magnitude. For all other fuels this tax is set relative to their WTW- CO_2 emissions compared to gasoline. The implementation of this tax starts in 2013 and is increasing by 0.015 EUR per kg CO_2 per year up to 2050. That way renewable fuels with lower CO_2 balances will have lower tax levels in the future.

The costs of various renewable fuels in comparison to conventional fuels – gasoline - including all taxes in 2050 are depicted in Fig. 7.

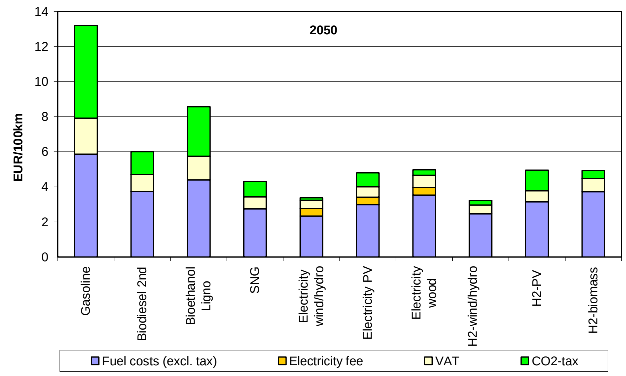

Fig. 7: Transport service fuel costs in 2050 per 100 km.

As it can be seen in Fig. 7, the fuels with the lowest WTW CO_2 emissions - electricity and hydrogen from wind and hydropower – are the cheapest ones by 2050. With CO_2 tax all renewable fuels could become competitive with fossil fuels starting from about 2020. With no switch to CO_2 based tax system renewable fuels would become competitive with gasoline ten years latter, about 2030. Due to introduction of CO_2 based tax, the economic attractiveness of all renewable fuels increases.

Since fuel costs are relatively small part of the total transport costs, in the following are shown total specific transport costs for different fuels and vehicles (biofuels are used in conventional ICE vehicles, electricity in battery electric vehicles, and hydrogen in fuel cell vehicles) per 100 km driven.
Currently, the share of fuel costs is relatively low comparing to the total transport costs. These costs, especially by electricity and hydrogen, are largely determined by cost of vehicles, see Fig. 8.

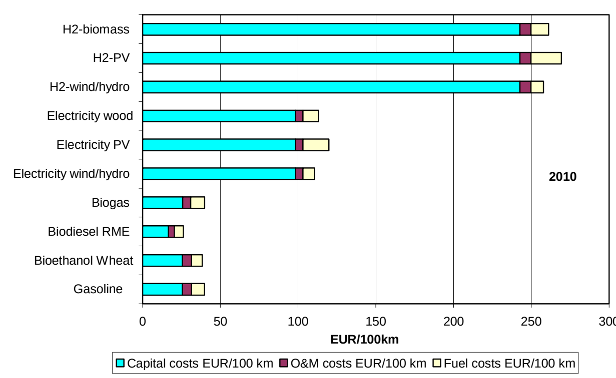

Fig. 8: Total specific costs of transport in 2010 per 100 km.

However, these costs should be significantly reduced by 2050.
Fig. 9 shows total specific costs of transport in 2050 per 100 km driven.

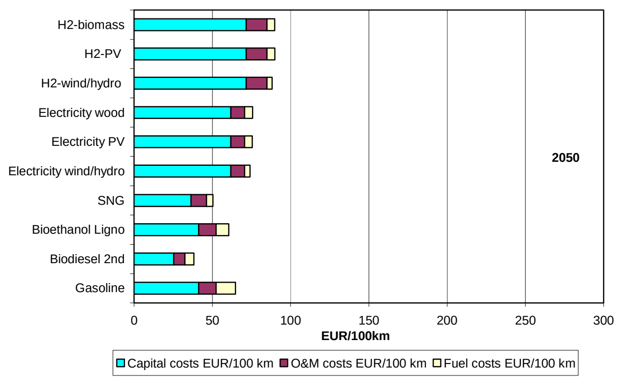

Fig. 9: Total specific costs of transport in 2050 per 100 km.

Finally, which renewable fuels will be used in the future depends on their total mobility costs and CO_2 balances. Fig. 10 provides a comparison of specific CO_2 emissions and costs of mobility with renewable fuels and gasoline.

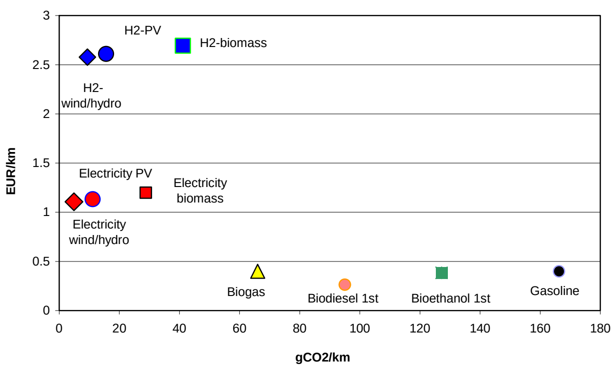

Fig. 10: Comparison of specific CO_2 emissions and costs of mobility with different fuels in 2010.

The major perception of these figure is that mobility provided with renewable fuels, especially hydrogen and electricity, has already much lower WTW-emissions than in case of conventional fuels and technologies. However, the mobility costs are much higher and not competitive on the market.

In the future this situation could be significantly changed mostly due to efficiency improvements, cost reductions (due to technological learning), introduction of CO_2-based tax system, and the switch from 1st to the 2nd generation biofuels.

Fig. 11 depicts comparison of specific CO_2 emissions and costs of mobility with different fuels in 2050.

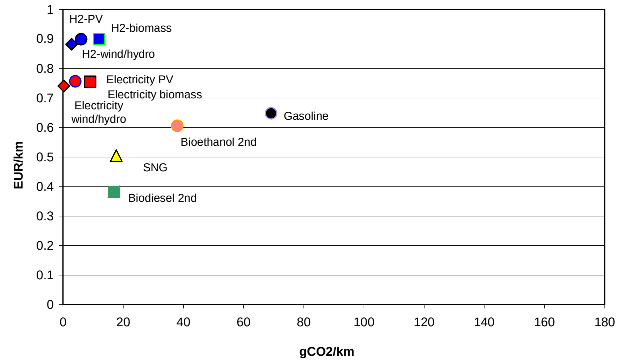

Fig. 11: Comparison of specific CO_2 emissions and costs of mobility with different fuels in 2050.

5. CONCLUSIONS

The major conclusions of this analysis are:

- The environmental performance of 1st generation biofuels is currently rather modest. The economic prospects for the 1st generation biofuels could be much better with the implementation of CO_2 based tax system. Moreover, their potentials are very restricted especially due to limited crops areas;
- There are much higher expectations from 2nd generation biofuels which could – in a favourable case – enter the market between 2020 and 2030. The major advantage of the 2nd generation biofuels is that they can be produced from different lignocellulosic materials, which are not in competition with a food production. These advanced biofuels have significantly better ecological and energetic life-cycle performance in comparison to the 1st generation;
- Since 2nd generation biofuels could enter the market between 2020 and 2030, 1st generation biofuels will remain in the market at least until 2030. However, if a CO_2 based tax is introduced it is very likely that 1st generation biofuels could become irrelevant in the long term;
- With respect to hydrogen and electricity from RES: In 2010 and 2050 electricity is slightly favorable from ecological point-of-view given the same RES. Most favorable are wind and hydro followed by PV and biomass;
- Despite very good CO_2 balances of hydrogen from renewable energy sources, use of hydrogen in a passenger cars will not become competitive before 2050 due to high capital costs;
- Similar as with hydrogen, electricity from renewable energy sources will remain an expensive option for mobility.

This leads to the final conclusion that “renewable fuels” will play a significant role only if the proper mix of CO_2-taxes, intensified R&D, and corresponding riding down the Learning Curve are timely implemented.

6. NOMENCLATURE

ES – Energy service
FF – Fossil energy
FT-Diesel – Fischer-Tropsch Diesel
GHG – Greenhouse gas
H2 – Hydrogen
ICE – Internal combustion engine
LCA – Life cycle assessment
PV – Photovoltaic
RE – Renewable energy
RES – Renewable energy sources
R&D – Research And Development
RME – Raps-Methyl-Ester
SNG – Synthetic natural gas
TTW – Tank-to-wheel
VAT - Value added tax
WTT – Well-to-tank
WTW - Well-to-wheel

7. ACKNOWLEDGMENTS

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