Perspectives for alternative energy carriers based on renewables from technical and energetic point-of-view

Amela Ajanovic[1], *Gerfried Jungmeier* [2], *Martin Beermann* [2]

[1] Energy economics Group, Vienna University of Technology, Austria
e-mail: Ajanovic@eeg.tuwien.ac.at
[2] Joanneum Research Graz, Austria
e-mail: gerfried.jungmeier@joanneum.at, Martin.Beermann@joanneum.at

Abstract - *Alternative energy carriers (AEC), based on renewable CO_2-poor or CO_2-free sources of energy, are of central importance for the transition towards a sustainable energy system. The most important AEC currently discussed are: hydrogen and electricity from renewable energy sources and other AEC based on biomass. The core objective of this paper is to provide an appraisal of the prospects of these AEC up to 2050 from a technical and energetic point-of-view. The major conclusion is that there is no single "one size fits all" energy carrier which can be considered to serve all problems alone. All AEC analyzed in this paper still face major problems in different parts of the overall energy service providing chain.*

Keywords – Energy carriers, technical maturity, conversion efficiency, energetic performance

1. Introduction

The current energy supply is mainly based on fossil fuels. Alternative energy carriers (AEC) – based on renewable, CO_2-poor or CO_2-free sources of energy - are of central importance for the transition towards a sustainable one, see e.g. IEA [1].

The most important AEC currently under discussion are: hydrogen and electricity from renewable energy sources (RES), bioethanol, biogas, biodiesel, and other AEC based on biomass, e.g. 2nd and 3rd generation biofuels like bioethanol from lignocelluloses (raw materials are all cellulosic materials e.g. residuals and waste products from agriculture and wood industry).[1]

Some of these AEC like biofuels 1st generation have also been criticized in recent years, mainly because of relatively high GHG emissions and competition with food production.

The core objective of this paper is to provide an appraisal of the prospects of AEC from RES up to 2050 from a technical and energetic point-of-view[2]. The technical aspect will consider the maturity of the technology. The energetic assessment will analyze the overall performance of AEC in the whole energy chain.

The analysis is conducted for the time period up to 2050 and for the specific situation of EU-15 countries[3]. The full analysis is original work by the authors.

2. AEC: Technical maturity

Alternative energy carriers from RES can be divided in four groups: (i) mature AEC which are already in use; (ii) immature AEC which are still in the developing stage; (iii) AEC in the labour stage; and (iv) technology surprise, see Figure 1.

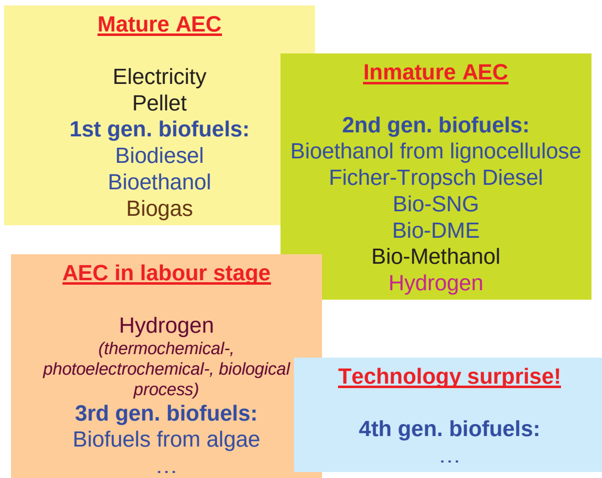

Figure 1. Maturity stage of different alternative energy carriers

2.1 Mature AEC

The most important technologically mature AEC are

[1] In addition, there are other possible AEC from fossil sources like e.g. LNG, CTL, GTL which are not analyzed in this paper.

[2] This paper summarizes the major results of Ajanovic et al [2]

[3] E.g. no bioethanol production in Brazil or South-East Asia is considered.

electricity from hydro power, wind, PV and biomass as well as biofuels 1st generation.

The 1st generation biofuels are mostly produced from agricultural feedstocks, such as sugar cane, corn, soy, palm oil, rapeseed, sunflower and wheat. There are still some problems associated with conventional biofuels ranging from GHG emissions to the competition with food production.

The big advantage of biofuels is that they can be used in conventional internal combustion engines and that no additional infrastructure is needed. They are currently most important alternative energy carriers for transport sector.

The most important 1st generation biofuels are bioethanol, biodiesel and biogas.

Bioethanol can be used directly as a motor fuel or blended with gasoline. It is produced through fermentation of sugar of starch. Most important feedstocks for bioethanol production are sugar cane in Brazil, corn in the US and wheat in Europe.

Bioethanol can also be used for the production of ETBE which blends more easily with gasoline. Biodiesel is a substitute for fossil diesel. It is derived from vegetable oils - mostly rapeseed oil, sunflower oil and soybean oil - through transesterifiction. Also residual oils and fats are suitable for biodiesel production.

Biogas could be produced through anaerobic digestion of manure and other digestible feedstocks like green maize or grass. It can be used for heat and power generation. With slight adoptions, upgraded biogas (bio-methane) can be used in gasoline vehicles.

2.2 Emerging AEC

Very high expectations for the future related to the 2nd generation biofuels. These advanced biofuels could be produced from different lignocellulosic materials (e.g. woody and herbaceous plants such as perennial grasses and fast growing tree species). 2nd generation biofuels have also higher energy yields and significantly higher GHG reduction potential. The only problem is that these biofuels are still in the developing stage and may become commercially available only in the next decades.

The most important **2nd generation biofuels** are: bioethanol based on lignocellulosis, Fischer-Tropsch diesel, Bio-SNG (Synthetic Natural Gas) and Bio-DME (Dimethyl Ether).

Advanced bioethanol could be used in the same way as conventional bioethanol. In case of hydrolysis, sugars are at first extracted from lignocellulosic materials, and then fermented into ethanol.

Fischer-Tropsch diesel could be a full substitute of fossil diesel. In this case lignocellulosic feedstocks are gasified to produce syngas which is than transformed into liquid hydrocarbons, mostly diesel and kerosene.

Bio-SNG is a fuel that can be used in gasoline vehicles with slight adaptations. It is produced in two steps, lignocellulose materials are gasified to produce syngas which is than transformed into methane.

Bio-DME is produced in a similar way as bio-SNG, but bio-DME can be used as a fuel in diesel vehicles. Some slight modifications of vehicles are needed.

In category emerging AEC belong also bio-methanol and hydrogen.

Methanol is also an option to be considered as an energy carrier for a clean and sustainable energy future. Currently, the major feedstock for the methanol production is natural gas and in some regions e.g. China coal. However, recent research is focused on production of methanol in more sustainable way. A promising method is the production of bio-methanol from synthesis gas produced out of biomass. Methanol can be used as a fuel in conventional fuel cells. In that case, methanol has to be reformed to hydrogen that is converted in the fuel cell. The advantage of methanol is that it contains low energy chemical bonds and therefore it can be reformed to hydrogen at relatively low temperatures (250-350°C) (Breure [3]).

Since methanol was originally recovered from wood as a by-product of charcoal manufacture, synonyms for methanol are wood alcohol, wood naphtha, woos spirits or methyl alcohol. Currently, bio-methanol from RES is not on the market (DMA, [4]).

Hydrogen is considered as one of the cleanest and most innovative energy carrier to supply energy services. It is the simplest, lightest and most abundant element in the universe. It constitutes about three-quarters of the mass of the universe, but it does not exist on the earth in elemental form in quantities associated with energy use. However, it can be produced from different energy sources: fossil energy, nuclear energy as well as renewable energy sources. The main requirement for worldwide hydrogen energy long term vision is the production of hydrogen from renewable energy sources.

Hydrogen has the potential to reduce greenhouse gas emissions, climate change, global warming, and to increase energy diversity and supply security. In the last fifteen years the number of hydrogen vehicles, stationary fuel cell systems and refuelling stations is growing.

Today, the largest part of hydrogen, about 60%, is directly produced from fossil fuels and about 40% of it is a by-product of the petrochemical industry and the electrolyses for chlorine production.

The different processes of hydrogen production can be grouped into three categories: thermal, electrochemical and biological process, see Table 1.

Some of these processes are well developed, such as steam reforming of natural gas, coal gasification and electrolysis. The steam reforming of natural gas has been used in chemical, petroleum and other industries process for years. Coal gasification is one of the oldest methods of producing hydrogen and very suitable for coal producing countries like China and South Africa. However, biomass gasification process needs additional improvements. Water electrolysis is also well developed technology. Then again all biological processes are still under fundamental research.

Table 1. Features of major hydrogen production processes (Ajanovic et al [2]) Ajanovic [6])

Primary Method	*Process*	*Feedstock*	*Energy*	*Stage of Development*
Thermal	*Steam Reforming*	*Natural Gas*	*High temperature steam*	*Developed commercial technology*
	Thermochemical Water Splitting	*Water*	*High temperature heat from advanced gas-cooled nuclear reactors*	*Fundamental research*
	Gasification	*Coal*, Biomass***	*Steam and oxygen at high temperature and pressure*	**Developed commercial technology* ***Proven technology*
	Pyrolysis	*Biomass*	*Moderately high temperature steam*	*Proven technology*
Electro-chemical	*Electrolysis*	*Water*	*Electricity from wind, solar,hydro and nuclear*	*Developed commercial technology*
	Electrolysis	*Water*	*Electricity from coal or natural gas*	*Developed commercial technology*
	Photoelectrochemical	*Water*	*Direct sunlight*	*Fundamental research*
	Photobiological	*Water and algae strains*	*Direct sunlight*	*Fundamental research*
Biological	*Anaerobic Digestion*	*Biomass*	*High temperature heat*	*Fundamental research*
	Fermentative Microorganisms	*Biomass*	*High temperature heat*	*Fundamental research*

One possibility to avoid some problems with hydrogen such as storage and refuelling infrastructure could be the use of **carbazole**. Carbazole itself is not burned; it only discharges the hydrogen (Renzenbrink [5]). It is actually an energy-carrying substance which will be recycled and not consumed. The new technology has a marked advantage in allowing existing service station infrastructures to be used. Another advantage is that no pressure is required; the substance N-ethylcarbazole is similar to diesel in many ways. One liter of N-ethylcarbazole allows almost twice as much hydrogen (54 grams) to be stored as in the equivalent volume of a 700-bar hydrogen tank. The range and power would be equivalent to today's vehicles (Elector, [7]).

However, experiments with carbazole use in cars are in their initial stages but hold a lot of promise for the future (Hudston, [8]). Carbozole can also be used for the stabilization of the electricity system and for energy storage in solar powered homes (Elector, [7]).

2.3 AEC in the labor stage

Beside the hydrogen production using thermochemical water splitting, photoelectron-chemical or biological processes, which are shown in Figure 1 in category "AEC in the labour stage" are also biofuels produced from algae.

Fuels produced from algae are considered to be third generation biofuel. Third generation biofuels seek to improve the feedstock rather than improving the fuel-making process.

The algal organisms are photosynthetic macro- or micro-algae growing in aquatic environments. Macro-algae or ''seaweeds" are multicellular plants growing in salt or fresh water. Microalgae are microscopic organisms that that could also grow in salt or fresh water. Optimal temperature for growing many microalgae is between 20 and 30°C. Macro- and micro-algae are currently mainly used for food, in animal feed, in feed for aquaculture and as bio-fertiliser. However in the future they could be used for bioenergy generation (biodiesel, biomethane, biohydrogen), or combined applications for biofuels production and CO_2 mitigation. Theoretically, algae are a very promising source of biofuels. Some algae produce up to 50% oil by weight [Demirbas et al, [9]). However, mass algae production for biofuels is still an unproven technology (Campbell, [10]).

According to Seaweed Energy Solutions AS (SES), ([11]) which is a Norwegian registered company focused on large-scale cultivation of seaweed primarily for energy purposes, bio-energy production utilizing the Earth's vast oceans offers tremendous opportunity as a worldwide renewable energy resource. Current advanced and proven technologies in marine biology, offshore structures, aquaculture and biomass processing are bringing this promise ever closer to commercial reality.

The European offshore area (Exclusive Economic Zone, EEZ) is about 7 million km2. A seaweed farming cluster covering an area of 500 km2 would yield about 10 million tonnes of wet weight seaweed per year (assuming 200 tonnes/ha). For example, five such farming clusters (2,500 km2) spread around in the European waters from Norway to Portugal would represent only 0.03 % of the European EEZ, and would yield 50 million tonnes seaweed annually. This biomass may be converted to about 2.1 billion litres of bioethanol or alternatively 1 billion m3 bio-methane (12.6 TWh). 2.1 billion litres from seaweed would represent about 26 % of European bioethanol production and 2.5 % of global production in 2010 (SES, [11]).

According to the U.S. Department of Energy, algae can produce up to 30 times more energy per acre than land crops such as soybeans, which are currently used for biofuel production. The main reason is that they have a simple cellular structure, a lipid-rich composition and a rapid reproduction rate. Many algae species also can grow in saltwater and other harsh conditions - whereas soy and corn require arable land and fresh water. To replace all diesel in the USA with soy biodiesel, it would be necessary half the land mass of the U.S. to grow those soybeans. On the other hand, if algae fuel replaced all the petroleum fuel in the United States, it would require 15,000 square miles (about 39,000 square kilometers), which is roughly the size of Maryland [Hartmann, [12]).

Algae could be used for making vegetable oil, biodiesel, bioethanol, biomethanol, biobutanol and other biofuels.

In the last decades biofuels are considered to be a good way to reduce GHG emissions. But, the problems with first generation biofuels are numerous and well-documented in the last few years, ranging from net energy losses, high greenhouse gas emissions to increasing food prices. Taking into account the sustainability and economic factor biofuel from algae seems to be very promising fuel for future.

However, further research and development are necessary to establish an economical industrial scale production of algal biofuels (Singh et al, [13]).

2.4 Technology surprise

Although 2nd generation biofuels are still in developing stage and 3rd generation in labour stage, there are already efforts towards so-called "4th generation biofuels".

Fourth generation technology combines genetically optimized feedstocks, which are designed to capture large amounts of carbon, with genomically synthesized microbes, which are made to efficiently make fuels. Key to the process is the capture and sequestration of CO_2, a process that renders fourth generation biofuels a carbon negative source of fuel. However, the weak link is carbon capture and sequestration technology, which continues to elude the coal industry [Rubens, [14]).

3. Method of approach

One of the main problems of energy carriers are the losses occurring in the whole energy chain – from the production of AEC from primary energy (PE) to their use for providing energy services (ES), see Figure 2. The energy losses depend on the efficiency of the conversion process (Tc) at the each transformation stage as well as efficiency of the finally used technology, e.g. cars.

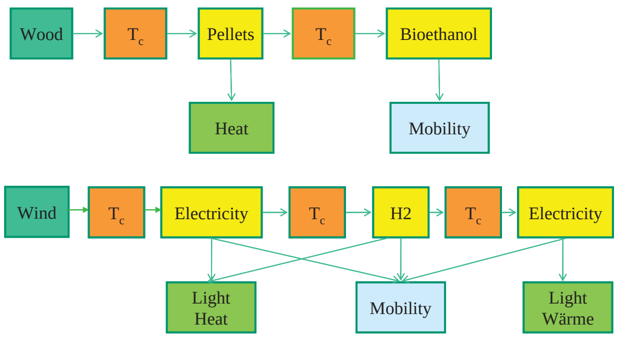

Figure 2. Examples for energy chains assigned to the AEC pellets, electricity, bioethanol and hydrogen

Some examples for chains assigned to the AECs pellets, electricity and hydrogen are depicted in Figure 3. For example, hydrogen can be used as storage for electricity from renewable energy sources and then according to requirements of use again converted to electricity. Unfortunately, in case of the long energy chains – due to many conversion process and corresponding energy losses – total energy and environmental balances could be relatively poor, see Fig. 3.

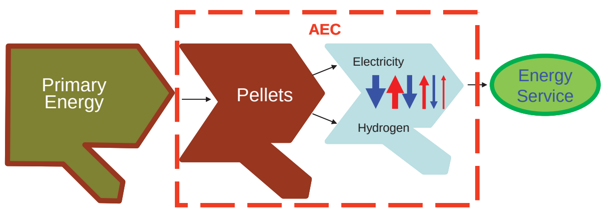

Figure 3. Example for the cascadic use of AECs: Electricity can be converted into hydrogen and vice versa again and again before it is converted into a service

The system boundary outside which environmental impacts are ignored must include all life cycle stages, significant energy uses, material flows and GHG emissions. In addition, for a valid comparison, the system boundaries should be set so that the same energy and product services are provided by both the study and the reference systems (Bird, [15]). In addition to a cradle-to-grave analysis (Well-to-Wheel analysis for fuels) including the entire supply chain from primary energy to energy or transport service, the systems were also analysed cradle-to-gate (Well-to-Tank analysis for fuels) including the supply chain from primary energy to final energy (AEC), see Figure 4.

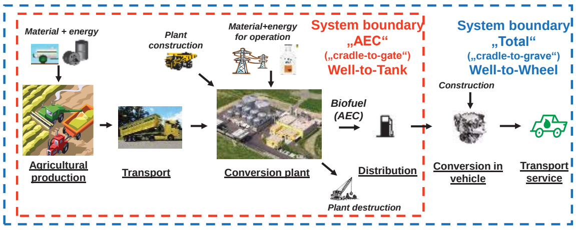

Figure 4. System boundary definition - example of a biofuel supply chain

Primary energy demand includes all energy inputs which are needed to deliver an alternative energy carrier or useful energy. The amount of primary energy demand is subject to feedstock and technologies used. In this analysis the primary energy demand is divided into:

- Fossil energy sources: coal, natural gas and crude oil
- Renewable energy sources: biomass, solar energy, water and wind
- Other energy sources: waste (e.g. waste combustion) and nuclear energy

Co-products as electricity and heat that substitute reference systems are considered by accounting the avoided cumulated primary energy demand of the substituted reference systems. In case non-energy co-products of the AEC-systems (e.g. fertilizer from biodiesel production) substitute reference systems the avoided primary energy demand is accounted zero since the co-product is not used energetically. In Figure 5 the contributions to cumulated primary energy demand are shown for the example of biodiesel from rapeseed.

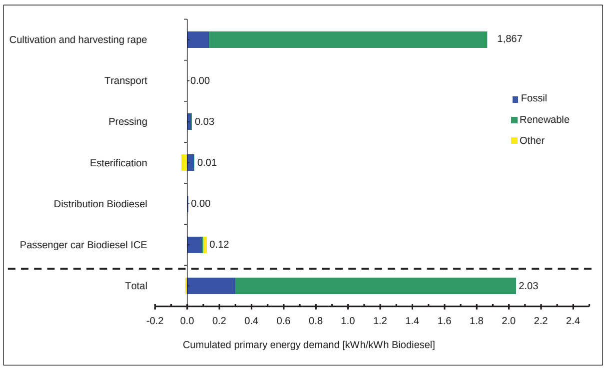

Figure 5. Contributions to cumulated primary energy demand (example biodiesel from rape seed)

The cumulated primary energy demand (CED) of an AEC is calculated as follows.

$$CED_{AEC} = \frac{input_{PE}}{\eta_{sys}} + \sum_{i=1}^{m} CED^{i}_{PE_{prod}} + \sum_{j=1}^{n} CED^{j}_{transp} + \sum_{k=1}^{o} CED^{k}_{Constr+Dism} + \sum_{k=1}^{o} CED^{k}_{Operat} \quad (1)$$

And the overall system efficiency:

$$\eta_{sys} = \prod_{k=1}^{n} \eta^{k}_{process} \quad (2)$$

CED_{AEC}	Cumulated primary energy demand of AEC [kWh_{CED} / kWh_{AEC}]
$input_{PE}$	energy content of the primary energy resource (e.g. biomass)
η_{sys}	system efficiency (energy out/energy in based on heating values) as product of k individual process efficiencies $\eta_{process}$
CED_{PEprod}	Cumulated primary energy demand related to i production processes of the primary energy carrier (machines, auxiliary energy and materials in agricultural production)
CED_{trans}	Cumulated primary energy demand related to j transport processes (machines, auxiliary energy and materials)
$CED_{Constr+Dism}$	Cumulated primary energy demand related to the construction and dismantling of k production facilities (energy and materials)
CED_{Operat}	Cumulated primary energy demand related to the operation of k production facilities (auxiliary energy and materials)

In general each individual contribution to the CED_{AEC} can be a sum of renewable, fossil and other energy sources. CED_{PEprod}, CED_{trans} and

$CED_{Constr+Dism}$ commonly have a large share of fossil inputs, whereas CED_{Operat} can also have a large share of renewable input, e.g. process heat or electricity supplied by renewable sources.

4. Results

Table 2 show the cumulated primary energy demand in the life cycle related to the use of different AEC-systems compared to fossil reference systems. All AEC-systems reduce the cumulated fossil primary energy demand compared to the fossil reference systems. However among the AEC-systems there are considerable differences for the cumulated primary energy demand, including renewable and other primary energy carriers. The results are discussed for the three AEC-groups biofuels, electricity and hydrogen.

Among the AEC considered those based on biomass (see Table 2 and Figure 6) have the highest cumulated primary energy demand. Fossil energy carriers are supplied by the ecosphere and require energy for their large-scale extraction, transport and some processing in refineries, while no conversion processes are required. Biofuel production based on agricultural or forest biomass requires energy for its production and conversion processes associated with process efficiencies and thus energy losses (see Table 2). The AEC-systems are based on different renewable primary energy sources (referring to "renewable (biomass)" in Figure 6) like agricultural crops or wood and on different conversion technologies as thermochemical or biochemical processes. Therefore the results in Figure 6 cannot be compared directly in terms of energy efficiency.

Table 2. WTW Cumulated primary energy demand per kWh biofuel compared to fossil fuels

AEC	Year	Fossil	Renewable	Other	Total
		WTW			
		WTW [kWh/kWh]			
SNG Wood (forest)	2010	0.2	1.5	0.0	1.7
	2050	0.2	1.4	0.0	1.6
FT-Diesel Wood (forest)	2010	0.2	3.1	0.0	3.3
	2050	0.2	1.8	0.0	2.1
Bio-methan Corn (silage)	2010	0.3	4.2	0.0	4.5
	2050	0.3	3.7	0.0	4.0
Bio-ethanol Straw	2010	0.3	2.4	0.0	2.7
	2050	0.3	2.2	0.0	2.5
Bio-diesel Rape	2010	0.3	1.7	0.0	2.0
	2050	0.3	1.7	0.0	2.0
Bio-ethanol Wheat	2010	0.8	1.7	0.0	2.6
	2050	0.5	1.7	0.0	2.3
CNG	2010	1.2	0.0	0.0	1.2
	2050	1.2	0.0	0.0	1.3
Gasoline	2010	1.3	0.0	0.02	1.3
	2050	1.3	0.0	0.03	1.4
Diesel	2010	1.3	0.0	0.0	1.3
	2050	1.3	0.0	0.0	1.4

Bio-methane from corn has a high WTW cumulated primary energy demand. The energetic system efficiency as the ratio between energy in the methane per energy input of corn (heating value) was about 33% in 2010 (39% in 2050). 67% (61%) of the primary energy content in the corn remains in the substrate which is commonly used as fertilizer in agricultural production systems. In addition, biogas production requires input of heat which is assumed to be produced in biogas heating plant, resulting in the "renewable (other)" share of the cumulated primary energy demand in Figure 6. Bioethanol from wheat in 2010 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 (Austrian electricity mix assumed) and heat (supplied by CNG in 2010).

WTW-cumulated primary energy demand for 2050 is lower than for 2010 for all AEC, see Table 2.

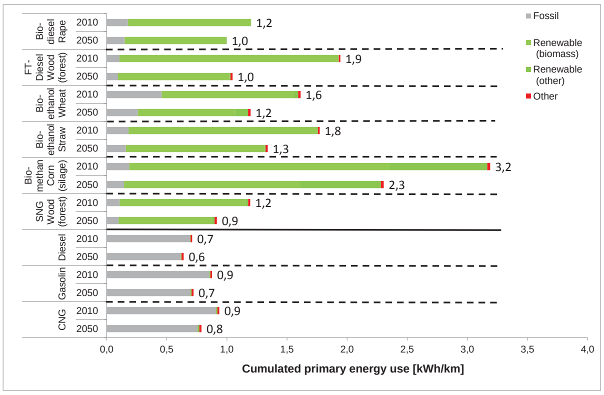

Figure 6. Cumulated primary energy demand of transport service with biofuels

All AEC-systems providing electricity for transport service have a lower fossil as well as a lower cumulated primary energy demand compared to the fossil reference system (see Table 3 and Figure 7). For hydropower-, windpower- and PV-stations the conversion efficiency is accounted with 100% since the energy potential of water, wind and sunlight is provided for free by the ecosystem. The WTW cumulated primary energy demand for electricity from wood includes avoided emissions from substituted reference biomass heating station.

Table 3. WTW Cumulated primary energy demand per kWh renewable electricity compared to electricity from CNG

AEC	Year	Fossil	Renewable	Other	Total
		[kWh/kWh]			
Hydropower	2010	0,4	1,1	0,09	1,5
	2050	0,4	1,1	0,09	1,5
Windpower	2010	0,4	1,1	0,10	1,6
	2050	0,4	1,1	0,10	1,5
PV	2010	0,6	1,1	0,16	1,8
	2050	0,6	1,1	0,11	1,8
Wood (forest) CHP	2010	0,2	1,0	0,02	1,3
	2050	0,3	0,7	0,03	1,0
CNG CHP	2010	2,4	0,0	0,0	2,4
	2050	2,3	0,0	0,1	2,4

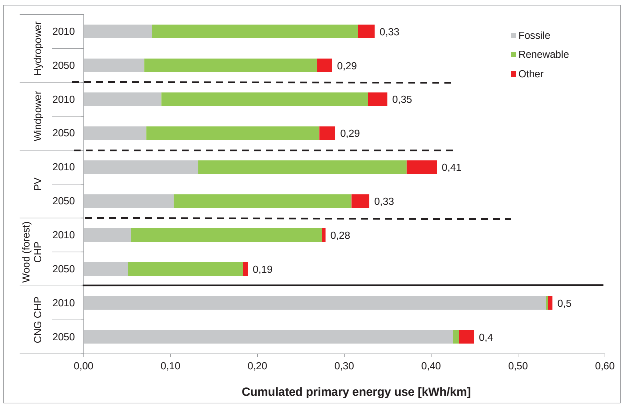

Figure 7. WTW Cumulated primary energy demand of transport service with electricity

All AEC-systems providing hydrogen for transport service have a lower fossil as well as a lower cumulated primary energy demand compared to the fossil reference system (see Table 4 and Figure 8).

Table 4. WTW Cumulated primary energy demand per kWh renewable hydrogen compared to hydrogen from CNG

AEC	Year	Fossil	Renewable	Other	Total
		[kWh/kWh]			
Hydropower + Electrolysis	2010	0,2	1,7	0,05	1,9
	2050	0,3	1,5	0,07	1,9
Windpower + Electrolysis	2010	0,3	1,7	0,07	2,0
	2050	0,3	1,5	0,08	1,9
PV + Electrolysis	2010	0,6	1,7	0,16	2,4
	2050	0,6	1,6	0,10	2,3
Wood (forest) gasification	2010	0,4	2,2	0,15	2,7
	2050	0,4	1,7	0,12	2,2
CNG reforming (no CCS)	2010	1,9	0,0	0,05	1,9
	2050	1,9	0,0	0,07	2,0
CNG reforming (with CCS)	2010	2,0	0,0	0,05	2,1
	2050	2,0	0,0	0,07	2,1

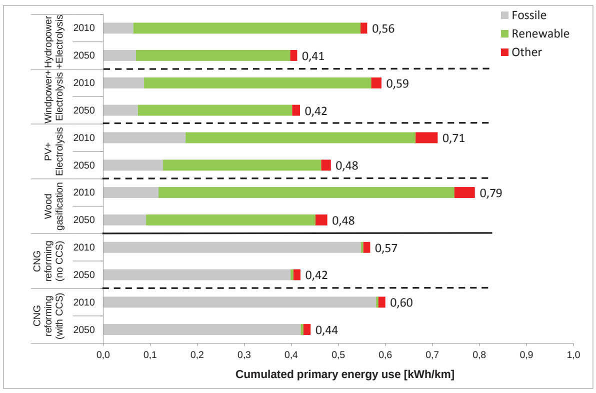

Figure 8. WTW Cumulated primary energy demand of transport service with hydrogen

Table 5 presents the WTW GHG emissions of all investigated AEC-systems and compares the results of AEC supply chains based on different primary energy carriers (biomass feedstock and residues, other renewable sources).

Table 5. WTW Cumulated primary energy demand of all AEC investigated

WTW Cumulated primary energy demand [kWh / km]	Biodiesel	Bioethanol	Biomethan	FT-Diesel	SNG	Electricity	Hydrogen
Feedstock							
Rapeseed	1.2						
Sunflower	1.1						
Wheat		1.7					
Corn maize		1.7					
Sugar-beet		1.7					
Green maize			3.2				1.9
Grass			2.0				
Short rotation crops (wood)				2.0	1.2	0.9	0.9
Residue							
Straw, con stover		1.8		2.1	1.3	0.3	0.8
Forest wood residues				2.0	1.3	0.3	0.9
Wood industry residues				2.1	1.3	0.3	0.8
Liquid manure			1.3				
Waste fat	1.2		0.9				
Renewable sources (non biomass)							
Windpower						0.3	0.6
Hydropower						0.3	0.6
Photovoltaik						0.4	0.7

5. Conclusions

The major conclusion of this analysis is that there is no single "one size fits all" energy carrier which can be considered to serve all problems alone. All AEC analysed in this paper still face major problems in different parts of the over-all energy service providing chain. Table 6 summarizes the pros and cons for the major performance parameters of AEC. It is especially important to point out the following core current weaknesses (see also Faaij [16] and IEA [17]):

- With respect to electricity the prevailing problem is still lack of proper storages. This is especially important for harvesting electricity from volatile RES.
- The major barrier for a broader use of 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, overall conversion efficiency in the fuel providing chain is still moderate.
- Regarding 1st generation biofuels the major problems are still high CO_2 emissions due to rather large amounts of fossil fuel inputs and low over-all conversion efficiency in the fuel providing chain.
- 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.
- For 2nd generation biofuels immature production processes and corresponding high production costs are the major impediments.

Table 6. Survey on major problems related to the broader use of AEC as of 2012

	Production	*Storage*	*Conversion into services*	*CO_2 emissions*
Electricity	No problem	Storage of larger amounts is still a major problem	No problem	Depends on source of production (no problem with RES)
Hydrogen	Problem of low efficiency and of high investment costs	minor problem	A proper reliable and affordable conversion technology (fuel cells) is not yet available	Depends on source of production (no problem with RES)
Biodiesel and Bioethanol 1st generation	Problem of low efficiency and high fossil inputs	No problem	No problem	Problem of still large shares of fossil inputs
Biogas	Problem of high investment costs & low scaling and low learning effects	No problem	No problem	No problem
Biodiesel and Bioethanol 2nd generation and SNG	Problem of high investment costs, not technologically mature	No problem	No problem	No problem

References

[1] IEA, 2011: World energy outlook, Paris, 2011

[2] Ajanovic A., Jungmeier G, Beermann M., Haas R., Zeiss Ch.: Perspectives for alternative energy carriers in Austria up to 2050, Final report of project for FFG, Vienna 2012.

[3] Breure B., 2005: Methanol as a new energy carrier. TU Delft, 2005

[4] DMA, 2011: Methanol Economy, Danish Methanol Association, TM01-2, 2011

[5] Renzenbrink, T., 2011: Renewable Fuel Offers Alternative to Battery Powered Electric Cars, http://www.techthefuture. com/energy

[6] Ajanovic A.: On the economics of hydrogen from renewable energy sources. Dissertation. Vienna University of Technology. 2006

[7] Elector, 2011: Carbazole: The electric fuel? New type of fuel for fuel cell cars, http://www.elektor.com/news/carbazole-the-electric-fuel.1878692.lynkx

[8] Hudston, G., 2011: Carbazole Safe And Eco-Friendly Fuel Of Future, http://www.sooperarticles.com

[9] Demirbas A., M.F. Demirbas, 2011: Importance of algae oil as a source of biodiesel. Energy Conversion and Management 52 (2011) 163-170

[10] Campbell P.K., T. Beer, D. Batten: Life cycle assessment of biodiesel production from microalgae in ponds. Bioressource Technology 102 (2011) 50-56

[11] SES, 2011:Renewable energy from see. http://www.seaweedenergysolutions.com/index.php

[12] Hartman E., 2008: A Promising Oil Alternative: Algae Energy. The Washington Post. January 6, 2008

[13] Singh A., P.S. Nigam, J.D. Murphy, 2011: Renewable fuels from algae: An answer to debatable land based fuels. Bioresource Technology 102 (2011) 10-16

[14] Rubens C.,2008: WTF Are Fourth-Generation Biofuels?, earth2tech http://earth2tech.com/2008/03/04/wtf-are-fourth-generation-biofuels/

[15] Bird N., A. Cowie, F. Cherubini, G. Jungmeier, 2011: Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy. Strategic report by IEA Bioenergy.

[16] Faaij, A.P., 2006: Bio-energy in Europe: Changing technology choices. Energy Policy 34, 2006, 322- 342.

[17] IEA: Energy Technology Perspectives, OECD/IEA, Paris 2010