ALTER-MOTIVE

State of the art for alternative fuels and alternative automotive technologies

A report compiled within the European research project

Deriving effective least cost policy strategies for alternative automotive concepts and alternative fuels

Intelligent Energy-Europe (IEE), STEER

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List of Abbreviations

AAMT	Alternative Automotive Mobility Technology
AER	All Electric Range
AF	Alternative Fuel
BD	Biodiesel
BEE	Biomass Energy Europe
BEV	Battery electric vehicles
Biodiesel	Collective name for all kinds of biomass-based diesel like fuels, e.g. FAME and FT-diesel
BE	Bioethanol
BF	Biofuel
BM	Biomethane
BTL	Biomass To Liquids (used as a proxy for all biomass based synthetic fuels, e.g. methanol, DME, FT-fuels, biomethane, H_2)
BTL FT	Biomass-based Fischer Tropsch fuels
CGH_2	Compressed Gaseous Hydrogen
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
DDGS	Dried Distillers Grains with Solubles (a protein rich co-product to grain ethanol)
DME	Di-methyl ether
EEA	European Environment Agency
EF	Entrained flow gasifiers
ETBE/MTBE	Ethyl-Tertiary-Butyl-Ether / Methyl-Tertiary-Butyl-Ether
EU	European Union
FAEE	Fatty Acid Ethyl Esters (same as FAME but with ethanol instead of methanol)
FAME	Fatty Acid Methyl Esters, e.g. RME and SME (biodiesel)
FC	Fuel Cell
F-T Synthesis	Fischer Tropsch Synthesis
GHG	Greenhouse Gases
GTL	Gas to Liquids
GV	Gas Vehicles
H2/H_2	Hydrogen
HEV	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
IEA	International Energy Agency
IFEU	Institut für Energie und Umweltforschung Heidelberg ; Institute for Energy and Environmental Research Heidelberg
J/KJ/MJ/PJ/TJ	Joule / Kilo Joule / Mega Joule / Peta Joule / Tera Joule
LH_2	Liquid hydrogen
LUC/ILUC	Land Use Change / Indirect Land Use Change
LS/SS	Large Scale / Small Scale
MCFC	Molten carbonate fuel cell
Mg	Magnesium

MIT	Massachusetts Institute of technology
N.A.	Not Available
N/NOx	Nitrogen / Nitrogen-Oxygen compounds
NG	Natural gas
NGV	Natural Gas Vehicles
NiMH	Nickel Metal Hydrate
PC	Passenger Car
PEMFC	Polymer Exchange Membrane Fuel cell
PHEV	Plug-in hybrid electric vehicles
PME/FAME	Plant Methyl Ester – Fatty Acid Methyl Ester
PVO	Pure Vegetable Oil / Plant Vegetable Oil
PW	Pathway
RME/REE	Rapeseed Methyl / Ethyl Ester (biodiesel)
SME	Sunflower Methyl Ester (biodiesel)
SNG	Synthetic Natural Gas (biomethane produced via gasification)
SNG-digestion	Substitute Natural Gas (upgraded biogas produced through digestion)
SUV	Sports Utility Vehicle
TTW	Tank to Wheel
Wh/kWh/Mwh	Watt hour/ Kilo Watt hour/ Mega Watt hour
WTT	Well to Tank
WTW	Well to Wheel

1 Executive summary

This report summarizes the major results of WP3 of ALTER-MOTIVE. The target of the project ALTER-MOTIVE is to derive least cost strategies for the promotion of alternative fuels (AFs) and alternative automotive technologies (AAMTs) by using a set of well established models. To meet this objective it is necessary to have clear understanding of the current state-of-the-art and improvement potentials for these various AFs & AAMTs for passenger transport.

To meet the above-stated target of the project ALTER-MOTIVE it is necessary to use a proper dynamic modelling framework. This framework must be based on a sound database for the various considered AFs & AAMTs for passenger transport. The major objective of this report is to summarize the analyses conducted within work package 3 (WP3) of this project. The work in WP3 focused on providing this database including a comprehensive technical, economic and ecological assessment of AAMTs and AFs. The ecological assessment is conducted along the whole Well-to-Tank (WTT) and Tank-to-Wheel (TTW) chain for the investigated AFs and AAMTs. Hence, this documentation is the basis for further analyses in the scope of the *ALTER-MOTIVE* project.

The database is organised in Excel-files that contain relevant technical, environmental and economic data delivering specific costs, carbon emissions and where possible also NOx emissions for all relevant technologies using alternative fuels. The main results of this database with respect to AFs and AAMTs are presented below[1].

The state of the art assessment of the AFs and AAMTs is qualitatively and quantitatively described including detailed technical descriptions, their current economical and environmental performance and the plant size range within EU and further examples. In addition to this, a special section on the technical improvement potentials is included for each AF and AAMT studied.

The major results for biofuels vs fossil fuels are illustrated in Figure 1-1 where both 1st and 2nd generation biofuels as well as fossil fuels are compared depending on their economic and environmental performance. It should be noted that all these figures correspond to a snapshot in time of their performance in 2010 based on average input values along the WTW chain.

1 This database is available for download from www.alter-motive.org

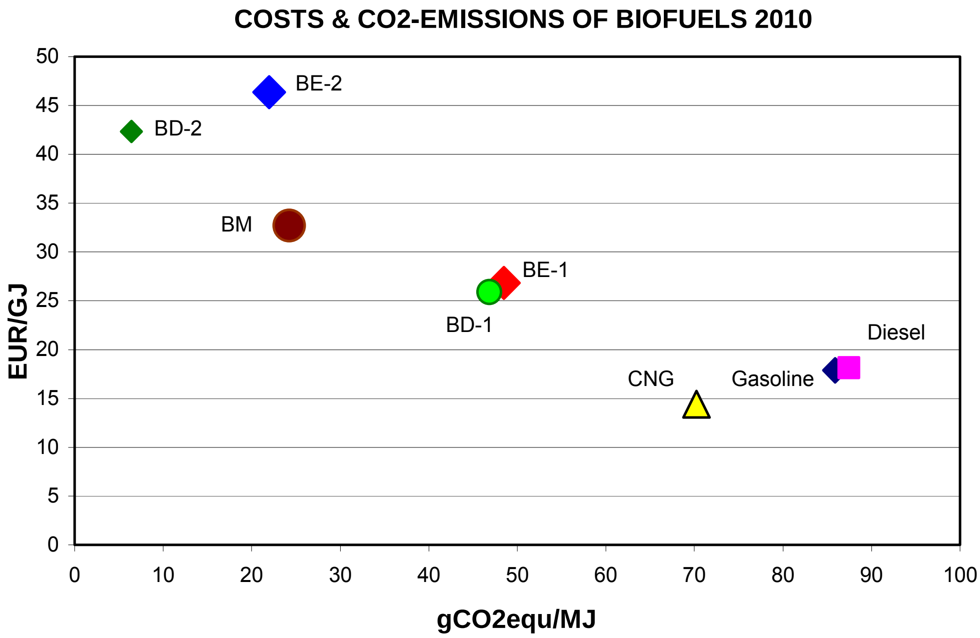


Figure 1-1. Biofuels vs. fossil fuels – state of the art assessment 2010 of production costs [€/GJ] (exclusive taxes) and WTW CO_2 emissions [g CO_{2equ}/MJ]

BD: Biodiesel, BE: Bioethanol, BM: Biomethane

The results are: With respect to the ecological performance of BF-1 the best option corresponds to biogas with lowest specific emissions. Biomass-to–liquid (BTL) performs better than 2nd generation bioethanol in terms of delivered costs and in terms of CO2 emissions per Megajoule (MJ). This is very arguable as 1st generation technologies are already at commercial level and their economic performance depends highly on feedstock cost management and by-product value. The values provided here for 2nd generation biofuels are still disputable as they are based on R&D or demonstration figures, but still no scalable experience has been obtained. BTL has the prospect to offer lower emissions in this case due to the co-generation assumption covering high energy inputs; however, the capital requirements observed are very high. Along the whole chain biodiesel from rapeseed and bioethanol from wheat are exhibiting the higher CO2eq emissions per delivered MJ of fuel due mostly by cultivation and fertilizers use as well as the use of fossil based inputs.

For all pre-selected pathways, by-products were considered in all cases as they result to have a positive influence in costs and emissions performance. However, the use of by-products and the way they are characterized in analysing biofuels production from well to tank is not always comparable with other studies, as assumptions regarding their use and value differ greatly. The specific values for all AF and AAMT pathways can be observed at the WP3 'State of the Art databases' in D5 at the *ALTER-MOTIVE* website.

With respect to AAMT State of the Art assessment, the modification of the existing internal combustion engine to run on alternative fuels, able to be blended with fossil diesel and gasoline or natural gas performs differently in terms of emission reductions stating better for biodiesel and biomass-to-liquids than for gasoline or flex-fuel vehicles running on ethanol mixtures.

Moreover, AAMTs including parallel hybrids, battery electric vehicles (BEVs) and hydrogen technologies combined with ICEs have been assessed on their economic performance, see Fig. 1-2, and on their environmental performance, see Figure 1-3.

Hybrid vehicles may serve as a bridging technology. They do not have most of the disadvantages of pure BEV: They are economically almost competitive, use less fuel than conventional gasoline and diesel vehicles and can compete with BEVs also on WTW CO2 emissions, except for BEVs running on electricity based on pure renewable energy sources, see Figure 1-3.

The specific capital costs are the highest component of the driving costs for all alternative powertrains (and conventional cars as well). Hybrids, battery electric vehicles and plug-in hybrids take into account the actual costs for batteries as well as for fuel cells. However, these costs can be reduced until 2020 based on technical improvement potentials.

The costs per km driven C_{km} in Figure 1-2 are calculated as:

$$C_{km} = \frac{IC \cdot \alpha}{skm} + p_f \cdot FI + C_{O\&M} \qquad [€/km]$$

where:

IC…….Investment costs [€/car]

α……..Capital recovery factor

skm…specific km driven per car per year [km/(car.yr)]

p_f……..fuel price [€/litre]

$C_{O\&M}$…operating and maintenance costs

FI……..fuel intensity [litre/100 km]

Figure 1-3 provides a comparison of specific CO2 emissions and costs of conventional and hybrid gasoline and diesel vehicles with pure BEV based on different electricity generation mixes and FCV with H2 from RES or natural gas.

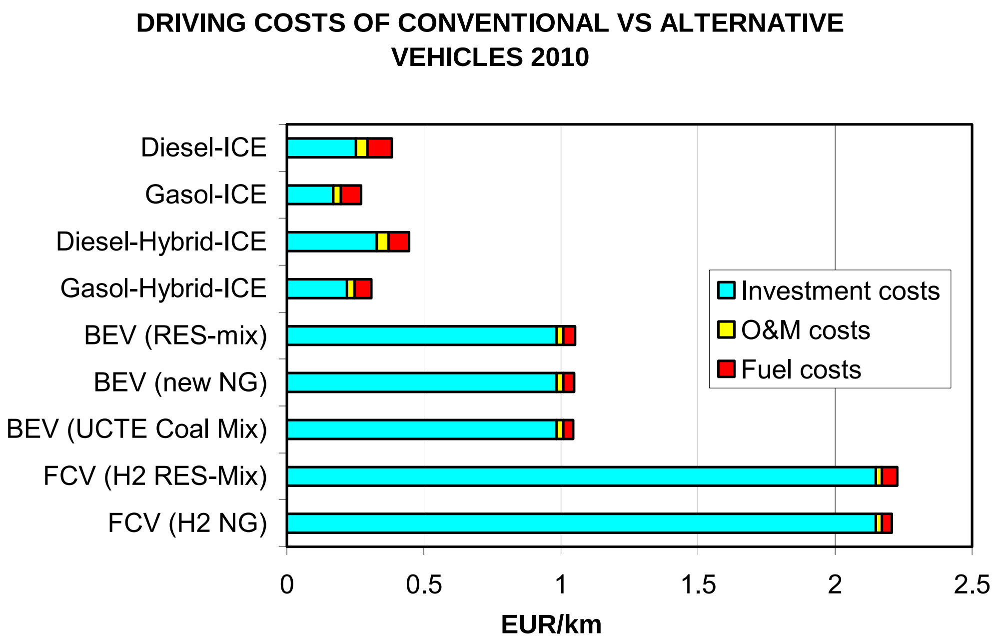


Figure 1-2. Hydrogen and Electric vehicles vs conventional passenger cars – State of the Art of economic assessment of driving costs 2010 (Size of vehicle: 80 kW)

(H2: Hydrogen, ICE: Internal Combustion Engine, FCV: Fuel Cell vehicle, BEV: Battery Electric Vehicle, NG: Natural gas, RES: Renewable energy sources)

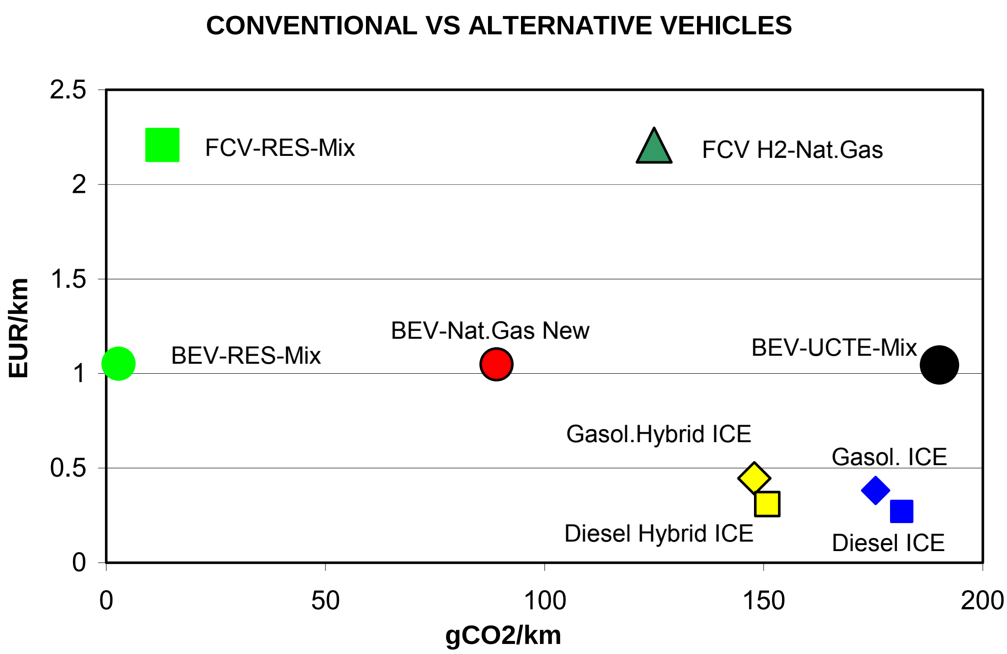


Figure 1-3. Comparison of specific CO_2 emissions and driving costs of conventional and hybrid gasoline and diesel vehicles with pure BEV based on different electricity generation mixes and FCV with hydrogen from NG vs RES

(H2: Hydrogen, ICE: Internal Combustion Engine, FCV: Fuel Cell vehicle, BEV: Battery Electric Vehicle, NG: Natural gas, RES: Renewable energy sources)

The major perceptions of Figure 1-3 are: (i) Hybrid ICEs are an alternative with slightly higher costs but clearly better performance than conventional vehicles; (ii) BEV as well as FCV are only preferable to conventional cars if they are fully based on RES.

Yet, it is important to note that there are considerable technical improvement potentials. A broad summary of the reviewed main technical improvement potentials for both AFs and AAMTs (see separate chapters) include:

- Developments of biodiesel and bioethanol processes and product specifications to better perform at combustion. Feedstock availability and competition issues put pressure to research further in expanding biomass feedstock and including waste streams.
- Advanced fermentation and thermal conversion for 2nd generation research and development are expected to gain further actions as they move from pilot to demo to early commercial stages. The potential to contribute are high but several economic and energetic bottlenecks need to be solved.
- Biogas offers a high potential as AF and upgrading needs to be made more competitive and technically feasible in order to gain further momentum and market share as a transport fuel. Further bottlenecks relate to infrastructure expansion and coordination with natural gas networks.
- The internal combustion engines exhibit important technical improvements with the potential to increase efficiency and reduce emissions with moderate extra costs. Several of these technologies are highlighted and include among others the application of engine test bed, optimised fuel injection and electronic systems, modern valve controlling and innovative gear drives (e.g. duplex clutch, continuous automatic gearbox, hydraulic impulse store).
- Further improvements include chassis suspension and brake technology, reduction of rolling resistance of tyres (e. g. innovative materials or optimised tyre profiles), enhanced aerodynamics, weight saving constructions (e. g. substitution of steel by plastics and carbon fibres, substitution of conventional headliners by light-emitting diodes) and material grade from renewable raw materials and optimisation of the power train. In addition, driving styles exhibit substantial fuel saving potentials.
- Additional modification on ICE include the adaptation of motors to run on biodiesel or bioethanol low or high blends with a potential to reduce emissions further while making less changes in technology.
- BEVs are still an immature technology. Major R&D and demonstration activities relate to further development of battery technologies and technology improvements indicate a

wide range of weight and costs reduction potentials until 2020 probably explained by the different scaling factors for battery and cell sizes;

- Across the review several experts in Europe and Worldwide foresee battery costs in 2015 and onwards varying between 370 and 580 €/kWh (references in section 6.2.3) while others consider possible a factor 5 in cost reduction based on the developments.
- Fuel cell research and development (R&D) is aimed at achieving high efficiency and durability, low material and manufacturing costs of the fuel cell stack and in addition is currently being considered for hybrids electrics as E-Mobility is expected to gain larger shares.
- Technical improvements for fuel cells include power density and platinum loading which are necessary to go on commercial scale. A cost evaluation on fuel cells for automotive power trains suggests that in future for high production significantly lower costs for fuel cell systems vary between 26 to 100€ per kW (references in section 6.2.3) by 2020 following mass production and technology learning.

2 Introduction

This report is a deliverable of the EU-founded project “Deriving an (least-cost) action plan for promoting alternative automotive Technologies and alternative fuels”- *ALTER-MOTIVE*. The core objective of the project *ALTER-MOTIVE* is to derive effective least-cost policy strategies to achieve a significant increase in innovative alternative fuels and corresponding alternative more efficient automotive technologies to head towards a sustainable individual & public transport system.

The major objective of this report is to summarize the analyses conducted within work package 3 (WP3) of this project. It provides a comprehensive technical, economic and ecological assessment of AAMTs and AFs. This documentation is the basis for further analyses in the scope of the *ALTER-MOTIVE* project.

In this report following issues are treated in detail:

- Technical, economic and ecological assessment of AFs including natural gas, biofuels from first and second generation, biogas and hydrogen.
- Technical, economic and ecological assessment of AAMTs including hybrid and electric technologies, fuel cells and modifications on internal combustion engines for the use of biodiesel, bioethanol (e.g. Flex-fuel-Vehicle) and BTL for mobility applications.
- An analysis and classification of the technology pathways based on their Well-to-Tank and Tank-to Wheel performances in terms of economics and CO_2 eq-emissions.

Activities within WP3 also encompass fuels and technology assessment elaborating on potential technology trends with taking into consideration the latest information as well as future directions adopted by companies, research and development projects as well as Governments at EU level. Detailed techno-economic descriptions of AFs cover possible feedstock, production, distribution, refueling and blending, storage and conversion focusing on 1st and 2nd generation biofuels, as well as hydrogen technologies and for AAMTs mapping latest research & development and demonstration projects for the state of the art as well as of future improvement potentials. The work has been organized in two main tasks namely; the creation of a technology database as input for the subsequent modeling working packages and a well-to-wheel analysis (economics and environment) in order to characterize relevant technology pathways.

So the analyses documented in this report are completed by a technology database which comprises two subparts; AF and AAMT. This technology database provides the basis for a quantitative characterization of the technologies (Technology Database) including investment costs, efficiency, plant size range, lifetime, availability as well as indicators like CO_2-emissions and costs designed on the requirements on the WP6.

The investigations conducted are based on original information provided by *ALTER-MOTIVE* project partners in different countries as well as on existing studies and databases from other projects (e.g. REFUEL, CONCAWE, TRIAS, BEE and EEA)

The deliverable is organized as follows. In the next section the method of approach is described. Then for biofuels and hydrogen the detailed analyses for the whole fuel production chains are described. In Section 6 the analyses for the alternative automotive technologies are summarized. Conclusions complete this report.

3 Method of approach

3.1 Technical assessment

The technologies assessed in this project are considered to have significant impact and potential to reduce CO_2 emissions as alternatives for transport fuels and mobility technologies until 2020. However, all these options experience a different stage of development and a state of the art marked by poor economic performance (not competitive) besides various technology and economic bottlenecks and limitations that hinder their entrance into the markets.

Table 3-1: Summary of analyzed AF pathways

Well - to - Tank			
BIOFUELS PATHWAYS	Feedstock - Cultivation	Production Processes	Fuel + Filling stations
Ethanol	Sugar beet	Fermentation	Ethanol
Ethanol	Wheat	Fermentation - Consider DDGS uses	Ethanol
Ethanol (2nd Generation)	Wood	Hydrolysis and Fermentation	Ethanol
Biodiesel FAME	Rapeseed + methanol/ethanol	Extraction-Esterification	Biodiesel
Biodiesel FAME	Sunflower seed + methanol	Extraction-Esterification	Biodiesel
BTL	Wood (waste and farmed) - Wood chipping	BTL Plant: Gasification, FT Synthesis, Electricity	Synthetic diesel + Electricity
Biogas	Wet manure	Biogas generation fermentation, heat, CH4 extraction	Compressed Biogas (CBG) + CNG station - electricity
Biogas	Dry manure	Biogas generation fermentation, heat, CH4 extraction	Compressed Biogas (CBG) + CNG station - electricity
HYDROGEN PATHWAYS	Feedstock - Cultivation	Production Processes	Fuel + Filling stations
Compressed Hydrogen	Natural Gas	Central Steam Reforming	Compressed Hydrogen - FS
Liquid Hydrogen	Natural Gas	Central Steam Reforming	Liquified and Compress Hydrogen - FS
Compressed Hydrogen	Electricity Mix - EU	central electrolysis/ on-site electrolysis	Compressed Hydrogen - FS
Compressed Hydrogen	Offshore wind	central electrolysis/ on-site electrolysis	Compressed Hydrogen - FS
Compressed Hydrogen	Wood (waste and farmed)	Gasification - electrolysis	Compressed Hydrogen - FS

In Table 3.1 the AF assessed in this report including biofuels from 1st generation such as bioethanol from grains as well as biodiesel routes from biological oil raw materials from rapeseed and sunflower.

In addition to these routes biogas ("biomethane") from dry and wet manures and grass has also been assessed. Hydrogen has been considered to be produced from natural gas and EU Electricity mix pathways besides renewable routes including wind and biomass gasification. Last but not the least, 2nd generation routes such as lignobioethanol, which is the emerging process for the fermentation of alcohol based on lignocellulosic material available in wood and waste feedstock streams as well as biomass-to-liquids (BTL) routes including the gasification and synthesis of farmed and waste wood.

The Alternative Automotive Technologies analysed in the *ALTER-MOTIVE* project are summarized in Table 3-2 and include both adaptations of existing internal combustion engines (ICE) to be able to run on bi-fuels combinations such as Biodiesel, Bioethanol or Biogas and that are known in the markets as flex-fuel vehicles (FFV) or natural gas vehicles (NGV) and baseline bi-fuel vehicles.

Furthermore, the complete chain of AAMTs towards electro-mobility includes the consideration of ICE Hybrids, plug-in hybrids and dedicated electric vehicles such as battery electric vehicles (BEV). In addition to the electro-mobility technologies, hydrogen ICE's and fuel cells have also been considered.

Table 3-2: Summary of analyzed AAMT

Alternative Fuels Pathways	Conversion - AAMT
Gasoline	(ICE-Gasoline port injection and direct injection) and hybrid port injection and direct injection - ref. Hybrid fuel cell
Diesel fuel	(ICE-Diesel direct injection) and Hybrid diesel direct injection
CNG Bi-fuel	(ICE - Gasoline port injection)
Diesel/Biodiesel blend	(ICE-Diesel direct injection) and Hybrid diesel direct injection
Gasoline/Ethanol blend	(ICE-Gasoline port injection and direct injection) and hybrid direct injection
Ethanol	(ICE-Gasoline port injection and direct injection) or Flex-Fuel-Vehicle (FFV)
Biodiesel FAME/HVO	(ICE-Diesel direct injection) and Hybrid diesel direct injection
BTL	(ICE-Diesel direct injection) and Hybrid diesel direct injection
Biogas	(ICE - Gasoline port injection) and hybrid port injection
Compressed Hydrogen	(ICE - Gasoline port injection) and hybrid port injection and Fuel Cells
Liquid Hydrogen	(ICE - Gasoline port injection) and hybrid port injection and Fuel Cells
Electricity	Electric car

The technical assessment of AFs & AAMTs was conducted based on a survey of existing literature as well as presentations on the topic. All AFs and AAMTs are being assessed following a similar structure that identifies the current *state of the art* of the producing and consuming technologies describing the production process or the technology as well as mapping the present development along the technology curve (e.g. Research, Demonstration and/or commercial) based on their production figures. For commercial and demonstration technologies the assessment includes production/demonstration plants characterization at EU scale.

The technological assessment is complemented by the Well-to-Tank and Tank-to-Wheel economical and environmental assessments which are explained in further details in the coming sections. In addition, the literature survey and research is complemented with interviews with selected experts for both AFs and AAMTs in order to validate, update or confirm existing information and assumptions for future possible developments and trends.

The technical improvement potentials have also been researched and performed for AFs and AAMTs and result from the identification of existing technical difficulties, obstacles or "technical bottlenecks" which are currently hindering the innovation and development pace. These technologies (either existing or emerging) exhibit various potentials for improvement especially in efficiency and performance improvements for AF and fuel consumption and emissions reduction for AAMTs. Initial estimates of cost reduction and innovation potentials due to technical improvements are indicated.

3.2 Economic assessment

Biofuels

Several factors, such as feedstock price, conversion costs, and different promotion policies, have an impact on biofuel costs. The largest part of the biofuels' costs is feedstock cost and these are currently largely dependent on prices of agricultural markets. Feedstock costs differ as per the type of crop used, harvesting technologies, and agricultural subsidies for crops and regions and currently very volatile.

Besides feedstock costs, the scale of the conversion facility have a considerable impact on biofuel production costs. For all alternative fuels two scales of the conversion facility, small and large scale was analyzed.

The following components are used to calculate the costs of biofuels:

- Feedstock costs – C_{FS}
- Other energy inputs costs (e.g. electricity, heat etc) – C_I
- Annual capital costs – CC
- Operations and maintenance costs – $C_{O\&M}$
- Total by-product credit – R_{BP}

Finally specific biofuel production costs (C_{BF}) for year t are calculated as follows:

$$C_{BF} = C_{FS} + C_i + CC + C_{O\&M} - R_{BP} \qquad \text{[c€/kWh Biofuel]}$$

However, it has to be noted that distribution and retail costs as well as policies (subsidies, taxation respectively tax exemption of biofuels are not included in specific biofuel production costs. Net feedstock costs are calculated for every year as:

$$C_{FS} = P_{FS} \cdot FQ \cdot f_{TC}$$ [c€/kWh Biofuel]

Where:

P_{FS}.......................*Feedstock market price [c€/kWh Feedstock]*

FQ…………………...*Feedstock quantity used per ton biofuels [kWh FS/kWh BF]*

f_{TC} ....*Factor for considering feedstock transaction costs*

Annual capital costs are calculated as:

$$CC = \frac{IC \cdot \alpha}{P \cdot T}$$ [c€/kWh Biofuel]

Where:

IC…..Investment *costs [€]*

α…….*Capital recovery factor*

P…..*Capacity [kW]*

T…….*Full load hours*

Revenues from by-products (i.e. the sales value of rapeseed-cakes, electricity, glycerine, animal feeds etc.) produced in the chain of different biofuels processing ways play a minor role regarding the overall biofuels costs. However, the way in which by-products are used has a significant impact on total greenhouse gas emissions. The role of by-products could be even lower in the future due to oversupply. For example, currently demand for glycerine is limited for a number of food, beverage, personal care and oral products, as well as pharmaceutical and other industrial uses. With the increasing biodiesel production it will be necessary to create additional markets for the by-products like glycerine.

Hydrogen

Hydrogen, as a secondary energy carrier, could be produced using different primary energy sources: fossil energy, renewable energy or nuclear energy. In the scope of this report cost of hydrogen produced from natural gas from Russia, natural gas EU-mix, electricity EU-mix and electricity from offshore wind are analysed. Of all the cases, most important input is electricity or natural gas.

Following components were considered to calculate the costs of hydrogen:

- Input (energy) costs - C_E
- Yearly capital costs – CC
- Operations and maintenance costs – $C_{O\&M}$

Finally specific hydrogen production costs (C_{H2}) for year t are calculated as follows:

$$C_{H_2} = C_E + CC + C_{O\&M} \qquad [c€/kWh\ H_2]$$

However, to obtain total hydrogen costs, also distribution and retail costs as well as policies (subsidies, tax exemption of hydrogen) have to be included. It is assumed that fix operating costs are 4.5% of capital costs.

3.3 Environmental assessment

This part gives the detailed results of the GHG balance of all pathways considered. It details the processes included in each pathway and gives the GHG balance for the total pathway as well the contribution of each of the main stage. To justify the data used into the analysis, first a review of updated literature on LCA analysis focusing on biofuels was performed.

Argonne (2009), ESU (2008), IFEU[2] (5/2003), US EPA (2002) NREL (1998) are the major references on the LCA, also for the methodological efforts they made to offer evaluations comparing the conventional fuels to the biofuels. Although different studies use different grounds and methodologies, hence, making the comparison is not always easy; the major differences arise around the type and use of by-products. Just to mention, a land use change (LUC) is also a key factor in the final results.

Concerning the by/co-products, many fuel processes produce by-products (minor) or co-products (same order of magnitude) together with the fuel itself. How should these other outputs be taken into account? The so called allocation method (mass, energy, price) aims at splitting the cost between the various products. But how should resources, energy, GHG emissions and costs be apportioned between the different products of a single process? They are straightforward, but they have no logical or physical relevance as these costs are incurred simultaneously for all products. In this way the results are transparent (as suitable) but necessarily arbitrary.

Further, details can mislead the analysis and is crucial to associate the uncertainties for each process (e.g.: NOx emissions can contribute around 20-30% of total emission from a biofuel chain and have uncertainty range of ±200%. This would raise the question why to devote so much time

2 A value added from IFEU study is the fact that introduces some modifications on the RME assessment. New data on the nitrous oxide emissions trigger numerically more favourable results in the categories ozone depletion and greenhouse effect. Other outcomes, regarding the honey production and its co-products only marginally affect the overall assessment.

to an item that may contribute 1 or 2%. Typically for biofuels transport, minor agricultural inputs (seeds, herbicides, etc.) have little impact. Energy/emissions embedded in plants and equipment are minor in most fuel chains and quite often are of same order of magnitude. Plants and equipment are more relevant for vehicles (TTW analysis) and can vary by vehicle type.

Comparison on GHG balance between the major studies reveals high GHG figures from IFEU due to the assumptions that N_2O emissions are linked to fertiliser use. Concerning the savings, achievable savings in terms of energy, conventional fuel substitution and GHG emissions the ETSU study is far from the other studies results.[3] CONCAWE (2/1995) and latest updated reports (10/2008), presents the results in terms of gCO_2eq/MJ as presented in database. Although this is not the only reason that justifies the choice for study, it is also important to emphasize that other studies present analysis using different indicators mostly related to emissions avoided or just comparing advantages from different fuel options.

The CONCAWE comprehensive analysis has been selected due to the most consistent approach and updated offered, in comparison to other similar studies. Main studies on biofuels do not present major changes in the key parameters. The focus on CONCAWE has the advantage to cover the whole process we are investigating with a major consensus on results, allowing for some final considerations.

The best estimate and the range of variability are given for the GHG. In CONCAWE, the ranges are obtained adopting a Monte Carlo simulation combining the range of variation of individual process. The minimum value is taken as P20 (20% of observed values will be below that value) and the maximum as P80. Five stages are considered for the analysis:

- **Production and conditioning at source**
    - Includes all operations required to extract, capture/cultivate the primary energy source. In most cases, extracted or harvested energy carrier requires some of the treatment or conditioning before it can be transported.
- **Transformation at source**
    - Used for the cases where a major industrial process is carried out at or near the production site of the primary energy (i.e. gas-to-liquids plant).

[3] Gover, M.P. et al (1996) Alternative road transport fuels – a preliminary life-cycle study for the UK. ETSU report R92 volumes 1 & 2. Oxford: Energy Technology Support Unit.

- **Transportation to EU**
  - Is relevant to energy carriers produced outside the EU and request long distance transport. This step is used also when a significant transport vector is required to move the raw materials to a processing plant (i.e. biomass).

- **Transformation in EU**
  - Includes the processing and transformation taking place near market place to produce a final fuel according to specification (oil refineries, hydrogen reformer).

- **Conditioning and distribution**
  - It refers to the final stage required to distribute the fuels from import or production point to the refuelling sites (road transport) available to the vehicle tank (natural gas compression).

4 Biofuels: State of the art and technical improvement potentials

Biofuels are liquid or gaseous fuels made from biological (renewable) feedstock, such as agricultural crops, oils, fat, forestry and wood-processing by-products or organic wastes. Conventional fuels such as gasoline and diesel are gradually being replaced by alternative fuels of biological origin such as bioethanol, biodiesel, biogas etc. Resultantly, global demand for liquid biofuel has tripled between 2000 and 2007 and this growth will continue in the near future followed by future target and investment plans by different countries (OECD/IEA, 2008). The main drivers in OECD countries behind the biofuel policy implementation and production growth are energy supply security, rapid growing crude oil price and demand, conventional fuel being the significant source of air pollution, support for agricultural industries and rural communities, environmental concern and awareness (IEA, 2007). The success of alternative fuels in the marketplace will depend on numerous factors, including public understanding and consumer awareness; economics; automobile performance; availability of fuels, vehicles, and distribution and marketing systems; and changes in technology. Compared to other sustainable transport options, such as the electric or fuel-cell powered vehicle, biofuels have the advantage that they can be implemented without any fundamental changes in fuel distribution and end use: most biofuels can be blended with gasoline or diesel and used with only minor changes to fuelling points and vehicles (Refuel, 2008). Another major advantage of biofuels over most other fuel types is that they are biodegradable, and most of them are relatively harmless to the environment if spilled.

Biofuels are broadly classified into three generations based on the production and feedstock utilization. '1st generation biofuels' are biofuels made from sugar, starch, vegetable oil, or animal fats. The basic feedstock for the production of 1st generation biofuels are often seeds or grains such as wheat, corn etc. that yield starch which is then fermented into bioethanol, or sunflower seeds or rapeseeds, which are pressed to yield vegetable oil that can be used to transform into biodiesel. Moreover, Sugarcane for example in Brazil is the most common feedstock for bioethanol. 1st generation biofuels show benefits in terms of GHG emission reduction and energy balance but still give many concerns especially food v/s fuel debate (Refuel, 2008).

2nd generation biofuel are produced from a huge variety of non-food crops feedstock. These include waste biomass, wheat straw, the stalks of corn, wood, and energy plants such as *jatropha, miscanthus* etc. 2nd generation biofuels use biomass-to-liquid technology (BTL), including lignocellulosic biofuels, syngas-based fuels etc. Many second generation biofuels under development are biohydrogen, DME, Bio-DME, Fischer-Tropsch diesel, biohydrogen and mixed alcohols.

3rd generation biofuel or Algae fuel is a biofuel from cellulosic algal feedstock. This generation of biofuel has the potential for lower biofuel production costs due to simpler feedstock processing, lower energy inputs, and higher conversion efficiencies and hence is economically attractive (Carere, Sparling, Cicek, & Levin, 2008). An overview of the major biofuels technologies, processes and feedstock is summarized in Table 4-1.

Table 4-1: Biofuels from 1st, 2nd and 3rd generation

1st generation	2nd generation	3rd generation
Technology – Economical and well established	Technology involved – High Cost of production	Technology involved – Advanced technology, high investment
Feedstock – Rapeseed, wheat, soybean, sugarcane, other starch rich food crops	Feedstock – Cellulosic Biomass (agri. & organic waste, straw, stalk), used oil & fat	Feedstock – Algal biomass
Products – bioethanol biodiesel (FAME)	Products – synthetic fuels produced via gasification e.g.FT diesel, Biolignoethanol	Products – Algal oil (Oilgae)
Level – Commercial	Level – Mainly demonstration or R&D	Level – Research and technology development
Advantages – Env. friendly, economic and social security	Advantages – Non-competitive with food, easy and ample feedstock availability	Advantages – Low input high yield feedstock
Problems – Limited feedstock (food Vs fuel), Blending regulations	Problems – High cost of production at the moment, infrastructure development	Problems – Process optimization, scale up, high investment

Source- Own elaboration

4.1 Biodiesel Technology Assessment

4.1.1 State of the art

Biodiesel refers to the diesel obtained from vegetable oil- or animal fat-based feedstock which chemically consists of long-chain alkyl (methyl, propyl or ethyl) esters. Biodiesel is typically made by chemical process called *'Transesterification'* in which lipids (e.g., vegetable oil, animal fat) react with alcohol to produce long chains of mono-alkyl esters of fatty acids. This end product shows similar combustion properties as petroleum diesel, and hence can be used in the existing internal combustion engines without major modifications. The production process of biodiesel is simple and well understood at different scales. Biodiesel can be used in pure, or blended with diesel as a good substitute in the transport and energy sectors. Most of new cars do not have a technical compatibility to use pure biodiesel (B100) but many of the flexi fuel cars run well on different blends (B5, B10). Biodiesel can be used in standard diesel engines and is thus distinct from the vegetable and waste oils where significant conversions in diesel engines are needed. Another important advantage is that it can be transported and distributed in the infrastructure available today (Kaltschmitt et al. 2002, Vogel et al. 2004, Friedrich 2004). The potential of biodiesel production are very high across the world. The global production of biodiesel reached around 360 PJ (8.6 Mtoe) showing an increase by the factor of 10 from 2000 to 2007, fetching 2% of total diesel fuel demand (OECD/IEA, 2008). In Europe the demand of diesel out of total road transport fuel is around 70% of which 2% is being met by biodiesel.

Biodiesel Feedstock: A variety of feedstock oils can be used to produce biodiesel, mainly they include; virgin oil feedstock (rapeseed and soybean oils - most commonly used and other crops such as mustard, palm oil, hemp, *jatropha*), waste vegetable oil (WVO) and animal fats including tallow, lard, yellow grease and as a by-product from the production of Omega-3 fatty acids from fish oil. Out of these, pure vegetable oil (PVO) extraction is realized well at commercial level across the world. In the US where only 20% of transport fuel is diesel, soybean is used as main feedstock for biodiesel production. In Europe then main feedstock is rapeseed oil, sunflower oil, and imported palm oil. Mostly rapeseed oil is being used as a main feedstock for the production of biodiesel in leading countries (e.g. Germany and France). However, multi-feedstock source plants with their own preparations using recycled oils and animal fats are part of the new trend in biodiesel production (OECD/IEA, 2008), (Refuel, 2008). In 2008, the total production of biodiesel in Europe from all different types of feedstock was 7,755,000 tonnes, which represented an increase of around 35% over annual production of 2007. For 2008, the major production share in Europe accounted 2,819,000 tonnes by Germany, followed by France of around 1,815,000 tonnes (European Biodiesel Board 2009).

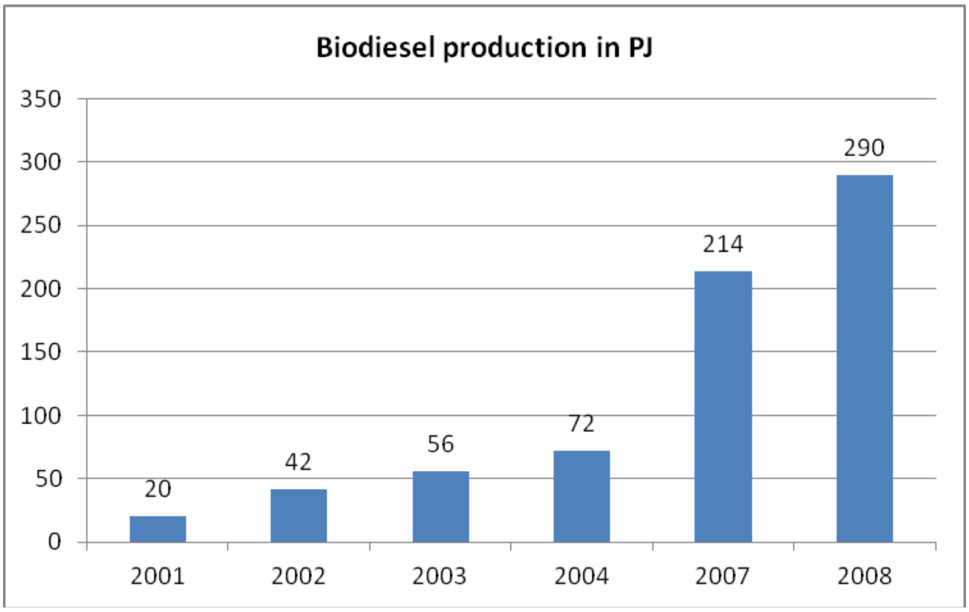


Figure 4-1: Biodiesel production in the EU-27 until 2008

Source – European Biodiesel Board

4.1.1.1 Production Process

The biodiesel productivity per land area from different oil-seed crops in the amounts 33.494 to 50.241 GJ (0.8 to 1.2 toe) of biodiesel/ha, while oil palm yields about 159.098 to 167.472 GJ (3.8 – 4 toe) of biodiesel/ha (SET-Plan, 2009). In Europe the biodiesel production cost (rapeseed) varies between 16.6 and 17.5 € per GJ (60 and 63 €/MWh) (oil price 50 €/bbl) and the investment capital costs for a biodiesel plant from vegetable oils are about 200 – 500 €/kW biodiesel (SET-Plan, 2009). However, the bio-diesel productivity per land area in EU is of the order of 37.68 to 50.24 GJ (0.9 to 1.2 toe) biodiesel/ha (EC, SETIS workshop 2010). Biodiesel is produced from the combination of two main processes, the first one being the *pressing and extraction* of oil from the oilseeds and the second is a chemical process called *transesterification.* Theoretically, pure vegetable oil (PVO) can be used directly in the motor as diesel substitute but the pure use creates some serious engine problems due to its relatively high viscosity leading to incomplete combustion, choking of the fuel injectors and poor atomization of the fuel. Therefore, once the oil passes pressing and extraction stage it is then passed through chemical process of *transesterification* to produce *or fatty acid methyl ester (FAME) or biodiesel.* The term FAME in this report is used for all kind of Biodiesel derived from various feedstock. For examples, RME/REE is used for Rapeseed Methyl/Ethyl Ester, SME/SEE for Sunflower Methyl/Ethyl Ester. The process to adapt PVO to the engine performance requirements basically involves transforming the large molecule structures (triglycerides) into smaller chains (methyl or ethyl esters). Glycerol and protein rich cake are by-products of this process which are separated from the resulting Plant Methyl Ester (PME). The following section explains the process of extraction and *transesterification* for obtaining plant methyl esters.

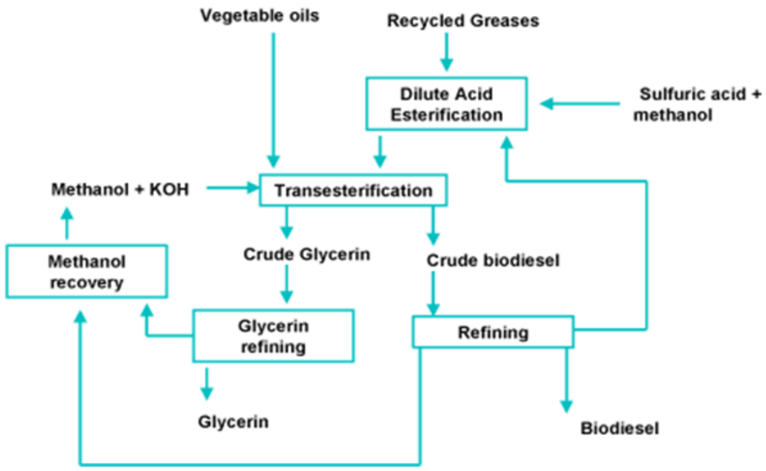
Oil extraction: PVO extraction capacities vary on different scales, for example, large scale plants may be able to process up to 4,000 ton oilseed per day while small ones up to 25 ton oilseeds per day. The production process and its complexity also varies according to the scale, for example large scale plants use only mechanical pressing of the oilseeds while the small ones use pressing and filtering processes to obtain pure vegetable oil. Moreover, few large scale capacity plants also use oilseed crushing combined with extraction of the oil through chemical solvents. Noticeably, there is no major difference between the production of vegetable oil for energy or for the food industry. Only some minor considerations like final quality of oil or variation in the taste are acquired by modifications in final product.

For initiating the production process the seeds are crushed through mechanical press to obtain two main products crushed seed cake & crude press oil. Crude press oil is filtered and dried in ordered to obtain the desired oil quality for *transesterification*. The crushed seed cake still has high oil content so it undergoes a flaking process followed by extraction process with chemical solvents (e.g. hexane) to recover the leftover oil. The extraction process leads to two main products, one being a high protein meal used for the animal feeding industry and the other is a combination of oil and hexane. The oil and hexane are distilled at the *miscella distillation process* for separation and recovery. The obtained oil is then treated with the vegetable oil from the crushing process and is subjected to *transesterification* process and production of biodiesel. Figure 4-2 includes an illustration of biodiesel production route. The process explained is the state of art production process in many of the high capacity oil mills across Europe. The extraction of oil in this type of facilities may achieve amount as high as 97-99% (Naik, Goud, Rout, & Dalai, 2009) (Kaltschmitt et al. 2002, Vogel et al. 2004, Friedrich 2004).

Figure 4-2: Biodiesel production route (first generation)

Source - Own elaboration

Once the crude oil from oilseed feedstock is obtained it is conducted to the *transesterification* process in order to produce pure fame. During few last decades several patents with various production possibilities and combinations have been proposed in *transesterification technology***.** Among them, the most important ones are made by *Ballestra, BDI, Connemann, Campa Biodiesel, ENA-Biodiesel, Energea, Kirchfeld, Lurgi, IFP* and *Westfalia*. This makes evident that it is a well developed and commercial state of the art technology (Kaltschmitt et al. 2002, Friedrich 2004) for



biodiesel production.

Figure 4-3 illustrates the production process of biodiesel from various transesterification.

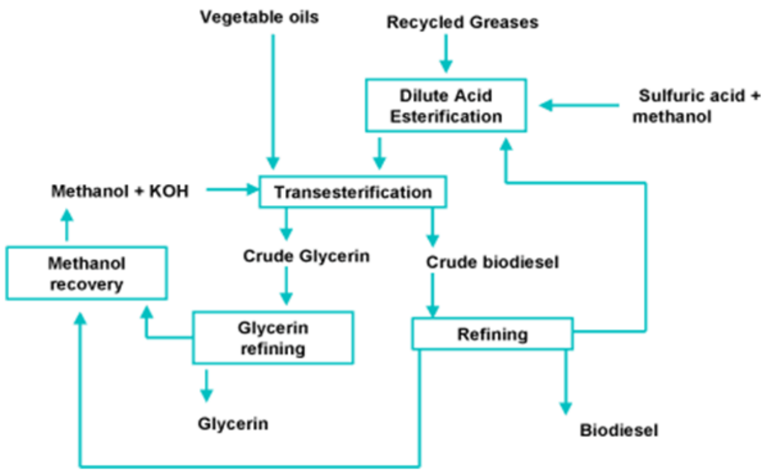


Figure 4-3: Transesterification flowchart for Biodiesel Production
Source - own elaboration

There are 3 main ways of *transesterification* process:

1. Base catalyzed transesterification of the oil (catalytic transesterification)
2. Direct acid catalyzed transesterification of the oil
3. Conversion of the oil to fatty acids and then to biodiesel

From these three basic processes, the most common one used for the production of biodiesel is *Base Catalyzed Transesterification* due to its advantageous economic performance requiring low temperatures and pressures and producing a biodiesel with 98% purity. (Kaltschmitt et al. 2002, Vogel et al. 2004, Friedrich 2004).

4.1.1.2 Classification of the technology

Biodiesel technologies are currently at commercial scale with only some processes being still on demonstration or at research and development phases as this is an industrial branch with constant improvements. Biodiesel from rapeseed and sunflower (as in Germany, France), soybean (as in US, India and Brazil), palm oil (as in Malaysia and Indonesia) are at commercial scale across the world, however diesel from used oil and animal fats is in demonstration (or on the interphase of demo and commercial). Biodiesel from Algae (3rd generation) is still at R&D phase and investors/scholars see huge potential in it. However extraction process, efficiency, cost of production and scale up are still unsolved questions. The examples of 2nd generation biodiesel from *jatropha* and *miscanthus* etc are in non-commercial level at this time, although pilot and demonstration facilities are being developed. Therefore it is anticipated that, these 2nd generation biofuels could significantly reduce CO_2 emission, do not compete with food crops and can offer better engine performance.

4.1.1.3 Fuel Quality and Specification

At EU Level the European Standard (EN 14214) for biodiesel describes the technical requirements and test methods for fatty acid methyl ester to assure the quality of the biodiesel delivered (e.g. blended or in pure form) to the end users. The standard itself has also been accepted by motors manufacturers which guarantee their products performing correctly under biodiesel blends.

The European Standard was published originally in autumn 2003 and has been updated in 2008 and 2009 following the transition of national standards and the merging of them with the EN norm. The EU standard exists in three official versions (English, French and German) and the main differences related to cold weather requirements (see Table 4-2 and Table 4-3).

Table 4-2: Biodiesel Specification for the EU, USA and for Petroleum Diesel

Biodiesel Standards		**EUROPE**	**USA**	**PETROLEUM DIESEL**
Specification	Units	EN 14214:2008	ASTM D 6751-07b	EN 590:1999
Applies to		FAME	FAEE	Diesel
Density 15°C	g/cm³	0.86-0.90		0.82-0.845
Viscosity 40°C	mm²/s	3.5-5.0	1.9-6.0	2.0-4.5
Distillation	% @ °C		90%,360°C	85%,350°C - 95%,360°C
Flashpoint (Fp)	°C	101 min	93 min	55 min
CFPP	°C	* country specific		* country specific
Sulphur	mg/kg	10 max	15 max	350 max
CCR 100%	%mass		0.05 max	
Carbon residue (10%dist.residue)	%mass	0.3 max		0.3 max
Sulphated ash	%mass	0.02 max	0.02 max	
Oxid ash	%mass			0.1 max
Water	mg/kg	500 max	500 max	200 max
Total contamination	mg/kg	24 max		24 max
Cu corrosion max	3h/50°C	1	3	1
Oxidation stability	hrs;110°C	6 hours min	3 hours min	N/A (25 g/m3)
Cetane number		51 min	47 min	51 min
Acid value	mgKOH /g	0.5 max	0.5 max	
Methanol	%mass	0.20 max	0.2 max	
Ester content	%mass	96.5 min		
Free glycerol	%mass	0.02 max	0.02 max	
Total glycerol	%mass	0.25 max	0.24 max	

Table 4-3: Member State specific values for EN 14214 on cold filter plugging point (CFPP)

national versions of EN 14214	Standard	Season	Dates of season	Max CFPP (°C)
United Kingdom	BS EN 14214	Summer	16th March - 15th November inclusive	-5°C
		Winter	16th November - 15th March inclusive	-15°C
Austria	ÖNORM EN 14214	Summer	1st April - 30th September	+5°C
		Winter	1st October - 28th February	-20°C
		Spring	1st March - 31st March	-15°C
Estonia	EVS EN 14214	Summer	1st May - 30th September	-5°C
		Winter	1st December - 29th February	-26°C
France	NF EN 14214	Summer	1st April - 31st October	0°C
		Winter	1st November - 31st March	-15°C
Germany	DIN EN 14214	Summer	15th April - 30th September	0°C
		Winter	16th November - 28th February	-20°C
		Spring	1st March - 14th April	-10°C
		Autumn	1st October - 15th November	-10°C
Greece	ELOT EN 14214	Summer	1st April to 30th September	+5°C
		Winter	1st October to 31st March	-5°C
Ireland	IS EN 14214	Summer	16th March - 21st October	-5°C
		Winter	22nd October - 15th March	-15°C
Italy	UNI EN 14214	Summer	March 16th - November 14th	0°C
		Winter	November 15th - March 15th	-10°C
Netherlands	NEN EN 14214	Summer	1st May - 30th September	0°C
		Winter	1st December - 29th February	-15°C
		Rest of year		-5°C
Portugal	NP EN 14214	Summer	1st April - 14th October	0°C
		Winter	1st December - 28/29th February	-10°C
		Spring	1st March - 31st March	-5°C
Spain	UNE EN 14214	Summer	1st April - 30th September	0°C
		Winter	1st October - 31st March	-10°C

Source: http://www.biofuelsystems.com/biodiesel/specification.htm

4.1.2 Plant size ranges in EU

The plant size for biodiesel production in Europe ranges between 12,000 to 250,000 ton biodiesel per year. Table 4-4 summarizes some aspects of these plants including feedstock used, production technology, plant capacity and investment. Technologies were information was found are described in brief in this section.

Table 4-4: Summary of Biodiesel Production Plants Examples in EU Member States

Biodiesel Plant/Country	Feedstock	Prod. Technology	Capacity	Investment
Biodiesel Kärnten/ AT	Multi Feed	BDI technology	50,000 t/a	14,5 Mio €
Agropodnik / CZ	RS oil	Oil mill+ Campa biod.	50,000 t/a	7-8.5 Mio €
ADM Connemann/ DE	RS oil	Oil mill+ Connemann	1,130 Ml/yr	10 Mio €
BIO Oelwerk Magd./DE	RS oil	Oil mill+ Connemann	50,000 t/a	20 Mio €
MUW in Greppin /DE	RS oil	Continuous/Dr Pollert	150,000 t/a	25 Mio €
SARIA Bioindustries/DE	Agri. & food waste	BDI technology	12,000 t/a	10 Mio €
Novaol SRL / IT	RS & SF	Ballestra	250,000 t/a	n.a. Mio €
Ekoil Biodiesel/Slovakia	Multi Feed	Ekoil process	40,000 t/a	2 Mio €
Stocks Valles /	Multi Feed	BDI technology	30,000 t/a	4.5 Mio €
Diester Industries	Multi-Feed	Transesterification	2,250 Ml/yr	NA
Biopetrol Industries	RS oil	Transesterification	840 Ml/yr	500-700 mio €
Verbio / De	Multi-Feed	Transesterification	510 Ml/yr	300-400 mio €
Cargill / De	Multi-Feed	Transesterification	42 Ml/yr	33 million €
Biodiesel Amsterdam	UCO Tallow	Transesterification	100,000 t/yr	80 mio €

RS Oil: Rapeseed oil, SF: Sunflower, UCO: Used cooking oil, BDI: Biodiesel International

Source – European Biofuel Technology Platform

4.1.3 Economic Assessment of Biodiesel

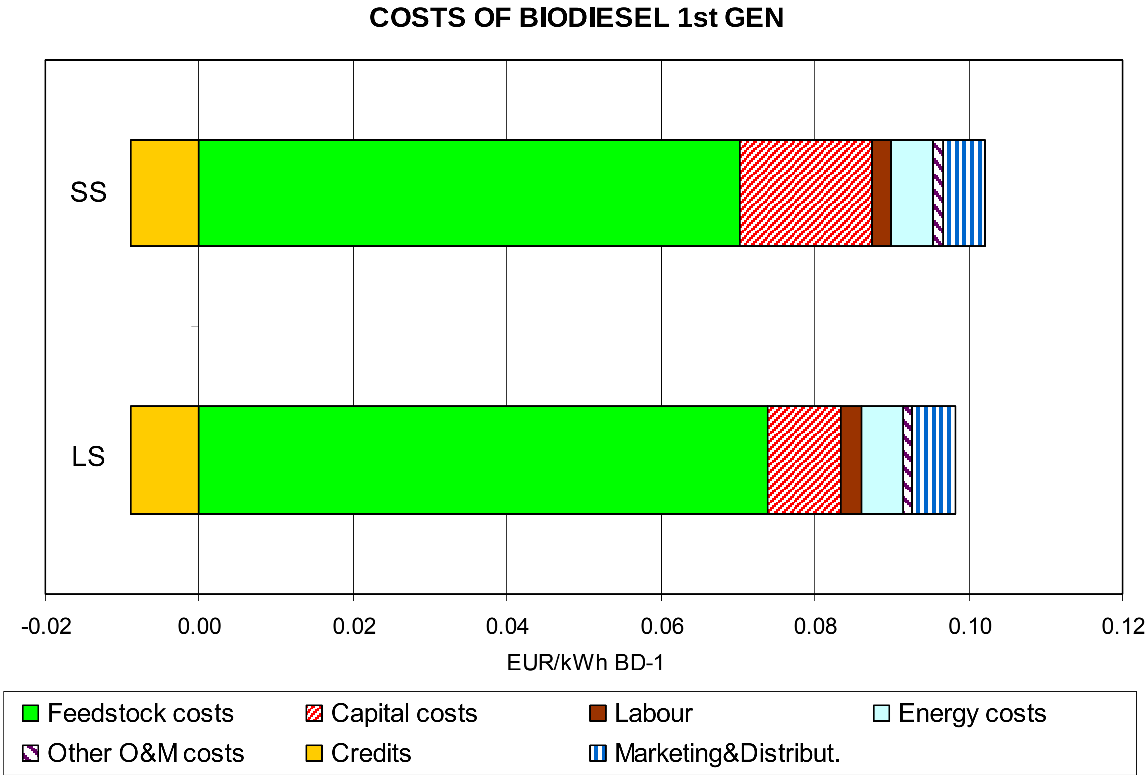


Figure 4-4 describes the current (2010) costs of biodiesel produced from rapeseed and sunflowers – the most popular feedstock for biodiesel in Europe. Obviously, feedstock costs hold the largest share of about 80% of the overall production costs followed by capital and operating costs. Some other interests in the production process are revenues/credits from by-products (such as glycerine). They can have a significant positive impact in cost of production, if considerable additional amounts are produced.

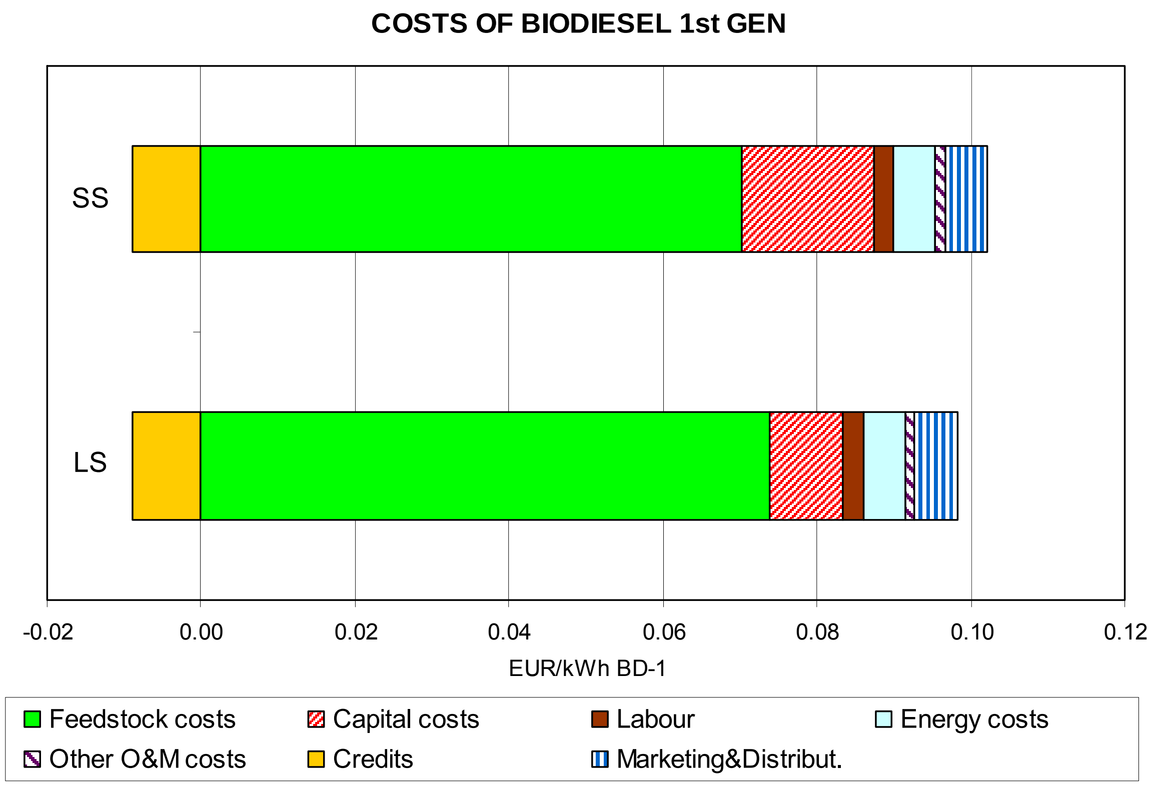


Figure 4-4: Costs of Biodiesel 1st generation production from rapeseed or sunflower seeds (costs as of 2010)

The feedstock producer prices are volatile over time and also vary by region and country. In Figure 4-5 producer prices for rapeseed, wheat, maize and sunflower seed in selected European countries are illustrated in comparison to corresponding yields. Across the European countries the agricultural yield of feedstock is – with the exception of maize – very different. For example, yield of wheat in Spain is two times lower than in Germany. Further, rapeseed yield in Germany is much higher than in Italy and Spain. It can be stated that for the analysed feedstock there is no clear correlation between producer prices and yields.

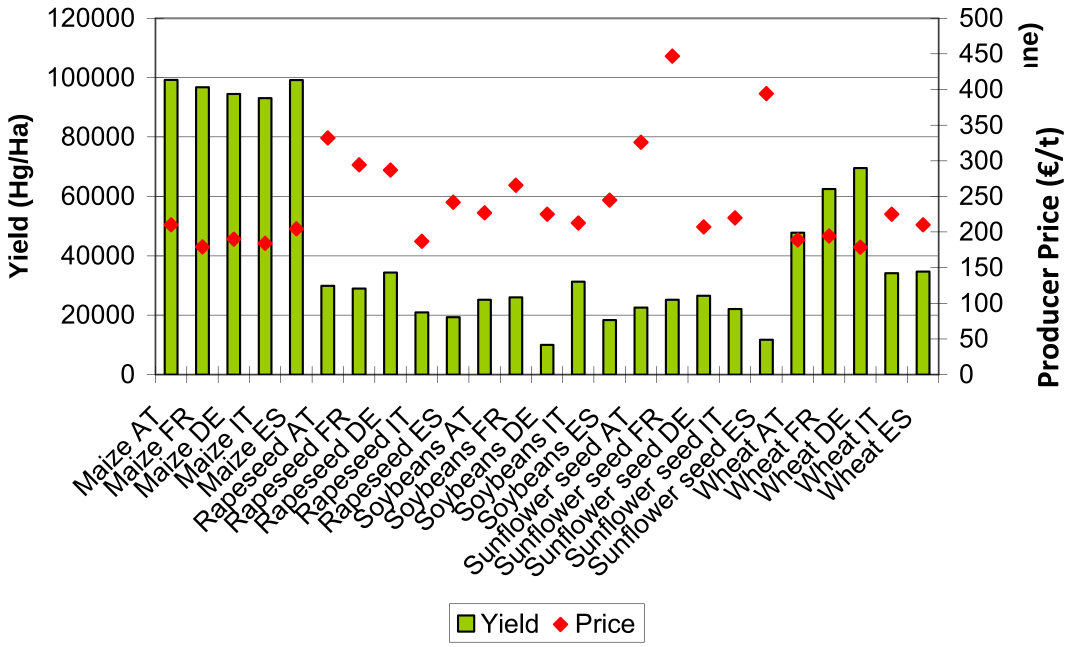


Figure 4-5: Feedstock prices vs. yields in selected EU countries 2007

4.1.4 Environmental assessment of Biodiesel

Rapeseed to FAME & FAEE (RME & REE)

The RME (rapeseed to FAME) provides various alternative disposal routes especially the protein meal and glycerin co-products. Meal is either used as animal feed or to generate biogas to provide heat and power for the plant. Glycerin is used either as a chemical or as animal feed or to generate biogas. Surplus biogas is used to generate electricity but no credit is given for surplus heat. Other results we can obtain from the same pathways as the RME but with methanol replaced by bioethanol (REE). Although technically feasible, this process is not commercially used so far.

Data presented in the Database concerning the RME (glycerin as chemical, meal as animal feed) give a total WTT GHG emitted best estimate of 43.5 (g CO_2 eq/MJf). This best estimate covers a range of 38.5 to 52.3. The pathway followed covers the rapeseed farming, the rapeseed for road transport, the raw oil to refined oil, the refined oil to FAME (transesterification) with glycerin as a chemical and biodiesel distribution (blended). The composition of results is detailed in Table 4-5.

Table 4-5: WTT Emissions for Biodiesel (RME)

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	**29,61**
Transport to plant	g CO_2eq/MJ	**0,42**
Oil Mill	g CO_2eq/MJ	**2,84**
Esterification	g CO_2eq/MJ	**10,38**
Distribution & Retail	g CO_2eq/MJ	**1,27**
Total WTT Emissions	g CO_2eq/MJf	**43,5**

Sunflower seed to FAME (SME)

The pathway is the same as for rapeseed, but using sunflowers as feedstock and includes biodiesel from sunflower (SME) with glycerin as chemical, meal as animal feed. Steps are cultivation, drying, transport (road 50km), oil mill, SME manufacture and distribution & retail. Total WTT emissions equal to a best estimate of 32.2 g CO_2eq/MJ with a min. of 29.8 and 34.9. The WTT emissions are illustrated in Table 4-6.

Table 4-6: WTT Emissions for Biodiesel (SME)

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	**17,22**
Transport to plant	g CO_2eq/MJ	**0,28**
Oil Mill	g CO_2eq/MJ	**2,73**
Refining+esterification	g CO_2eq/MJ	**10,38**
Transp. To refueling st.	g CO_2eq/MJ	**0,83**
Total WTT Emissions	g CO_2eq/MJf	**32,2**

Soybeans to FAME

The pathways are based on soya bean farming in Brazil, transport of soybeans over land and sea to Europe for oil/meal and FAME production locally. In CONCAWE soya meal attracts a credit related to wheat substitution. In a variant 1 case, glycerin is used as animal feed. In variant 2, glycerin is used to generate biogas to supply part of the FAME plant energy requirement. Values we retain are quite smaller in comparison to some results offered in previous CONCAWE analysis where cultivation and transport to plant emissions seems quite high (56.40) in comparison to calculated 18.56 and 11.81.[4] The results are included in

4 Such difference need to be better investigated in order to make evidence of reasons that drive to such range.

Table 4-7.

Table 4-7: WTT Emissions for Biodiesel (Soybeans)

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	**18,56**
Transport to plant	g CO_2eq/MJ	**11,81**
Oil Mill	g CO_2eq/MJ	**5,46**
Refining +Esterification	g CO_2eq/MJ	**10,38**
Distribution & Retail	g CO_2eq/MJ	**1,27**
Total WTT Emissions	g CO_2eq/MJf	**47,50**

Palm oil to FAME

Palm fresh fruit bunches are crushed and processed at the site (i.e. South-East Asia) to produce palm oil which is then shipped to Europe for processing into FAME. Some variants cover important aspects of palm oil production (how organic waste material is disposed off). Traditionally it is left to rot in anaerobic conditions in a lagoon generating CH_4. In another variant these emissions are deemed to have been avoided. In another situation a heating oil credit is given for heat generated with the crushed bunches. Another option is derived where glycerin from FAME production is used to generate biogas and supply to the FAME plant energy needs instead of chemical substitution. The emissions we focused on are from imported palm oil, glycerol to biogas, CH_4 emissions from waste. Results are displayed in Table 4-8.

Table 4-8: WTT Emissions for Biodiesel (Palm oil)

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	**14,2**
Transport to plant	g CO_2eq/MJ	**4,35**
Oil mill	g CO_2eq/MJ	**22,52**
Esterification	g CO_2eq/MJ	**10,38**
Distribution & Retail	g CO_2eq/MJ	**1,27**
Total WTT Emissions	g CO_2eq/MJf	**52,8**

4.1.5 Technical innovation potential for Biodiesel

Diesel engines have the ability to operate on a variety of biodiesel produced from different feedstock. However, major issues with bio-diesel fuel are fuel filtration, storage life, storage temperature, temperature tolerance and the affinity to hold water.

Cold Starting - Cold starting can sometimes be a problem when using biodiesel blends. This is due to biodiesel thickening more during cold weather than fossil diesel. Possible solutions to overcome this problem can be having an onboard fuel heating system or using biodegradable additives which reduce the viscosity (ESRU, University of Strathclyde). Noticeably this kind of problem occurs mainly with higher blends of biodiesel.

Clogging - Another problem is biodiesel's behavior as a **solvent** that can cause clogging with higher concentrations of biodiesel ultimately resulting in chocking of filters. Changing the fuel pump shortly after switching to high-concentration biodiesel blends can be a possible solution. Moreover, biodiesel can also cause degradation of fuel systems and break down of rubber components. Some other parts such as fuel lines and fuel pump seals can also get damaged due to their rubber or rubber-like composition. The remedy can be replacing such components (ESRU, University of Strathclyde).

Biodiesel fuel supports bacterial (microbial) growth that can clog fuel lines, filters and injectors. B20 diesel fuel, with no more than 20% biological content supports these microbes readily. Also, Bio-diesel is less stable over time, significant degradation of fuel starts with the fuel older than 90 days. Resultantly, Operating performance and lifetime of fuel injection systems can be adversely affected due to use of fuels with reduced stability (Puetz, 2009). In cold weather stability of the fuel is further decreased and it starts getting clumpy, like wax, and other particulates come out of the solution. Water aggregating from the humidity dilutes the fuel, supports bacterial growth and rusts the fuel system components. Moreover, in cold weather water can form ice crystals leading to blockage of fuel lines and damaging pumps (US Department of Transportation, 2007).

Also, in some engines, there can be slight **decrease in fuel economy and power**. On an average, there is about a 10 percent reduction in power. In other words, it takes about 4.16 liters (1.1 gallons) of biodiesel to equal 3.78 liters (1 gallon) of standard diesel. Another major drawback to biodiesel is connected to the bigger picture, namely the market and associated logistics. Of these, the most important is **cost**. According to the EPA, pure biodiesel (B100) can cost anywhere from 1.47 € to 2.26 € ($1.95 to $3.00) per gallon, while B20 blends average about 22 to 30 € cents (30 to 40 $ cents) more per gallon than standard diesel.[5] This all depends on variables such as the feedstock used and market conditions.

Quality control system - Biodiesel production facilities need to be accredited and follow quality definitions for the production process. The implementation of a quality monitoring system for the final biodiesel blend product at gas stations is required.

[5] Exchange rate as per 29th April 2010

4.2 Bioethanol Technology Assessment

4.2.1 State of the art

Bioethanol is known as a petrol substitute fuel obtained from the fermentation of renewable starch / sugar rich feedstock sources. The production of bioethanol from traditional means or 1st Generation bioethanol is based upon starch crops like corn (e.g. US) & wheat and from sugar crops like sugarcane (e.g. Brazil) and sugar beet. In Europe bioethanol is commonly produced from sugar beet, wheat, barley and potatoes. Furthermore, the fermentation of pre-treated lignocellulosic material such as wood and straw is also being developed at the moment at pilot/early commercial scale plants in various parts of the world, called as 2nd Generation bioethanol or specifically cellulosic ethanol. It is important to note that ethanol can also be obtained by the so called alcohol synthesis reacting ethylene gas $(CH_2)_2$ with water or steam. The ethanol productivity per land area is, in the EU, in the order of 41.86 - 83.73 GJ/ha (1 – 2 toe ethanol/ha) for cereals as feedstock and 83.73 - 125.60 GJ/ha (2 – 3 toe ethanol/ha) for sugar beet (SET-Plan, 2009).

Bioethanol is chemically the union between hydrocarbons, water and one OH-group (alcoholic group), for example ethanol or ethyl alcohol (C_2H_5OH) is the most common bioethanol used as transport fuel. It is a clear, colourless liquid fuel, with an aromatic odour and burning taste and is easily flammable. Ethanol is mainly used as a blend with petrol (gasoline) e.g. E5, E10, E15, these blends (especially up to E25) do not require too many changes at engine level. However, few car manufacturers, mainly in Brazil, have developed engines that can run on pure ethanol. Moreover, major concerns with high ethanol blends are vapor pressure within the blends and affinity of alcohol towards water. Theoretically, it is also possible to blend bioethanol with fossil diesel but diesel motors require special developments and modifications and these types of engines are only at R&D stage and are not foreseen to be produced by car producers in the near future. In 2008 the world production of bioethanol accounted 1,382 PJ (66 Billion litres) out of which around 85% was produced just by Brazil and the US (Renewable Fuel Association, 2008). Currently, across the world bioethanol is the most common biofuel, accounting for more than 90% of total biofuel usage (IEA, 2007).

The main biofuels currently introduced in the European market are ethanol and ETBE as a derivative of ethanol. ETBE (ethyltertiarybutylether) is only a partial biofuel, since the butyl part of the molecule is derived from fossil fuel sources. The current gasoline fuel specification EN228 allows a blending of 5 vol.-% of ethanol (E5) or 15 vol.-% of ETBE to gasoline. All filling stations in Sweden and Germany already offer E5 and some other countries (like France) promote ETBE blending with gasoline. E10 fuel is compatible to most of the fleet vehicles except some old DI gasoline vehicles with first generation fuel injection systems. E85 fuel (blend of 85% ethanol+15% gasoline) is widely available in Sweden, being introduced in France, and under discussion in Spain and Germany. The use of E85 however, requires some adaptations of materials of the fuel supplying system and the engine. This is due to the corrosive impact of ethanol and its worse cold starting properties compared to gasoline. A number of car manufacturers offer flex fuel vehicles approved for usage of E85, neat gasoline, and any mixtures thereof, mainly on the Swedish market and few models on the French and German market (European Biofuel Technology Platform, 2009).

Based on the feedstock there are different processes to obtain starch/glucose that later is fermented into alcohol (bioethanol). This part describes the general production processes which include feedstock preparation, glucose fermentation, distillation and rectification. For the case of sugar and starch crops, the feedstock preparation required before the fermentation process has been explained in the *feedstock* (*biomass) treatment.* Lignocellulosic biomass is converted to ethanol by acid or enzymatic approaches breaking apart or hydrolyzing the hemicelluloses and cellulose chains to form their components sugars. These sugars are then fermented into bioethanol similar to other sugar and starch crops.

The latest concept in bioenergy utilization processes from biomass feedstock is "*Biorefineries*". It refers to enhance the combined production systems and adding value at all stages of production chain with potential and technical feasibility that can help to fully exploit the biomass feedstock for multiple purposes of food, bio-based chemicals, synthetic materials, biofuels and biogas (that can be used to produce electricity and heat). The production of ethanol could either be embedded in such a bio-based refinery or be the start point for this technology. The following section states the production of bioethanol from sugar and starch crops (sugar beet and wheat) as the main reference feedstock in Europe as they are already available at commercial level.

4.2.1.1 Production Process

The production of alcohol from agricultural materials is not a new practise. Fermentation processes of sugar derived from crops followed by distillation is a well established commercial technology and has been improved considerably over past few years. Ethanol is commercially produced two ways, using either the *wet mill* or *dry mill process*. Wet milling involves separating the grain kernel into its component parts (fibre, protein, and starch) prior to fermentation. And in the dry mill process entire grain kernel is ground into flour. The starch in the flour is converted to ethanol during the fermentation process, creating carbon dioxide and distillers' grain. As stated earlier, bioethanol is obtained by transforming sugars (sucrose, glucose normally obtained from starch) with the help of enzymes in the fermentation processes, followed by a distillation, rectification and dehydration process. The preparation process of *'hydrolysis'* is very crucial for starch crops (such as wheat, corn, barley or potatoes) as the starch should be first converted into sugar (glucose, fructose, sucrose etc.) which later undergoes fermentation process. At first the feedstock is delivered by truck or rail to the ethanol plant where it's loaded in storage bins designed to hold the supply for plant for 7–10 days. The feedstock then goes for *Milling process* where it is screened for removing debris and ground or crushed (depending on the nature of feedstock). Then the *cooking process* is done where the starch is physically and chemically prepared for fermentation. There are three main processes involved in cooking namely, *Hot Slurry, Primary Liquefaction and Secondary Liquefaction.* In hot slurry process the feedstock is mixed with water, the pH is adjusted to about 5.8, and an alpha-amylase enzyme is added. The slurry is heated to 82–90°C for 30–45 minutes to reduce viscosity. In primary liquefaction process the slurry is then pumped through a pressurized jet cooker at 105°C and held for few minutes and cooled subsequently. Later-on in secondary liquefaction, the mixture is held for 1–2 hours at 80–90°C to give the alpha-amylase enzyme time to break down the starch into short chain dextrin. After pH and temperature adjustment, a second enzyme, glucoamylase, is added and the mixture is now considered ready for fermentation.

4.2.1.1.1 Alcohol Fermentation (Batch and Continuous Processes)

In general, the fermentation process uses yeast to transform sugar/saccharine into ethanol and carbonic acid. Yeast produces an enzyme called *zymase* that transforms glucose into ethanol. There are three fermentation processes depending on the type of feedstock namely *the batch process, the cascade process* and *the continuous process*.

Batch Process - The batch process is the classical fermentation process that has been used in the alcohol industry for more than 100 years. The input mash receives a substantial amount of yeast and air until it reaches a proper composition. This mash is then continuously transported until the fermentation tank is filled up. At this time the fermentation has already begun and will continue until ethanol is produced. This process has been improved in the last few years considerably

(Kaltschmitt et al. 2002, Vogel et al. 2004, Schmitz 2003, Wyman 1998). The batch process has a strong and robust fermentation process. After that, the ethanol is obtained to be distilled and rectified.

Cascade Process – The ethanol produced during fermentation process has high water content. In the first fermentation process the mash is being aerated to avail the optimal yeast amount. In the second fermentation tank, the sweet mash is converted to ethanol through anaerobic fermentation processes. Some of these processes may also include yeast washing and recovery. The cascade production process as illustrated has demonstrated a higher efficiency for obtaining ethanol than other processes. One important factor during the process is reducing water content during fermentation, such that extra energy can be saved in subsequent distillation process. Noticeably, this high efficient process also requires careful monitoring of infections if long processing intervals are performed (Thuijl et al. 2003, Schmitz 2003, Wyman 1998).

Continuous Process - This process has only one processing unit where the complete fermentation takes place continuously and yeast is provided with all necessary inputs for processing. There are three important technologies for this continuous process such as the *Uhde process* developed in the 1970's and the *biostill process* and the one from *Kelsall* (Schmitz 2003) characterized by process automation and higher energy efficiency.

4.2.1.1.2 Alcohol Separation and Rectification

After the fermentation process is completed successfully, the alcohol produced should be separated from the fermentation substrate. This separation is performed with the help of a series of distillation, rectification and dehydration steps. The fermented mash is pumped into a multi-column distillation system where additional heat is added. The columns utilize the differences in the boiling points of ethanol and water to boil off and separate the ethanol. By the time the product stream is ready to leave the distillation columns, it contains about 95% ethanol by volume. The residue from this process, called *stillage*, contains non-fermentable solids and water which is pumped out from the bottom of the columns.

Many times, the raw alcohol produced with help of a continuous mash distillation column has a purity of only 82 to 87%. This product requires further cleaning and a higher alcohol concentration in order to be used as a fuel for transport. This is obtained through alcohol rectification which removes contaminants from it considerably increasing its concentration to almost 96%. The proof ethanol still contains about 0.3 to 5% water hence is subjected to dehydration. During the dehydration process it is passed through a molecular sieve to physically separate the remaining water from the ethanol based on the different sizes of the molecules. This step produces completely anhydrous (waterless) ethanol.

4.2.1.1.3 ETBE Production

Another important stage practiced in some EU Member States concerns the transformation of bioethanol by adding isobutylene and forming ethyl tertiary butyl ether (ETBE), which provides all the beneficial properties of ethanol and lowers vapour pressure to the blend. It is commonly produced at the oil refinery and is then included as an additive to gasoline, reducing transportation and distribution costs of blends considerably (Wyman 1998).

4.2.1.2 Ethanol from Lignocellulosic Biomass

Sugar and starch crops constitute only a huge portion of feedstock being used across the world to produce bioethanol. A latest view for producing ethanol from non-food crop is via lingo-cellulosic bioethanol. Most of the plant matter like wood, leaves, agricultural waste consists of cellulose, hemicellulose and lignin. The fibrous cellulose and hemicellulose are basically the carbohydrates consisting of sugar in polymer chains which are not digestible by the common yeast. Therefore, this new technology focuses on producing bioethanol from lignocellulosic feedstock via breaking down the carbohydrate chains into their component sugars for fermentation. The details of this process can be seen in Section 4.4.

4.2.1.3 Biomass Pre-treatment

In general the complete pre-treatment process aims to produce a biomass that is amenable to the subsequent biological, chemical and physical processes to obtain sugars from cellulose. The mechanical pre-treatment of biomass refers to cleaning and reducing the size of biomass in order to destroy its cell structure, making it accessible for the following biological and chemical treatment. The type of process depends greatly on the type of feedstock in order to minimize degradation of the usable substrate and maximize the sugar yield. Various R&D efforts aim to reduce costs significantly in this process. Further detailed information can be found in Hamelinck et al. 2004, Aden et al. 2003. The pre-treatment of biomass feedstock consists of a mechanical pre-treatment that cleans and reduces the size of feedstock followed by a hemicellulose hydrolysis and lignin removal. Afterwards, the cellulose obtained from the pre-treatment is conducted to the major hydrolysis step (acid or enzymatic hydrolysis) where the cellulose is converted into sugars for fermentation.

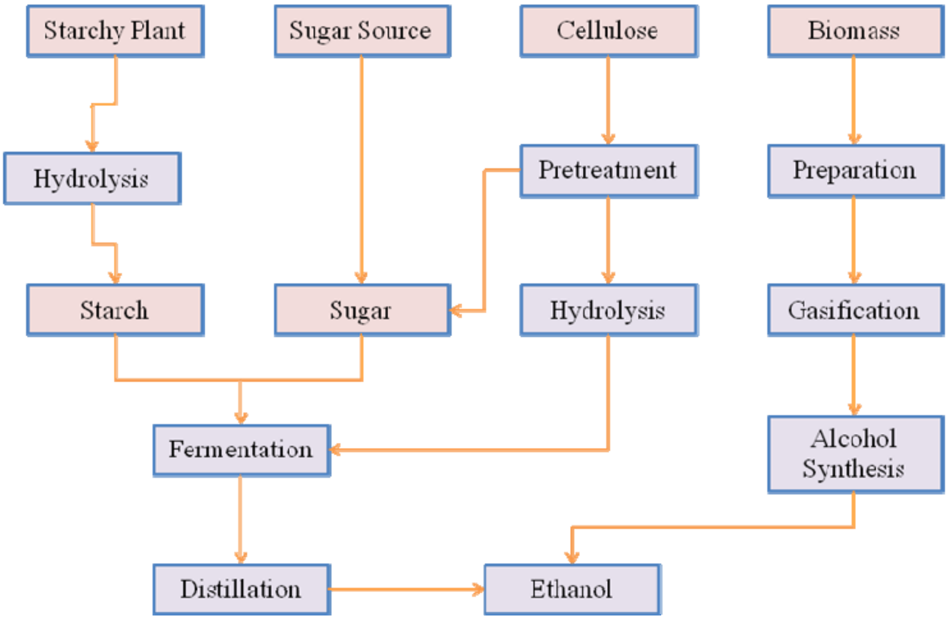


Figure 4-6: Summary Ethanol Production

Source - Own elaboration

4.2.1.4 Classification of the technology

Bioethanol technologies are considered as commercial scale processes for the strict case of obtaining ethanol from biomass feedstock for transport. The technology is based on the production of ethanol for beverages with other product requirements as a automobile fuel. The fermentation processes (batch or continuous) are currently being improved to increase efficiency and reduce energy consumption and especially with the case to expand the feedstock supply base, the pre-treatment options for wood and lignocellulosic material is currently being researched. This is further explained in the section on second generation biofuels. In Europe the existing commercial plants are focused on using one or two types of feedstock which however results in a disadvantageous economic performance in case wheat or sugar feedstock prices fluctuate in volatile global markets as has been the case in the last years. Therefore, a trend is to expand the feedstock base as a strategy to manage economic performance but the processes require adjustments and expansions with significant capital investments. The use of co-products and the added value they represent are a constant activity for research, testing, pilot and demonstration across the existing facilities.

4.2.2 Plant Size Ranges in EU

In recent years various new plants are being built across Europe including 3 new plants in Germany with expected capacities of 500,000 tons per year. Spain has recently announced the construction of a plant in cooperation with Abengoa industries which are leader in the ethanol production in USA too. These projects are based on ethanol production from sugar or starch based crops. Further information about the market development can be found in the biofuels barometer from June 2005 (Biofuels Barometer 2005). The total installed Production capacity of Europe has reached 6 billion litres and another 2 billion litres capacity are under construction. By 2011 the EU production capacity is expected to reach approximately 8 billion litres (SET-Plan, 2009). There are small and large scale production facilities with capacities that range between 50,000 and 300,000 m^3 per year. Table 4-9 includes a list of examples in various EU Member States.

Table 4-9: Summary of Bioethanol Production Plants Examples in EU Member States

Bioethanol Plant/Country	Feedstock	Prod. Technology	Capacity (litres/yr)	Capacity (TJ)	Remarks
Abengoa/Spain	Wheat	Fermentation	510,000,000	10740.5	
AB Bioenergie/France	Wheat, beets	Fermentation	50,000,000	1052.9	
Agroethanol AB/Sweden	Wheat, barley	Fermentation	50,000,000	1052.9	
Crista Union /France	Beet	Fermentation	150,000,000	3158.9	8 different production units
Kwst/Germany	Sugarbeet, molasses	Fermentation	20,000,000	421.2	Ethanol storage space of 22,000 m^3
NBE /Germany	Rye	Fermentation	-	-	
MBE/Germany	-	Fermentation	-	-	
Saint-Louis Sucre/France	Beet and Molasses	Fermentation	15,000,000	315.9	
Sauter/Germany	Rye	Fermentation	310,000,000	6528.6	
Südzucker/Germany	Wheat	Fermentation	260,000,000	5475.6	
Sekab/Sweden	-	Fermentation	-	-	
Tereos/France	Wheat, beets	Fermentation	50,000,000	1052.9	

4.2.3 Economic assessment of Bioethanol

Ethanol production is rising rapidly in many parts of the world mainly due to higher oil prices, which are making ethanol more competitive, especially in combination with government incentives. The EU is today the third largest producer of bioethanol in the world behind the United States and Brazil, but its production is much lower than in the first two (Ajanovic 2011).

Preferred feedstock for ethanol production is sugarcane, corn, wheat, sugar beet and barley. Depending on climatic factors different feedstock are used in different regions. Mostly due to the different feedstock and energy costs, bioethanol costs are very different in different countries and regions. European ethanol production is more expensive than production in Brazil and United States. Production costs for ethanol are at present lower in Brazil, less than half of the costs in Europe. Figure 4-7 illustrates bioethanol costs in Europe for two different feedstock, sugar beet and wheat, as well as for large- and small-scale processing plants. It is obvious that ethanol costs are much lower in case of the large scale production. The largest part of the total ethanol costs are feedstock costs. Main by-products of ethanol production are pulp and protein-rich Dried Distillers Grains with Solubles (DDGS), which could have positive impact on total ethanol production costs.

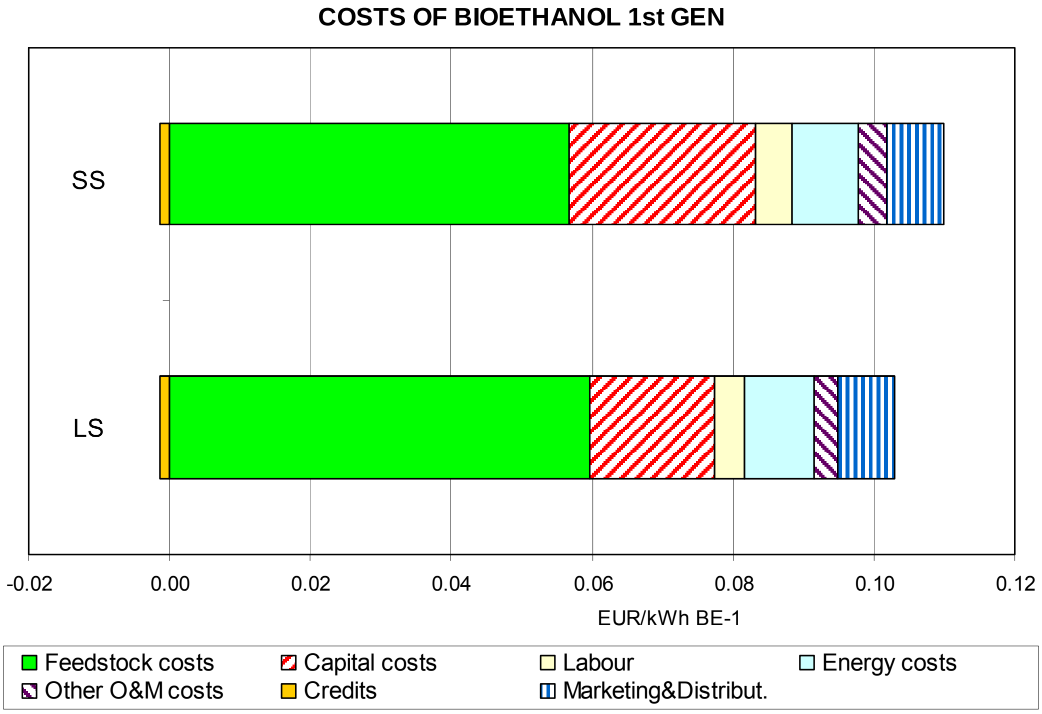


Figure 4-7: Costs of bioethanol 1st generation from wheat or maize (as of 2010)

4.2.4 Environmental assessment of Bioethanol

Ethanol from Wheat

Five options are taken into account for the assessment; these different pathways are considered according to way of power supply the ethanol plant:

First option is to heat the ethanol plant with a NG-fired steam boiler and electricity is imported from the grid. DDGS is used either as animal feed or as a co-fuel in a coal power station. The straw is not used and assumed to be ploughed back into the field.

Second option considers the energy to ethanol plant provided by a NG-fired CCGT sized to provide the required heat. Surplus electricity is produced and exported, and in CONCAWE this drives to a credit calculated by comparison to a state-of-the-art stand alone NG fired CCGT (benefit from use of CHP in the ethanol plant).

Third option focuses on the energy input for bioethanol plant provided by lignite or brown coal-fired CHP plant sized to provide the required heat.

Fourth option has energy for the ethanol plant provided by a straw-fired CHP plant sized to provide the required heat. Fertilizer inputs are adjusted to compensate for the loss of soil nutrients from straw.

Finally, fifth option considers the heat and power requirements of the ethanol plant are provided by biogas produced from DDGS. A small electricity import is still required. A credit is generated for export of fermentation residue return to the wheat field as fertilizer.

Values proposed consider the conventional process using NG-fired steam boiler and electricity imported by the grid, with DDGS used as animal feed.

Table 4-10: WTT Emissions for Bioethanol from wheat

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	23,43
Transport to plant	g CO_2eq/MJ	0,38
Ethanol Plant	g CO_2eq/MJ	21,12
Distribution & Retail	g CO_2eq/MJ	1,54
Total WTT Emissions	g CO_2eq/MJf	46,5

Bioethanol from Sugar beet

Sugar beet to ethanol pathways analyzed cover three alternative pathways. In the first and second- pulp is used as animal feed while slops are either not valorized or used as feedstock to biogas. In third alternative both pulp and slops are used for producing biogas. The values stated retain the option where pulp is used as animal feed slops to biogas.

Table 4-11: WTT Emissions for Bioethanol from sugar beet

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	11,54
Transport to plant	g CO_2eq/MJ	0,84
Ethanol plant	g CO_2eq/MJ	9,47
Distribution & Retail	g CO_2eq/MJ	1,54
Total WTT Emissions	g CO_2eq/MJf	23,4

Bioethanol from Sugarcane

Sugarcane is grown and turned into ethanol in Brazil and the bagasse is used as fuel. Ethanol is shipped to Europe where it is blended with gasoline. An updated analysis proposed modify a former option where bagasse was used to externally generate heat, displacing fossil diesel. In the updated version the option is disallowed and no credit is generated.

Table 4-12: WTT Emissions for Bioethanol from sugarcane

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	14,45
Transport to plant	g CO_2eq/MJ	0,85
Ethanol plant	g CO_2eq/MJ	0,6
Ethanol shipping	g CO_2eq/MJ	7,69
Distribution & Retail	g CO_2eq/MJ	0,44
Total WTT Emissions	g CO_2eq/MJf	24,2

Bioethanol from Farmed and Waste Wood

Waste/Farmed wood to ethanol analysis drives to the more generic cellulose-to-ethanol pathways where wood is a proxy for a number of possible feedstock. Results are confirmed by a former study by *National Renewable Energy Laboratory* (*NREL*)

Table 4-13: WTT Emissions for Bioethanol from farmed wood

WTT Emissions		Small Scale
Cultivation	g CO_2eq/MJ	6,28
Transport to plant	g CO_2eq/MJ	0,88
Ethanol plant	g CO_2eq/MJ	13,33
Distribution & Retail	g CO_2eq/MJ	1,54
Total WTT Emissions	g CO_2eq/MJf	22,0

Table 4-14: WTT Emissions for Bioethanol from waste wood

WTT Emissions		Small Scale
Waste collection&chipping	g CO_2eq/MJ	0,95
Transport (road+sea)	g CO_2eq/MJ	3,19
Ethanol plant	g CO_2eq/MJ	13,33
Distribution & Retail	g CO_2eq/MJ	1,54
Total WTT Emissions	g CO_2eq/MJf	19,0

4.2.5 Technical Improvement Potential for Bioethanol

During the last three decades the ethanol industry has improved a lot both in ethanol yields and reducing production costs. For example, Brazil has managed to reduce production costs by approximately 3% per year while in the US ethanol production costs have been reduced by two-thirds since the 1980's. All these improvements have been possible through a combination of new, high yielding feedstock varieties, improved cultivation, harvesting, extraction, fermentation and distillation processes. Shifting to larger production plants and adoption of energy-saving technologies coupled with changes in the use of by-products (bagasse, stillage) have increased energy efficiency, and reduced production costs by 2 to 3-fold in the past 30 years (GAVE programme, 2006). Current efforts are mostly focused on improving production yields and lowering energy use, and include improvements of feedstock production; fermentation and distillation (see Table 4-15).

Table 4-15: Technological improvement potentials in fuel-ethanol production chains

Area	Developments	SoA & Potentials
Crop production	High yielding varieties (use of BT); reduced tillage; decline in fertilisation	Reduce feedstock costs 20-30% Commercial. Several infl. factors
Starch hydrolysis	Improved enzyme technology; On-site enzyme propagation	R&D. Scale-up diff. due to use of Enzyme/Feedstock specific
Fermentation	High-concentration wort; CO2 ethanol stripping: continuous membrane bioreactor (removes ethanol, but not yeast); yeast strain selection; continuous fermentation units; yeast immobilization	R&D and Demo. Potential to increase efficiency and reduce O&M costs
Distillation	Pressure-swing adsorption; dehydration with molecular sieves	Advanced technologies can increase efficiency and reduce cost of production
Process control	System automation; integrated thermal engineering (capture and re-use of process heat)	Energy efficiency potential. Increase acceptability
Co-product use	Bagasse combustion; corn stillage refinery; corn-fibre oil and gum	Commercial. Increase eff. And reduces costs by 25-30%. Emissions reduction increase
Genetic Improvements	Feedstock, Enzymes	Can bring down the costs lower by 20-40 Cents of current costs

Source - (Uil, 2003), (GAVE programme, 2006)

Optimization of classical ethanol production from sugars and starch is an ongoing process and will continue in the coming years especially by state-of-the art technology and advanced biotechnology. Overall, the main contributors to the production costs of bioethanol are feedstock and investment costs and –to a lesser extent– energy costs. Bioethanol production costs are most sensitive to feedstock costs, which are subjected to market conditions. This applies especially to bioethanol from sugar beets and grains where raw material costs account for 50-70% of total production costs, whereas this is 25-50% for bioethanol processes based on lignocelluloses. The capital costs are a more important cost driver for lignocelluloses technologies where they account for 30-60% of the production costs. Energy costs are a factor only for conventional bioethanol production with a limited effect on production costs. The oil price is a major, volatile factor for the competitiveness of bioethanol in the transport fuel market, but this applies equally to all types of bioethanol and other biofuels (GAVE programme, 2006).

Between 40 and 45% of the ethanol lifecycle emissions arise from the feedstock production (net of co-product credits) and the remainder is from the ethanol production process (IEA BIOENERGY TASK 39, 2009). Within the feedstock production portion, the GHG emissions are split about equally between emissions associated with land use and emissions associated with fertilizer production and cultivation. The co-product credits are about equal to either the land use emissions or the fertilizer and cultivation related emissions.

Genetic improvement and use of advanced biotechnology in the feedstock and enzymes used in process have been far and well recognized to maximize the ethanol production (Dinus, 2001). Exploitation of advancement in trait (of enzymes and fungi used in fermentation process), breeding, and gene transfer technologies are few techniques that provide promising solutions to enhance productivity and efficiency. The cost of ethanol can come down to by 40 cents per gallon over the next ten years by taking advantage of exciting new tools in biotechnology that can improve yield and performance in the conversion process (Wooley, Ruth, Glassner, & Sheehan, 2009).

Very High Gravity fermentation technology - Doing the fermentation process at high yeast concentrations can result in higher ethanol productivity per unit fermenter volume and higher starting ethanol concentration for distillation. The dissolved solids in feedstock substrate above 30 wt/vol% can lead to more than 16 vol% of ethanol after fermentation (EPM, 2006). The yeast can be later recovered by centrifugation and recycled to the fermenter in a batch processes. Many advanced continuous production processes use *saccharification and fermentation (SSF)* combined with yeast propagation. This allows a higher concentration of yeasts in the fermentation process thus optimizing productivity. Furthermore, modern plants are equipped with computerized process control reducing labor costs.

Quality and productivity improvements of bioethanol production are achieved by using **Optical sensor system**. Bioethanol is produced by the fermentation of carbohydrate rich substrates and subsequently is distilled under controlled conditions of pressure and temperature. After first distillation the ethanol solution contains, approximately, 50% of water and 50% of ethanol. In order to obtain a solution with 95% of ethanol (dehydrated/anhydrous ethanol), a second distillation by extractive distillation and pervaporation membranes techniques is done. If ethanol does not meet the required quality specification, it becomes necessary to reprocess the ethanol which increases process time and costs. The optical fiber sensor technology facilitates the real time liquid concentration in ethanol-water system and improves the quality and efficiency of ethanol production (Gusken, et al.).

Use of **thermophilic microorganisms** – This is a latest development in ethanol fermentation process. Thermophilic microorganisms (especially fungi) grow and ferment optimally at temperatures of 50°C and higher, are tolerant to fluctuations in and can ferment a broad range of sugars. They also have rapid growth rates and high activity with increased production rates (TMO Biotech, 2006). During the ethanol production process up-stream liquefaction usually takes place at higher temperatures while the downstream distillation takes place at higher temperatures as well. Thus, the use of thermophiles for fermentation can potentially save cooling and heating operations and energy use.

Improvement of bioethanol recovery by **advanced filtration membrane**. As illustrated above the recovery of ethanol by a pervaporation separation technique can be enhanced by employing a silicone rubber-coated silicalite membrane. Ethanol recovery can be improved by using ethanol permselective silicalite membranes coated with *KE-45 silicone rubber* as a hydrophobic material. This process may lead to the ethanol with concentration 67% (w/w), and 10 times higher the amount than using a non-coated membrane (Ikegami, et al., 2003).

4.3 Biogas Technology Assessment

4.3.1 State of the art

The term "biogas" refers to the gas produced by biological breakdown of organic matter in the absence of Oxygen (anaerobic digestion). During the bio-chemical process various types of bacteria break down the organic matter (feedstock) to form a secondary energy carrier, a burnable gas which mainly consists of methane (between 50-75%), carbon dioxide (between 25-45%) and few more gaseous components like water vapors, Carbon Monoxide (CO), Hydrogen (H), Nitrogen (N) etc. The process of biogas generation by bacteria goes through several complex biological processes being carried in a closed environment (called as digester or fermenter). This process is similar to what takes place in the rumen of a cow, so biogas plants are often referred as anaerobic digesters (AD) or anaerobic fermenter.

Biogas can be produced from a huge variety of organic waste (containing carbohydrates, fatty acids, cellulose and proteins etc). Anaerobic decomposition and formation of methane commonly occurs when organic waste are stockpiled (in fermenters) or used as landfill, or when immersed in water, as occurs naturally in swamps. The speed of the digestion process is mainly influenced by the composition of the feedstock. Biogas can be used to generate electricity, heat and biofuels and the fermentation residues, called digestate, can be used as a fertilizer.

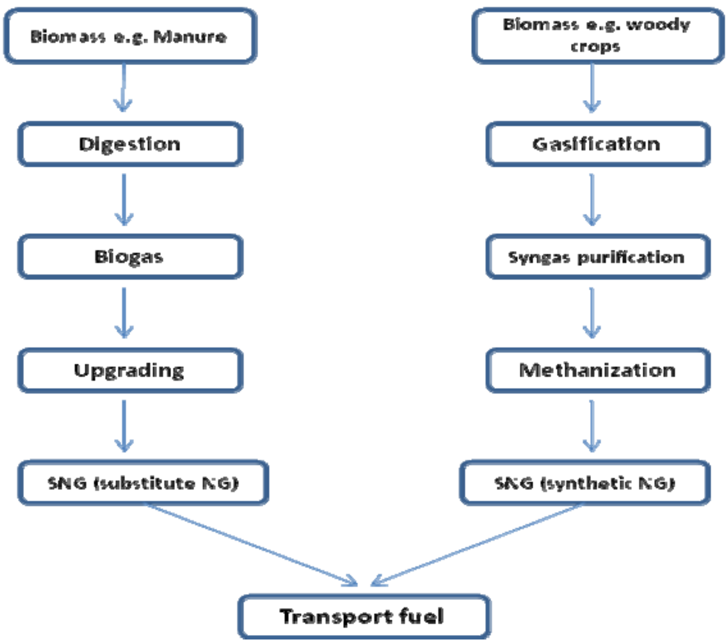


Figure 4-8: Overview of Biogas as transport fuel

Source: own elaboration

According to EurObserv'ER: there is a huge increase in production of biogas in Europe during last years, mainly for production of electricity by cogeneration (76.1% of increase in electricity production between 2006 and 2007). The electricity produced by cogeneration represented 58.4% of electricity production from biogas compared with 55.3% in 2006. However, the amount of heat produced from biogas, increased by 2.5% last year to 149,426,892 GJ (356,900toe) (Markets & Finance for Biomass and Biofuels, 2008). According to another figure by EurObserv'ER, out of total 247,021,200 GJ (5,900 Ktoe) biogas in Europe, 49% is produced by Landfill gas, 36% from agricultural plants and 15% by sewage sludge treatment (COGEN Europe Annual Conference, 2009). The European biogas electricity production in 2006 was 62,179,200 GJ (17,272 GWh) per year, of which 26,416,800 GJ (7,338 GWh) was produced by Germany alone. Biogas in Europe now represents 1.2% of the annual production of electricity and nearly 10% of renewable energy, with an installed power close to 1500MW (Energy Solutions - Waste-to-Energy).

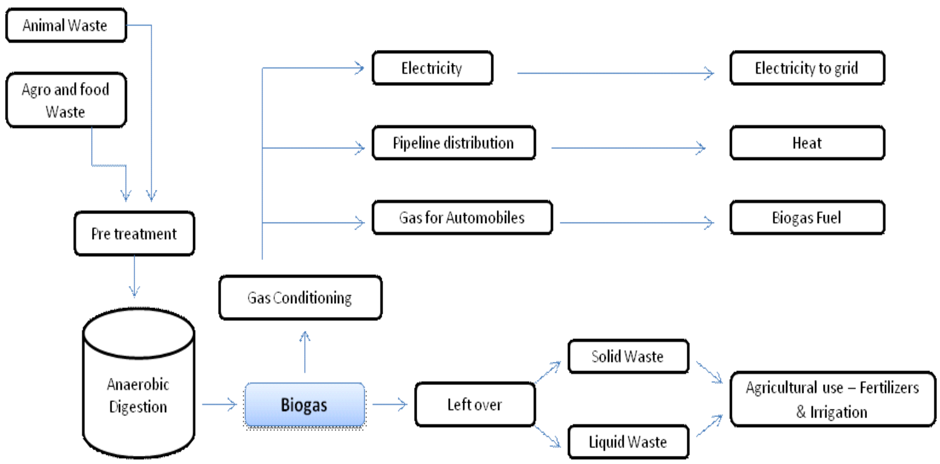


Figure 4-9: Overview of Biogas production and utilization

Source – www.theukproject.com

4.3.2 Technical innovation potential of Biogas

Once upgraded to the required level of purity (and compressed or liquefied), biogas can be used as an alternative vehicle fuel in the same forms as conventionally derived natural gas. The market for biogas as vehicle fuels has been growing rapidly the last 2-3 years. Today there are 12,000 vehicles driving on upgraded biogas/natural gas and the forecast predicts 500 filling station and 70,000 vehicles by 2010 (Persson, 2007). Particularly in Europe, with about 1,500 vehicles and 22 biogas refueling stations, Sweden is the most advanced country. It is followed by Switzerland which has about 600 biogas vehicles running on a mix of biogas and natural gas. Also, the cities of

Lille (France, 124 vehicles), Reykjavik (Iceland, 44 vehicles) and Roma (Italy, 12 vehicles) developed viable and important biogas fleet realizations (Plombin, 2003).

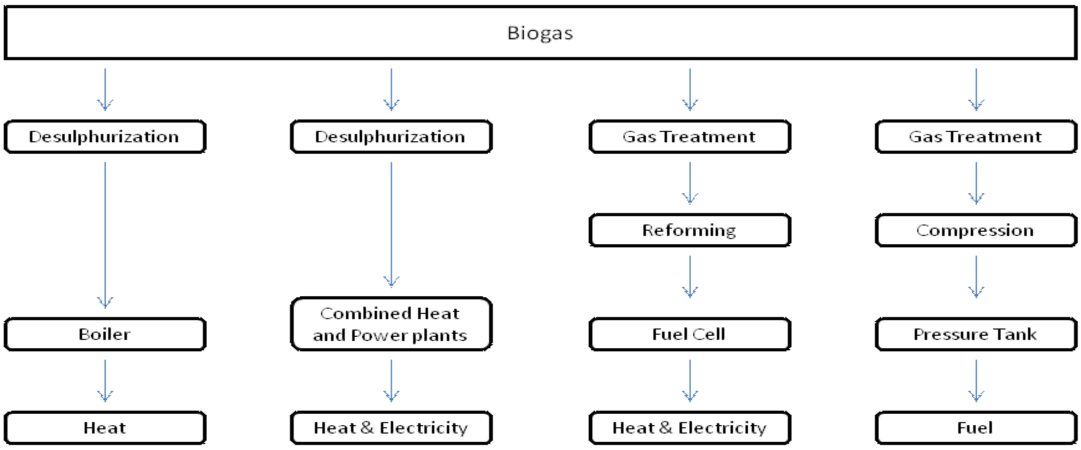


Figure 4-10: Biogas upgrading & utilization

Source – IEA, 2005

According to Persson et al. (2006) one of the most important and efficient ways of integrating the biogas into the entire EU energy sectors is by upgrading the biogas to natural gas quality and integrating it into the natural gas grid. The bottleneck however in this area is the economy of each treated m^3-biogas, by various available upgrading technologies. Typical costs for an upgrading plant treating $200m^3$ per hour of raw gas are in the order of 1.5 Euro cents per kWh (Margareta Persson, SGC). The cleaning and upgrading of Biogas is a must due to i) Preventing mechanical wear, ii) Preventing corrosion, iii) Enhancing calorific value of the gas, iv) Increasing driving distance (better average), v) Standardization of the gas for even fuel quality.

Table 4-16: Biogas Upgrading Processes

Process	Description
Adsorption (PSA – Pressure Swing Adsorption)	CO_2, higher CxHy, H_2S, SI-,Fl-, Cl-components, odor will be removed by activated carbon / carbon molecular sieve like PEG, MEA, DEA[6]
Scrubbing	CO_2 and H_2S are absorbed by means of scrubbing fluid (e.g. water, amines, glycol, ethane, other gases etc.)
Membrane separation	CO_2 is separated due to different permeation rates at a membrane
CO2 liquefaction	CO_2 is liquefied by high pressure and low temperatures and separated by rectification column
Cryogenic Process (Lab stage)	CO_2liquification and rectification at app 50 bar, -80ºC, freezing out of CO_2

Source: Dirkse, E.H.M., Technologies for biogas upgrading (2007)

6 PEG = Polyethylene glycol, MEA = Mono Ethanol Amine, DEA = Di Ethanol Amine

Table 4-17: Performance and Cost Comparison of different processes

Technique	Inv. Cost €	Running costs €	Cost price of upgraded biogas €/Nm^3 biogas	Max. achievable yield %	Max achievable purity %
Chemical Absorption	869,000	179,500	0.28	90	98
High pressure water scrubbing	440,000	120,000	0.15	94	98
PSA – Pressure Swing Adsorption	805,000	187,250	0.26	91	98
Cryogenic Process	908,500	397,500	0.40	98	91
Membrane Separation	749,000	126,750	0.22	78	89.5

Source: IFP project Biogas upgrading, TU Eindhoven, 2008

SNG-digestion – SNG (Substitute Natural Gas) is upgraded biogas produced through digestions consisting mainly of methane, its quality is close to that of natural gas (50-70% CH_4 and 30-50% CO_2). This is a mature technology for waste treatment and is mostly used for combined heat and power (CHP) production. Although SNG-digestion is currently used as an automotive fuel for city buses on a small scale in several European cities, it is expected that CHP will remain the main application of the future due to the limited availability of biomass feedstock.

Biohydrogen (digestion) – Similar to the production of SNG-digestion, biohydrogen can be also produced by anaerobic digestion. Compared to the production process of SNG from biogas, hydrogen production requires an additional process step, i.e. steam reforming, to convert the methane from biogas into H_2 and CO. The hydrogen yield is then increased by applying the water gas shift, which converts the remaining CO with water into H_2 and CO_2. After the CO_2 removal, the end product H_2 remains, this can be used as an automotive fuel.

4.3.3 Plant size ranges in EU

In the coming years the economy of scale of upgrading facilities will be met by competition from economy of numbers of installations. It is obvious that the treatment price will be reduced due to the increasing numbers of upgrading facilities installed and also by the economically downscaling of the upgrading facilities fitting to the modular biogas plants existing in countries like Germany and Austria. In Sweden, Gothenburg Energy is planning a 100 MW gasification and methanisation plant. The plan is that the initial plant of 20 MW will be in operation 2012 and the additional 80 MW in 2016, and inject the renewable methane gas into the gas grid or sold as motor fuel (Persson, 2007).

Table 4-18: Upgrading plants in Sweden, operation or construction phase, 2007

Upgrading method	Number of plants
Absorption, water scrubber, regeneration	15
Absorption, water scrubber, no regeneration	6
Adsorption, PSA	7
Absorption, COOAB	2
Absorption, Selexol	1

Source - (Persson, 2007)

Table 4-19: Biogas plants across the EU – selected examples

Name	Country	Feedstock	Gas production	Electricity Production	Investment (Mio. €)
Ebersdorf Biogasanlage Niederl – Ebersdorf	Austria	Liq. manure, maize silage, sugar beet chips	6,700 m^3 per day	4,000 MWh per year	1,7
Gasdorf - BIO ENERGIE Lukas-Pfeiler-Tscherner GmbH & Co KG	Austria	Liq. manure, maize silage, Rye, Sunflower	6,000 m^3 per day	3,566 MWh per year	1,7
LUTOSA, Leuze-en-Hainaut	Belgium	Waste water from potato	24,000 m^3 per day	137,481 kWh per year	2,0
Domaine des Saugealles	Switzerland	Solid & liq manure (cattle), waste oil, household waste	172,000 m^3 per year	375, 000 kWh per year	0,6 (only installation costs)
Kupferzell	Germany	Manure, organic waste, left over (maize, rye, juice, vegetables)	2.2 Mio m^3 per year	4.3 Mio kWh per year (combined from 2 plants)	1,2
KBK Kussmaul Biokraft Gmbh & Co. KG	Germany	Dung. Liq manure, crop silage, food leftover	2.53 Mio m^3 per year	5.8 Mio kWh per year	2,7
Formigara Formigara (Cr)	Italy	Liq. Manure, silage, milk serum, triticale	15,000 m^3 per day	9.100 MWh per year	3,5
Oczyszczalnia Œcieków - Wielopole S¹deckie Wodoci¹gi	Poland	Sewage sludge	1,300 m^3 per day	1,800 MWh per year	2,5
Bioplinarna Farma Ihan	Slovenia	Liq.manure, slaughter house waste	7,000 m^3 per day	4,500,000 kWh per year	3,0
Planta de Purines de Almazán (Soria)	Spain	Pig Manure	1,500 Nm^3 per day	162 680 kWh per year	12,3
BIOGEN Twinwoods Anaerobic Digestion (AD) Plant	UK	Liq. Manure, food waste	-	10,300 MWh per year	-

Source - Biogas Regions project, 2008

4.3.4 Economic assessment of Biogas

Unlike biodiesel and bioethanol, where feedstock costs have a huge impact on total biofuel cost, in biogas – using mostly waste biomass and manure and green maize as well as grass – the share of feedstock in over-all costs is lower. The largest part of total production costs are capital costs wherefrom a large share is for upgrading biogas to biomethane for feed-in into the CNG grid.

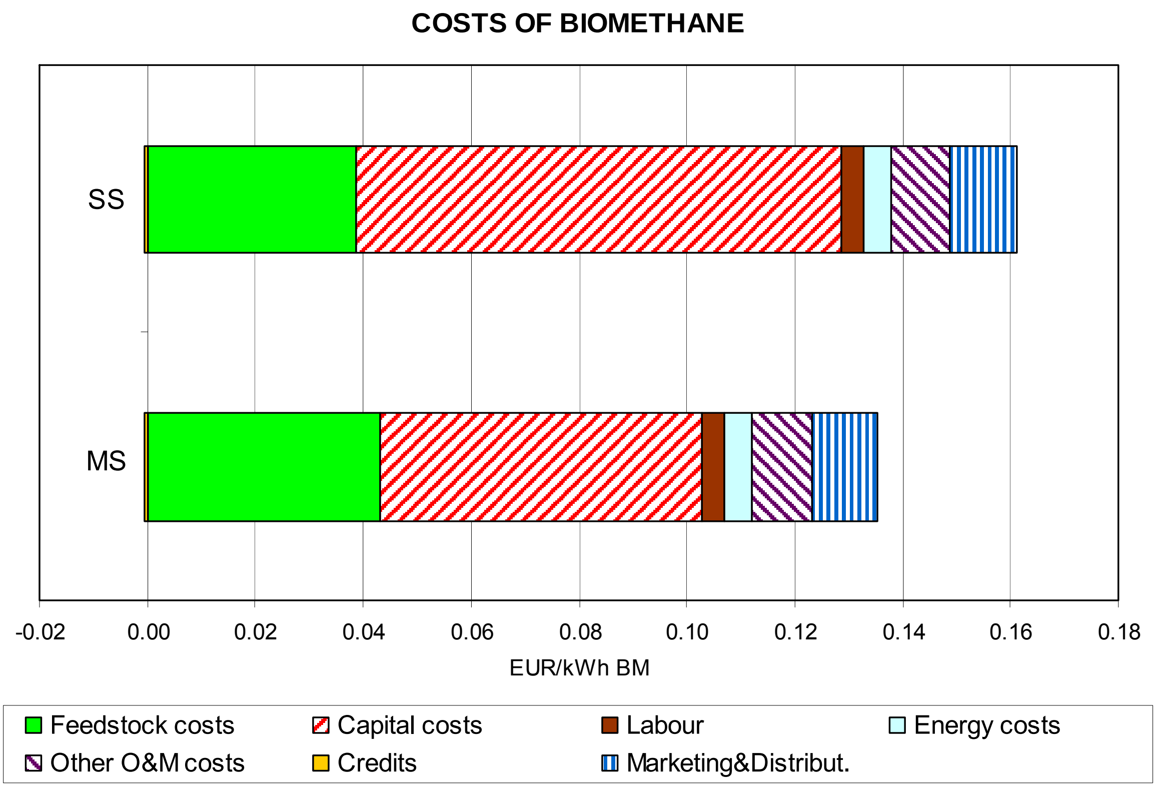


Figure 4-11: Costs of biomethane from a mix of manure, green maize, grass (as of 2010)

4.3.5 Environmental assessment of Biogas

Biogas Production (Manure)

Liquid or dry manure is collected from farms and turned into biogas in a central plant. The biogas is treated and upgraded before being fed into an existing NG pipeline to be used as automotive fuel.

Table 4-20: WTT Emissions for Biogas (manure)

WTT Emissions		Small Scale
Road Transport	g CO_2eq/MJ	2,14
Fermentation and upgrading	g CO_2eq/MJ	7,64
Pipeline	g CO_2eq/MJ	0,00
Filling station	g CO_2eq/MJ	2,86
Total WTT Emissions	g CO_2eq/MJf	12,60

4.4 2nd Generation Biofuels Technology Assessment for Lignocellulosic Ethanol & BTL

2nd generation biofuels are made from non-food crops and inedible waste products, chiefly cellulosic materials. When these fuels enter the market in significant quantities in the next 10-20 years, there are projected to be significant trade flows of both cellulose materials and biofuels. 2nd generation biofuel technologies are divided in bio-chemical and thermo-chemical processes. Biochemical processes mostly focus on the production of ethanol by enzymatic degradation, while thermo-chemical processes can produce a range of fuels including Fischer-Tropsch diesel, biomethanol, bio-DME, SNG etc. It is estimated that Europe itself can supply its own biomass needs for biofuels, but it will come at high cost. There are an estimated 4,300 PJ of residues available in the EU27 with a cost range of 1.1 - 8.1€/GJ; 39% in agricultural residues, 39% in wood processing residues, and 22% in logging chips, roadside hay and construction waste (Bardley, Cuypers, & Pelkmans, 2009).

4.4.1 Lignocellulosic Ethanol - State of the art

Lignocellulosic ethanol is a 2nd generation biofuel produced from cellulose and hemicellulose by pre-treatment and hydrolysis to sugars, and subsequent fermentation. Lignocellulosic biofuels can be produced from agricultural and forest residues, wood wastes, the organic part of municipal solid wastes (MSW) and energy crops such as energy grasses and short rotation forestry. The difference in process steps between starch (as in 1st generation) and lignocellulosic feedstock is that lignocellulosic biomass requires a more complicated hydrolysis stage. The reason for this is that cellulose in the wood contains carbohydrate polymers made up of long chains of glucose and a more complex set of enzymes are required to break the long chains. Therefore lignocellulosic bioethanol is technically more demanding and expensive, however because of higher feedstock supply and expected scale up it would be possible to have equal or lower costs than current bioethanol (RESTMAC, 2006). Lignocellulose utilizes low cost feedstock with the advantage that it is either available in large amounts as agricultural residues (e.g. straw) or that it can be cultivated with high yield per hectare and low energy inputs (GAVE programme, 2006). The lignin, also a major constituent of lignocellulose cannot be fermented to ethanol and hence can be used for heat and power (CHP) production. For the production of bioethanol from lignocellulosic materials several pilot plants are in operation but wide scale commercialization is unlikely to occur before 2015 (OECD/IEA, 2008). Lignocellulosic biofuels are expected to deliver more environmental benefits in terms of GHG emission reduction, land use requirement and higher feedstock flexibility than first generation biofuels, but still the future costs are subjected to uncertainties.

The biochemical processes involve the conversion of cellulose or hemicellulose by enzymes and micro-organisms to bioethanol through a saccharification stage followed by fermentation. On the other hand, Thermo-chemical processes are based *on pyrolysis or gasification* to produce a wide range of lower chain hydrocarbons from the synthesis gas: synthetic diesel (FAME), synthetic biomethane, methanol or dimethyl ether. Concerning *enzymatic hydrolysis (biochemical process),* various cellulase enzymes are already available for a wide variety of uses in the paper and textile industry, yet these processes do not involve an extensive hydrolysis of cellulose required for ethanol production from lignocellulosic feedstock. The extensive use of cellulase enzymes normally occurs at high market prices representing a cost barrier for making production competitive with fossil fuel prices. So the thermo chemical process is seen better over biochemical process for commercialization of lignocellulosic. However, currently both biochemical process and thermo-chemical processes are unproven on the commercial scale and are under development & evaluation. Several demonstration plants are operating, under construction or planned in the US and the EU (refer the section 3.4.1.2 for the production figures in EU). There are currently no clear distinguished technical or economic advantages between the biochemical and thermo-chemical pathways. Both conversion routes offer a relatively low biofuel conversion efficiency of around 35 % and similar potential yields in energy terms per tonne of feedstock. Lignocellulosic ethanol production through enzyme hydrolysis is expected to produce up to 300 l ethanol/tonne of feedstock, whilst the BTL route could yield up to 200 l biodiesel/tonne of feedstock (SET-Plan, 2009).

Production costs of second generation biofuels are uncertain as very little data is available but significant improvements in the technology are required for commercialization. Production of bioethanol from lignocellulosic biomass is mainly based on latest and advanced technology but the long term gain are expected to be higher followed by technological learning.

4.4.1.1 Production Process

As discussed already, second generation bioethanol can be produced by two main production routes, i.e. *thermochemical and biochemical*. In Thermal process bioethanol can be produced via gasification of the lignocellulosic feedstock at a high pressure and in absence of inert gases. The resulting syngas is then converted, through a catalytic synthesis, into a mixture of alcohols including ethanol as the main component. Higher alcohols such as propanol, butanol, pentanol, hexanol and others are also produced. The distillation is carried out to separate the alcohols which can be efficiently blended with gasoline. Meanwhile, this technology is rather old and further breakthroughs in the field of efficient catalysts are required to make it commercially viable. Another thermochemical process involves a moderate pressure (up to 3 bar) gasification of lignocellulosic matter in the absence of inert gases. After purification, the syngas is fermented into bioethanol at 37–39 ^{o}C using bacteria such as *clostridium* species (Phillips, Aden, Jechura, & Dayton, 2007). The overall production of bioethanol from lignocellulosic biomass includes mainly these steps: (1) production and pre-harvest of feedstock; (2) logistics; (3) conversion to bioethanol.

The currently existing pilot and demonstration plants in Europe mainly use the biochemical route which shows an important potential for further development with the progress in biotechnology and the opportunities offered by biorefineries. In the biochemical pathways, the lignocellulosic feedstock is firstly pre-treated in order to make the cellulosic component more accessible to the cellulases for the subsequent enzymatic saccharification step. During the pre-treatment a significant portion of hemicelluloses is converted into monosaccharides, mostly xylose (a C5 sugar). C6 sugars – mainly glucose are released after the enzymatic hydrolysis step and are then fermented with or without the C5 sugars depending on the design options. Several technology options are under development including separate hydrolysis and fermentation (SHF) or simultaneous saccharification and co-fermentation (SSCF) of C5 and C6 sugars with or without on-site production of the cellulases. The main challenges of the *biochemical route* concern the integration of the system which requires a coordinated effort in improving each step to achieve an overall higher efficiency and a decreased production cost of bioethanol. In that sense, a particular attention should be paid to the feedstock cost. One of the strong assumptions in developing second generation bioethanol is the possibility to process low-cost feedstock. The idea is that second generation bioethanol could valorize agricultural or forestry ‘‘wastes”. However, with time, this way of thinking is being changed. The cost of the available lignocellulosic feedstocks even in the case of agricultural residues may not remain low in long term (Gnansounou, 2009).

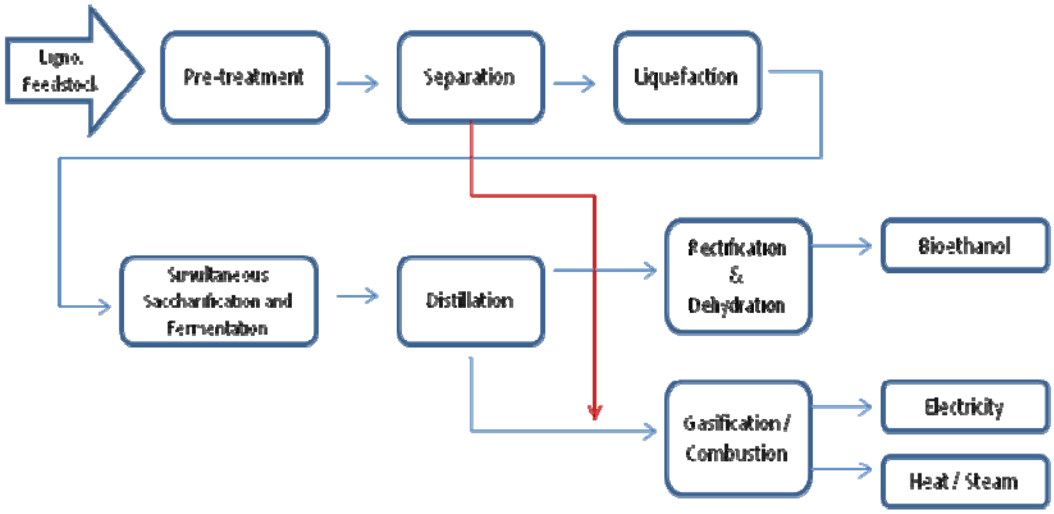


Figure 4-12: Scheme for bioethanol production from lignocellulosic materials

Source - Self elaboration

4.4.2 Plants in the EU

Table 4-21: Second generation bioethanol, pilot, demonstration and projected commercial plants in Europe.

Operator	Location	Ethanol capacity (t/yr)	Scale	Status
Abengoa Bioenergy	Salamanca, Spain	4000	Demo	Under construction, start-up 2009
BioGasol	Bornholm, Denmark	4000	Demo	Planned start-up 2009
DTU, BioGasol	Copenhagen, Denmark	10	Pilot	Operational, start-up 2006
SEKAB	Örnsköldsvik, Sweden Örnsköldsvik, Sweden Örnsköldsvik, Sweden Örnsköldsvik, Sweden	100 4500 50,000 120,000	Pilot Demo Demo Comm.	Operational, start-up 2004 Planned start-up 2011 Planned start-up 2014 Planned start-up 2016
Inbicon, DONG Energy	Fredericia, Denmark Fredericia, Denmark Kalundborg, Denmark	110 1100 4000	Pilot Pilot Demo	Operational, start-up 2003 Operational, start-up 2004 Under Const, start-up 2009
Procethol 2G, Futurol	Pomacle, France Pomacle, France	140 2840	Pilot Demo	Under Const, start-up 2010 Planned
Süd-Chemie	Münich, Germany	2	Pilot	Operational, start-up 2009

Source - (Gnansounou, 2009)

4.4.3 BTL (Biomass to liquid) - State of the art

BTL is an advanced, state of the art renewable fuel production process that uses *pyrolysis* and gasification techniques to produce a synthesis gas from which a wide range of biofuels can be produced. BTL represents a further application of the already existing gas-to-liquid (GTL) technology currently used by oil and energy industry across world. GTL technology is also known as Fischer-Tropsch Synthesis (F-T Synthesis) named after the German scientists Franz Fischer and

Hans Tropsch and first patented in 1925. Currently, BTL is at demonstration or R&D level but once widely available on commercial scale, it could contribute significantly in achieving the ambitious EU biofuel goals. Projections for technically feasibility of BTL on large scale range from 5 to 10 years (OECD/IEA, 2008). However, whether BTL will be actually produced on a large scale basis depends on political and economic factors such as CO_2 emission reduction goals, price of competing products such as fossil diesel and gasoline as well as cellulosic ethanol.

Even though, the GTL technology has been introduced long ago, it has only regained more attention until recently with the set up of large-scale GTL manufacturing plants in various parts of the world (e.g. Malaysia, Qatar). Moreover, the current extension of the GTL technology in Europe into the innovative BTL process, opens a window for the production of renewable fuels from a wide variety of biomass feedstock giving a transformation signal to the transport sector to look for sustainable oriented alternatives that would contribute to the reduction of GHG emissions while offering progressive scenarios to a secure and sustainable future fuel supply.

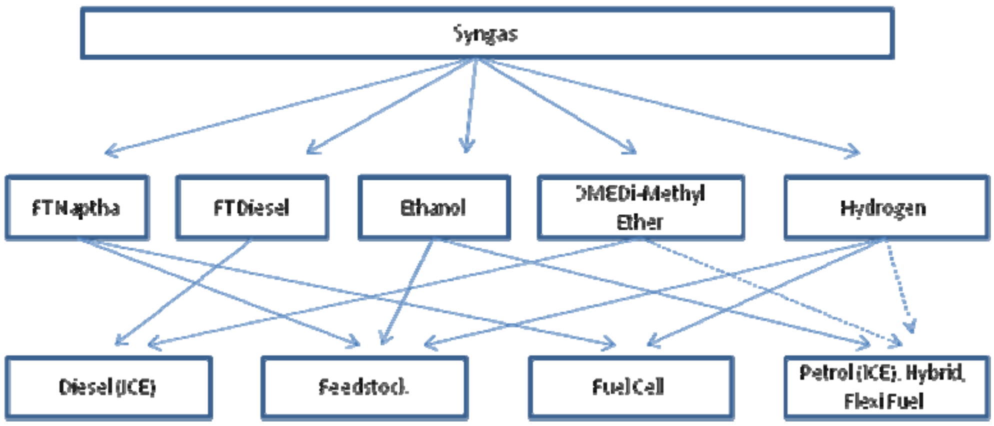


Figure 4-13: Fuels obtained via GTL processing of syngas

Source - Phillips, Aden, Jechura, Dayton, & Eggeman, 2007

4.4.3.1 Production Process

There are 2 main methods for synthetic biofuel production via biomass gasification and catalytic conversion to liquid, namely *Fischer-Tropsch process* and *Mobil Process*. Both the processes have the advantage of producing liquid transport fuels with the ability to use almost any type of low moisture content. The feedstock is gasified in the first stage of the process to produce gas called as *pyrolysis*. The gas produced is then treated further for cleaning, removing tars, particulates and gaseous contaminants, and to adjust the ratio of the required gases (hydrogen and carbon monoxide). The result is a balanced syngas that can be used in the second, catalytic, stage. Several BTL fuels, such as F-T Diesel, F-T Naphtha, Biomethanol, Bio-Di-Methyl-Ether (DME), and Bio-Hydrogen, can be obtained after a synthetic gas (syngas) of biomass origin is transformed by means of chemical syntheses. This section states concisely some gasification possibilities and gas cleaning technologies resulting in alcohol products suitable for further transportation purposes (European Biofuel Technology Platform, 2009), (Phillips, Aden, Jechura, Dayton, & Eggeman, 2007).

4.4.3.1.1 Feedstock Handling & Preparation

There are two types of biomass feedstock that can be employed to produce BTL fuels – woody and herbaceous. Woody feedstock comprises wood chips, wood powder and sawdust, obtained from ordinary forestry (wood logs), short-rotation forestry, various wood residues and wood waste. Herbaceous feedstock includes chaffed dedicated energy crops and straw. The biomass feedstock is first dried to lower level of moisture required for proper feeding into the gasifier. *Concentrated and dilute acid* processes for pre-treatment of biomass have been commercialized in the past particularly in the former Soviet Union, Germany and Japan. However, these processes remain far from cost-effective options as they require high amount of acids making them economically unfavourable. Acid recovery and its reutilization are being studied and are likely to be an option for reducing costs in the long run. Work at the moment is ongoing to enhance the pre-treatment methods such as steam explosion, ammonia steam explosion, acid processing and synthesizing more efficient enzymes. However, the chemical structure of the crop and forest residues are highly variable which creates added complexity compared to the homogeneity of starch or sugar crops.

4.4.3.1.2 Gasification

Fischer-Tropsch Gasification

The Fischer-Tropsch process is a catalyzed chemical reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms. Generally the catalysts used, for the following reaction, are based on iron and cobalt.

$$(2n+1)H_2 + n(CO) \rightarrow C_nH_{2n+2} + nH_2O$$

During the process the biomass chemically converts to a mixture of syngas components (CO, H_2, CO_2, CO_4, etc.), tars, and a solid "char" that is mainly the fixed carbon residual from the biomass plus carbon (coke). Cyclones are used at the exit of the gasifier to separate the char and sand from the syngas.

The FT process is an established technology and is already applied on a large scale from coal or natural gas. However, one problem is the high capital cost of the multistage process. This may be greater when biomass is used as feedstock, since the scale of operation may be limited by the distance over which biomass can be transported to the factory at an economic price. Hence, the economy of scale is decreased compared to a large coal or gas-based operation. Running and maintenance costs are also comparatively high.

Mobil Process

This is a two stage catalytic process. In the first stage LINK methanol is produced. The methanol is then used as feedstock to generate hydrocarbons of varying chain length, using a *zeolite catalyst*. In the conversion, a number of reactions take place in the gas phase. The conversion is initiated by the removal of water to produce Di-methyl ether:

$$2CH_3OH(g) \rightarrow CH_3OCH_3(g) + H_2O(g)$$

This is followed by various other reactions in which further molecules of water are removed resulting in gradual increase in chain length. These reactions include the following.

$$2CH_3OCH_3(g) + 2CH_3OH(g) \rightarrow C_6H_{12}(g) + 4H_2O(g)$$
$$3CH_3OCH_3(g) \rightarrow C_6H_{12}(g) + 3H_2O(g)$$

As a result of other dehydration reactions occurring in parallel, a mixture of hydrocarbons is produced of which about 80% is suitable for petrol production. The mixture contains (w/w) around 50% highly branched alkanes, 12% highly branched alkenes, 7% cycloalkanes and 30% aromatics.

4.4.3.1.3 Gas Cleanup and Conditioning

This step consists of multiple operations: reforming of tars and other hydrocarbons to CO and H_2; syngas cooling/quench; and acid gas (CO_2 and H_2S) removal with subsequent reduction of H_2S to sulfur. The hot syngas is cooled through heat exchange with the steam cycle and additional cooling via water scrubbing. The scrubber also removes impurities such as particulates and ammonia along with any residual tars. The cooled syngas then enters an amine unit to remove the remaining CO_2 and H_2S.

4.4.3.1.4 Alcohol Synthesis

The cleaned and conditioned syngas is converted to alcohols in a fixed bed reactor. The mixture of alcohol and unconverted syngas is cooled through heat exchange with the steam cycle and other process streams. The liquid alcohols are separated by condensing them away from the unconverted syngas. Though the unconverted syngas has the potential to be recycled back to the entrance of the alcohol synthesis reactor, this recycle is not done in this process design because CO_2 concentrations in the recycle loop would increase beyond acceptable limits of the catalyst.

4.4.3.1.5 Alcohol Separation

The alcohol stream from synthesis is depressurized in preparation of dehydration and separation. Another rough separation is performed in a flash separator and the evolved syngas is recycled. The depressurized alcohol stream is dehydrated using vapor-phase molecular sieves and is then introduced to the main alcohol separation column that splits methanol and ethanol from the higher molecular weight alcohols.

Figure 4-14: Production process flow diagram

Source - Phillips, Aden, Jechura, Dayton, & Eggeman, 2007

Similar to alcohol synthesis, GTL synthesis can produce a wide range of products. Unlike oil refining, the GTL yield can be feasibly optimized to a larger extent. BTL naphtha is an excellent chemical feedstock for further processing and could be regarded also as a hydrogen carrier for FC in the medium to long-term. F-T diesel is the only BTL fuel that seems ready for a large-scale application in ICE. Methanol is not regarded as a convenient fuel for ICE, but can be used as low blend in gasoline and it is still a potential hydrogen carrier for FC. DME could become a prospective fuel for ICE in the medium to long-term. A key advantage of DME is that it is compatible with LPG and its infrastructure.

Besides the production of fuels through Fischer Tropsch synthesis, progressive bioenergy concepts from biomass feedstock is focusing currently on the potential and technical feasibility of so called **"Biorefineries"** which refer to combined production systems that will fully exploit biomass feedstock for food purposes as well as for bio-based chemicals and synthetic materials, biofuels and biogas combined with the production of electricity and heat adding important value to all stages of the production chain. With respect to BTL some systems already produce electricity and heat (Combined Heat and Power) which are being adapted to produce biofuels. Furthermore, various chemicals are also possible from the production of synthetic gas from biomass obtained in the first stage of the BTL process offering wider options to fully use the biomass chain. The estimated production costs for Fischer-Tropsch diesel from biomass vary from 0.30 - 0.50 €/l for very large (several million m^3/y) or large installations (ca. 240.000 m^3/y). Since the investment costs are a significant part of the production costs, large-scale production is required, up to several million m^3/y, in order to make use of scale-effects (GAVE programme, 2006).

4.4.4 Classification of the technology

Second generation biofuels technologies are currently experiencing the euphoria and partially the disillusion phases with research and demonstration projects mostly for bioethanol from lignocellulosic sources and for biomass gasification and biomass to liquids routes. The disillusion phase come partially as companies have promised to move from pilot to demonstration and commercial stages earlier than 2010, however due to technical and partially financial matters, these promises have not been fulfilled meaning that the risks to scale up these technologies still are under estimated and/or clearly still do not fulfill investors security, technical adequate performance and economic competitiveness. In particular the BTL plants are moving from pilot to bigger demonstration projects and the biomass supply in the form of wood chips or wood residues for gasification involve complex logistics when gaining experiences for scaling the plant capacities up. Innovative concepts for biomass supply are referred as “promising” however also involving distribution complexities if the biomass is gathered and pretreated in “pyrolysis oil centers” as proposed by the Karlsruhe Institute of Technology and the resulting oil being transported to gasification centers. It may add to the economics of the plant however, pyrolysis oil transport involves certain security and safety requirements. The use of a broader feedstock base as promised by second generation fuels are still to be proven as the processes will require operational adjustments depending on the feedstock. Besides supply constrains, BTL routes also exhibit the constrain that they are energy intensive processes and they perform good in terms of emissions and less by costs if co-generation is considered (with subsequent electricity and heat production) meaning an additional income in case support schemes are also offered, however, this adds to the capital requirements and the competition of biomass for three uses. The advantage is to have a plant able to generate energy for three purposes, but the set up of this scheme add to the complexity of realizing the projects and bringing it closer to the markets.

With respect to bioethanol from lignocellulosic sources, at least more demonstration projects across Europe are being announced and the euphoria phase is moving closer to the realization of bigger demonstration plants. The enzymatic processes for pre-treatment of lignocellulosic material are sensible to various technical issues but enzymes companies claim at least that their products are available at much lower prices, the step now is to gain experience with defined crops and feedstock. Additionally bioethanol from lignocellulosic could be observed as an incremental innovation that can be adapted to existing bioethanol plants producing from grains or sugar canes routes. This add a sense of reality to the way this technology could diffuse into the markets in a pre-commercial and early commercial stages hand by hand to existing commercial bioethanol plants. These hybrids concepts will not only be important for Europe but also for USA and especially Brazil and other sugar exporting countries with ethanol capacities already established for longer time.

4.4.5 Plants in the EU

Table 4-22: Overview of 2nd Generation Biofuel Technologies and production

Biofuel group	Specific biofuel	Production process	Companies
Bio-ethanol	Cellulosic ethanol	Biochemical: Enzymatic hydrolysis & fermentation	Abengoa, Iogen,Sekab, Poet
Synthetic biofuels	Fischer-Tropsch diesel (FT), Synthetic diesel, Biomethanol, Dimethyl ether (DME), Heavy alcohols (butanol and higher), P-series (ethanol + MTHF etc.)	Thermo-chemical: Gasification and synthesis	Choren, Lurgi, Range Fuels, Chemrec, Enerkem
Biodiesel (hybrid of 1st and 2nd gen.)	Green pyrolysis diesel, H-Bio	Thermochemical: Pyrolysis Hydrogenation (refining, also applied to veg oils)	Dynamotive, Ensyn, BTG
Methane	Bio synthetic natural gas (SNG)	Thermo-chemical: Gasification and synthesis	Nexterra, ECN
Biohydrogen	Hydrogen	Thermo-chemical: Gasification & synthesis Biological	

Source - (OECD/IEA, 2008)

4.4.6 Economic assessment for 2nd Generation Biofuels

Due to the problems related to the 1st generation biofuels, such as insufficient reduction of CO_2 emissions and competition with food production, interest in 2nd generation biofuels is increasing. This new production technology should enable the use of wide range of new feedstock such as waste cellulosic materials, grasses, whole plants and trees.

Currently only few 2nd generation demonstration plants are operating, so the production costs of second generation biofuels are still uncertain. High production costs could be decreased with the scale-effects. The expected costs for small and large-scale 2nd generation production plants are shown in Figure 4-15 and Figure 4-16. The estimated production costs for 2nd generation Biodiesel (BTL (FT)) are in the range from 18 c€/kWh to 28 c€/kWh. The costs of cellulosic 2nd generation ethanol are estimated in a range between 17 c€/kWh to 23 c€/kWh, depending on the production scale and feedstock used, see Figure 4-16. Note, that large-scale production is still hypothetical.

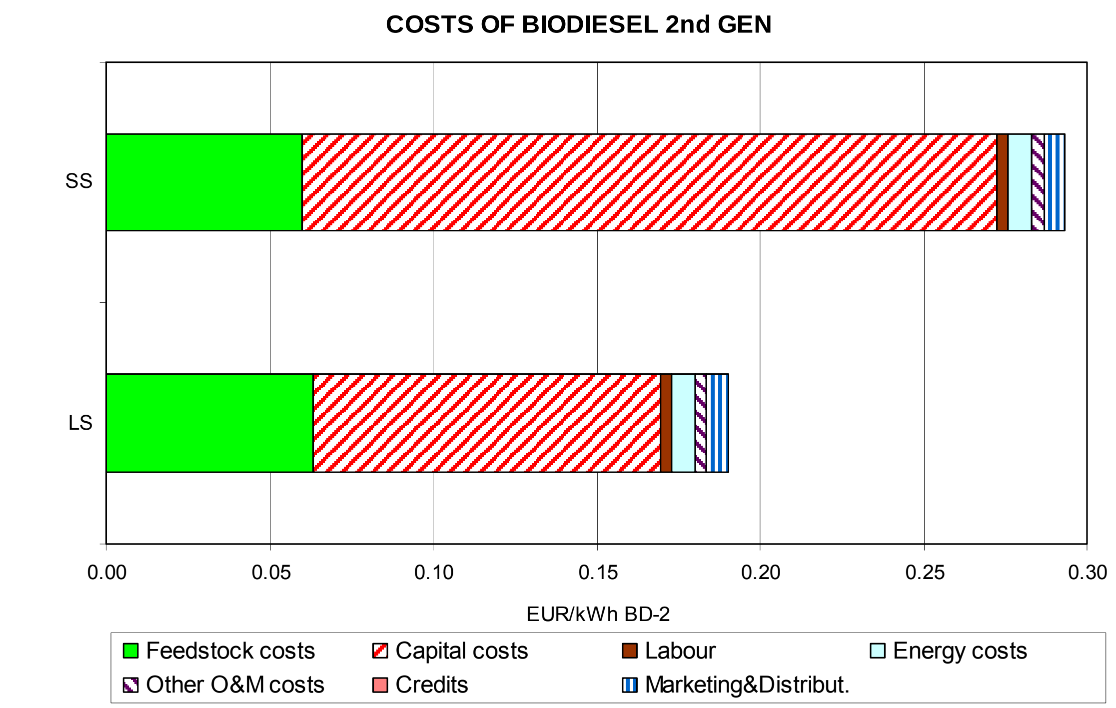


Figure 4-15: Costs of Biodiesel 2nd generation (as of 2010, Note that LS figures are rather hypothetical, Feedstock wood residues)

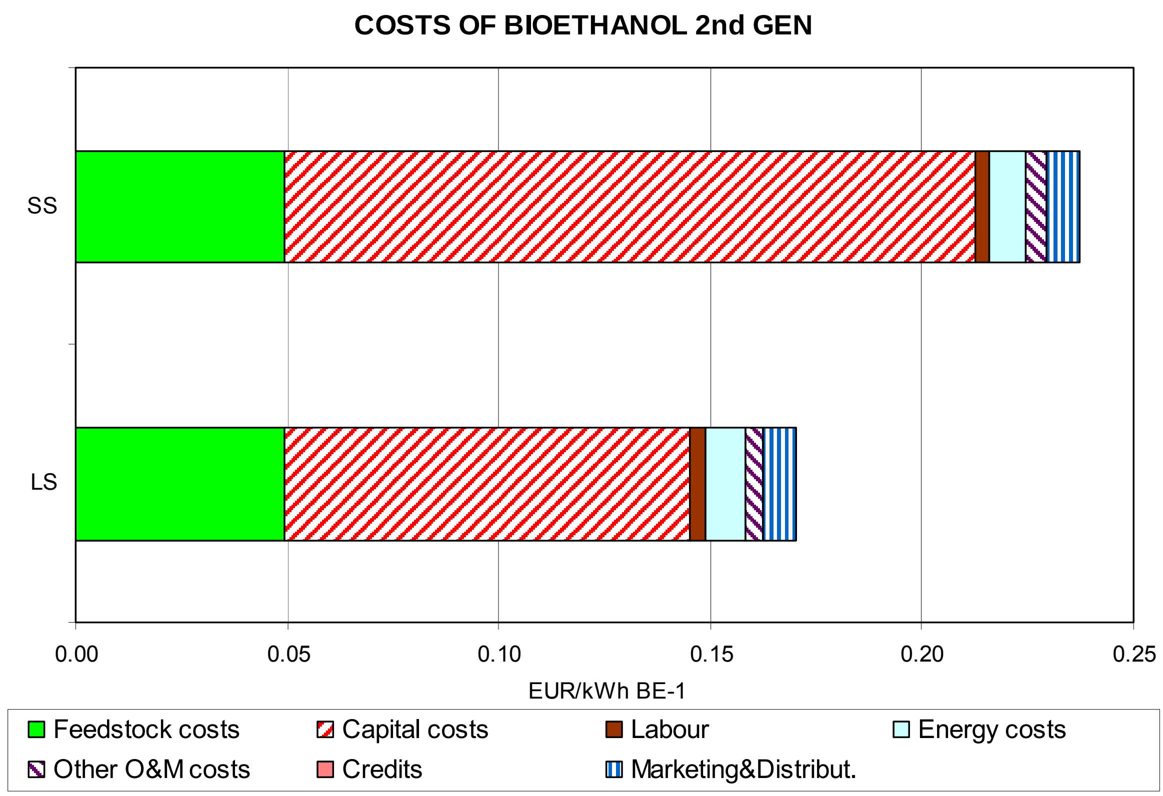


Figure 4-16: Costs of Bioethanol 2nd generation (as of 2010, Note that LS figures are rather hypothetical, Feedstock straw)

4.4.7 Environmental assessment of 2nd Generation Biofuels

BTL Fischer-Tropsch

The following are both Biomass-to-Liquids pathways: wood gasification by Fischer-Tropsch synthesis. Emissions values differ from production of feedstocks considering that wood farming and chipping for farmed wood is (in terms of emissions) almost five times higher than the wood waste collection. On the other side, emissions in the transport to plant step are four times higher for wood waste than for farmed wood.

Table 4-23: BTL (FT) farmed wood

WTT Emissions		Small Scale
wood farming &chipping	g C O_2eq/MJ	5
Transport to plant	g C O_2eq/MJ	0,7
Gasifier + FT plant	g C O_2eq/MJ	0
Distribution & Retail	g C O_2eq/MJ	1,2
Total WTT Emissions	g C O_2eq/MJf	6,9

Table 4-24: BTL (FT) wood waste

WTT Emissions		Small Scale
waste collection and chipping	g C O_2eq/MJ	0,8
Transport to plant	g C O_2eq/MJ	2,9
Gasifier + FT plant	g C O_2eq/MJ	0
Distribution & Retail	g C O_2eq/MJ	1,2
Total WTT Emissions	g C O_2eq/MJf	4,8

4.4.8 Technical Innovation Potential for 2nd Generation Biofuels

Technology improvements for the biochemical route, in terms of feedstock pre-treatment, enzymes and efficiency improvement and cost reduction: Feedstock pre-treatment technologies are inefficient and costly. Improvements in physical, chemical and combinations of these pre-treatments need to be achieved to maximise the efficiency of pre-treatment in opening up the cellular structure of the feedstock for subsequent hydrolysis. Dilute and concentrated acid processes are both close to commercialisation, although steam explosion is considered as state-of-the-art. New and/or improved enzymes are being developed. The effective hydrolysis of the interconnected matrix of cellulose, hemicellulose and lignin requires a number of cellulases, those most commonly used being produced by wood-rot fungi such as *Trichoderma, Penicillum*, and *Aspergillus*. However, their production costs still remain high. Recycling of enzymes and simultaneous saccharification and fermentation (SSF) processes are potential ways to reduce costs.

Table 4-25: Technical Innovation Potential for 2G Biofuels

Area	Developments	State of art & Potential
Feedstock pre-treatment	Improvements in physical & chemical (or both) treatment processes	Commercial / Demo – High potential efficiency increase Cost reductions 10-30%
Enzyme technology	Effective hydrolysis of cellulose, enzymes. Variability of feedstock	Potential to increase efficiency and reduce costs. Crop management, Demo.
C5 and C6 Sugar digesters	Biotech. development for fermentation of both types of sugars	Potential to increase efficiency. Costs reductions unclear. Demo
Large-scale biomass gasification	FT tolerant to fluctuations in feedstock, by-product generation	Demo. Direct entrained flow gasifiers (COP, O&M costs high)
Thermochemical technologies	Fischer-Tropsch method Methanation	Pyrolysis-gasification of biomass Demo. Business model to scale up Potential costs reduct. (20-40%)

Source - Self elaboration

A key goal for the commercialisation of ligno-cellulosic ethanol is that all sugars (C5 pentoses and C6 hexoses) released during the pre-treatment and hydrolysis steps are fermented into ethanol. Currently, there are no known natural organisms that have the ability to convert both C5 and C6 sugars at high yields, although major progress has been made in engineering micro-organisms for the co-fermentation of pentose and glucose sugars. The conversion of glucose to ethanol during fermentation of the enzymatic hydrolysate is not difficult provided there is an absence of inhibitory substances such as furfural, hydroxyl methyl furfural, or natural wood-derived inhibitors such as resin acids. Understanding and manipulating process tolerance to ethanol and sugar concentrations and resistance to potential inhibitors generated in pre-saccharification treatments remains a scientific goal.

Technology improvements for the thermo-chemical route, in terms of feedstock pre-treatment, gasification and efficiency improvement and cost reductions: BTL faces the challenge of developing a gasification process feasible at high scale and meeting product quality standards. In spite of many years of research and progress, cost effective and reliable methods of large-scale biomass gasification remain elusive. The goal should be to develop reliable technologies that have high availability and produce clean gas that does not poison the FT catalysts. Given the constraints on scalability and the level of impurities in the desired syngas, pressurised, oxygen-blown, direct entrained flow gasifiers appear to be the most suitable concept for BTL.

Technologies that have potential for second generation biofuel production are of two types:

• Thermochemical technologies, relying mainly on pyrolysis-gasification of biomass

• Biological technologies, involving enzymatic hydrolysis and fermentation of biomass.

Thermochemical conversion: The first stage of the process, called the pyrolysis gasification stage, can be used with a number of carbon feedstocks. Coprocessing of all or part of the biomass resource mixed with other carbon feedstocks (charcoal, petroleum residues, organic waste, etc.) may offer an intermediate solution with respect to resource availability. To bring down the investment required to implement these technologies, each gasification/ synthesis installation must process in excess of one million tonnes of biomass yearly. This volume requirement implies pretreatment units able of processing hundreds of thousands of tonnes of biomass a year, to obtain an easily transported feedstock with high energy content.

Biochemical conversion: In this conversion pathway for lignocellulosic biomass transforms into cellulose and hemicelluloses to obtain fuels (ethanol, butanol, fatty acids, etc.). Another component of plant, lignin, is used primarily to meet the energy needs of the conversion process, and/or is sold as a feedstock for chemicals and materials industries. Establishing sustainability, with diversified feedstock source is under development around the world. Moreover, pretreatment and hydrolysis of lignocellulose are technical and economic bottlenecks. The successful industrial development of the biological pathway requires a systems approach integrating the different processes in the biomass value chain, making the fullest possible use of the plant matter, with technical, economic and environmental validation of the various technological building blocks.

4.5 Biomass production potentials

The worldwide demand for food, animal feed and bioenergy is rising and creating additional pressure on the available area of land. In the future crops for food, feed and energy may compete for agricultural land causing environmental and nature protection concerns (e.g. Fisher et al., 2010). Considering the ongoing debates on direct and indirect land use change (DLUC/ILUC) estimates of future demand and the amount and suitability of land potentially available are highly unpredictable. The balance of evidence indicates there is sufficient land available to satisfy the demand to 2020, but this needs to be confirmed before global supply of bioenergy increases significantly. Current policies do not ensure that additional production moves exclusively to suitable areas. Attempts to direct agricultural expansion to particular areas face significant implementation and enforcement challenges (Gallagher, 2008).

4.5.1 Methods for estimating potentials

The increasing global demand for biofuels has evoked many studies and opinions, regarding the amount of biomass that can be produced in a sustainable way.
Key factors controlling the biomass potential are:

(1) Land availability- Taking into account land claims for many functions, especially agriculture, food demand and biodiversity. The land primarily claims for food production, and consequently the land remaining for biomass production, this also critically depends on chosen nutritional requirementsin the human diet. Globally the fraction of animal protein in the human diet (meat and dairy) is increasing, especially in South East Asia. Meat and dairy production requires substantially amounts of feed (factor 3-10 to convert vegetable resources into meat). Consequently, the global trend of more meat and dairy consumption also involves a substantially increasing claim for land.

(2) Agricultural yield- The production potential of the land remaining for biomass production critically depends on the estimated agricultural efficiency and the underlying assessments of soil fertility, crop choice, water, fertilizer limitations etc. All in all, calculations on biomass potentials are depending on a complicated and interrelated chain of factors, not only relating to technical issues, but also to social, political and moral choices. As a consequence, literature studies on the global biomass potential range up-to about 200-500 EJ/yr for the year 2050. Two different approaches found in literature to estimate the biomass potential are stated following, although some studies also use 'hybrid' approaches.

4.5.1.1 Land balancing method ('food first paradigm')

Most studies on the potentials for biofuels are based on a "land balancing" methodology, taking into account the demand for land for other purposes like food production and biodiversity among others as well as underlying factors such as agricultural efficiency, soil fertility, crop choices, etc. Eventually, the land balancing methods end up with the land available for biomass production. By taking into account the selected agricultural yields, the resulting annual production potential (in

GJ) can be estimated. This approach can be extended with calculation of fuel prices (e.g. Refuel project; 2008a; 2008b).

4.5.1.2 Economic equilibrium approach

In this approach biomass production, and fuels types produced are assumed to be completely controlled by market prices of bio-fuels in relations to the prices of (fossil) fuels and other (non biofuel) crops that compete for the same land (e.g. Siemons 2004).

4.5.2 Assumptions and limitations

4.5.2.1 Impact of assumptions on future agricultural developments

A range of studies indicate that the largest uncertainty for the availability of biomass for energy production is the availability of land for energy crop production. The availability of land is mainly determined by the demand of land for agricultural purposes (and thus by the productivity of the land). Another critical variable in future outcomes of analyses on production potentials and availability of feedstock for biofuels is the expected increase in agricultural productivity. Most studies estimate future yield levels through extrapolation of past trends, in some cases corrected for economic investment levels related to food prices, or constrained by yield plateaus. Bindraban et al. (2009), however, emphasize that realistic estimates should be explicitly based on production ecological principles. Moreover, recent development in underlying drivers for agricultural productivity should be accounted for in short-term projections. Also it is likely that yield increases will be limited in the coming decade because of decreasing availability of water, fertile land and other natural resources, decreasing increase in crop production potential, decreasing investments in agricultural infrastructure (such as irrigation facilities), and the decrease in the overall investments in agricultural research and development over the past decades (Bindraban, 2009). Agricultural development is a long term process because of large time lags.

4.5.2.2 Limitations of categorizing biomass streams

Potentials for different biomass categories have overlaps. For example, if you grow more wheat, you have less land available for sugar beet etc. It is important to realize that there are several limitations in merging sector-focusing potentials into a total potential. Obviously, overlap between biomass categories and/or system boundaries are possible sources of inaccuracy. This is particularly relevant when summarizing numbers from assessments of high disaggregation in terms of biomass categories and/or system levels. Inconsistent and/or ambiguously defined spatial delimitations and time scales may be considerable sources of inaccuracy when summarizing or comparing potentials from separate assessments. Inconsistent spatial delimitations are probably the greatest source of error of the two. The varying definitions of the "EU" (for example with or without Rumania and Bulgaria), and the ad-hoc inclusions of adjacent non-EU countries (Ukraine), are a particular restriction in the synthesis of potentials for the EU (BEE, 2008).

4.5.2.3 Impact of assumptions for other land claims

Environmental criteria and related EU policies, such as the projected increase of organic agriculture, can result in a decrease of the productivity and thereby limit the amount of surplus land that can be used for energy crop production. However, it should be noted that such criteria are often not well defined. So far, most studies restrict the potential taking into account the certain aspects or limitations that implicitly limit or reduce the environmental impacts. In contrast, recent studies quantify biomass potentials relative to several scenarios, reflecting different assumptions on agricultural yield, sustainable farming practices and nature conservation etc. (e.g. Guenther et al, 2010). The major drivers in the scenarios are the projected demographic changes and the associated food demand on the one hand and, on the other hand, technological progress in the agricultural sector.

4.5.3 Current discussion on direct and indirect land use changes

Currently, the discussion on biomass potentials focuses on the impact of biomass production on direct land use change (LUC) and indirect land use changes (ILUC), as these mechanisms may have important consequences for the overall greenhouse gas reduction of biomass.

Land use change*:* Several studies show that conversion of natural ecosystems or pastures into cropland for biofuels can result in large greenhouse gas emissions that drastically reduce the mitigation benefits of the biofuels initiative. This is especially the case when the conversion involves soils with high carbon stocks. The globally increasing demand for biomass can be met either by reclaiming new crop land and the associated potentially negative effects of LUC, or alternatively by increasing the productivity of the existing land. The relative contributions of yield growth and cropland expansion for increasing crop output depends on the relative economics of these two principal supply side options, which varies between crops and regions. However, large and rapid increase in inelastic biofuel demand increases the relative contribution of cropland expansion, since this is the major near term response to food price spikes (Berndes et al., 2010; Fischer et al, 2010).

Indirect land use change*:* Recent research indicated a further source of emissions from increased biomass for energy production. If bioenergy cropping occurs on land previously used for food, feed or fiber production, then it displaces the previous production of them. As demands for displaced production remain, it will be produced somewhere else, which might result in converting other land (and respective carbon emissions) to produce the respective amounts of food, feed, or fiber. These emissions from ILUC are caused by the displacing bioenergy production and can, in the net balance, negate any positive climate effects. The extent to which ILUC may occur and to which extend it can cause GHG emissions is under debate (Fritsche et al, 2009). Scientists are challenged by quantifying ILUC and linking it to specific biofuel projects. The uncertainties make consideration of the effects of ILUC effects a controversial matter when policy instruments are developed. On the other hand, policy makers have to respond to the concerns that ILUC can drastically reduce the climate benefit of ambitious bioenergy initiatives. Current policies driving the biofuel demand may lose public acceptance unless ILUC effects are considered in a satisfactory way (Berndes et al, 2010; Tillman et al, 2009).

By the end of 2010 the European Commission will have to report on LUC, which also will include a methodology for calculating the effects of ILUC. Both Berndes et al. (2010) and Fritsche et al (2009) advise to reduce LUC related risks on the short term by: (1) prioritizing the use of residues and wastes; (2) support for dedicated production systems for 2nd generation feedstock provided that they do not cause unacceptable LUC related problems; (3) favoring of feedstock supply systems that have low land demands and/or use areas not attractive for food production and with low risks of high LUC emissions; (4) promotion of productivity increases in agriculture.

4.5.4 Biomass Potentials and Impacts for Future Biofuels Trends

This section will describe the potentials for the selected biofuel feedstock according the various studies reviewed. The biofuels selected relate to a literature review of the most important studies with respect to the Well–to-tank (WTT) and tank-to-wheel (TTW) analysis covering energy balances, GHG emissions and economics, along the whole production chain at the European level (Toro et al., 2009). Selected pathways of alternative fuels (AF) include first and second generation biofuels, natural gas (LNG, CNG) as well as hydrogen and electricity, and their corresponding AAM technologies as described in chapter 2. The potentials for different biomass categories have huge overlap. Consequently, it would be very ambiguous to provide separate potentials for all the separate biomass streams considered in the *ALTER-MOTIVE* project, as listed in Table 3-1: Summary of analyzed AF pathways.

As a realistic alternative, the underlying sections provide the biomass potentials reported in literature for the main biomass categories, and where available also indicating potentials of sub-categories. Each section lists the separate potentials reported in the key literature, i.e. REFUEL (2008), EEA (2006/2007) and BEE (2008). Where available, additional literature results are provided, including the RENEW study (2008). In addition section 3.6 provides as brief vision on future biomass imports into Europe. The main biomass potential categories listed include:

- Energy crops
- Wood biomass / forests
- Waste
- Overview of all streams, including bandwidth of the estimates

4.5.4.1 Energy crops potential (agriculture)

Dedicated energy crops differ from conventional crops as they are optimized for their energy content. Double cropping systems combine different crops at one field to achieve higher yields.

4.5.4.1.1 Energy crops potential according to Refuel

In Refuel (2008b) no aggregated potentials for energy crops are reported. But the report provides potentials on the crop type level, including crop potentials for: (a) Woody (i.e. poplar, willow, eucalyptus etc.); (b) Grassy (miscanthus, switch grass, reed canary grass); (c) Oil crops (rapeseed, sunflower); (d) Sugar crops (sugar beet); (e) Starch crops (wheat, barley, rye, maize, sorghum). These separated crop potentials that are provided in following paragraphs that can be aggregated into energy cops, resulting in the following estimates:

- 2010: 7 EJ/y for oil, sugar and starch crops combined up to 17,2 EJ/y by also including woody and grassy crops
- 2020: 10,9 EJ/y for oil, sugar and starch crops combined up to 27,4 EJ/y by also including woody and grassy crops

- 2030: 14 EJ/y for oil, sugar and starch crops combined up to 35,7 EJ/y by also including woody and grassy crops

4.5.4.1.2 Energy crops potential according to European Environment Agency (EEA)

Wheat whole plant feedstock assumes the use of both straw and corn for biofuel production. The EEA has indicated potentials for crops for biogas, under which maize, double cropping, switch grass and grass cuttings are aggregated. Whole wheat plant as a feedstock is included in the category crops for lignocellulosic ethanol, together with barley.

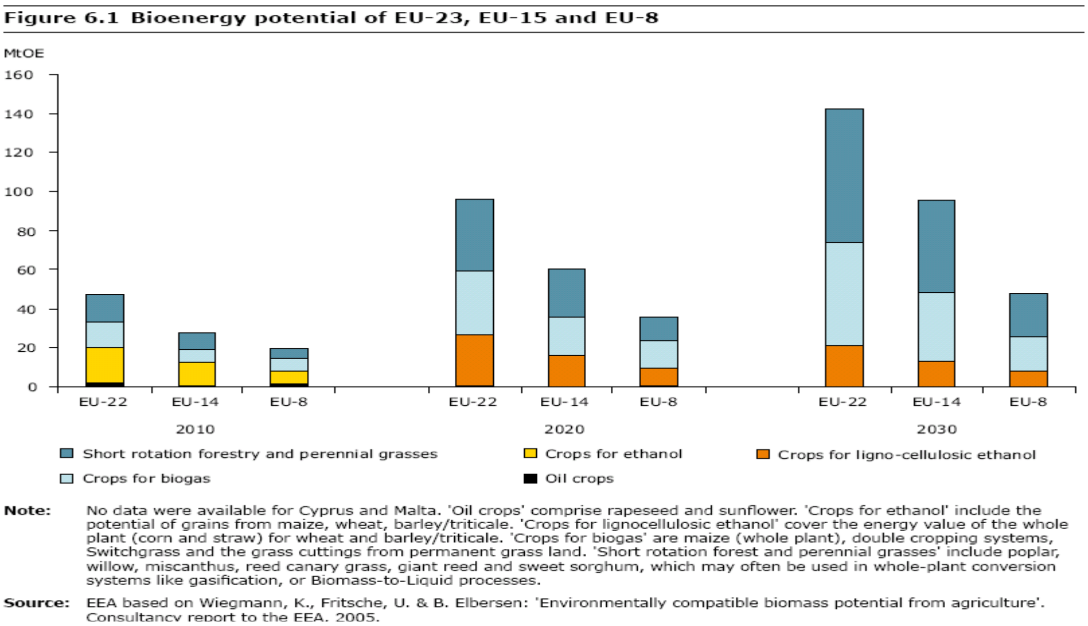


Figure 4-17: Environmentally-compatible agricultural bioenergy potential

Source: EEA, 2006.

4.5.4.1.3 Energy crops potential - BEE

The table below (Table 4-26) gives an overview of energy crop potentials compiled in the Biomass Energy Europe (BEE) study (2008). It should be realized that energy crops potentials expressed only in energy units does not give a clear view. As discussed in earlier, land availability is definitely the main and limited factor or resource influencing potential.

Table 4-26: Overview of energy crop potentials compiled in the BEE study (2008)

Study, Scenario	**Geographical coverage**	**Time frame**				
		2000	2010	2020	2030	2040
van Dam et al. 2006 depend on scenario and a crop (conventional and cellulosic)	CEEC				2,03-11,65 EJ/y	
EEA 2006	EU-22		1,97	4,01	5,96	
Ericsson & Nilsson 2004	EU-27		2,12			
scenario 1					6,7	
scenario 2*					8	
scenario 2b						
scenario 3a						18,5
scenario 3b						22,2
Fischer et al. 2007	EU-27 plus Norway, Switzerland and Ukraine				1st 2nd	
Arable land Baseline					5,9 8,9	
Arable land Low					5,6 8,6	
Arable land High					6,9 10,4	
Pasture land Baseline and Low					- -	
Pasture land High					- 3,1	
Ganko et al. 2008	EU-25 excluding Cyprus and Malta					
SP		1,43				
S1			2,39			
S2			4,76			
Nielsen et al. 2007, yield:		10% arable land		20% arable land		30% arable land
10 t/ha		2,04		4,08		6,13
20 t/ha		4,08		8,17		12,25
30 t/ha		6,13		12,25		18,38

Simons et al. 2004			0,8	0,8		
Thran et al. 2006	EU-25					
CP (Current Policy)		1,18	3,46	7,79		
E+ (Environmental +)		0,69	1,07	2,6		

Note: For estimations underlying this table, see BEE (2008).

4.5.4.2 Wood biomass potential (forests)

Wood feedstock based on waste that occurs during harvestings and processing represents a sizeable input for the production of biofuels. In existing reports wood feedstock has been described using different methodologies.

4.5.4.2.1 Forests biomass potential according to Refuel

Refuel has included waste products from forestry with felling residues amounting to 1.4 EJ/year. However taken into account the balance between the Net Annual Increment and the actual fillings plus residues grows to 2.7 EJ/year. This balance is considered sustainable since it doesn't reduce the existing stock of forest. Refuel is not focusing on forest residues and has received data from Karjalainen et al and the FAO.

4.5.4.2.2 Forests biomass potential according to European Environment Agency

The European Environment Agency has assessed the wood-based potentials on a more aggregate level only distinguishing in the calculation but produced aggregated outcomes (Table 4-27). Forestry biomass comprises of residues from harvest operations that are normally left in the forest after stem wood removal. In addition, complementary fillings are analyzed that describe the difference between the sustainable harvest level and the actual harvest needed to satisfy round wood demand.

Table 4-27: comparison of results for forest residues with other studies

Reference	**Geographical coverage**	**Energy potential from forest residues in MtOE**		
		2000/2005	2010	2020
This study, environmentally-compatible potential	EU-13	11.0	11.5	12.3
	EU-21	14.3	14.9	15.9
This study, baseline without environmental constraints	EU-13	18.1	18.9	20.3
	EU-21	24.1	25.1	26.8
Bioenergy's role in the EU Energy Market – A view of developments until 2020 (Siemons *et al*., 2004)	EU-15	17.5	19.3	21.3
Bioenergy's role in the EU Energy Market – Biomass availability in Europe (Nikolaou *et al.*, 2003)	EU-14	14.8		
Estimation of Energy Wood Potential in Europe (Karjalainen *et al.*, 2004)	EU-25	12.4		
Effect: EU forest for renewable energy to mitigate climate (Meuleman *et al.*, 2005)	EU-15	3.2		

Source: EEA, 2006

Note: EU-13 comprises EU-15 Member States without Greece and Luxembourg; Eu-21 comprises EU-25 member States without Cyprus, Greece, Luxembourg and Malta; EU-14 comprises Eu-15 Member States without Luxembourg.

4.5.4.2.3 Forests biomass production potential according to Biomass Energy Europe (BEE)

The project Biomass Energy Europe (BEE, http://www.eu-bee.info) has published a recent deliverable that is a meta-study on biomass potential assessments. As the aim of BEE is to improve comparability of future biomass assessment, it can be very useful as comprehensive and actual study to be used in *ALTER-MOTIVE*.

BEE criticizes that currently three different methodological approaches that are used need to be harmonized: resource-focused, demand-driven and wood resources balance. Table 4-28 shows the forest biomass assessments at global and European level in EJ/Year

Table 4-28: Forest biomass assessments at global and European level in EJ/Year

Reference	Scenario	Time frame				
		2000-2006	2010	2017-2020	2030-2040	>2040
Studies focusing on the European scale						
Alakangas et al. 2007	2006 potential	3.925	-	-	-	-
Asikainen et al. 2008	2005 potential	1.630	-	-	-	-
Ericsson & Nilsson 2006	Low biomass harvests	-	-	1.8	1.8	1.8
	High biomass harvests	-	-	1.8	2.4	2.4
EEA 2007	Baseline (maximal environmental limitations)	-	0.342	0.356	0.380	-
	Baseline + 75% recovery of residues	-	0.576	0.599	0.640	-
	Complementary fellings – protected area and deadwood	-	0.115	0.100	0.100	-
	Complementary fellings – protected area	-	0.136	0.119	0.122	-
	Complementary fellings	-	0.160	0.143	0.146	-
Reference	**Scenario**	**Time frame**				
		2000-2006	**2010**	**2017-2020**	**2030-2040**	**>2040**
Studies focusing on the European scale						
EEA 2007	Summary energy potential from felling residues and complementary fellings					
	Max – protected area and biodiversity scenario	-	1.015	0.936	0.931	-
	Max – protected area scenario	-	1.137	1.041	1.048	-
	Max scenario	-	1.275	1.168	1.180	-
Hetsch et al., Mantau et al. 2008	Policy targets (current use) on wood energy	2.971	3.712	6.065-4.688	-	-
	Supply of wood for energy	2.971	3.174	3.889-3.480	-	-
	Balance	0	-0.538	-2.176-1.208	-	-

Source: BEE, 2008

4.5.4.2.4 Forests biomass production potential according to RENEW

Within the RENEW project (2008), wood feedstock have been divided into a number of sub-feedstock:

Forestry:

- Logging residues
- Thinning Wood
- Root Biomass
- Wood Balance

Wood industry:

- By-products from sawmills
- By-products from pulp & paper industry
- By-products from board industry
- By-products from other wood processing industries

The following Table 4-29 shows the biomass potential from wood-based feedstock in PJ/year. SP is a baseline scenario (2000-2004), while the other two scenarios simulate the expected situation for 2020. S1 assumes a more intensive forestry exploration with higher potentials than the baseline, while S2 emphasizes sustainability aspects and therefore leads to lower potentials.

Table 4-29: Residue biomass potential in Europe (PJ/yr)

Biomass assortments	SP	S1	S2
FORESTRY WOOD	682,8	787,9	769,3
Logging residues	65,4	90,8	52,1
Thinning wood	306,8	408,9	379,2
Roots and stumps	7,6	3,4	5,1
Wood balance	303	284,8	332,9
WOOD INDUSTRY BY-PRODUCTS	50,5	67,7	57
AGRICULTURAL RESIDUES	1 831	1 566,8	1 477,8
Cereal straw	855,2	703,38	631,1
Maize straw	764,1	683,63	683,6
Oilseed straw	240,5	217	217
TOTAL	2 564,3	2 422,4	2 304,2

(Source: RENEW (2008), Scope EU-25 excluding Malta and Cyprus, including Bulgaria, Romania and Switzerland)

4.5.4.2.5 Waste production potential according to Refuel

The Refuel studies (2008a, 2008b) do not provide biomass potentials for waste.

4.5.4.2.6 Waste production potential according to EEA

The European Environmental Agency (EEA,2006) classifies municipal waste as follows:

- The component of municipal solid waste which is of biological origin (mainly kitchen and garden waste, paper and cardboard, but also the component of other waste fractions which are of biological origin)Wet manure consists of manure from cows, pigs and laying hens
- Dry manure entails manure from fattening hens

In the EEA report, municipal waste, wet and dry manure have been considered as feedstock:

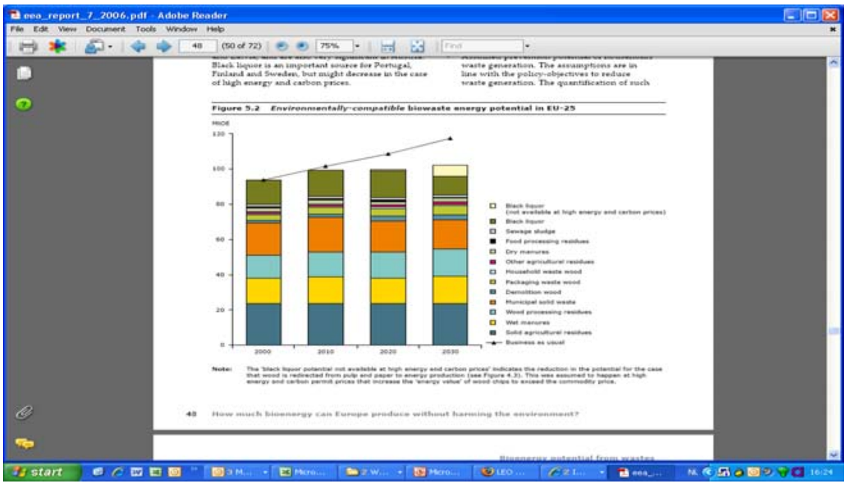


Figure 4-18: Environmentally-compatible bio-waste energy potential in EU-25

Source: EEA, 2006/2007

4.5.4.2.7 Waste production potential according to BEE

The Biomass Energy Europe project (BEE, 2008) has included a review on several studies including agricultural residues and organic waste; however methodologies used between the studies differ. Livestock residues (wet & dry manure) is frequently used in methodologies, while waste streams are sometimes very aggregated or divided into sub streams of organic, municipal and industrial waste.

Selected studies give a good overview of biomass availability from agricultural residues and organic waste in Europe. Results from selected studies review with a reference to spatial coverage and biomass potential from agricultural residues and waste are presented in Table 4-30.

Table 4-30: Overview of biomass potentials from agricultural residues and waste for selected studies on the European level (10^9 GJ/year); compiled in the BEE study (2008)

Reference	Scenarios	Geogr. Coverage	Time frame								
			2000	2004	2005	2005-2025	2010	2020	2030	2025-2045	>2045
Eriksson&Nilsson 2006	Short term (10-20 years), medium term (20-40 years), long term (>40 years)	EU15				0,7				0,6	0,5
		EU25				0,9				0,9	0,6
		EU25 + Ukraine + Belarus				1,0				1,1	0,7
Siemons_et_al_2004	Technical proposal	EU15 + accession countries + BG and RO					3,25	4,25			
De_Noord_et_al_2004	Realistic potential	EU15 + Norway	1,451				0,669	0,129	0,692		
Krause&Oettel_2007	2003-2005 technical potential	EU25		1,00	1,15						
Edwards_et_al_20	2005 technical potential	EU25+2			0,230						
De_Wit_&_Faaij_2008	Technical and economic potential, Bio-physical modeling of land required for food and feed	EU27 Member States + Switzerland, Norway, Ukraine					3,9	3,5	3,1		
Ganko_et_al_2008	SP scenario	Europe						1,829			
	S1 scenario	Europe						1,565			
	S2 scenario	Europe						1,476			
Nikolaou_et_al_2003	Technical potential -> available resource potential -> energy potential	Europe	2,016								
Thraen_et_al_2007		EU28	8,825				2,863	2,853			

4.5.4.3 Overview and ranges of EU biomass potentials

As explained in the previous chapters, the potentials reported in literature vary widely, depending on the method of analysis. By bringing together a number of key studies an overview table could be established, also showing the bandwidth of the estimates. In this way, the overview Table 4-31 given below was compiled, including the different feedstock on the intermediate aggregated level i.e. agriculture, forestry and waste, focusing on 2010, 2020 and 2030. In addition, Section 4.5.4.3.2 provides the available additional information on a more detailed feedstock level (crops). In addition to this general overview, sections 4.5.4.4 & 4.5.4.5 provide the overview graphs on EU biomass potentials as reported in BEE (2008) and EEA (2006, 2007), respectively.

4.5.4.3.1 Overview biomass potential agriculture, forestry and waste

The Table 4-31 below was compiled on the basis of the numbers listed in Refuel (208), EEA (2006/2007) and BEE (2008). The Table 4-31 shows that the total biomass potentials for Europe projected for 2020 are in the order of 10 Exa Joule, with limited increase in potential afterwards. The various literature sources report different relative shares for the contribution of agriculture, forestry and waste, but have in comment that they project an increase of the relative share of agriculture towards 2020.

Table 4-31: Total biomass potentials for EU-25 projected for 2010, 2020 & 2030

Source	Country	Units	2010				2020				2030			
	EU-25		AG	FRT	WT	ToT	AG	FRT	WT	ToT	AG	FRT	WT	ToT
IEA 2006	(no Bu & Ro)	MtOE	47	43	99	189	96	39	99	234	142	39	102	283
IEA 2006		EJ	1.9	1.7	4.1	7.8	3.9	1.6	4.1	9.7	5.9	1.6	4.2	11.8
Refuel 2008	EU27 (-Ukraine)	EJ	2.5				3.85							
BEE review 2008 Lower bound	EU-27	EJ	0.8	1	2.9	4.7	0.8	0.9	1.5	3.2	6	0.9	3.1	10
BEE review 2008 Upper bound	EU-27		6.1	3.2	3.9	13	12	3.9	4.3	20	8	2.4	3.1	14

*AG: Agriculture; FRT:Forestry; WT:Waste; ToT: Total

4.5.4.3.2 Biomass potential on the feedstock level (crops)

Data listed in the Refuel (2008) study, available on the level of crop types. Note that the supply potentials, although, all denoted in energy terms are not comparable to one another in terms of possible biofuel output. i.e. the efficiency of processing feedstock into fuel can introduce substantial deviations (Refuel, 2008).

Table 4-32: Biomass potentials in Europe on feedstock level in EJ/Yr

Crop Type	Woody	Grassy	Oil	Sugar	Starch
2010	4,4	5,8	1,7	2,9	2,4
2020	7,2	9,3	2,6	4,6	3,7
2030	9,5	12,2	3,3	6	4,7

The EEA study (2006/2007) does not provide any further aggregated data on biomass feedstock potential other than the breakdown to the level: agriculture-forestry-waste, as presented earlier in this report. Uslu (2009) provided some more detailed underlying potential from the EEA project on the various waste streams, as listed in the table below. Additional more detailed information from the EEA, is most likely difficult to obtain (Uslu, 2009). For algae there have been a few studies but useable potential have not been reported as this resource is quite new with many techno-economic issues (Uslu, 2009).

Table 4-33: Aggregated EEA data on waste and residues for 2 different scenarios

		PJ	PJ	PJ	PJ	PJ	PJ	PJ
		2000	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
EU25	Solid Agricultural Residues	989,5	1031,7	1077,1	1117,5	988,8	984,9	994,6
EU25	Wet Manures (large farms)	340,1	358,8	351,4	399,2	359,1	328,8	344,9
EU25	Wet Manures (small farms)	269,8	273,8	271,7	288,4	286,2	284,8	304,5
EU25	Wood processing residues	545,1	613,5	690,8	778,3	579,4	615,8	654,7
EU25	MSW (waste not going to landfill recyling or composting)	155,8	311,8	515,1	568,9	307,2	414,0	404,6
EU25	MSW (waste going to landfill)	560,2	458,2	276,7	270,5	462,8	278,8	225,0
EU25	MSW (waste being composted)	38,5	50,9	62,3	62,8	50,9	54,5	47,1
EU25	Demolition Wood	68,8	85,4	103,5	122,3	85,4	103,5	122,3
EU25	Packaging Waste Wood	131,1	166,0	208,2	257,2	156,6	185,5	217,5
EU25	Household Waste Wood	31,0	34,2	36,7	38,6	34,2	36,7	38,6
EU25	Black Liquor (always available)	571,9	641,8	718,0	767,5	619,8	637,4	432,8
EU25	Black Liquor (not available at high wood chip price)	0,0	0,0	0,0	0,0	1,2	33,4	264,0
EU25	Other agricultural residues	45,0	44,2	45,3	46,5	44,2	45,5	48,7
EU25	Dry Manures (large farms)	17,9	18,8	18,8	20,5	17,9	18,4	16,9
EU25	Dry Manures (small farms)	71,7	75,1	75,4	82,0	73,6	67,6	66,7
EU25	Food processing residues	30,2	30,2	30,4	31,4	30,1	30,1	31,2
EU25	Sewage sludge	57,8	59,2	59,2	59,7	59,2	59,2	59,7
EU25	**Total biowaste**	**3924,4**	**4253,8**	**4540,5**	**4911,5**	**4156,7**	**4179,0**	**4273,9**

4.5.4.4 BEE overview results

The Biomass Energy Europe study (2008) provides an overview of the total biomass potentials in the EU-27, as well as the breakdown over the underlying categories (see Table 4-34).

Table 4-34: Overview graph of EU-27 biomass potentials in EJ per year: total and relative share of energy crops; forestry and waste streams

	2000	2010	2020	2030	2040
EU27					
Energy crops on agricultural and marginal land	0.7-1.4	0.8-6.1	0.8-12	6.0-8.0	6.1-22
Forestry and forestry residues	1.0-3.9	1.0-3.2	0.9-3.9	0.9-2.4	2.4
Agricultural residues and organic waste	2.0-2.8	2.9-3.9	1.5-4.3	3.1	n.a.
TOTAL	3.7-8.1	4.7-13	3.2-20	10-14	n.a.

Table 4-34 shows that the biomass potential assessments differ substantially among different studies. The lowest and the highest estimate of the total biomass potential differ by a factor 2 - 3 for the time window 2020 - 2030. Towards 2050 the various potential estimated differ by up to a factor 5. This is mainly caused by large uncertainties connected to the energy crops on agricultural and marginal land. The large uncertainties in the total estimates largely result from the huge uncertainty in the sub stream “dedicated energy crops”. As explained earlier, these uncertainties can mainly be explained by ambiguous and varying methods of estimating (future) biomass production and availability as well as ambiguous and varying assumptions on system-external factors that influence potentials (such as land use and biomass production for food and fiber purposes). In contrast to energy crops, the potentials for forestry and forestry residues (called ‘wood fiber system residues’) and agricultural residues and organic waste (called ‘food system residues & organic waste’) do not show a clear trend over time. These findings emphasize the strong need to improve the accuracy and comparability of future biomass resource assessments for energy by reducing heterogeneity and by increasing the degree of harmonization.

4.5.4.5 EEA overview results

By translating the land potential derived from the crop mixes the EEA study (2006, 2007) arrives at a total energy potential for the EU-25 of 1.7 EJ (47 MtOE) in 2010, 4.0 EJ (96 Mtoe) in 2020 and

5.9 EJ (142 MtOE) in 2030. This implies that between 2010 and 2030 the energy potential increases by a factor of around 3.3.

In the Table 4-35 the results are presented for the EU-15 and EU-10 (estimated for the E-8). It is clear that the EU-15 has a greater bioenergy potential than the EU-10 and that this difference increases towards 2030. This relatively stronger increase for the EU-15 is related to the fact that liberalization of agricultural markets has a stronger effect on these Member States. On the other hand, both total and transport energy consumption in the EU-10 are much lower than in the EU-15, and, at the time of writing, a substantial difference was expected to remain, in spite of increasing convergence. Therefore it was to assume that some new Member States will export their biomass or biofuel to EU-15 Member States.

Table 4-35: Bioenergy potentials for EU-15 and EU-8 in Mtoe

Year	Total EU-15	Total EU-8	Ratio EU-15 : EU-8
2010	27.2	19.5	1.4 : 1
2020	59.8	36.0	1.7 : 1
2030	95.0	47.3	2.0 : 1

4.6 Biomass import

The European Commission has put forward a proposal for a Directive to achieve by 2020 a 20% share of renewable energy on average in the EU, and a sub target of 10% renewable energy in transport (EU, 2009). The 10% target for renewable energy is expected to be predominantly met by the application of biofuels. A considerable share of these biofuels will have to be produced domestically, not only for reasons of improving energy security within Europe, but also because of growing global competition for biofuels and feedstocks, as result of global trends of lowering dependencies from fossil fuels (Günther et al, 2010).

From a sustainable point of view, residues of processes have the largest potential for future imports, because the competition with local applications is mostly limited, while in addition such streams will be generally easy to collect. Examples are the residues of the palm oil production in SE Asia (e.g the approximately 420 PJ of Palm Kernel Expeller or the estimated 1200 PJ of rice chaff); similar waste streams exist for e.g. bagasse (Koppejan et al, 2009).

In addition, many woody waste products from forestry are available that is currently not used and could be imported to Europe. Currently 18 PJ of wood pellets is globally produced and traded, predominantly originating from Canada, Russia, the Baltic and Scandinavia. According to Dornburg et al. (2008) on the long term (2050) 40-170 EJ of waste streams will be available from forestry and agriculture. The extent of import of these streams into Europe will depend on the future development of global demand, supply and costs.

5 Alternative fuel chains

5.1 Hydrogen Technology

Hydrogen is found naturally in bonded from within many hydrogen-rich compounds. Hydrogen can be produced directly from all primary energy sources as well as from secondary energy sources (e. g. ethanol, biogas, methanol, gasoline). It cannot be extracted like natural gas or oil, but needs to be released by use of energy like natural gas, biomass or coal of electricity or high temperatures. Hydrogen is non-toxic, non-poisonous and does not contribute to groundwater pollution. It does not create "fumes" or other harmful emissions; in fact, using hydrogen in fuel cells produces only electricity and pure water (National Hydrogen Association).

About fifty million tons of hydrogen (54-65 Mt) is produced each year worldwide, which is enough to fuel 600 – 720 million fuel cell vehicles (Linde, 2003; IEA, 2007). Only about 5 % of total hydrogen production is sold on the free market (Ball et al., 2009). Grid-electricity plays an important role in the initial phase of hydrogen introduction, especially it is required to produce hydrogen directly at the fillings station and avoid major infrastructure investment. However this method is very expensive and is subjected to several other affecting the total performance and economy of hydrogen production. For fluctuating electricity sources however, grid integration of large quantities might cause instabilities to the electricity network and producing hydrogen might help to solve this problem. Such hydrogen is nowadays mainly used to supply the industrial site with electricity and thermal heat (Zittel et al. 1998). But there is also an important conventional use of hydrogen in the chemical and petrochemical industry (see the figure below).

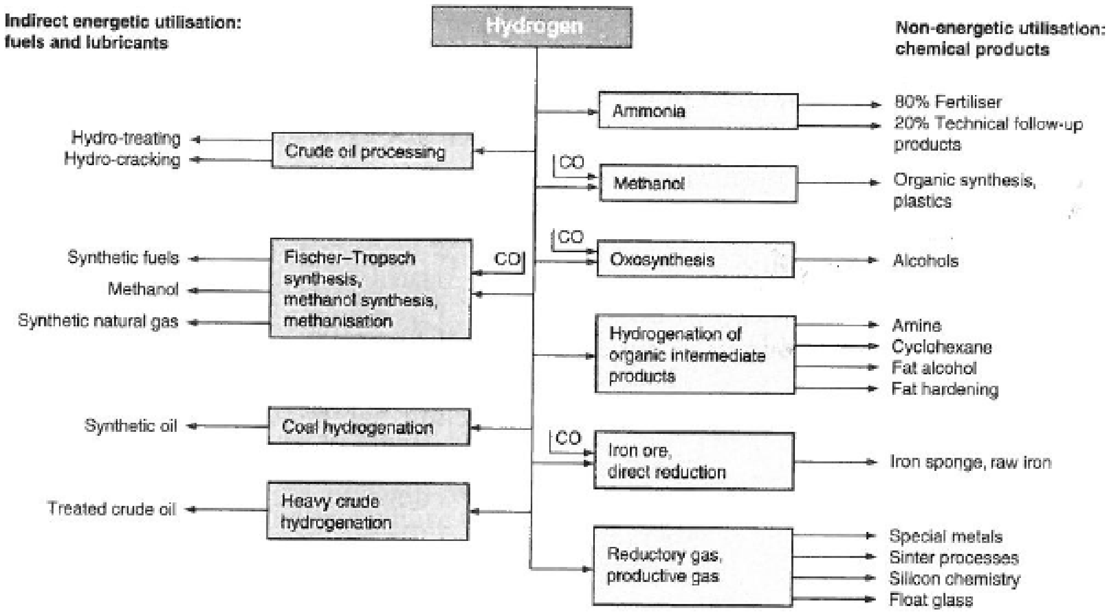


Figure 5-1: Industrial use of hydrogen.

Source: Ball et al., 2009

Nuclear power is seen critical as it still holds unsolved problems of radioactive waste, but it is seen as an important energy source for hydrogen production in various studies and national hydrogen roadmaps. Moreover, promising new hydrogen production technologies like solar or nuclear water splitting or high temperature electrolysis are in a very early stage of development and very expensive.

5.1.1 State of the art

Car manufacturers are currently developing drive concepts for both: liquid and gaseous hydrogen and no clear preference has become apparent so far. There are various differences between both the forms of fuel viz. handling, filling stations infrastructure and supply, and especially the energy content. Liquid hydrogen has higher energy content than gaseous hydrogen and hence it allows larger driving distances. However about ¼ of the energy contained in the hydrogen is needed in form of electricity to cool down hydrogen to -253 °C. The energy content of 1 Nm^3 gaseous hydrogen is equivalent to 0.3 l of diesel, 1 litre of liquid hydrogen equivalent to 0.24 l of diesel or 1 kg of hydrogen equivalent to 2.79 kg of diesel (HyFleet:Cute, 2010). Gaseous and liquid hydrogen storage options are required as both drive concepts are developed hand in hand. The suitability of other storage options for passenger cars (like metal hydrides or chemical compounds) is uncertain. Gaseous hydrogen storage is suitable in 700 bar carbon reinforced steel, aluminium or plastic vessels, liquid hydrogen storage in super insulated stainless steel tanks.

Hydrogen Production

Subject to the energy source, various hydrogen production technologies are available these days. Today natural gas reforming, coal gasification and water electrolysis are proven technologies, which are applied at an industrial scale all over the world. Also in the near future (2030 and beyond) these seem to be the most likely hydrogen production technologies. All hydrogen production processes are based on the separation of hydrogen from hydrogen-containing feedstocks. 95 % of the hydrogen, which is produced in the USA today, uses a thermal process with natural gas as the feedstock [steam methane reformation] (National Hydrogen Association). Generally the production technologies can be sub-divided into on-site (at the filling station) and off-site production options. On-site production saves expenditures for hydrogen distribution and is therefore a viable solution especially in the initial phase of development or at remote locations. Two technologies are suitable for on-site production: natural gas reforming & electrolysis (see Figure5-2 and Table 5-1). In case of natural gas reforming the effects of economy of scale result in higher specific costs and lower efficiency compared to large scale natural gas reforming. Additionally, on-site natural gas reforming results in a certain amount of local emissions, as carbon management (carbon capture and sequestration) is not possible on a small scale.

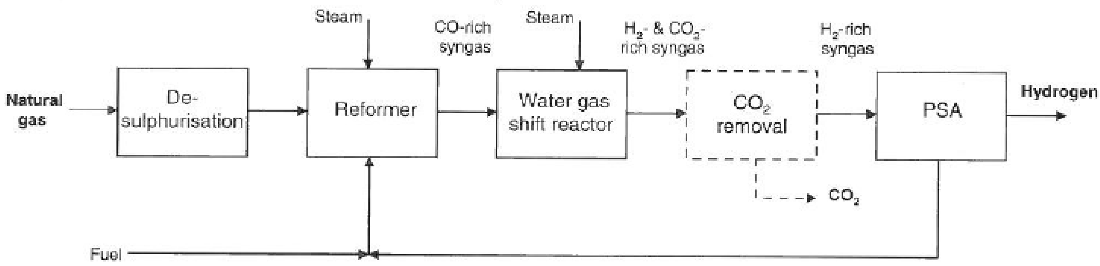


Figure 5-2: Natural gas reforming

Source: Ball et al., 2009

In case of electrolysis, the effect of economy of scale is hardly noticeable due to its modular design. Efficiency and costs are nearly the same compared to large scale electrolysis. On-site production results in supply of gaseous hydrogen, as on-site liquefaction (on a small scale) is highly inefficient and expensive. Large scale, centralised production has the advantage of higher efficiencies and lower costs (only conditionally true for electrolysis) and the possibility to apply carbon capture and sequestration in case of fossil hydrogen production options. Furthermore it is possible to co-produce electricity (exception electrolysis) and to place a liquefaction plant next to the production plant. The drawback of large scale production is on the other hand, that distribution distances increase with the capacity of the production plant.

Electrolysis of water means splitting water to hydrogen (the desired product) and oxygen by supplying electricity to the process. The process can be understood as the reverse of a fuel cell where hydrogen is consumed and electricity is produced. Water electrolysers are commercially available from several companies. The different electrolysers are classified after their type of electrolyte. Today's leading electrolysers are based on a liquid, alkaline electrolyte. Another class of electrolysers are the PEM (Polymer Electrolyte Membrane) electrolysers. At present, the PEM technology has higher electricity consumption than the alkaline based technology; however the potential for increased energy efficiency in the long term is better. The PEM electrolysers are close to commercialization, but still too expensive.

The gasification of coal to produce hydrogen has undergone further development in the last decade and is now also a commercial available process. Apart from this, there are other methods still at the research and development stage, particularly those based on biomass, but also biological hydrogen production (Ball, M. et al., 2009).

Table 5-1: Major hydrogen production processes

Primary Method	Process	Feedstock	Energy	Emissions
Thermal	Steam Reformation	Natural Gas	High temperature steam	Some emissions. Carbon sequestration can mitigate their effect.
	Thermochemical Water Splitting	Water	High temperature heat from advanced gas-cooled nuclear reactors	No emissions
	Gasification	Coal, Biomass	Steam and oxygen at high temperature and pressure	Some emissions. Carbon sequestration can mitigate their effect.
	Pyrolysis	Biomass	Moderately high temperature steam	Some emissions. Carbon sequestration can mitigate their effect.
Electrochemical	Electrolysis	Water	Electricity from wind, solar , hydro and nuclear	No emissions
	Electrolysis	Water	Electricity from coal or natural gas	Some emissions from electricity production.
	Photoelectrochemical	Water	Direct sunlight	No emissions
Biological	Photobiological	Water and algae strains	Direct sunlight	No emissions
	Anaerobic Digestion	Biomass	High temperature heat	Some emissions
	Fermentative Microorganisms	Biomass	High temperature heat	Some emissions

Source: Hydrogen production overview 1.008, fact sheet series, National Hydrogen Association, 2004

Today the direct use of hydrogen for energy purposes is mainly for power and heat generation and plays only a minor role in vehicle technologies. Most of the hydrogen is used as a raw material for the production of a wide range of substances. This is mainly ammonia and methanol synthesis, but also iron and steel production, treatment of edible oils and fats, glass and electronics industry etc. The main indirect application of hydrogen for energy production is the petrochemical hydration of conventional fuels (HyFleet:Cute, 2010).

5.1.1 Plant size ranges

A flow scheme of a typical hydrogen plant is shown in Figure: 5-3.

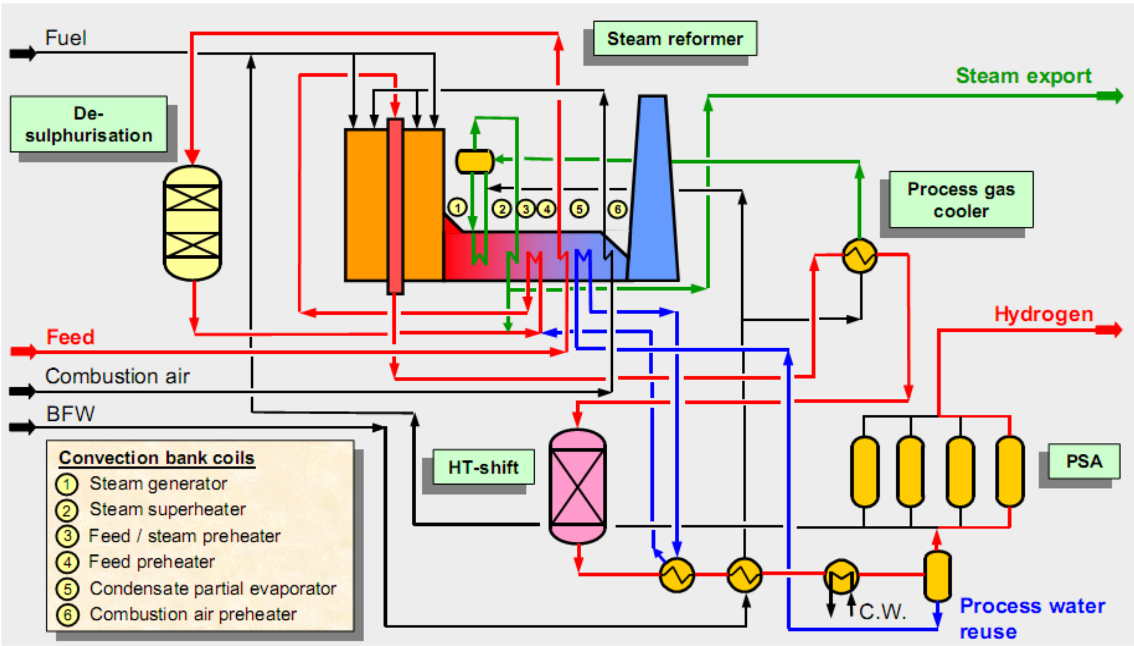


Figure 5-3: Hydrogen production flow processes

Hydrogen production overview 1.008, fact sheet series, National Hydrogen Association

Hydrogen production from biomass is more reasonable on a medium scale as long-distant transport of biomass to the production site is inefficient, due to its low energy content in comparison to its volume and mass.

Table 5-2: Hydrogen production technologies (small to large scale)

Hydrogen production technologies		
Small scale		
	Electrolysis on site Grid electricity	2.5 MW
	Reforming on site Natural gas	0.95 MW
Medium scale		
	Staged reforming off site Biomass plantation - Miscanthus Biomass residual - forestry	25 MW
Large scale		
	Electrolysis off site Wind power Solar power Nuclear power	200 MW
	Reforming off site Natural gas Natural gas with CCS	800 MW
	Gasification off site Hard coal and lignite Hard coal with CCS	850 MW

Source: self elaboration based on Toro, F., Hasenauer, U., et. al 2008

Liquefaction is not reasonable on a small scale (e.g. at the filling station), as the efficiency decreases significantly at smaller scales. Therefore liquid hydrogen has to be delivered from an off-site, large scale production/liquefaction site. The liquid hydrogen is delivered by trucks. In order to gain reasonable driving ranges with gaseous hydrogen it is compressed. 700 bar is state of the art for passenger cars and allows driving distances of about 600 km (BMWA 2005). To allow a smooth refuelling process at the filling station a pressure gradient is required and gaseous hydrogen is therefore provided at a pressure of 880 bar at the filling station. Gaseous hydrogen is available from on-site or from off-site production. Pipeline distribution is the most efficient option at high volumes. The distribution of gaseous hydrogen with trucks is highly inefficient at high volumes. The specific hydrogen storage cost (c/kWh stored hydrogen) is highly dependent on the fuel consumption of the vehicle and from the annual driving distance. Therefore public buses have much lower specific on-board storage costs than private passenger cars.

Table 5-3: Hydrogen conditioning and distribution technologies (small to large scale)

Liquification	
	Electrolysis on site
	Grid electricity
	Solarthermal power
	Wind power
	Nuclear power
Distribution: pipeline	
	25 MW, 100 km, 30 bar
	200 MW, 500 km, 30 bar
	850 MW, 800 km, 30 bar
Distribution: cryogenic truck	
	variable distances
Compression at the FS	
	30 to 880 bar
Filling Station (storage and refueling)	
	CGH2 880 bar (110 t/a)
	LH2 (110 t/a)

Source: self elaboration based on Toro, F., Hasenauer, U., et. al 2008

5.1.2 Economic assessment of Hydrogen Technologies

Hydrogen is widely considered as one of the cleanest and most innovative energy carriers, which has potential to reduce local and global emissions and to increase supply security. Hydrogen can be produced using fossil energy, renewable energy or nuclear energy. The different resources and processes can be used for hydrogen production. Some of them are suitable for on-site, small-scale hydrogen production, such as electrolysis, and some of them are suitable for large central hydrogen production. Central hydrogen production can take advantage of economies of scale. The advantage of on-site hydrogen production is that hydrogen transportation costs are avoided. If centralized hydrogen production is assumed, the hydrogen must be transported to the point of use in trucks, train, ships or via pipeline (Ajanovic, 2008).

Currently the largest part of hydrogen is produced by steam reforming of natural gas – this is the cheapest solution - but hydrogen based on renewable energy is one of the best solutions from an environmental perspective. In Figure: 5-4 hydrogen costs are shown for a different primary energy sources – renewable and fossil energy. The economics of scale is obvious by steam reforming of natural gas, but not in the case of hydrogen production via electrolysis. The share of primary energy costs in the hydrogen cost is in range from 55% for hydrogen from natural gas to 84% for hydrogen from renewable energy.

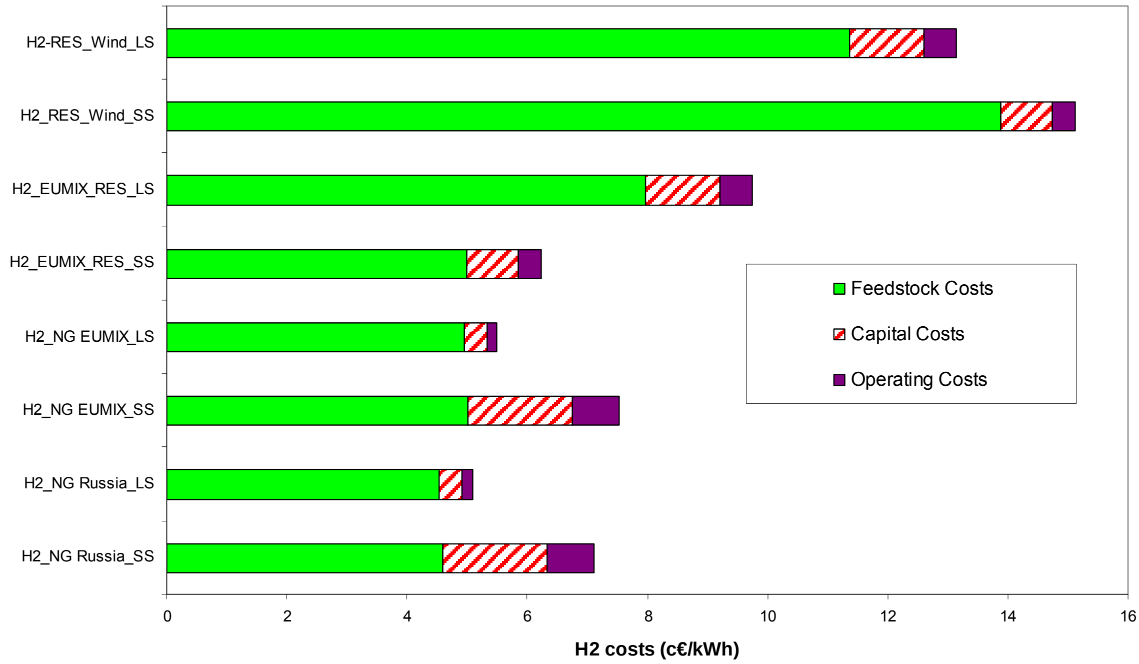


Figure 5-4: Production Costs of H2 from various RES and NG sources (as of 2010)

(H2: Hydrogen, ICE: Internal Combustion Engine, FCV: Fuel Cell vehicle, BEV: Battery Electric Vehicle, NG: Natural gas, RES: Renewable energy sources, LS: Large scale, SS: small scale)

5.1.3 Environmental assessment of Hydrogen technologies

H_2 natural gas from Russia and H_2 natural gas EU mix

CONCAWE takes into account pathways describing the local production of hydrogen with a small steam reformer installed at the refueling station followed by compression. The only difference is the supply origin of the natural gas. We consider two options: Imported Russian gas (7000 km) and EU mix (1000km).

Table 5-4: WTT emission for piped NG Russia, on-site reforming

WTT Emissions		Small Scale
NG extraction&processing	g CO_2eq/MJ	5,7
NG transport	g CO_2eq/MJ	22,1
NG Distribution	g CO_2eq/MJ	0,8
On-site reforming	g CO_2eq/MJ	84,7
Compression	g CO_2eq/MJ	10
Total WTT Emissions	g CO_2eq/MJf	123,2

Table 5-5: WTT emission for NG EU-mix, on-site reforming

WTT Emissions		Small Scale
NG extraction&processing	g CO_2eq/MJ	4,9
NG transport	g CO_2eq/MJ	2,8
NG Distribution	g CO_2eq/MJ	0,9
On-site reforming	g CO_2eq/MJ	86,6
Compression	g CO_2eq/MJ	10
Total WTT Emissions	g CO_2eq/MJf	105,2

H_2 renewable

Electricity to Hydrogen. Electrolysis can be done making use of any electricity source. It can be a large central plant or a small on-site installation. From a central plant hydrogen can be piped to the refueling station and compressed or liquefied and transported by road. From an onsite-plant hydrogen must be compressed. Selected option considers the wind off shore electricity production. This pathway assumes central electrolysis and hydrogen distribution as it is most applicable to stranded electricity that cannot be supplied into the grid.

Table 5-6: WTT emission for Wind offshore central electrolysis

WTT Emissions		Small Scale
Wind offshore	g CO_2eq/MJ	**0**
Electricity distribution	g CO_2eq/MJ	**0**
Electrolysis (central)	g CO_2eq/MJ	**0**
Gaseous hydr distrib.&comp.	g CO_2eq/MJ	**9,1**

5.1.4 Technical innovation potential of Hydrogen technologies

Fuel cell transport applications such as cars, buses, taxis, forklifts, motorbikes and trucks are currently being developed, tested and demonstrated at EU, national and local level. What is needed additionally is in particular a coordinated approach towards increased project funding, regulatory support and development of technical standards both at EU and at Member State level (HyFleet:Cute, 2010). Using hydrogen as a fuel in internal combustion engines (ICE), that are typically based on ICEs designed for the combustion of natural gas (CNG), means benefiting from advantages that hydrogen provides in comparison to fossil fuels. However, substantial research and fundamental adjustments are necessary to make them powerful components in vehicles. But as most components are identical with those used in conventional diesel engines, the costs at present remain much lower than those for fuel cell propulsion systems (Hyfleet:Cute, 2010). But in contrast to electric cars the range with more than 400 km is clearly longer. The actual problem is the absence of area-wide filling stations.

In the future hydrogen will be made partly from biogenic wastes (e. g. vegetable oils, animal fats, algae oils) or from renewable sources (e. g. wind energy, hydrogen energy). In doing so the hydro treating of vegetable oil technology (HVO) seems much more likely than the use of fatty acid methyl esters technology (FAME). The use of hydro treated vegetable oils (HVOs) allows up to 30 % admixing. In contrast FAME can only be mixed up to 8 %. Furthermore during production of HVOs propane is generated as by-product and no storage stability problems are known. Coevally are free of aromatics, oxygen or sulphur and possess high cetane numbers. In addition the production of hydrogen with the aid of bio-reactors and green algae can be conceivably.

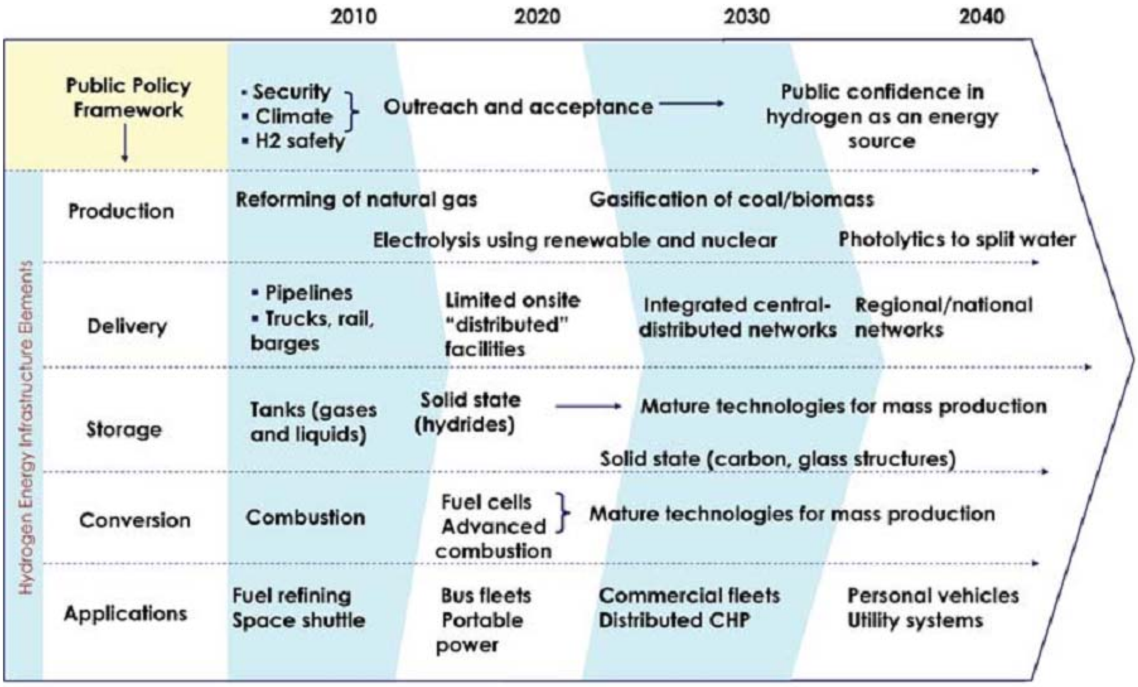


Figure 5-5: Hydrogen R&D development pathways
Source: US Department of Energy, Hydrogen Posture Plan

The 700-bar-fuell-filling – the so called ionic compressor - demonstrates yet another technical innovation. This technology enables budget-priced, service-reduced and energy efficient filling stations.

Comparison of WTT emissions

The graph (Figure 5-6) depicts the comparison of Total WTT emissions according to the different biofuels considered.

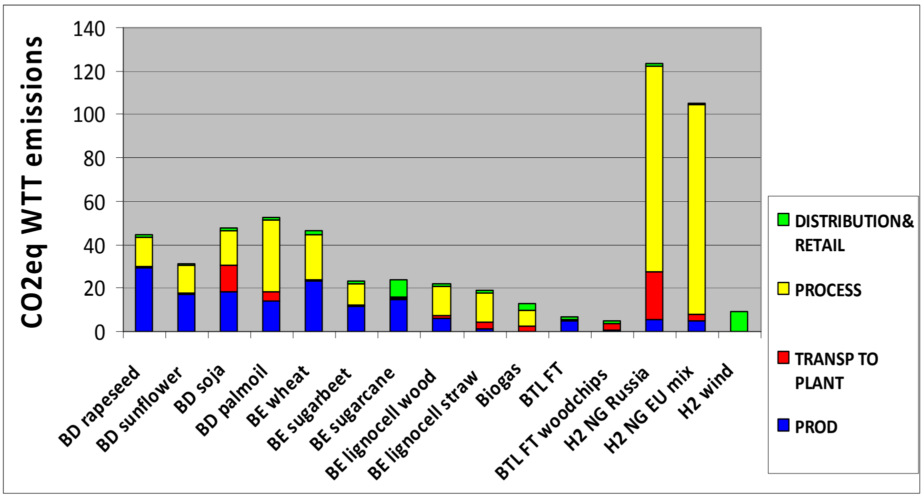


Figure 5-6: Comparison of Total WTT emissions from different alternative fuels
Source: Own elaboration

As we could expect, major emissions come from the H_2 production by natural gas that present higher equivalent emissions in comparison to all the other biofuels. The smallest emissions come from the BTL Fischer-Tropsch with woodchips as feedstock, where emissions are in fact due to the transport to plant stage. Biodiesel from rapeseeds performs the highest level of emissions in production stage as the Biodiesel from palm oil has the highest emissions at the process stage.

However, the environmental analysis needs some improvements to make clearer, consistent and easier way to compare the final data concerning the WTT emissions. Although, as stated before, the CONCAWE studies seems to offer the most reliable and consistent analysis, figures presented needs further specification of some energy input data.

The following graphs show different values of WTT emissions calculated by the IFEU study where the emissions are presented in a different way (energy saved/km and CO_2 emissions avoided). The different parameters used do not allow an easy comparison but overall conclusions are similar with a strong consensus over the BTL FT as the best performances in terms of WTT emissions.

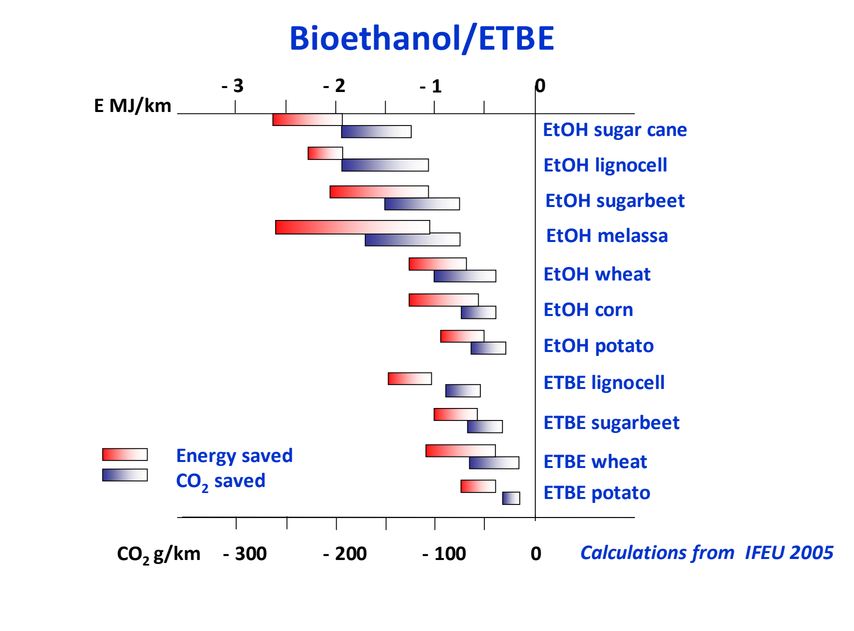


Figure 5-7: Different values of WTT emissions from Bioethanol/ETBE according to IFEU study
Source: IFEU

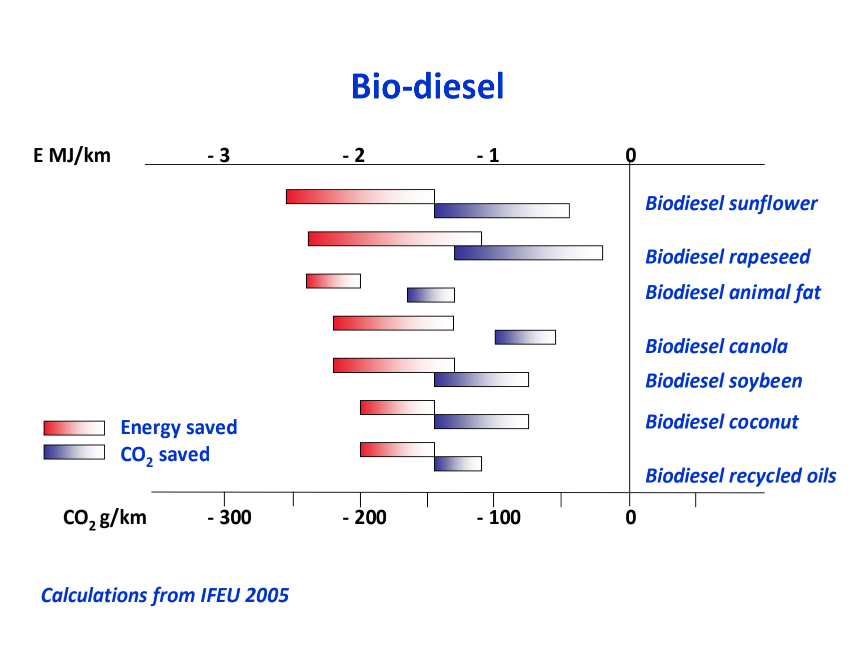


Figure 5-8: Different values of WTT emissions from Biodiesel according to IFEU study
Source: IFEU

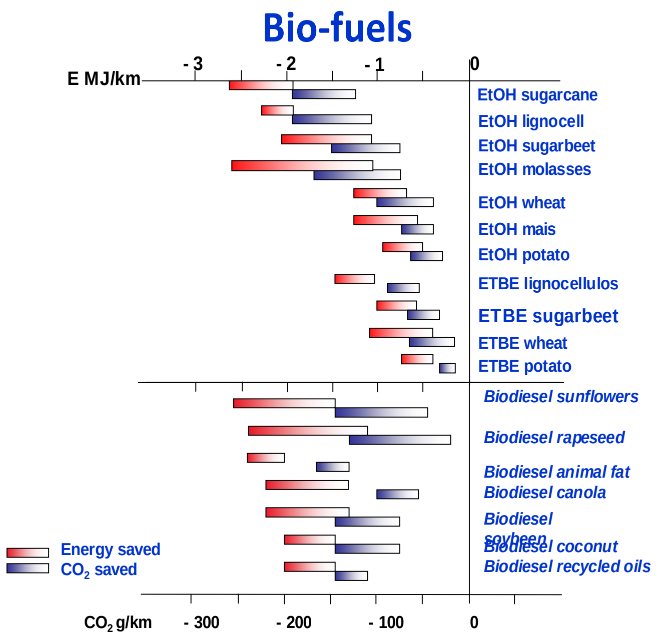


Figure 5-9: Different values of WTT emissions from different Biofuels according to IFEU study
Source: IFEU

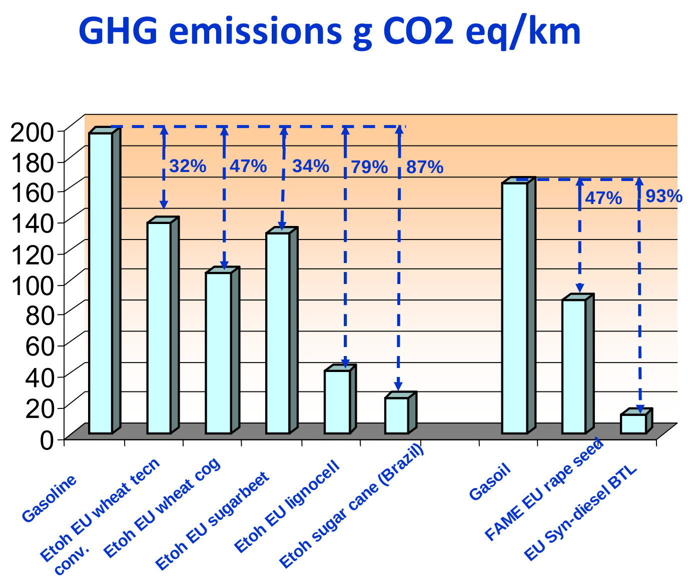


Figure 5-10: GHG emissions from different Biofuels according to IFEU study
Source: IFEU

6 Alternative automotive technologies

Alternative fuel vehicles include any dedicated, flexible-fuel, or dual-fuel vehicle designed to operate on at least one alternative fuel (Energy Policy Act). An alternative fuel vehicle can be combined with an internal combustion engine designed to run on more than one fuel, usually gasoline blended with either ethanol or methanol fuel or diesel blends with biodiesel. Flex-fuel engines are capable of burning the high fuel blends (E5, E85 etc) in the combustion chamber as fuel injection and spark timing are adjusted automatically according to the actual blend detected by electronic sensors (Rutz & Janssen, 2007). Flex-fuel vehicles where the two fuels are blended in the same storage tank are distinguished from bi-fuel vehicles, where two fuels are stored in separate tanks and the engine runs on one fuel at a time, for example, compressed natural gas (CNG), liquefied petroleum gas (LPG), or hydrogen. However, a hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle. The term most commonly refers to hybrid electric vehicles (HEVs), which combine an internal combustion engine and one or more electric motors.

6.1 ICE modifications for Biodiesel, Bioethanol and Biogas/NG

6.1.1 State of the art

Currently a huge diversity of fuels and power trains are available in Europe at different levels of R&D, demonstration and commercialization (see Table 6-1), due to the rapid technological diversification carried by and vehicle manufacturers. Cost reduction, efficiency increase, achieving lesser emissions and sustainable development are few drivers for technological development and diversification. In recent years the European Automobile Manufacturers Association (ACEA) members have introduced more than 50 latest technologies into their vehicles, reducing emissions by over 13%, and many more are in the pipeline. Vehicle aerodynamic improvements, vehicle load reduction, using advanced vehicle accessories (power steering, a/c etc), reducing engine and drive train losses are few of them. The 15 ACEA members invest € 26 billion (5% of their turnover) every year in R&D (European Automobile Manufacturers Association, 2010). To reach the motives of CO_2 reduction and increased efficiency, the future seems to depend on a combination of multiple technological developments entering in the market, customized for different usage, driving circumstances and consumer preferences etc. Advanced vehicle technologies commercially available nowadays serve the multiple propose of enhancing performance, fuel savings and better efficiency of a vehicle. Engine modifications (such as reduction of pumping losses, reduction in engine friction, and/or improved combustion) and vehicle modifications (such as regenerative braking, automatic start/shut off, and reducing aerodynamic drag) are few technological advancements of commercially existing ICEs vehicles that contribute in GHG emission reduction and better resource utilization (Kobayashi, Plotkin, & Ribeiro, 2008) . However, the internal combustion engine and its modifications could remain the dominant source of power in the coming decades due to the high cost of alternatives. Over the next 30 years, ICE technology will continue to improve, given the availability of suitable and appropriate cleaner enabling fuels (World Business Council for Sustainable Development, 2004).

Table 6-1: AAMT: State of the Art

	Commercial	**Demonstration**	**R&D**
Technologies	**LNG/CNG** **Flexi fuel** (BD/BE) **Bi-fuels** (NG/CNG+Gasoline/Diesel) **Electric Vehicles** *(Micro-MildHybrid (HEV)* *Full Hybrid* *BEV (only light vehicles, no convertor, DC Motor, Range<100 km)* **Battery types** *Lead-Acid, NiCd, Nickel Metal Hybrid (NiMh)* **Infrastructure** *Private Connections* *Public Connections (unidirectional)*	**Solo BD/BE** **Electric Vehicles-FCV** *Enhanced HEV-PHEV* *PHEV* *BEV (with convertor, AC Motor, Range > 100 km)* **FC hybrids** **Battery types** *Lead-Acid, NiCd, Nickel Metal Hybrid (NiMh), Lithium-Ion* **Infrastructure** *Private Connections* *Public Connections (unidirectional)*	**Electric vehicles** *PHEV, FCV* *Plug-In functionality for FCV/HEV* *BEV (with convertor, AC Motor)* **Battery types** *Lead-Coal, NiCd, NiMh, Lithium-Ion-Nanotechnology, innovations* **Infrastructure** *Private and Public Connection ports with vehicle to grid functionality (bi-directional)*

Source- Own elaboration

The potential benefits of the introduction of new technologies in transport are significant. Some authors consider that the EU could achieve a 20% reduction of its energy consumption compared to the projections for 2020 on a cost-effective basis if today's most advanced technologies were fully integrated in the market (Steenberghen & Lopez, 2007). Moreover, multiple powertrain technologies have the potential to offer personal vehicle fuel economy improvements by 20% to 50% compared to today's gasoline vehicles and diesel electric hybrids have the potential to increase fuel economy by 70% (EPA, 2005).

In the EU, the numbers of alternative fuel vehicles vary among the member states. Germany, France, The Netherlands and Sweden account for the maximum share of alternative fuel vehicles across Europe. 2008 data for Germany shows around 215,000 NGVs, 12,000 hybrids and around

3,000 electric vehicles. In France maximum share of alternative fuel vehicles is held by NGVs (155,000; around 80% of all, in 2008), nearly 19,000 hybrids and nearly a total of 3,000 flex-fuel and electric vehicles. In The Netherlands, figures from 2007 show a total of around 234,000 vehicles, of which NGVs count 220,000, EVs around 10,000 and around 2,000 hybrids. Moreover, Sweden accounts for nearly 200,000 FFVs and about 3000 NGVs, hybrids and EV's. However, Czech Republic and Greece show a decreasing number of AFVs over the time (being 7,200 in 2000 to 5,300 in 2007 in Czech Republic and 2,200 in 2000 to 500 in 2007 in Greece).[7] CNG has been most popular in Italy, where there are currently 432,900 NGV, equivalent to 1.2% of the overall car stock and the highest proportion in Europe. Vehicles using gaseous fuel have been relatively successful in Sweden and Germany, where they account for 0.3 and 0.1% of the total car stock, respectively (Hill, 2008).

Gas fueled vehicles work by using methane (CH_4) stored in the tank in a gaseous state. However, for transportation of gas itself, it is either liquefied and stored at very cold temperatures (LNG) or compressed into tanks so that it does not take up as much physical space in the vehicle (CNG). There are essentially four types of GVs (PikeResearch, 2009); Table 6-2 summarizes the type of NG vehicles available in market. The NGVs require spark plugs to ignite the gas in the chamber. Consequently, NGVs are not typically bi-fuel with diesel (diesel engines use pressure for ignition instead of spark plugs). The dual-fuel engines do not usually have spark plugs. Instead, they use the diesel in the piston cylinder to ignite the larger amount of natural gas that then provides the power for the engine.

Table 6-2: Types of NGVs

Vehicle Type	**Description**	**Examples of Models**
Dedicated CNG vehicles	Vehicles that only use CNG and do not have a gasoline tank in the vehicle	Doblò Natural Power Turbo, Fiat Panda Natural Power
Dedicated LNG vehicles	Vehicles that only use LNG; these are generally only M/HDtrucks	Chevrolet/GM medium duty trucks
Bi (or multi)-fuel vehicles	Vehicles that run on both CNG/LNG and gasoline, or other fuels	Golf BiFuel, Passat TSI EcoFuel, Fiat 500 1.4 Natural Power Turbo Concept[8]
Dual-fuel vehicles	Vehicles that burn two fuels at the same time; these are typically diesel and natural gas	2002 VAUX HALL ZAFIRA COMFORT DUAL FUEL GREEN (LPG&PETROL), Opel Zafira ecoFLEX Turbo CNG

Source- Own elaboration

[7] Deliverable-3 (D3) of workpackage-2 (WP2) of Altermotive project

[8] Natural Gas / Biogas & Petrol Car

6.1.2 Economic and Environmental assessment of ICE modifications[9]

The following emission figures are from the CONCAWE analysis and refer to TTW emissions for some passenger cars (ICE) according to the biodiesel, bioethanol, flexi-fuel vehicle ethanol and BTL (FT) fuels used. Values for the time horizons refer to the year 2002 and 2010. This is a discrepancy with other values that refer to vehicle at the year 2005-2010. The reference values for gasoline and diesel have been calculated based on the CONCAWE version 3.

Biodiesel

Table 6-3: TTW Emissions for ICE Biodiesel

TTW emissions - [g CO2 eq/km]		2002	2010
Specific CO_2 emissions	g CO_2 eq/km	139.6	122.8
Specific N_2O emissions	g N_2O/km	3.0	1.5
Specific CH_4 emissions	g CH_4/km	0.3	0.2

Bioethanol

Table 6-4: TTW Emissions for ICE Bioethanol

TTW Emissions - [g CO_2 eq]		2002	2010
Specific CO_2 eq Emissions	g CO_2 eq/km	149	134.1
Specific N_2O emissions	g N_2O/km	0.9	0.9
Specific CH_4 Emissions	g CH_4/km	0.9	0.9

Flexifuel vehicle-Ethanol

Table 6-5: TTW Emissions for Flexifuel vehicle on Ethanol

TTW Emissions - [g CO_2 eq]		2002	2010
Specific CO_2 eq Emissions	g CO_2 eq/km	155	137,8
Specific N_2O emissions	g N_2O/km	0.9	0.5
Specific CH_4 emissions	g CH_4/km	0.9	0.5

ICE BTL-FT Bio Diesel

Table 6-6: TTW Emissions for ICE BTL-FT Bio Diesel

TTW Emissions - [g CO_2 eq]		2002	2010
Specific CO_2 eq Emissions	g CO_2 eq/km	139.6	122.8
Specific N_2O emissions	g N_2O/km	0.3	1.5
Specific CH_4 emissions	g CH_4/km	0.3	0.2

9 ICE modifications include the adaptations of existing gasoline and diesel passenger cars to be able to run with biofuels blends (e.g. biodiesel, bioethanol) and almost dedicated bi-fuels such as flex fuel vehicles.

Following graph compares the TTW emissions (g CO_2 eq/km) of the four alternative automobiles that produce emissions. Noticeably, electric and hydrogen vehicles are not included in it as they do not produce emissions at the TTW level. As expected, vehicles using biodiesel and BTL-FT biodiesel fuels perform the best in terms of TTW emissions. The efficiency values adopted here correspond to the reference vehicles used for the CONCAWE Version 3.

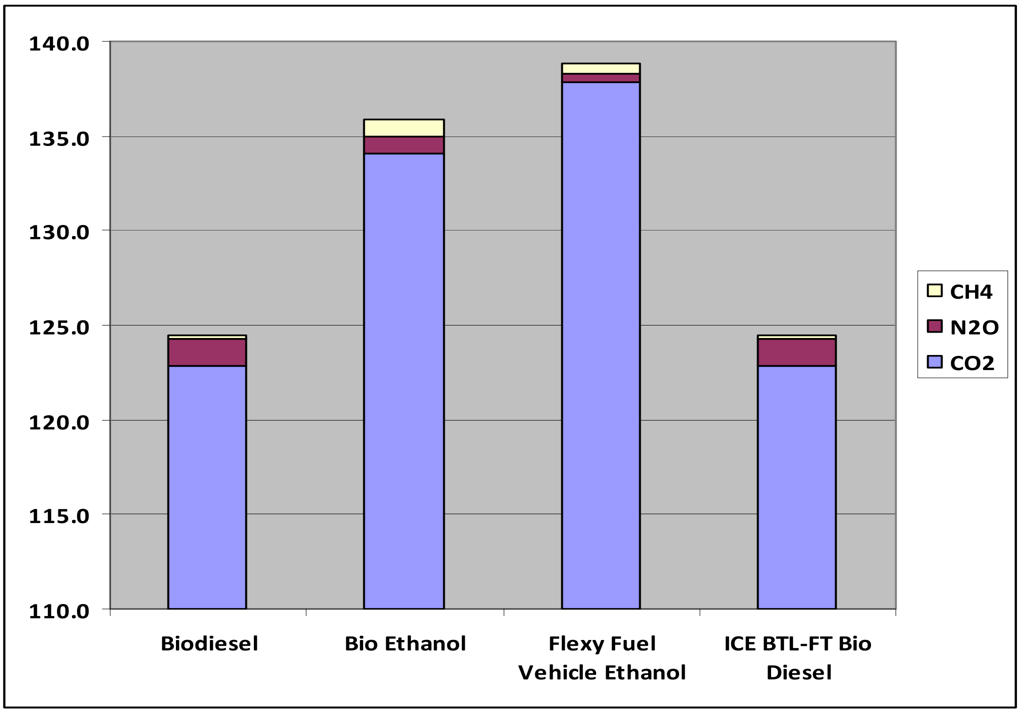


Figure 6-1: TTW comparison between four different AAMTs for 2010 (g CO_2 eq/km)

6.1.3 Technical improvement potential of ICE modifications

As discussed earlier, it is quite possible to have manifold solutions for the future technological developments and modifications. With rapid pace of development and innovation, it is not probable to say which technology will prove to be the most viable solution to current motives. However, two broad categories of technologies can be improved to reduce the fuel usage and GHG emissions in vehicles. These two technological modifications can be incorporated into a vehicle at engine or transmission level (www.fueleconomy.gov).

6.1.3.1 Engine Technologies

Variable Valve Timing & Lift – improves the engine efficiency by optimizing the flow of fuel & air into the engine for various engine speeds. Also called *as variable valve actuation (VVT), variable-*

cam timing and variable valve timing and lift electronic control. Valves control the flow of air and fuel, into the cylinders and exhaust out of them. When and how long the valves open (timing) and how much the valves move (lift) both affect engine efficiency. Optimum timing and lift settings are different for high and low engine speeds. Traditional designs, however, use fixed timing and lift settings, which are a compromise between the optimum for high and low speeds. VVT&L systems automatically alter timing and lift to the optimum settings for the engine speed.

Cylinder Deactivation - saves fuel by deactivating cylinders when they are not needed. Also called *multiple displacement, displacement on demand (DOD), and variable cylinder management*. This technology simply deactivates some of the engine's cylinders when they are not needed. This temporarily turns 8- or 6-cylinder engine into a 4- or 3-cylinder engine. This technology is not used on 4-cylinder engines since it would cause a noticeable decrease in engine smoothness.
Example : GM's Displacement on Demand, it automatically turns off half of the cylinders during lightload operating conditions, enabling the working cylinders to achieve higher fuel efficiency through better thermal, pumping and mechanical efficiency. Under light loads, the control module automatically closes both intake and exhaust valves for half of the cylinders.

Turbochargers & Superchargers - increase engine power, by downsizing of engines (the use of a smaller capacity engine operating at higher specific engine loads) without sacrificing performance or to increase performance without lowering fuel economy. Turbochargers and superchargers are fans that force compressed air into an engine's cylinders. A turbocharger fan is powered by exhaust from the engine, while a supercharger fan is powered by the engine itself. Both technologies allow more compressed air and fuel to be injected into the cylinders, generating extra power from each explosion. A turbocharged or supercharged engine produces more power than the same engine without the charging, hence it makes possible to use smaller engines without sacrificing performance. With this technology efficiency between 2 to 7.5% can be increased.

Integrated Starter/Generator (ISG) Systems - These systems automatically turn the engine off when the vehicle comes to a stop and restart it instantaneously when the accelerator is pressed so that fuel isn't wasted for idling. In addition, regenerative braking is often used to convert mechanical energy lost in braking into electricity, which is stored in a battery and used to power the automatic starter. With this technology efficiency between 0.5 to 8% can be increased.

Direct Fuel Injection (w/ turbocharging or supercharging) – it delivers higher performance with lower fuel consumption. Also called *fuel stratified injection or direct injection stratified charge.* In conventional multi-port fuel injection systems, fuel is injected into the port and mixed with air before the air-fuel mixture is pumped into the cylinder. In direct injection systems, fuel is injected directly into the cylinder so that the timing and shape of the fuel mist can be precisely controlled. This allows higher compression ratios and more efficient fuel intake, which deliver higher performance with lower fuel consumption.

6.1.3.2 Transmission Technologies

Continuously Variable Transmissions (CVTs) have an infinite number of "gears", providing seamless acceleration and improved fuel economy. Most conventional transmission systems control the ratio between engine speed and wheel speed using a fixed number of metal gears. Rather than using gears, the CVTs in currently available vehicles utilize a pair of variable-diameter pulleys connected by a belt or chain that can produce an infinite number of engine/wheel speed ratios.

This system has several advantages over conventional transmission designs:

- Seamless acceleration without the jerk or jolt from changing gears
- No frequent downshifting or "gear hunting" on hills
- Better fuel efficiency

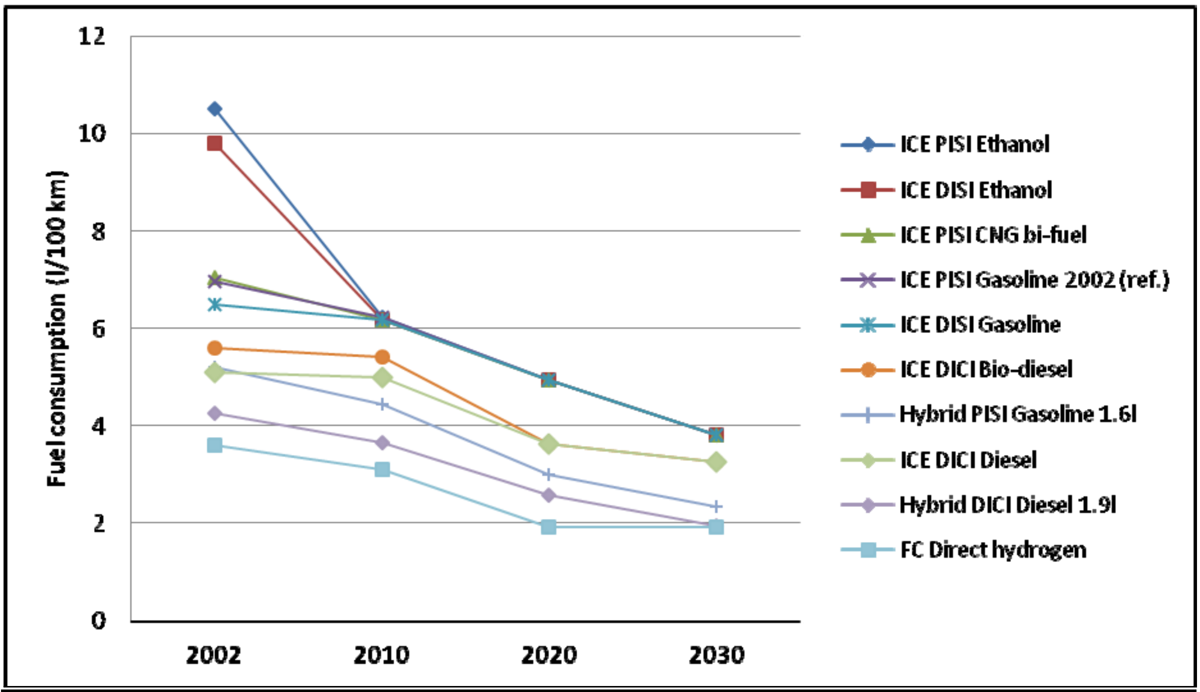
Automated Manual Transmission (AMT) - Automated manual transmissions combine the best features of manual and automatic transmissions. Manual transmissions are lighter than conventional automatic transmissions and suffer fewer energy losses. AMT operates similarly to a manual transmission except that it does not require clutch actuation or shifting by the driver. Automatic shifting is controlled electronically (shift-by-wire) and performed by a hydraulic system or electric motor. In addition, technologies can be employed to make the shifting process smoother than conventional manual transmissions.

Table 6-7: Examples of Advanced Technologies in the global market and expected increase in efficiency

Technology	Sample Manufacturers (Models)	Increase in fuel efficiency (%)
Variable Valve Lift & Timing	Honda (Honda DOHC i-VTEC® System), Toyota (Toyota VVT-i,), BMW (BMW VALVETRONIC), Ford F-150	1-9
Gas Direct Injection (S)	Audi (A3, A4, A6), Isuzu (Rodeo), Mazda (Speed 6)	3-15
Cylinder Deactivation	Chevrolet (Trailblazer, Impala SS), DaimlerChrysler, Honda (Odyssey, Pilot, Hybrid Accord), Honda Accord (V6)	7-7.5
AMTs	Ford (Fusion), BMW, Jaguar, Audi (A3, TT), VW (Beetle, Jetta)	7-9
CVTs	Honda (Civic), Ford (Five Hundred, Freestyle) Nissan (Murano), Audi MultiTronic CVT	3-8

Source – US EPA Interim Report: New Powertrain Technologies & Their Projected Costs (2005); Kobayashi, Plotkin & Ribeiro, (2008)

Assuming the technological improvements in various ICEs, Figure 6-2 shows a picture on fuel consumption improvements by 2030. The literature based study was done mainly following EUCAR, CONCAWE; W2W Analysis of Future Automotive Fuels and Powertrains in the European Context, Energy efficiency technologies for road vehicles (Kobayashi, Plotkin, & Ribeiro, 2008), GM/LBST (2002); WTW Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems-a European Study, Weiss, M. A., Heywood, J.B. Schafer, A., & Natarajan, V. K. (2003); Comparative Assessment of Fuel Cell Cars, Bodek, K., & Heywood, J. (2008). Europe's Evolving Passenger Vehicle Fleet: Fuel use and GHG Emissions Scenarios through 2035, Cheah, L. (2007). Factor of Two: Halving the Fuel Consumption of New US Automobiles by 2035 and IEA 2008; Energy Technology Perspectives-Scenarios & Strategies to 2050. The graph summarizes how Fuel consumption (l/100 km) can be reduced through 2030 following current developments. For example, ICE Ethanol shows substantial improvements by 2030 as compared to 2002.



PISI: Port Injection Spark Ignition, DISI: Direct Injection Spark Ignition, DICI: Direct Injection Compression Ignition
FC: Fuel Cell

Figure 6-2: AAMTs fuel consumption improvements until 2030
Source- Own calculations and elaboration

6.1.3.3 Bioethanol and Biodiesel ICE technical improvements

The usable fuels in such FFVs include regular gasoline as well as several alternative fuels such as M-85 (85% Methanol & 15% gasoline), E-85 (85% Ethanol & 15% gasoline) or pure mixed alcohol. The difference between regular vehicles and FFV's is a small computer microprocessor (ethanol sensor) within the fuel system. This processor detects what fuel blend is being utilized and automatically adjusts the engine's ignition timing and air/fuel mixture ratios accordingly. The FFV chip adjusts the engine's optimum performance for any ratio of gasoline to fuel alcohol (Standard Alcohol Company).

Air Fuel Mix - 14.6 Kg of air is required for the complete combustion of 1 Kg of non-oxygenated petrol fuel. The oxygen present in the ethanol (around 3.5% in E10 blend) can affect the air to fuel ratio at which the engine is operating. Therefore, it is usually necessary for certain car engines to have the air : fuel ratio adjusted to the oxygen content in the ethanol blend. For example, air / fuel ratio for a *VW Golf* running on 22% ethanol is 12.7:1, which is slightly lesser than the 14.6:1 air / fuel ratio that is used for conventional fuels. The engine management systems fitted in many modern FFVs (like *Mercury Grand Marquis, Ford Escape Hybrid*) electronically sense and change the air & fuel mixing ratio of ethanol in order to maintain the proper stoichiometric ratio. For some vehicles, the maximum oxygen content that can be compensated for is 3.5% oxygen (E10 ethanol fuel blends). However, older vehicles are usually not fitted with engine management systems; instead they operate with a normal fuel carburetor system. Thus, the carburetor air fuel mixture needs to be adjusted manually, in order to compensate for the increased oxygen content present in ethanol blended fuels (ESRU, University of Strathclyde). Considering the current needs and Brazilian success, many countries are adapting ethanol based strategies. Sweden, for instance, heavily subsidizes ethanol fuel and cars, and some 80 percent of Saab's sales in Sweden are models that run on a mix of 85 percent ethanol and 15 percent gasoline, known as E85 (Edmondson, 2007).

Almost all modern diesel engines can run on biodiesel blends provided that the biodiesel is of high enough quality. Biodiesel blends of up to 20 percent can work in any diesel engine with no modifications to the engine or the fuel system. Generally speaking biodiesel requires much less engine modification than bioethanol. However, biodiesel has a cleansing effect that may release deposits accumulated on tank walls and pipes from previous diesel fuel usage. The release of deposits may end up in fuel filters initially, so fuel filters should be checked more frequently at first (ESRU, University of Strathclyde). Few other modifications involved on Biodiesel ICE are:

Rubber Seals: With some older vehicles rubber seals used in the fuel lines may require replacing with non-rubber products such as VITONTM. This is due to the way biodiesel reacts with rubber. If a low blend is used (5% biodiesel for example) then the concentration of biodiesel isn't high enough to cause this problem.

Engine Timing: For higher blends engine performance can be improved with a slight change to engine timing, 2 or 3 degrees for a 100% blend. The use of advanced injection timing and increased injection pressure has been known to reduce NOx emissions. It is worth noting that catalytic converters are just as effective on biodiesel emissions as on fossil diesel.

However, use of 100 % Biodiesel in ICE needs significant changes in engine and adopting a series of precautions. Indeed, unless the proper precautions are taken, biodiesel fuels can cause a variety of engine performance problems including filter plugging, injector coking, piston ring sticking and breaking, seal swelling and hardening/cracking and severe lubricant degradation. Bio-diesel fuels also require special treatment at low temperatures to avoid an excessive rise in viscosity and loss of fluidity (ACEA).

6.1.3.4 NG (Biogas/LNG/CNG) ICE technical improvements

Natural gas vehicles (NGVs) operate on the same basic principles as gasoline-powered vehicles. The fuel is mixed with air and fed into the cylinder where it is then ignited by a spark plug to move a piston up and down. Hence, natural gas can power all the same vehicles currently powered by gasoline and diesel fuel. However, since natural gas is a gas rather than a liquid at standard pressure and temperature, some modifications are required to make an NGV work efficiently. These changes are primarily in the fuel storage tank, fueling receptacle/nozzle and the engine (NGV America). Some of the technological improvements involved at engine level are (IANGV, 2007) :

Lean Burn: Stoichiometric combustion occurs when the chemically exact amount of fuel is added to the air that can bring complete combustion of fuel. This offers clean combustion and exhaust gases. The drawback is that the power output of the engine may be lower and its fuel consumption slightly higher when compared with a diesel engine. The lean burn system employs an air/gas mixture that has more air than the stoichiometric ratio in the combustion cylinder. Looked at the other way, it requires less fuel in the cylinder. This can result in lower fuel consumption compared to stoichiometric combustion with the power output usually maintained by turbocharging.

Carburetor: The carburetor is generally used in stoichiometric engines as it can deliver the right balance of fuel for the air entering the engine. Provided the carburetor is located in reasonably close proximity to the intake of the engine and there are not highly variable load demands, the system works very well.

Single Point Injection: It is an electronically controlled carburetor. The advantage is that the gas is delivered more accurately in accordance with engine demand. Again the injector is still some distance from the inlet (like the carburetor) and so its response to quickly changing conditions is not ideal.

Multi Point Injection: It has an injector for each cylinder, so the injectors can be placed in close proximity to the cylinder's intake port. It also enables fuel to be delivered precisely as required to each individual cylinder (called sequential) and enables more sophisticated technologies such as skip-firing to be used. Skip-firing is when only some of the cylinders are operating (the other cylinders are being skipped). This enables even more efficient use of the fuel at low loads, further lowering fuel consumption and un-burnt hydrocarbon emissions.

It should be noted that no system is inappropriate, each of them have the benefits and costs. Carburetors are no longer used on new cars today. Single point injection is currently only used by low cost cars. Multi point injection is the system used by most cars today and is the most sophisticated system generally available. To gain optimum performance, gaseous fuels should be used in dedicated vehicles rather than bi- or dual-fuelled systems; because the adjustments associated with bi-fuel operation meaning that the vehicle operates under less than optimum conditions on both fuels. (World Business Council for Sustainable Development, 2004).

6.2 Hybrids and Electric passenger cars

The classification of hybrid and electric cars into categories is not an exact science. Categories overlap and therefore the belonging to a certain category is often ambiguous. Having said this, please find hereafter the description of the main categories.

Mild hybrid - An electric engine/generator of modest size and power is integrated in the standard (ICE) drive train. Pure electric propulsion is not possible. The use of petrol/diesel is reduced, but not avoided. Fuel savings depend on driving patterns. Regular stop-and-go traffic, as is usually the case for inner-city driving, is ideal. Features include:

- Idle-off[10]: combustion motor stops, when car stops
- Regenerative braking: kinetic energy is recovered by electric engine when braking
- Power Assist and Engine Downsizing: dual system for providing power, needs a large enough electric motor and battery pack in order to support the combustion engine; allows downsizing of the combustion engine

Full hybrid - Main drivetrain by combustion engine. Stronger electric engine/generator and battery than mild hybrid. Therefore electric-only-drive possible for short distances, usually at reduced speed allows driving without local pollution, for example in city centers. Use of petrol/diesel is not avoided, because all propulsion energy ultimately comes from the combustion engine. Electric-only drive requires the introduction of electric auxiliary equipment, such as electric steering and the electric brake power assist unit. The additional electric drive train increases overall system power.

Plug-In Hybrid (PHEV) - There are different technological bases for PHEVs (see below). They have in common that the battery can be charged from the electric grid, therefore the use of gasoline can partly be avoided. Increased battery size and stronger electric drive train in comparison to mild or full hybrid. The amount of gasoline avoided strongly depends on battery size and daily usage pattern. The All Electric Range (AER) of currently announced PHEVs varies between 30 and 160 km. CO_2 emission avoidance may reach 100% under ideal circumstances (daily driving distance within AER or recharge during the day; use of electricity from renewable sources). In the worst case CO_2 avoidance may be close to zero (e.g. if the daily driving distance largely exceeds the AER or if the user does not plug in the car after using). PHEVs do not have range limitations, because the combustion engine is used when the battery is empty.

Parallel PHEV - Based on standard vehicle concept. A parallel PHEV uses a standard combustion drive train. Basically it consists of an enhanced full hybrid: larger battery, stronger electric drive train and electronics to connect to the electric grid. The electric engine adds to the overall system power, therefore the combustion engine can be downsized. When accelerating, the added power of electric and combustion engines is used. When cruising, the combustion engine drives the car and recharges the battery. Compared with a serial PHEV, the parallel PHEV is more efficient for long distance driving.

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[10] Also known as *Micro Hybrid, (e.g. VW Bluemotion)*

Serial PHEV - Pure electric drive train. A combination of a combustion engine and a generator (range extender) is added to a pure electric power train to allow driving distances exceeding the All Electric Range (also known as range extender). In contrast to the parallel PHEV, the maximum power at the wheels is therefore identical to the power of the electric engine. To overcome certain limitations (e.g. acceleration, maximum speed, trailer towing) a sufficiently strong electric engine is necessary. Another limitation is the power of the generator, which limits the possible continuous speed over long distances. Here some examples of the relation between the engine power and possible continuous speeds for a small vehicle are given as following:

- 18 kW -> 130 km/h
- 34 kW -> 160 km/h
- 53 kW -> 190 km/h

A **serial PHEV** is Ideal for stop-and-go conditions that normally reduce combustion engine efficiency. Compared to a parallel PHEV, a serial PHEV offers reduced efficiency when running on the combustion engine. The reason is the additional energy transformation: mechanical energy -> electric energy -> mechanical energy. Serial PHEVs cannot be based on standard ICE cars, because the standard ICE drive train is replaced by an electric drive train. The consequence is a significantly higher development effort for the manufacturer and therefore high upfront costs. On the other hand, technical complexity can be reduced, ultimately resulting in lower manufacturing costs at high production volumes. Also, a serial PHEV can serve as the technological basis of a (pure) Battery Electric Vehicle. In fact, a BEV can be a PHEV without the range extender option.

Battery Electric Vehicle (BEV) - A BEV is characterized by a pure electric drive train. The use of petrol/diesel is completely avoided. The amount of CO_2 emission depends on the source of the grid electricity. Using electricity from renewable resources completely avoids CO_2 emissions.
One of several ways to classify BEVs is the possible driving range: City BEVs or Extended Range BEVs:

City BEV - Range starting from approximately 30 km up to around 160 km. City BEVs are ideally suited for commuter cars, family second cars or local delivery vehicles. The daily range can be extended by recharging during stop-over.
Extended Range BEV - Range starting from approximately 160 km. Extended Range BEVs have an increased battery size and more powerful electric engine, compared to a City BEV. To increase the daily range beyond battery capacity, rapid battery charging is necessary. Besides the issues of

technical feasibility and charging infrastructure, frequent rapid charging reduces battery life expectancy. Battery change business models have been proposed to overcome range limitations.

6.2.1 State of the art

6.2.1.1 Commercially available vehicles

Kalhammer (Kalhammer 07, 2009) proposes the following commercialization categories, depending on the number of vehicles sold:

> 100: demonstration phase

> 1.000: pre-commercialization

> 10.000: early commercialization

> 100.000: full commercialization

According to this classification, the **Mild Hybrid** is the only type of hybrid/electric car that reached full commercialization. The Prius from manufacturer Toyota is the most successful model in this category, with far more than one million units sold. Currently, there are various **Full Hybrids** announced or already on sale. It is noticeable, that most full hybrids are large SUVs or limousines. It is obvious that in these cases the motivation for hybridization is not fuel saving, but rather increased system power with an ecological disguise. Examples are Lexus LS 600h (already on sale), BMW X6-Hybrid (sales starting April '10), Mercedes S-Class Hybrid, VW Touareg (sales start '10) or Porsche Cayenne Hybrid.

Some **PHEV**s have been announced. The most prominent, Chevrolet's Volt, will be released towards the end of 2010. Opel's Ampera, based on the same technical platform will be released shortly thereafter. Both are serial PHEVs and will offer an AER of 60 kilometers. The most prominent vehicle in the **City BEV** category is the Mitsubishi i-MIEV. It is commercially available in Japan since June 2009. The corresponding models with ICE, the Mitsubishi-i, sells at a price of 13,500 € and the price of i-MIEV is about 30,000 €. The i-MIEV is highly subsidized in Japan. It has been announced for other markets, including Europe, but prices have not yet been disclosed. Depending on driving characteristics, the AER is between 80 and 160 kilometers. The Li-Ion battery has a usable capacity of 16 kWh and has been developed for automobile use. Units produced and sold until Q1/2010: around 1,400.

The market of **Extended Range BEVs** presents itself at present as a niche market for customers who are not price sensitive. The models on offer are perfectly adapted to this niche. They are high-power sports cars, like the Tesla Roadster. The Tesla Roadster has an AER of more than 300 km, an engine of 200 kW power and the performance figures of a sports car. The battery consists of 7,000 Li-Ion (laptop) cells. With more than 1,000 units sold it is now in the pre-commercialization phase.

Another model in this category is the BMW MiniE. It is available in limited numbers (100s) in the US (on a leasing model) and for various trials in Europe. As for the Tesla, the battery consists of an assembly of laptop batteries (5,000 cells). Many more sports cars have been announced (e.g. from Ruf-Porsche, AMG, Shelby Super Cars, Lightning GT). Also a few family cars have been announced in the category of Extended Range BEVs, for example by the Chinese manufacturer BYD (Build Your Dreams) and by Tesla (Model S).

Under the current economic and regulatory framework, and due to high battery prices, vehicles with an extended all electric range currently cannot compete with ICE vehicles for mainstream usage. The prediction of the future development regarding battery prices vary widely, but even for the most optimistic predictions with respect to battery price decreases, price competitiveness of electric vehicles can only be achieved in the foreseeable future, if the overall commercial framework can be changed.

6.2.1.2 Technology

<u>Battery architecture</u>

An automotive battery is a complex system. The basic element is the battery cell. Multiple cells are grouped into a module. The battery consists of several modules. There are control electronics on cell and module level. A thermal system is needed to keep the temperature within the necessary limits. An overall battery control unit manages all functions of the battery (e.g. charging, discharging, thermal management, safety functions). Other functions are safety, mechanical and electrical integration, power and communications interfaces.

<u>Mid-term, Li-Ion will be the winning battery technology</u>

This view is shared by most players in the industry. C. Rosenkranz from Johnson Controls Saft stated ("JCS '09"): "Li-Ion is ... the obvious next step battery solution". Deutsche Bank concludes ("DB Research '08"): "Li-Ion is ... the winning battery technology". The main advantages of Li-Ion batteries, compared with concurrent battery technologies, are higher power and energy density and the potential to significantly reduce the cost within the coming years.

Depending on the usage, batteries with different characteristics are needed. Batteries with high specific power are used in HEVs, larger batteries with high specific energy capacity are used in BEVs. Medium power / medium energy batteries are used in PHEVs. NiMH is still mainly used for high power applications in HEVs (e.g. Toyota Prius) and also for smaller range PHEVs. Li Ion is the battery technology of choice for high specific energy applications (BEVs and PHEVs of extended range). Li-Ion technology offers about twice the specific capacity than NiMH. Li-Ion technology is also the only battery technology that can be designed to meet the performance requirements of all types of electric vehicles. For high power applications Li-Ion technology has progressed much more than NiMH technology in recent years, and Li-Ion also promises to reach lower specific costs. A replacement of NiMH by Li Ion can therefore be expected for most applications. Other battery technologies are not expected to reach an important role in the foreseeable future.

Most Li-Ion batteries used in currently available electric vehicles have not been specifically developed and built for automotive use. Instead, a large number of standard laptop Li-Ion cells are assembled to offer the necessary power and capacity. This has a number of drawbacks, including higher cost, lower reliability and more complex battery management. The battery of the Tesla Roadster combines around 7,000 laptop cells. The Mini E uses 5,000 cells. An example of a car in serial production that uses a battery specifically developed for automobile use is the Mitsubishi i-MIEV.

Li-Ion chemistries

Below follows a short description of some of the candidate chemistries used as cathode material for automotive Li-Ion batteries. We are still early in the development cycle, therefore it is still unclear, and which cathode material will be the ultimate winner. Nevertheless, Lithium Iron Phosphates are in a good position due to good safety, capacity and cost characteristics.

Lithiated Cobalt Oxide ($LiCoO_2$): Currently large scale use for consumer products (e.g. laptops), relatively expensive.

Lithium Nickel Cobalt Aluminium - NCA ($Li(NiCoAl)O_2$): High specific energy, lower cost than LiCoO2.

Lithium Manganese Spinel - LMS ($LiMn_2O_4$): High cycle life

Lithium Iron Phosphate - LFP ($LiFePO_4$): Low sensitivity to temperature and overcharge (safety), higher specific capacity than LMS, potentially lower cost than the other mentioned chemistries.

Manufacturing of Li-Ion batteries

Manufacturing facilities for Li-Ion batteries dedicated for automotive use are still very limited. But manufacturing capacities will be built up in the coming years. One example is Nissan. They announced to build battery factories in Sunderland, GB, and Portugal. Capacity will be 60,000 units per year in each site.

6.2.2 Economic and environmental assessment

The car ownership level in European Union is continuously increasing, but the share of alternative automotive technologies, such as electric vehicles, fuel cell vehicles, various types of hybrid systems and systems based on natural gas or biogas, is still very low, about 1%. All the advanced technologies have to be improved and the current investment costs have to be significantly reduced, especially by hydrogen powered fuel cell vehicles. For hydrogen vehicles it is very difficult to make a precise cost analysis, because at the present there are no market prices published for them.

In this study a basic structure of vehicles was assumed, except the power-train components is similar for all technologies. According to (Ajanovic et al, 2010), the total investment costs are divided in two parts – conventional and innovative part of vehicle:

$$IC = IC_{CON} + IC_{INNOV}$$

Where:

IC_{CON}: Investment costs for the conventional part of vehicle

IC_{INNOV}: Investment costs for the innovative part of vehicle.

The total transport costs are dependent on the fuel cost and investment cost for vehicle:

$$TC = FC + IC_{sp}$$

Where:

TC: Transport cost (EUR/km)

FC: Fuel cost (EUR/km)

IC_{sp}: Specific investment costs for vehicle (EUR/km)

For the calculation of the fuel costs (EUR/km) two factors are relevant: the energy efficiency of the vehicle and fuel price.

$$FC = EC \cdot FP$$

Where:

EC: Energy consumption (kWh/km)

FP: Fuel price at the refueling station (EUR/kWh)

The total annual specific investment costs for vehicles are calculated as follows:

$$IC_{sp} = \alpha \cdot IC / D_{km}$$

Where:

α: Capital recovery factor (-)

IC_{sp}: Specific investment costs for vehicle (EUR/km)

D_{km}: The annual number of kilometres driven per year (km)

Total transport costs for the most important alternative automotive concepts are shown in Figure 6-3. It can be noticed that the largest part of the total costs are the specific investment costs. Currently, the most expensive AAMT is fuel cell vehicle (FCV)

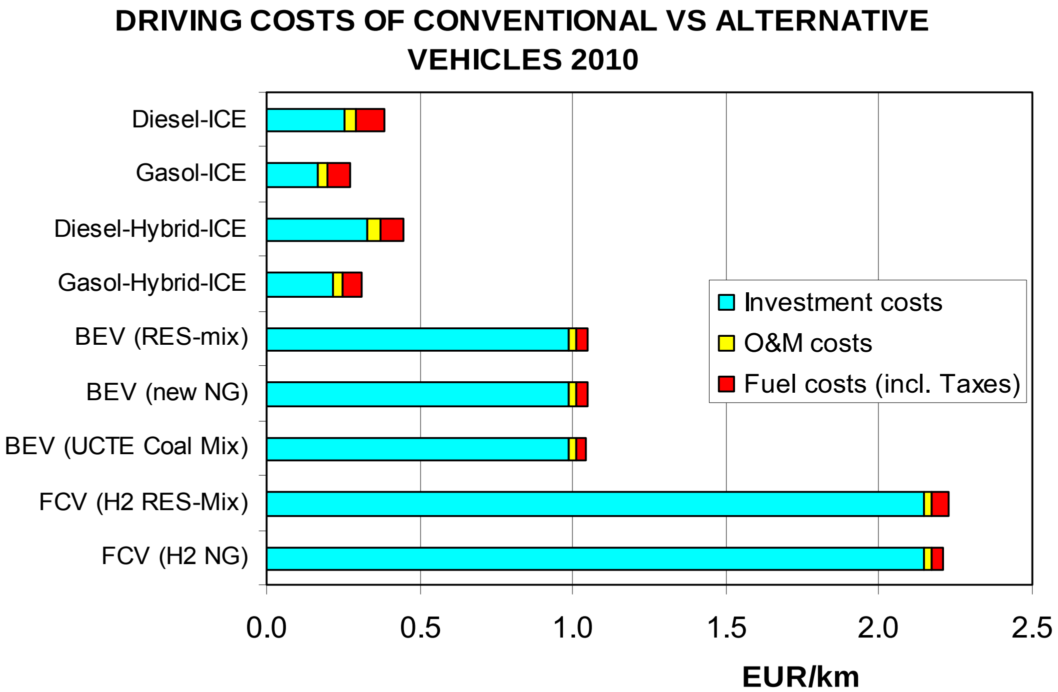

Figure 6-3: Transport costs of Alternative automotives

H2: Hydrogen, ICE: Internal Combustion Engine, FCV: Fuel cell vehicle; BEV: Battery Electric Vehicle, NG: Natural gas, RES: Renewable energy sources

Figure 6-4 provides a comparison of specific CO2 emissions and costs of conventional and hybrid gasoline and diesel vehicles with pure BEV based on different electricity generation mixes and FCV with H2 from RES or natural gas.

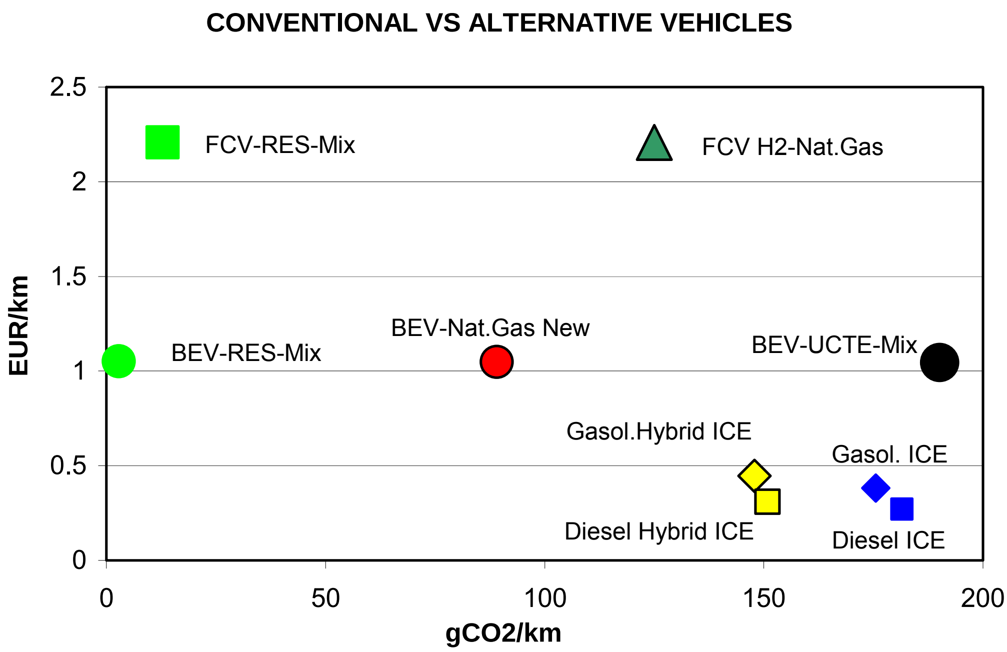

Figure 6-4. Comparison of specific CO_2 emissions and driving costs of conventional and hybrid gasoline and diesel vehicles with pure BEV based on different electricity generation mixes and FCV with hydrogen from NG vs RES

(H2: Hydrogen, ICE: Internal Combustion Engine, FCV: Fuel Cell vehicle, BEV: Battery Electric Vehicle, NG: Natural gas, RES: Renewable energy sources)

The major perceptions of Figure 6-4 are: (i) Hybrid ICEs are an alternative with slightly higher costs but clearly better performance than conventional vehicles; (ii) BEV as well as FCV are only preferable to conventional cars if they are fully based on RES.

6.2.3 Technical improvement potential

E-mobility is a young technology. Units sold so far a very low. As a consequence, the technology is still immature and there is improvement potential in many technical areas. The area where improvement is most important for the future success of e-mobility, is battery technology. Some researchers of the German aerospace centre (DLR) have developed new engine with internal combustion based on a free piston linear generator. This new technology makes it possible to design a new engine that can switch between any kind of fuel (gasoline, natural gas, hydrogen or ethanol) and convert it into electric energy without the losses of efficiency usually observed. The crankshaft of a traditional engine is replaced by a linear generator and an air spring. Electric energy is directly produced by the generator and can be used to propel the car through an electric engine. The rate of compression and the engine's capacity being variable; its running in reduced power is strongly optimised. The engine consumption and its pollutant emissions are reduced particularly at low speed driving (driving in town). According to researchers, this new engine should be launched in 5 or 6 years time from now. Besides its use in the combustion engines, the new generator could be used for stationary systems of energy production.

6.2.3.1 Battery Technology

Currently a lot of public and private money is dedicated for e-mobility research and development. Various industry consortia and state initiatives announced to invest considerable amounts of money in the advancement of battery technology. A few examples:

Out of the German "Konjunkturpaket II", 500 million Euros are available to support e-mobility activities. Supported areas include electro chemistry, and battery production. The German ministry for research (BMBF) supports the Innovation Alliance LIB 2015 with 60 million Euro. The industry partners (e.g. Evonik, BASF, Bosch, Daimler, VW) invest further 360 million Euro into the project.

IBM launched a development initiative for lithium-air batteries. The objective of the program is to increase specific capacity by a factor of 5 to 10, compared with current Li-Ion batteries. The time horizon of the program is 5 years. Five American research institutes are also participating in this effort.

<u>Battery costs:</u>
Apart from battery chemistry, battery costs also strongly depend on the size of the battery and on yearly production volumes. The predictions of the future developments regarding price and specific capacity of Li-Ion batteries that can be found in recent studies vary widely.

First the difference between cost per kWh on cell level and on battery level should be understood. It is obvious that the cost per kWh on battery level is higher because of the necessary additional components, such as battery management or the mechanical packaging. Also, this spread is higher for small batteries than for bigger batteries. Larger BEV batteries are ideally made of higher capacity cells than HEV or even PHEV batteries. Kalhammer ("Kalhammer '07", p. 45) gives the following scaling factors:

Table 6-8: Different cost factors involved in Battery Technologies

battery size (kWh)	cost scaling factor cell -> module	cost scaling factor cell -> battery
40	1.03	1.24
2	1.1	1.65

Example: For a cell cost of 500 €/kWh the cost at battery level would be 620 €/kWh for a 40 kWh battery, but 825 €/kWh for a 2 kWh battery.

Another important correlation exists between the size of individual Li-Ion cells and the cost per kWh of capacity. Battery cost decreases with increasing cell size. The number of cells per kWh and therefore the cost is smaller. The following table is derived from Kalhammer ("Kalhammer '07", p. 46):

Table 6-9: Scaling factors cost involved in Battery Technologies

scaling from cell size (Ah)	To cell size (Ah)	cost scaling factor
45	7	2.13
45	15	1.52
45	30	1.14
45	45	1
45	60	0.89
45	120	0.74

Another important factor for battery cost is the yearly production volume.

- Example; for a production volume of 2500 MWh/year: a 40 kWh battery for a small BEV would cost 232 $/kWh, a 14 kWh battery for a PHEV would cost 350 $/kWh (50 % more).
- Mass production: a five-fold increase of production volume leads to a 30% cost reduction.
- J. Grotenhorst ("Continental '09") expects the cell cost to decrease by 65% between 2010 and 2020.

Cost estimations:

Kalhammer summarizes the above mentioned cost influencing factors (battery capacity, cell size and manufacturing volume) in one table ("Kalhammer'07", p. 47). The following Table 6-10 is derived from this study, only the columns "battery cost ($/kWh)" have been added for increased informative value:

Table 6-10: Battery cost influencing factors

			for production of 500 MWh/year				**for production of 2500 MWh/year**			
			for production of 20 k batteries/year				**for production of 100 k batteries/year**			
vehicle type	Batt. Cap. (kWh)	cell (Ah)	Prod. rate (MWh/Y)	module cost ($/Kwh	battery cost ($)	battery cost ($/kWh)	Prod. rate (MWh/Y)	module cost ($/Kwh	Batt. cost ($)	battery cost ($/kWh)
Long Range BEV	40	120	500	285	13.680	342	2.500	195	9.285	232
			800	255	12.240	306	4.000	175	8.395	210
City BEV	25	45	500	380	11.875	475	2.500	260	8.150	326
			500	380	11.875	475	2.500	260	8.150	326
PHEV	14	45	500	380	7.075	505	2.500	260	4.850	346
			280	435	8.350	596	1.400	300	5.585	399
PHEV	7	30	500	435	4.305	615	2.500	295	2.750	393
			140	595	5.190	741	700	405	4.025	575
PHEV	4	15	500	575	3.265	816	2.500	395	2.240	560
			80	880	4.990	1.248	400	605	3.445	861
Full Hybrid	2	7	500	805	2.420	1.210	2.500	550	1.650	825
			40	1.465	4.395	2.198	200	1.010	3.025	1.513

Often cost estimations do not consider production volumes and they generally do not consider the above mentioned scaling factors of battery size and cell size. This might in part explain the big discrepancies between the cost estimations from different experts.

- Roland Berger ("Roland Berger '09") sees current production cost in China at 430 €/kWh, and elsewhere at 580 €/kWh
- Deutsche Bank ("DB Research '08") expects the battery supply contract for the coming Chevrolet Volt to be worth around $ 400 million. For 50,000 batteries with a capacity of 16 kWh each, this results in an estimated 500 $/kWh (370 €/kWh).
- The energy agency of NRW ("Köster '09", p. 31) gives the example of the cost reduction realised for laptop batteries: cost reduction by a factor of 5 between 1995 and 2005; cost is now at 220 €/kWh

Also for the future development there is a wide spread of estimations:

- Bosch: 350 €/kWh in 2015 (example of a 35 kWh battery, press release Jun-09)
- Roland Berger ("Roland Berger '09) estimates for 2012: production cost in China: 323 €/kWh, elsewhere: 475 €/kWh
- ("CONCAWE '07"): 600 €/kWh (2010+)

Battery weight and specific capacity

Specific capacity of Li-Ion batteries will increase over time, but the expectations of the increase vary widely among the experts

- current (2008) value for a Li-Ion battery is 120 Wh/kg
- Deutsche Bank ("DB Research '08", p. 23) mentions the example of specific capacity improvement for laptop Li-Ion batteries: increase of the specific capacity on cell level from 90 Wh/kg in 1990 to 232 Wh/kg in 2008
- Bosch expects 140 Wh/kg in 2015 (based on a 35 kWh battery; press release Jun-09)
- Continental expects a doubling of energy density between 2008 and 2020 ("Continental '09")
- Prof. Dr. Horst Friedrich, DLR: 300 Wh/kg in 2015 (corresponds to an increase of 150% over 7 years or an average yearly increase of 14% (source: www.atzonline.de))
- whereas the MIT predicts a yearly increase of specific capacity of only 1.6% over the next 25 years, corresponding to an improvement factor of 1.5 over the 25 years (MIT, p. 26) -> 180 Wh/kg in 2035

Battery lifetime

The two criteria which will be discussed in this paragraph here are the calendar life and the cycle life.

Calendar life: how many years a battery can be used until the usable capacity falls under a defined threshold (80% of original capacity).

Cycle life: how many charging cycle are possible, before the usable capacity falls under a defined threshold (80% of original capacity).

Both the calendar and the cycle life of a battery strongly depend on the technology used and on various usage conditions such as speed of charging, depth of discharge, temperature. Li-Ion batteries are sensitive against overcharging and against deep discharge. Both conditions may result in reduced usable capacity and decreased calendar life. Battery management systems have to prevent these conditions. Cycle life and calendar life of Li-Ion batteries show impressive improvements over the last years. It can not only be expected that batteries will soon last for the whole life time of a car, but will exceed car life time (and kilometrage) considerably. As a result new business models need to be established in order to fully use the battery.

Cycle life and calendar life of Li-Ion batteries depend mainly on charging/discharging characteristics and on the temperature. There is a strong correlation between an increasing number of deep discharge cycles (and elevated temperature) and a decreased battery life time. Li-Ion batteries are also sensitive to overcharge, which can lead to immediate cell damage. Yet latest test results show, that battery life time is becoming less of a concern. They also show that optimized charging/discharging management and battery temperature management is of a prime importance for any vehicle application. The goal should be to keep cell temperatures below 45 - 50°C ("Kalhammer '07", p. 28).

Recent advancements allow the conclusion, that batteries can still have a useful life time at the end of the vehicle life. As the battery will be (at least for the foreseeable future) the most valuable part of an electric vehicle of extended range, re-use of the batteries should be a primary goal.

Battery cycle life:

- For a given battery, the number of possible charging cycles (and total energy delivered over the battery lifetime) largely increases by reducing average Depth of Discharge (DoD). C. Rosenkranz ("JCS '09", p.13) shows the results of tests conducted with a delivery van (Daimler-Sprinter):
    - > 3,000 full cycles at 80% DoD
    - > 5,000 full cycles at 70% DoD
    - > 6,000 full cycles at 60% DoD
- cycle life of more than 3,000 cycles (at 80% depth of discharge (DoD)) has been demonstrated for various Li-Ion chemistries ("Kalhammer '07", p.29-33)
- ("DB Research '08", p. 13): > 7,000 charging cycles for Li-Ion batteries
- ("Evonik"): 2,000 - 2,500 cycles
- RWTH Aachen ("RWTH '09", p. 19): 5,000 cycles for high capacity battery
- G. Corsini ("Opel '09", p. 15) for the announced Opel Ampera: 4,000 cycles of 60 km

Battery calendar life:

- For a given battery, the calendar life strongly depends on the battery temperature. Tests ("JCS '09", p.14) show the following correlation:
    - calendar life at 30°C: 20 years
    - calendar life at 40°C: 10 years
    - calendar life at 60°C: 2.7 years
- calendar life can also be increased by lowering the average state of charge
- only 7 years ago, state-of-the-art calendar life of a Li-Ion battery was only 2 - 4 years

There have been big improvements of the battery cycle life for certain Li-Ion battery chemistries. 3,000 charging cycles and a battery lifetime of more than 10 years seem feasible in the not too distant future. Consequently, depending on the size of the battery, a car can theoretically run between 180,000 km (City-BEV with 60 km all electric range) and 900,000 km (BEV with 300 km all electric range). In other words, even for a City-BEV the battery will last for the whole lifetime of the car. For a longer range BEV the possible kilometrage of the battery exceeds the average kilometrage of the car more than four-fold. Taking into account, that the battery is the most expensive part of the vehicle, it is obvious, that new usage scenarios need to be developed in order to make maximum use of the battery.

Rapid charging: Rapid charging possibilities are especially important for pure electric vehicles. Manufacturers announce rapid charging within 15 and 30 minutes to 80% of the capacity. Apart from the already mentioned conflict between speed of charging and battery lifetime, let's just have a short look at what this would mean for the charging infrastructure. Let us assume a BEV with a usable battery capacity of 50 kWh, and rapid charging to 80% within 30 minutes. The resulting charging power is 80 kW, which exceeds the maximum power of a standard 3-phase 380V connection almost 5-fold. Let us now assume a public charging station that is visited by 60 customers per hour. Power consumption would then be 2400 kW. For comparison: a standard transformation station offers 630 kW.

Battery safety: Battery safety is a concern, but not an issue any more ("Kalhammer '07", pages 34,35; "MIT Powertrain '07", p. 26). Technical solutions exist. Safety risks can result from the following non regular battery conditions:

- overcharging
- shorting
- excessive temperature
- mechanical destruction of cell case

Systematic abuse of batteries can result in thermal runaway, accompanied by gas evolution and burning of vented electrolyte solvent, but only, if the protection devices are disabled. Modern battery architectures implement control strategies on cell, module and battery level. Under normal operation, charging/discharging management and battery temperature management non regular battery conditions are avoided. Various protection devices on cell level such as temperature and current sensitive fuses or voltage and pressure sensitive switches to interrupt current exist. They come into play, when normal operation conditions cannot be maintained.

Battery Management: Battery management is a challenging topic. It has to cover a multitude of functions:

- battery charge and discharge management
- thermal management
- Fraud resistant storage of battery usage history (charge/discharge-cycles, temperatures
- grid-connection-related functions
    - two-way-communication with the grid
    - management of bi-directional power transmission

Battery management has a big influence on battery life expectancy and on battery safety. Know-how of battery management will be a major key to success in the future e-mobility market

Research into future battery technologies: Among the development rends for new battery technologies the following two are the most promising, but they are still very far from realization for practical use.

Lithium-Sulphur battery

- theoretical maximum energy is > 4 x higher than that of Li-Ion batteries (> 2500 Wh/kg)
- a reasonable goal for practical realization is 350 - 400 Wh/kg (Kal, page 43); a 300 kg battery would then offer an electric range of 600 km at a consumption of 20 kWh/100 km.
- practical difficulties due to use of metallic lithium and elemental sulphur
- metallic lithium reacts with moisture and air, battery safety is therefore more of an issue
- Sion Power realised small cells with > 350 Wh/kg, but very limited cycle life of around 100 deep cycles
- cost projections provided by Sion Power are about one third higher than Li-Ion batteries
- in spring 2009 Sion Power partnered with BASF in order to advance the technology

Lithium-Air battery (Lithium oxygen)

- technology: replace the lithium cobalt oxide electrode in today's rechargeable lithium batteries with a porous carbon electrode; use oxygen in the air as a reagent
- inherently safe
- has the potential to increase specific capacity 10-fold, compared with current levels
- difficulties: allow the oxygen of the air to enter the battery, but avoid the intrusion of moisture
- cost: a lithium-air battery is potentially cheaper than Li-Ion, due to lower material cost (the new component is made of porous carbon, which is much less expensive than the lithium cobalt oxide)
- research is done by the University of St. Andrews/Scotland and since spring 2009 by IBM

- feasibility of the technology for practical use and time scale are unknown

Other battery issues: According to M. Marwede, Fraunhofer ISI ("Marwede '09", p. 12), the demand for lithium for Li-Ion batteries might reach one third of the yearly worldwide lithium production in 2030. Additionally, overall lithium reserves are limited. It is therefore important to study the possibilities of lithium recycling.

6.2.3.2 Drive Train

Motor, generator : There are no principal technical issues. Optimisation can be expected over time regarding efficiency, weight and cost when moving along the learning curve.

Power electronics : As for the electric motor, there are no principal technical issues. Optimisation can be expected over time regarding efficiency, weight and cost when moving along the learning curve. An example is given by Bosch: The first generation of power electronics for 50 kW electric power had a volume of 13 liters. The second generation has a volume of 5 liters. Currently Bosch is working on a 3-liter-version.

6.2.3.3 General Energy Saving Measures

Most of the measures described hereafter can also help standard ICE vehicles to reduce their energy consumption. In so far, a mutual boost of the respective activities can be expected. But due to the limiting factor of battery capacity (weight and cost), electric vehicles profit particularly from energy saving measures. The topics below show some of the activities, nevertheless, the list is not comprehensive.

Weight reduction: Weight reduction can be achieved through lighter components or a lighter structure of the car. As already mentioned, the weight of the components will be reduced with the number of units produced. Regarding the weight of the car structure, interesting information can be found in the report for the EU project "SuperLIGHT-CAR" ("SLC '09"). Based on a mid-sized car (VW Golf V), the project showed a weight reduction potential of 35% for the structure of the car (from 281 kg to 180 kg), without compromising the overall stability. The corresponding cost for these measures was found to be about 7,81 € per kilogram of weight reduction, which results in 790 € for the weight reduction of 101 kg.

LED head lights: Power consumption of LED head lights is much less than that of currently used head lights. First examples of cars using LED head lights are Audi R8 and Lexus LS 600h. The all-electric car Nissan "Leaf", announced for 2010, will also use LED head lights.

Electric auxiliary aggregates: Electric power steering and electric brake servo units are a necessary for all electric cars, but they can also reduce the overall energy consumption of the car.

Improved climatisation: Heating and cooling consume a lot of energy. Under unfavorable circumstances, climatisation can reduce the range of an electric vehicle considerably. For potential improvement, the following measures need to be evaluated:

- electric climate control (heating and cooling)
- improved thermal insulation of passenger cabin
- integration of thermal management of technical car components and air conditioning of passenger space
- use of heat exchangers
- use of latent-heat storage systems (PCM devices)

6.2.3.4 Infrastructure

The issue of infrastructure for electric vehicles is a large field. In the context of the current study, the topics can only be mentioned shortly in order to stimulate further thought. The complexity of the necessary infrastructure increases, as soon as purely electric vehicles are used. The introduction of PHEVs poses less issue, because they have an alternative to the electric plug. In the first phase of introduction, pure electric vehicles will mainly be used as commuter vehicles or as city vehicles. They can be charged at home or at the work place. The next phase, large scale introduction of BEVs for general use and longer driving distances, requires a (public) charging infrastructure.

The charging solution must be convenient for the users. For example, the refueling stops must not take too much time. Solutions could be rapid charging or a battery exchange infrastructure like the one proposed by project "Better Place". Whatever the solution will be, the infrastructure must be deployed in a sufficiently dense manner in order to be feasible for everyday users. And it must be standardized. The costly realization of multiple parallel infrastructures needs to be avoided. The realization of non-compatible infrastructures in different European countries also needs to be avoided.

So far, only potential obstacles have been mentioned. But there are also potential benefits of the widespread introduction of electric vehicles. The batteries of the electric vehicles can be used to offer services for the electric grid (Vehicle-to-Grid, V2G). The storage capacity of the batteries could be used for frequency stabilization, peak shaving, or as storage facility for fluctuating renewable energy sources. There is no clear view yet, which business models will be successful in the future. But in order to illustrate the potential, two hypothetical examples are given: A BEV with a 60 kWh battery for a 400 km range can store sufficient electric energy to supply a standard household for almost one week. Second example: If all German cars would be BEVs with 60 kWh batteries, the overall capacity would be sufficient to store the current renewable energy production of almost 10 days.

V2G services would need to be designed in a way that requires only minor user interaction. They also require extensive changes within the electric grid (-> Smart Grid). On the other hand, these changes are required anyway in order to support the further build out of renewable electricity production. For integration into the homes, an extension of the electric installation in the home is required (-> Smart Home). Using electric vehicles for V2G services requires that the vehicles should be connected to the electric grid as often as possible, ideally during each stop-over. The users most likely will not accept to plug in the vehicle during each stop-over, and even less during bad weather. This leads to the requirement of a contactless charging solution. At the same time, this would be a protection against vandalism. Developers of early experimental solutions suggest transmission losses of less than five percent.

Standardization

From the above mentioned issues it can be derived, that there is an important and urgent need for standardization. Standardization must be advanced immediately and needs to be completed before mass-introduction of electric vehicles can take place. Standardization is a real challenge: It must take place before the successful business models of the future are known. Therefore, standardization must cover all relevant areas and must be comprehensive.

Ideally, standardization should take place on an international level. More realistic is a standardization process on a European level. There are examples of successful European standardization processes, such as GSM in the mobile communication area.

In order to illustrate the extent of the standardization requirements, please find below a (non-comprehensive) list of topics:

- battery (mechanical dimensions, communication processes and storage of information such as temperatures, state of charging, charging and usage history, ..) communication between car and charging infrastructure
- integration into Smart Home, Smart Metering
- integration into Smart Grid
- billing solutions for V2G services
- vandalism-proof power connection

6.3 Fuel Cells for hydrogen conversion

6.3.1 State of the art

A fuel cell is an **electrochemical energy conversion device**. A fuel cell converts the chemicals, hydrogen and oxygen into water, and in the process it produces electricity. The battery is another electrochemical device that people are familiar with. A battery has all of its chemicals stored inside, and a chemical reaction occurs in the system to produce electricity and once the chemicals are finished battery eventually "goes dead". However, in a fuel cell, chemicals flow constantly into the cell so it never goes dead; as long as there is a flow of chemicals into the cell, the electricity flows out of the cell. Most fuel cells in use today use hydrogen and oxygen as the chemicals.

There are different types of Fuel cells, usually classified on the basis of operating temperature and the type of electrolyte they use. Table:6-11 gives a short summary of the current FCs with technological features and applications. Numerous organizations across the world are researching and developing FC technologies to make them more efficient and cost effective. 'The Fuel Cells and Hydrogen Joint Technology Initiative' adopted by the European Commission is such a program of public private partnership with industry in the lead. The Commission is funding 470 M€ from the 7^{th} framework Program (FP7) program for R&D of Fuel cells at all application levels.

Polymer exchange membrane fuel cell (PEMFC) is currently considered to be most significant for transportation applications. The PEMFC has a high power density and a relatively low operating temperature (ranging from 60 to 80 degrees Celsius or 140 to 176 degrees Fahrenheit). The low operating temperature means that fuel cell does not take very long to warm up and begin generating electricity. The fuel cell technology is considered more efficient than an internal combustion engine, and offers advantages of the electric drive (no emissions of pollutants, low noise emission) and avoiding the constraints of the battery technology. A study by the European Commission (Hydrogen Energy and Fuel Cells; A vision of our future) states that by 2020 if 5% of new cars are fuelled by hydrogen then average 2.8 gCO_2/km reduction can be achieved ultimately resulting in 15Mt CO_2 avoidance per year.

Table 6-11: Main characteristics of technically relevant fuel cells

Type	Electrolyte	Charge Carrier	Temperature range (^{o}C)	Power range / Efficiency	Start-up time	Application
Polymer exchange membrane fuel cell (PEMFC)	Proton conducting membrane (e.g., Nafion)	H^+ (Proton)	50-80	50kW / 25-45%	Immediate	Road Vehicles, stationary, heat and electricity generation, space travel
Alkaline fuel cell (AFC)	30-50%KOH	OH^- (Hydroxide)	60-90	7kW / 37-42%	Immediate	Space, road vehicles, submarines
Phosphoric-acid fuel cell (PAFC)	Concentrated Phosphoric acid	H^+ (Proton)	160-220	50kW / 37-42%	30min 'hot standby'	Stationary, heat and/or electricity generation
Molten-carbonate fuel cell (MCFC)	Molten Carbonates	Carbonate	620-660	250kW / 40-47%	Several hrs after starting	Stationary, heat and/or electricity generation, co-generation
Solid oxide fuel cell (SOFC)	Ion conducting ceramic	O^{2-} (Oxide)	800-1000	1kW-250kW / 44-50%	Several hrs after starting	Stationary, heat and/or electricity generation, co-generation
Direct-methanol fuel cell (DMFC)	Proton conducting membrane	H^+ (Proton)	80-100	mW to kW	Immediate	Portable, mobile

Source - (Weidemann, Schirrmeister, & Roser, 2009)

Fuel cell powered cars can be solely powered by Hydrogen (*Mercedes-Benz B-Class F-cell*), or can use internal combustion engines with fuel cells or can be hybrid vehicles; such as fuel cell electric vehicle (*Honda FCX Clarity, Chevrolet Equinox*). When hydrogen is used as a gaseous fuel in an internal combustion engine, it's very low energy density compared to liquid fuels is a major drawback requiring greater storage space for the vehicle to travel a similar distance as compared to gasoline. Hence it is considered that hybrid vehicles can be more efficient than conventional vehicles and result in lower emissions.

6.3.2 Production figures in the EU

Presently there are several European automakers involved in the development of fuel cells vehicles powered by H_2: Volkswagen, Peugeot, Renault, Opel, and Fiat. Few promising developments are listed in the next table and full overview is available at www.h2cars.de.

Table 6-12: Drive train concepts on gaseous and liquid hydrogen

Fuel Cell on Gaseous Hydrogen						
Automaker	**Vehicle name**	**Vehicle type**	**Energy storage**	**Power**	**Range**	**Speed**
DaimlerChrysler	Necar 4	Passenger car	2.5 kg, 35 Mpa	75 kW	200 km	145 km/h
Toyota	FCHV5	Passenger car	35 l, 50 Mpa	90 kW	500 km	
Ford	THINK FC5	Passenger car	35 Mpa	75 kW		128 km/h
Honda	FCX V4	Passenger car	130 l, 35 Mpa	60 kW	300 km	140 km/h
DaimlerChrysler	Sprinter	Light duty vehicle	35 Mpa	55 kW	150 km	120 km/h
Toyota	Hino Bus	Bus	25 Mpa	180 kW	300 km	80 km/h
DaimlerChrysler	Citaro Bus	Bus	35 Mpa	250 kW	300 km	80 km/h
Fuel Cell on Liquid Hydrogen						
Opel	HydroGen3	Pass.car	4.8 kg	75 kW	650 km	180 km/h
Renault	Laguna	Pass.car		30 kW	300 km	
MAN / Linde	SL 202	Bus	600 l.	140 kW	300 km	75 km/h

Source: www.h2cars.de

6.3.3 Economic and environmental assessment

Currently, it is very difficult to make a precise cost analysis, because at the present there are no market prices published for hydrogen vehicles. Fuel-cell vehicles are mostly produced as prototypes or in very small quantities. However, current costs of hydrogen fuel cells vehicles are quite high and not competitive on the market with the conventional automotive technologies. But by rising production numbers of hydrogen vehicles the prices can be decreased very fast. Moreover, increasing experience with advanced hybrid-electric vehicle technology and production could help lower the cost of fuel cell vehicles in the future. The projected high-volume manufacturing cost of automotive fuel cell systems has decreased from 275 $/kW in 2002 to 73 $/kW in 2008 (DOE, 2009). Since the fuel cell costs are the largest part of the total vehicles costs, about 80%, with the reduction of the fuel cell costs through the mass production hydrogen vehicles could become much more competitive with conventional ICE vehicles.

6.3.4 Technical improvement potential

Since the first commercial development of the PEM unit in the 1960s, the technology has evolved significantly and is still in the phase of rapid growth of technology life cycle (Mock & Schmid, 2008). Following forecasts and R&D activities (in demonstration phase) of several car manufacturers (like DaimlerChrysler, Ford, Honda etc) 2012 – 2015 looks critical time for fuel cell technology and is supposed to enter maturity phase by approx. 2015 (Crawley, 2006).

Fuel cell research and development (R&D) nowadays is aimed at achieving high efficiency and durability, low material and manufacturing costs of the fuel cell stack. PEM fuel cells are the current focus for light-duty vehicles because they have fast-start capability and operate at comparatively low temperatures (European HFP, 2005). Technical improvements in power density and platinum loading are necessary to go on commercial scale. A cost evaluation on fuel cells for automotive powertrains suggests that in future for high production volumes (approx. 1 million vehicles cumulative) significantly reduce the production costs for fuel cell stacks to around 9 to 30 €/kW (12–40$/kW) and systems 26 to 63€/kW (35–83$/kW) will be possible (Mock & Schmid, 2008). However, IEA (IEA, 2007) forecasts costs of around 100$/kW by 2015 following mass production and technology learning. Noticeably, future manufacturing costs of emerging technologies are not easy to evaluate because of the random dynamics involved in both product and process renovation and difficulty in obtaining any reliable cost data.

Today’s fuel-cell propulsion systems are successfully demonstrated in several cars and are safe and comfortable, but are still characterised by system costs of around 2,000-3,000 EUR/kW and lifetime around 3,000 h (EC; Hydrogen and Fuel Cells Review, 2007). To integrate FCs with propulsion systems it is necessary to further improve the key subsystems and components of FCs. Some of the Short term targets (2015) by European Hydrogen and Fuel Cell Technology Platform (2007) are:

- Operation under all ambient conditions including freeze start from -25 °C / +45 °C
- Maximum overall efficiency above 40 % with Lifetime of at least 5,000 h
- Operating range of vehicles above 400 km
- Cost reduction down to 100 EUR/kW, projection for >150,000 units per year
- Compact fuel-cell systems with 1.5 kg/kW and 1.5 l/kW for 100 kW systems

Major barriers in the cost reduction of fuel cells for transport are the high cost of the electrolyte membrane and the platinum catalyst. The cost of currently used ‘Nafion membranes’ ranges from

50 to 100 €/kW, where the thickness of the membrane (and related lifetime) is an important cost factor. The cost of the platinum catalyst per kW is around 50 € (assuming a power density of 0.6 W/cm^2 and a platinum load of $1mgPt/cm^2$) (EC; Hydrogen and Fuel Cells Review, 2007). To meet the R&D aims, intensive work is being done on new materials and novel design and fabrication methods for membranes, cathode catalysts and supports, cell hardware (including bipolar plates and seals). The next part states a few possible technological potentials that can be improved for future passenger cars and meeting customer expectations (Mock & Schmid, 2008).

Table 6-13: Technical improvement potentials in FC Vehicles

<table>
<tr><td colspan="2">Fuel cell</td><td>Hydrogen Storage</td><td>Vehicle performance</td></tr>
<tr><td>FC Components’ performance</td><td>Electrolyte</td><td rowspan="2">On-board storage of Hydrogen</td><td rowspan="2">Engine Efficiency
Power : Weight ratio
Temperature tolerance</td></tr>
<tr><td>Electrodes (MEA)
Stack power (Power output by each stack)
Stack power density (volumetric : gravimetric power density)</td><td>Catalyst loading (viz. Pt, Ru, Ir)</td></tr>
</table>

Source: (European HFP, 2005), (EC; Hydrogen and Fuel Cells Review, 2007), (Mock & Schmid, 2008)

Developments in Membrane Electrode Assemblies (MEAs): The MEA is the most important subsystem influencing the performance of PEFC systems and is responsible for 70 % of the projected future PEFC stacks cost (European HFP, 2005). Effective integration of membrane and electrodes is necessary to optimize mechanical and chemical interactions of the catalyst and to minimize interfacial resistance. Expansion of the operating range of MEAs (temperature, relative humidity, tolerance to air, fuel and system-derived impurities) also gives room for improvements.

Stack power: Power output of a typical middle class ICE passenger car ranges between 60 and 130 kW. Internal combustion engines (ICE) need so much of energy because of being excessively motorized and to be able to achieve short-term high power demand (e.g. when accelerating at a traffic light). However, electric vehicles, like a fuel cell car, in contrast have excellent acceleration attributes, so a value of 110 kW can be sufficient for everyday usage. Nowadays stack module,
Mk 1100, produced by Ballard Power Systems Inc. has a net power in range of of 100kW. Power density improvements at the level of the fuel cell stack are meant by improvements at the single cell level. Power density is defined by the voltage of the cell as well as the current flow through the active area of the cell. Recent stacks like the Ballard *Mk 900* have power densities of approx. 600mW/cm2. The target for 2015 according to DOE is a value of 1000mW/cm2.

Stack power density: Volume in a passenger car engine is always restricted due to performance reasons. Therefore for using a fuel cell in a car volumetric as well as gravimetric power density should be as high as possible. To become competitive with internal combustion engines, the future fuel-cells need to realize power densities of 1 W/cm² at cell efficiencies above 50% and at a total noble-metal loading of less than 0.3 mg per square centimetre (European HFP, 2005). Volumetric power density of the stack *Mk 1100* module, produced by Ballard Power Systems Inc. reaches approx. 1,340W/l. Honda claims to already have reached a value of approx. 1,900W/l for its latest stack. By 2010, Ballard Power Systems target the value of 2,500W/l over the officially targeted value of 2,000W/l by the U.S. Department of Energy (DOE). Gravimetric power density is approx. 1,000W/kg for the *Mk 1100* module. DOE goal for gravimetric power density of the stack is 2,000W/kg. Further research activities and new materials, e.g. thin metallic bipolar plates, should help for further improvements.

Platinum loading: To accelerate the chemical reaction of hydrogen and oxygen in the cell a catalyst is needed for low-temperature PEM fuel cells. The material commonly used is platinum and to a lesser extent ruthenium and iridium. Because of the high economic value of these materials it has always been a target to reduce usage of them within the fuel cell. Current loadings are 0.7mg/ cm2 for both electrodes together, according to DOE. However, target value of reduction to approx. 0.2mg/cm2 by 2015 is set by DOE. Noticeably, only 10–20% of the catalytic material gives chemical activity, so there is still potential for improvement, even ideas for platinum-free catalysts do exist. Alternatively non-noble catalysts, e.g. RuSe oxide, can be improved to reach similar performance and cost targets as MEAs with platinum-based catalysts; however a constraint is the limited availability of ruthenium compared to platinum.

Vehicle performance: An important advantage of fuel cell vehicles when being compared with conventional ICE vehicles is their high efficiency of fuel conversion. The maximum efficiency of a modern Diesel engine for passenger cars is at approx. 40%. Maximum efficiency of the fuel cell system used in the *Daimler Necar 4* vehicle in 1999 was 50%, for the F-Cell in 2002 it was almost 60%. Advanced technologies like start–stop system and software optimization can help to improve efficiency of the fuel cell system.

Furthermore, the **power-to-weight ratio** which is the ratio between power output of the vehicle and its curbweight (and therefore also includes the fuel storage system) can be improved. Current values for diesel cars are at approx. 70W/kg and for gasoline cars at approx. 90W/kg, however the value ranges around 50W/kg for fuel cell vehicles.

Temperature tolerance of the FCVs needs to be improved significantly. FCVs able to perform between -20°C and 45°C are targeted by 2015 (EC; Hydrogen and Fuel Cells Review, 2007). Currently, Honda's latest model *FCX Clarity* claims to be able to start at temperatures as low as −30 °C (DOE target for 2010 is −40 °C). However, this might negatively affect long-term durability, which for transportation fuel cells currently is at 2,000 h (stack)/1,000 h (system) according to DOE. A value of approx. 5,000 h (equivalent to approx. 250,000km of driving) has to be met in order to ensure a proper lifetime for the needs of future passenger cars.

Hydrogen storage: Between 1995 and 2001 many of the fuel cell vehicle models presented to public used fuel storage systems other than compressed hydrogen. In 2000 for example only half of the newly presented models used compressed hydrogen, whereas the rest was using liquid hydrogen, methanol, gasoline or a hydride storage system. From 2002 on this situation changed and nowadays nearly all models on the market are powered by compressed hydrogen from 350 or 700 bar storage system. These systems have energy densities of approx. 0.5–0.8kWh/l and 1.6–1.9 kWh/l which are significantly lower than the DOE target values for 2010 (1.5 kWh/l and 2.0 kWh/l) and 2015 (2.7 kWh/l and 3.0 kWh/l) and nearly ten times lower than the values for a conventional gasoline fuel storage system.

European Hydrogen & Fuel Cell Technology Platform (European HFP, 2005) targets to store 4-5 Kg of Hydrogen for a driving range of 500 to 600 km which corresponds to a liquid hydrogen volume of about 75 l, or a gaseous volume of over 120 l at 700 bar and ~20 °C. The current storage tanks used in vehicles are still bulky, so in order to confine this hydrogen quantity a volumetric energy density for the overall tank volume larger than 1.1 kWh/l needs to be achieved. Other hydrogen storage systems, like metal-hydrides, promise higher energy densities for the future but still are in an early research phase. From a potential customer point of view most important parameters with regard to the energy storage system are easy fuelling and everyday usage, safety and maximum driving range. Table 6-14 summarizes few more technical improvements that may help to make FC more efficient and cost effective.

Table 6-14: Technical improvements prospects in Fuel Cells

Developments in Electrolyte membrane	Membranes with reduced raw material cost, improved conductivity and mechanical / chemical / thermal stability over the entire temperature (around 120°C) and humidity range (below 10%)
Developments in Electrode	Developing electro catalysts with reduced precious metal loading, increased activity, improved durability / stability, reduced corrosion and increased tolerance to air, fuel and system-derived impurities
Developments in Gas Diffusion Layer (GDL):	Increase performance and water management by optimizing GDL properties (conductivity and hydrophobicity) and pore structure and improving GDL coatings
Developments in Bipolar Plates	Decrease weight and volume of bipolar plates, Design low-cost, scalable fabrication processes
Developments in Seals	Develop seals that achieve very low leak rates and can tolerate the entire fuel cell operating temperature and humidity range

Source: (European HFP, 2005), (EC; Hydrogen and Fuel Cells Review, 2007), (Mock & Schmid, 2008)

6.4 Internal combustion engine (ICE) on hydrogen for transport vehicles

6.4.1 State of the art

At the current market situation, hydrogen vehicles are being demonstrated at 2 levels; electric engines powered directly by hydrogen fuel cells (through PEM) and classic internal combustion engines powered by compressed hydrogen. The H_2ICEs are already taking advancement with recent technologies that enable car to switch back and forth easily between gasoline and hydrogen fuel. The primary reason for using hydrogen in internal combustion engines is that they already exist and are comparatively cheaper than other alternatives. Hydrogen-fueled internal combustion engines (H_2ICEs) are most likely to reach the consumer market first (hydrogencarsnow.com).

The *Mazda RX-8* uses a *RENESIS Hydrogen Rotary Engine*, which can ideally burn hydrogen without the problem of backfiring that can occur due to the burning of hydrogen in a traditional piston engine. Twin hydrogen injectors and a separate induction chamber help to maintain safer temperatures the flow of hydrogen fuel. The *BMW H2R Record* car, on the other hand is able to give an output of more than 210 kW or 285 bhp with its six-liter 12-cylinder. The H2R is equipped with modified engine and dual gasoline / hydrogen tanks that allows to chose the type of fuel to be used in combustion chambers. *FCX* hydrogen fuel cell / electric vehicle developed by Honda is another vehicle with enhanced fuel cell performance, energy efficiency, recycle-ability and even with the ability to operate in sub-zero temperatures. The *FCX* uses 8.3 pounds of H_2 is stored in two 5000-psi (41-gallon total capacity) aluminum tanks developed with carbon fiber and fiberglass layers (Gnoerich, 2008).

6.4.2 Economic and environmental assessment

Although the hydrogen use in fuel cell vehicles is the best way regarding energy efficiency and environment, hydrogen is also used in ICE vehicles. Comparing to fuel cell vehicles, hydrogen ICE vehicles have almost two time lower energy efficiency. At the same time investment costs for hydrogen ICE vehicles are more than three time lower than for fuel cell vehicles. The other advantage of the internal combustion engine vehicles is that they can also operate in a bivalent mode with gasoline and hydrogen, which might be of significant importance for the transition period to hydrogen as alternative fuel or the early market introduction.

A rapid increase of fuel cell vehicles with hydrogen on the market is not expected in the near future, mainly, because the costs of the fuel cells are still very high. In the meantime, the internal combustion vehicles powered by hydrogen could become an alternative to fuel cell vehicles because they are considerably cheaper and are thus more competitive compared to the conventional vehicles.

6.4.3 Production figures in the EU

The following table (Table 6-15) summarizes the production development across the EU by different companies, describing the type of technology used mostly dominated by PEM as well as the projected use for transport and the announced plans.

Table 6-15: Fuel Cell Vehicle production and development across EU

Company	Technology	Affiliation	Latest Prototypes	Declared plans
BMW	ICE LH2	ICE technology developed in-house, fuel tank links to Magna Steyr	7-Series limited production bi-fuel (2007) & H2 (2008); boosted test-bed engine giving 48% efficiency (2006)	Smaller, boosted engines in vehicles; combined pressure/cryo storage; no dates announced
Daimler	PEM, 700 Bar	Ballard; took over Automotive Operations in 2007 with Ford	B-series F-Cell (2008)	B-series available to HyCom projects from 2010; product on sale target 2012-15
Fiat	PEM, 350 Bar	Nuvera, Zero Regio project	Panda Hydrogen Concept (2006)	None specific
Ford	PEM & ICE 700 Bar	Ballard; took over Automotive Operations with Daimler in 2007; part own Mazda (Rotary H2 ICE)	Edge HySeries plug-in FC-HEV (2007)	ICE as bridge to fuel cell; FC products post 2015
GM	PEM, 700 Bar	Technology developed in-house	Chevy Equinox FC	100 Equinox demo from 2008 in USA; 1000 vehicle trial in California 2012-2014
Honda	PEM, 700 Bar	Technology developed in-house	FCX Clarity (2007)	Leasing of Clarity in Tokyo & LA from 2008; Home refuelling; first general product ca 2018
Nissan	PEM,350 & 700 Bar	FCtech. developed in-house. Batteries developed in collaboration with NEC	X-Trail FCV	Limited numbers of FCVs leased to specific customers
PSA	PEM Inter-changeable Cylinder	Intelligent Energy	H2Origin (2008)	None specific
Toyota	PEM, 700 Bar	Technology developed in-house	FCHV-6 (2007)	Fleet use 2010-2020; mainstream products 2020-2030; platinum-free PEM
VW	HAT-PEM, 700 Bar	Phosphoric acid technology developed in-house – previously used Ballard stacks	Space Up Blue (2007)	Running prototype 2010; products from 2020

Source – Roads2HyCom, 2008

6.4.4 Technical improvement potential

A hydrogen ICE can be classified based on location for fuel injection - Port injection and Direct injection. In port injected ICEs fuel is injected at the inlet port and air-fuel mixture is formed during intake stroke. This type uses common rail fuel injectors and uses mechanical cam to time the injection. In direct injection type the fuel-air mixture is formed inside the combustion chamber. Engine cannot backfire into the intake manifold. Direct injection H_2 ICE gives higher power output than the carbureted engines (Gnoerich, 2008). The combustion properties of hydrogen are different from gasoline or diesel. It burns much faster than those fuels, so getting the most out of hydrogen in an ICE requires optimizing the shape of the combustion chamber and calibrating the timing of the spark to avoid damaging knock. Hydrogen burns hotter than gasoline so certain engine modifications are necessary, however the basic engine block is same as a gasoline powered engine. Hydrogen modifications internally are mainly limited to the pistons; few other "external" modifications are associated to the engine are stated in following points (Ford):

- <u>Valves and valve seats</u> need to be especially hardened to overcome the reduced lubricating properties. Gasoline unlike hydrogen has some oil like properties that help to keep engine components properly lubricated.
- <u>Spark plugs</u> must use iridium to withstand the higher temperatures.
- <u>Ignition coils</u> must be different than conventional ICEs as hydrogen fuel has different properties.
- <u>Fuel injectors</u> need to be designed and timed according to fast ignition property of hydrogen.
- <u>Engine oil system</u> must include a separator to remove any hydrogen that might migrate into the oil and must be able to withstand higher temperatures and pressures.
- <u>Exhaust gas system</u> must be able sustain water produced by the hydrogen combustion. Head gasket, pistons, connecting rods and piston rings must be able to withstand the higher forces and pressures produced.

Hydrogen fuel cell / electric engine vehicles coupled with advanced vehicle technologies like cleaner burning, electricity regenerating properties etc can be more efficient over the time. Most of the automakers have followed hydrogen ICEs using traditional piston engines. BMW has gone one step further and have developed vehicle that uses liquid hydrogen as a fuel while virtually every other automaker has focused on compressed gaseous hydrogen. *BMW 100 7-series sedans* is such a dual fueled vehicle with the ability to run on either hydrogen or gasoline. Mazda has followed a different path of *Wankel rotary engines* that suits better to run on hydrogen with spontaneous combustion and the ability to use ceramic seals to avoid lubrication issues.

There is some **shortcomings** as-well of using hydrogen in ICEs. Hydrogen combustion in ICEs yields nothing but water and air (which is mainly nitrogen and around 20% oxygen). Burning hydrogen in air produces trace amounts of nitrogen oxides though; they are just a tiny fraction of what is produced when gasoline or diesel is burnt (Weidemann, Schirrmeister, & Roser, 2009). The other problem is power output. While hydrogen has higher mass energy density than gasoline (143MJ/kg vs. 46.4) its volumetric density tends to be very low. As a result, while gasoline has an energy density of 34.2 MJ/L, liquid hydrogen is only 10.1 MJ/L and compressed gaseous hydrogen (700 BAR) is only 5.6 MJ/L. That means ICEs tend to produce a lot less power on hydrogen than they do on gas (IEA, 2007). Ford combated this on its hydrogen V10 engine by supercharging it, making up some of the deficit.

The conversion of some of these heat engines into hydrogen is possible but one must keep in mind that the simple, robust and cheap storage from one to several kilograms of hydrogen is to be developed indeed to be imagined. In India many R&D initiatives have been taken to develop hydrogen internal combustion engines for moped and tricycles with an autonomy from 60 to 80 km intended to urban transport.

Concerning megawatt, they are important industrial facilities even electric plants which can be combined with units producing hydrogen from renewable energies via photovoltaic solar collectors or of wind mills. In deed these devices generate electricity but which is not easily usable because is produced in an intermittent and unstable way since related on the sun or the presence of the wind. Moreover this electricity is obtained in the form of direct current which requires to be converted into alternating current (by inverters) to be usable. On the other hand this direct current directly resulting from renewable energies is adapted to the electrolysis which while dissociating form water produces hydrogen. The thermal engines functioning then with this hydrogen drive alternators whose current can be directly usable or distributed in network.

7 Summary and discussion

To tackle the problems associated with constantly increasing fuel (energy) demand and to contribute to GHG mitigation, it has become very important to consider alternative fuels and alternative propulsion systems. The core objectives of this work package is to conduct a comprehensive economic and environmental assessment of different AFs/AAMTs and to assess whether and to what extent the AAMTs and AFs can be of economic and environmental relevance. Another objective is to analyze the improvement potentials of these AFs/AAMTs that may help in increasing efficiency, enhancing environmental performance and reducing production costs. The alternative fuel technologies analysed within this report are considered to have significant potentials to reduce GHG emissions between 40% and 85% (by first generation and second generation biofuels respectively), compared to conventional gasoline (Directive 2009/30/EC). While those of AAMTs have the potential to increase individual car fuel efficiency baround 12-16% and reduce total energy consumption to around 20% by 2020 in the European passenger car sector (CONCAWE, 2008; Steenberghen and Lopez, 2007; EPA, 2005). The development stadium of some of these technologies differs from early research and demonstration to fully commercial level. However, among all of them uneconomical performance is observed across the literature survey and database elaboration. In addition, both AFs and AAMTs exhibit a significant potential for improvement and technological learning translated in cost reductions with the expectations to reach competitiveness.

The research carried out in this WP confirms on one hand that second generation biofuels have a significant potential to expand production capacities, increase efficiency and scaling-up opportunities that will position them to compete with fossil fuels, but several technical and non-technical barriers such as biomass supply etc. need to overcome. On the other hand the existing ICE motor configurations show evidence of high technological improvements that will not only increase performance, reduce emissions and fuel consumption but also provide higher added value for the consumers.

Personal car is most important for general public mobility and the choice of automotive technology depends on the usages, driving locations and consumer preferences etc. In order to be more efficient and meet the sustainable practices, the automotive industry is developing and investing in many technologies, but today it is impossible to say which technology will prove to be the most viable. The largest part of total transport costs of AAMTs is the specific investment costs and hence currently, the most expensive AAMT is fuel cell vehicle (FCV). Various advanced technologies (like variable valve timing, gas direct injection, cylinder deactivation etc.) can increase the engine efficiency between 3 to 15% and can bring down the fuel consumption to 2-4 l/100 km by 2020. Some authors consider that the EU can achieve a 20% reduction in its energy consumption projections for 2020 by integration of currently available most advanced technologies into the market (Steenberghen and Lopez, 2007; EPA, 2005). Moreover, multiple powertrain technologies have the potential to offer personal vehicle fuel economy improvements by 20% to 50% compared to today's gasoline vehicles and diesel electric hybrids have the potential to increase fuel economy by 70%.

Currently, first generation biofuel production is well established at commercial level across the world and bioethanol is the most common biofuel, accounting for more than 90% of total biofuel consumption, where USA and Brazil produce around 85% of the total Ethanol produced around the world. For first generation biofuels, feedstock costs account for 50 to 70% of total production costs, followed by investment and operational costs. Multiple feedstock plants are common in Europe for both biodiesel and bioethanol but volatility of feedstock market prices over the time and regions affect the overall economical performance considerably. Moreover, revenues generated through the by-products are also very important for decreasing cost of production. Between 40 and 45% of the total ethanol lifecycle emissions arise from the feedstock (mainly transportation and processing); of which WTT emissions stand around 20 to 50 gCO_2eq/MJf. Ultimate production costs and emissions of first generation biofuels depend on the whole supply chain and are subjected to several variations like regions, practices, scale of production etc.

As per the results of this study, Biogas offers the best environmental performance (gCO_2eq/MJ) in comparison to energy price (€/GJ), but its cost of production currently is still very high. The production of Biogas for CHP generation is well established in Europe, but its application in transport is in early demonstration stage (for example in Sweden). Competition of biogas with conventional usage (CHP generation) and infrastructure development for fuel distribution and ICE adaptation are few other major concerns for adapting biogas as transport fuel.

For the production of 2nd generation biofuels (lignocellulosic ethanol and BTL) several pilot and demonstration plants are functional across EU but wide-scale commercialization is unlikely to occur before 2015. Currently the processes involved in biofuel production are unproven on the commercial scale and are under development and evaluation with conversion efficiencies of around 30-35%. Second generation routes perform well in terms of emission reduction potentials, but also exhibit constrains as they are high energy intensive processes and are not cost competitive. Unlike first generation biofuels, feedstock costs for second generation biofuels are lower but the processing and operational costs are much higher. In this case, the additional revenues generated from the by-products (DDGS, chemicals, lignin for CHP, etc) play a very important role. On the other hand, overcoming bottlenecks (mainly technical and process related), introducing technical improvements (in feedstock pretreatment, processing, enzyme technology etc), advanced use of biotechnology and the latest concept of integrated biorefinery may help in the future to bring the second generation biofuels to commercial scale beyond 2020. Biofuels offer solutions for emission reduction but to ensure constant future supply they need to be developed, produced and made available on a much larger scale. Noticeably, the success will also depend on the density of the corresponding distribution network.

Biomass is another important aspect of biofuel industry. Total biomass potentials for Europe according to different studies projected for 2020 vary between 8 to 20 EJ. Improvements in biomass resources are twofold i.e. improving the quality of the feedstock for specifications required for fuel productions and economically improving the yield of the feedstock production chains in order to reduce the cost of production. Concern of direct and indirect land use changes (LUC/ILUC), sustainable practices in agriculture etc are few other significant considerations.

For Hydrogen utilization, there is a well established network and usage for industrial purpose and CHP production; however its application in transport is still in infancy. Similar to first generation biofuels, feedstock costs is the biggest factor in total production costs followed by capital and operational costs. Moreover, like biogas as transport fuel, infrastructure, ICE adaptation and supply network costs are another major concern that will occur with further developments in Hydrogen as transport fuel.

For running the vehicle with low blend biofuel (B5 or E5) slight or no modifications are required in ICEs, but major changes are required when higher blend or pure biofuel (e.g. pure biodiesel) is used. ICE adaptation for dedicated or pure biofuel is still in infancy in Europe but well established for bi-fuel vehicles, especially propelled on gasoline/diesel and gas (NG/CNG/LNG). A large-scale switch to alternative fuels in Europe requires a well coordinated action plan by both public and private stakeholders to achieve high market penetration. However in the end it is a global market acceptance and penetration that will help to meet the challenges of climate change and to safeguard the competitiveness of the European automotive industry.

Currently, electro-mobility is young, and the future success depends a lot on decreasing battery costs. Based on technical improvement potentials, the objective for batteries cost is to reduce to

500 €/kWh for Li-Ion batteries by 2020. Battery electric vehicles produce very little emission but the emission generated during the production of electricity used for recharging should be considered. Another type of electrical vehicle, the fuel cell vehicles do not have clear defined time line for commercial scale-up, most of the studies foresee between 2015 and 2030 for commercialization. For fuel cells, scaling-up and reducing Platinum loading can help to bring down the cost of production to 26-200€/kW. Currently, it is very difficult to make a precise cost analysis of fuel cell vehicles, as there are no market prices published for hydrogen vehicles.

Despite the prospects of significant improvements, the quantification of technological improvements and learning until 2020 appears to have high degree of uncertainty, as it can only be done for some of the technologies or components (e.g. Batteries) because of the lack of necessary data and unforeseeable variables (such as feedstock yields). Moreover, the technological progress made by one technology can significantly affect (can enhance or reduce) the progress made by another one. Hence, the currently considered technology options cannot be overlooked as ‘negligible’ or prematurely selected as the ‘winner’. The projections can only be made based on several unapproved assumptions and overlooking other unforeseen factors (like economics, acceptance, feasibility etc) that may affect the market penetration and overall development of these technologies.

The innovation and improvement options in current industry may experience different stages of development and maturity with state of the art subjected to poor economic performance (not as competitive as conventional technologies), various bottlenecks and other hindrances associated with market penetration. The technical efficiency increase across the fuel production chains and automotive industry will offer possible solution for emission reduction and increasing efficiency (e.g. vehicle fleet, processing etc), but at the same time will result in higher investments, further R&D and integration efforts within specific technologies (like ICE adaptations for pure Biofuels, defining scaling-up opportunities for Biofuels, infrastructure development, integration of advanced technologies with the automotive industry).

The increasing diversity in innovation in current AAMTs with the time may rationalize to several mainstream solutions. It is also quite probable that different technical modifications and adaptations will offer different solutions to various segments of road transport as per their utility (such as heavy goods vehicles, buses and passenger cars). New technologies will come in low volume and a high cost premium, so the cost effectiveness needs to be controlled by harmonized and standardized supportive policy framework across Europe, such that the vehicles remain affordable and mobility is guaranteed.

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