Future Transport Fuels

Report of the
European Expert Group
on Future Transport Fuels

January 2011

Disclaimer:

This report reflects the views of the experts who have taken part in the European Expert Group on Future Transport Fuels. The views expressed herein do not necessarily represent the views of the organisations by which the experts have been nominated.

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Executive Summary

Transport fuel supply today, in particular to the road sector, is dominated by oil [1], which has proven reserves that are expected to last around 40 years [2]. The combustion of mineral oil derived fuels gives rise to CO_2 emissions and, despite the fact the fuel efficiency of new vehicles has been improving, so that these emit significantly less CO_2 , total CO_2 emissions from transport have increased by 24% from 1990 to 2008, representing 19.5% of total European Union (EU) greenhouse gas emissions.

The EU objective is an overall reduction of CO_2 emissions of 80-95% by the year 2050, with respect to the 1990 level [3]. Decarbonisation of transport and the substitution of oil as transport fuel therefore have both the same time horizon of 2050. Improvement of transport efficiency and management of transport volumes are necessary to support the reduction of CO_2 emissions while fossil fuels still dominate, and to enable finite renewable resources to meet the full energy demand from transport in the long term.

Alternative fuel options for substituting oil as energy source for propulsion in transport are:

- **Electricity/hydrogen,** and **biofuels (liquids)** as the main options
- **Synthetic fuels** as a technology bridge from fossil to biomass based fuels
- **Methane (natural gas and biomethane)** as complementary fuels
- **LPG** as supplement

Electricity and **hydrogen** are universal energy carriers and can be produced from all primary energy sources. Both pathways can in principle be made CO_2 free; the CO_2 intensity depends on the energy mix for electricity and hydrogen production. Propulsion uses electric motors. The energy can be supplied via three main pathways:

➢ ***Battery-electric***, with electricity from the grid stored on board vehicles in batteries. Power transfer between the grid and vehicles requires new infrastructure and power management. Application is limited to short-range road transport and rail. The development of cost-competitive high energy density batteries and the build-up of charging infrastructure are of the highest priority.

➢ ***Fuel cells powered by hydrogen***, used for on-board electricity production. Hydrogen production, distribution and storage require new infrastructure. Application is unlikely for aviation and long-distance road transport. The development of cost-competitive fuel cells, on-board hydrogen storage, and strategic refuelling infrastructure is of the highest priority.

➢ ***Overhead Line / Third Rail*** for tram, metro, trains, and trolley-buses, with electricity taken directly from the grid without the need of intermediate storage.

Biofuels could technically substitute oil in all transport modes, with existing power train technologies and existing re-fuelling infrastructures. Use of biomass resources can also decarbonise synthetic fuels, methane and LPG. First generation biofuels are based on traditional crops, animal fats, used cooking oils. They include FAME biodiesel, bioethanol, and biomethane. Advanced and second generation biofuels are produced from ligno-cellulosic feedstock and wastes. They include bioethanol, HVO, higher alcohols, DME, BTL and biomethane.

The production of biofuels from both food and energy crops is limited by the availability of land, water, energy and co-product yields, and sustainability considerations, such as the life-time accountancy of CO_2 emissions. Second generation biofuels from wastes and residues are also limited by the availability of these materials.

The development of feedstock potential and of optimised production processes is of the highest priority. A supportive policy framework at the EU level and harmonised standards for biofuels across the EU are key elements for the future uptake of sustainable biofuels.

Synthetic fuels, substituting diesel and jet fuel, can be produced from different feedstock, converting biomass to liquid (BTL), coal to liquid (CTL) or gas to liquid (GTL). Hydrotreated vegetable oils (HVO), of a similar paraffinic nature, can be produced by hydrotreating plant oils and animal fats. Synthetic fuels can be distributed, stored and used with existing infrastructure and existing internal combustion engines. They offer a cost-competitive option to replace oil-based fuels, with the perspective of further improved system performance with engines specifically adapted to synthetic fuels. The development of industrial scale plants for the production of cost-competitive synthetic fuels derived from biomass is of the highest priority, while efforts should be continued to improve the CO_2 balance of GTL and particularly CTL. DME (Di-Methyl-Ether) is another synthetic fuel produced from fossil or biomass resources via gasification (synthesis gas), requiring moderate engine modifications.

Methane can be sourced from fossil natural gas or from biomass and wastes as biomethane. Biomethane should preferentially be fed into the general gas grid. Methane powered vehicles should then be fed from a single grid. Additional refuelling infrastructure has to be built up to ensure widespread supply. Propulsion uses internal combustion engines similar to those for liquid hydrocarbon fuels. Methane in compressed gaseous form (CNG) is an unlikely option where high energy density is required. Liquefied methane gas (LNG) could be a possible option in these cases. Harmonised standards for biomethane injection into the gas grid and the build-up of EU-wide refuelling infrastructure are of the highest priority.

LPG (Liquefied Petroleum Gas) is a by-product of the hydrocarbon fuel chain, currently resulting from oil and natural gas, in future possibly also from biomass. LPG is currently the most widely used alternative fuel in Europe, accounting for 3% of the fuel for cars and powering 5 million cars. The core infrastructure is established, with over 27,000 public filling stations.

Single-fuel solutions covering all transport modes would be technically possible with liquid biofuels and synthetic fuels. But feedstock availability and sustainability considerations constrain their supply potential. Thus the expected future energy demand in transport can most likely not be met by one single fuel. Fuel demand and greenhouse gas challenges will require the use of a great variety of primary energies. There is rather widespread agreement that all sustainable fuels will be needed to resolve the expected supply-demand tensions.

The main alternative fuels should be available EU-wide with harmonised standards, to ensure EU-wide free circulation of all vehicles. Incentives for the main alternative fuels and the corresponding vehicles should be harmonised EU-wide to prevent market distortions and to ensure economies of scale supporting rapid and broad market introduction of alternative fuels.

The main alternative fuels considered should be produced from low-carbon, and finally from carbon-free sources. Substitution of oil in transport by these main alternative fuels leads then inherently to a decarbonisation of transport if the energy system is decarbonised. Decarbonisation of transport and decarbonisation of energy should be considered as two complementary strategic lines, closely related, but decoupled and requiring different technical approaches, to be developed in a consistent manner.

The different transport modes require different options of alternative fuels:

- **Road transport** could be powered by electricity for short distances, hydrogen and methane up to medium distance, and biofuels/synthetic fuels, LNG and LPG up to long distance.
- **Railways** should be electrified wherever feasible, otherwise use biofuels.
- **Aviation** should be supplied from biomass derived kerosene.
- **Waterborne** transport could be supplied by biofuels (all vessels), hydrogen (inland waterways and small boats), LPG (short sea shipping), LNG and nuclear (maritime).

1. Introduction: Alternative fuels at the core of sustainable transport

Transport has been the sector most resilient to efforts to reduce CO_2 emissions due to its strong dependence on fossil energy sources and its steady growth, offsetting the considerable vehicle efficiency gains made. Energy efficiency, transport efficiency, and effective transport demand management, can substantially contribute to reduce emissions. But the ultimate solution to near full decarbonisation of transport is the substitution of fossil sources by CO_2-neutral alternative fuels for transport.

Oil, the main energy source for transport overall, supplying nearly 100% of road transport fuels, is currently expected to reach depletion on the 2050 perspective. Substitution of oil therefore needs to start as soon as possible and increase rapidly to compensate for declining oil production, expected to reach a peak within this decade. Climate protection and security of energy supply therefore both lead to the requirement of building up an oil-free and largely CO_2-free energy supply to transport on the time horizon of 2050.

Increased energy efficiency is not an alternative to oil substitution but a bridge to alternative fuels. More efficient use of energy in transport stretches the potential for supply from finite oil reserves, contributes to curbing greenhouse gas emissions from the combustion of fossils, and facilitates full substitution by alternative fuels, which will be production limited rather than reserve limited, as fossil resources.

Therefore, a consistent long-term strategy should aim at fully meeting the energy demand of the transport sector from sustainable and secure largely CO_2-neutral sources by 2050.

Decarbonising transport is a core theme of the EU 2020 strategy [4] and of the common transport policy. The long-term perspective for transport in Europe has been laid out in the Commission Communication on the Future of Transport of 2009 [5]. The long-term objective of the European Union on CO_2 emissions is an overall reduction of 80-95% by 2050 [3].

The next 10 years are crucial for this 2050 vision. The upcoming White Paper on the European transport policy for the next decade should outline a transport action programme until 2020. It should define the overall framework for EU action over the next ten years in the fields of transport infrastructure, internal market legislation, technology for traffic management and decarbonisation of transport through clean fuels and vehicles.

Strategic initiatives that the European Commission is considering in this context should further develop the technology part. The initiative on Clean Transport Systems, foreseen for the end of 2011, should present a consistent long-term alternative fuel strategy and possible measures to take in the short and medium term. The Strategic Transport Technology Plan, foreseen for mid 2011, should set the priorities for research and technological development of key transport technologies, with an approach similar to the Strategic Energy Technology (SET) Plan launched for the energy sector [6].

The Commission is also reviewing the TEN-T Guidelines. The TEN-T Guidelines are the general reference framework for the implementation of the European transport network and for identifying projects of common interest. They focus on roads, railways, inland waterways, airports, seaports, inland ports and traffic management systems, serving the entire EU territory. The possible future integration of new infrastructure required for alternative fuels in all transport modes has been considered by the "Expert Group on Intelligent Transport Systems and New Technologies within the framework of the TEN-T" [7].

In this context of revising existing policies and launching new strategic initiatives for more sustainable transport in the EU, the Commission established in March 2010 a stakeholder **Expert Group on Future Transport Fuels** (members in Annex 1), with the objective of providing advice to the Commission on the development of political strategies and specific actions aiming towards the substitution of fossil oil as transport fuel in the long term, and decarbonising transport, while allowing for economic growth.

The Expert Group followed up on the work of the previous Contact Group on Alternative Fuels, which published a comprehensive report in 2003 [8].

The Expert Group on Future Transport Fuels, according to its mandate, should consider the mix of future transport fuels to have the potential for:

- Full supply of the transport energy demand by 2050
- Low-carbon energy supply to transport by 2050
- Sustainable and secure energy supply to transport in the longer term, beyond 2050.

Alternative fuels are the ultimate solution to decarbonise transport, by gradually substituting the fossil energy sources, which are responsible for the CO_2 emissions of transport. Other measures, such as transport efficiency improvements and transport volume management, play an important supporting role.

Energy carriers as transport fuels should be given particular attention, as they can be produced from a wide range of primary energy sources. They allow transport to take full advantage of the expected gradual decarbonisation of the energy system, resulting from a steady increase in the share of non-CO_2 emitting energy sources. Energy carriers as fuels also ensure the security of energy supply to transport by providing diversification of energy sources and suppliers, whilst allowing for a smooth transition from fossil to renewable energy sources.

Compatibility of new fuels with current vehicle technology and energy infrastructure, or alternatively the need for disruptive system changes should be taken into account as important determining factors influencing the introduction of alternative fuels.

The Expert Group on Future Transport Fuels was allocated the following main tasks:

- Assess market potential, technological issues, economic viability, industrial implications, social and demographic aspects, environmental impacts, and safety of the different fuels considered as part of a long term oil substitution for transport fuels
- Consider factors that could affect long term viability of alternatives, including security of supply, availability of feedstock, resources required for the fuel chain
- Design scenarios towards full substitution of fossil energy sources for transport fuels
- Devise a development and field testing programme and identify needs for public support
- Recommend actions and policy measures towards full substitution of oil as transport fuel.

This report provides a summary of the contributions and the main issues discussed by the Future Transport Fuels Expert Group in 2010, with recommendations for action by the European Commission.

Chapter 2 gives an overview on the present situation of fuel supply and prospects.

Chapter 3 discusses technologies, infrastructure needs, and potential of the different alternative fuel options.

Chapter 4 describes the fuels of choice for the different modes of transport.

Chapter 5 analyses the full system of fuels – infrastructure – vehicles with regard to well-to-wheels energy, greenhouse gas, and cost balances. It also addresses life cycle aspects.

Chapter 6 sets out a long-term strategy for the full substitution of oil as energy source in transport and the full decarbonisation of transport, on the time horizon of 2050.

Chapter 7 outlines a road map to achieve the long-term objectives.

Chapter 8 summarises recommendations for actions to be taken over the present decade, 2010-2020.

Annex 1 lists the members of the Future Transport Fuels Expert Group and the acronyms and abbreviations used in the report.

Annex 2 presents specific assessments of alternative fuels.

2. Current transport fuel supply and projections

Today oil is the main energy source for transport, as shown in Figure 1.

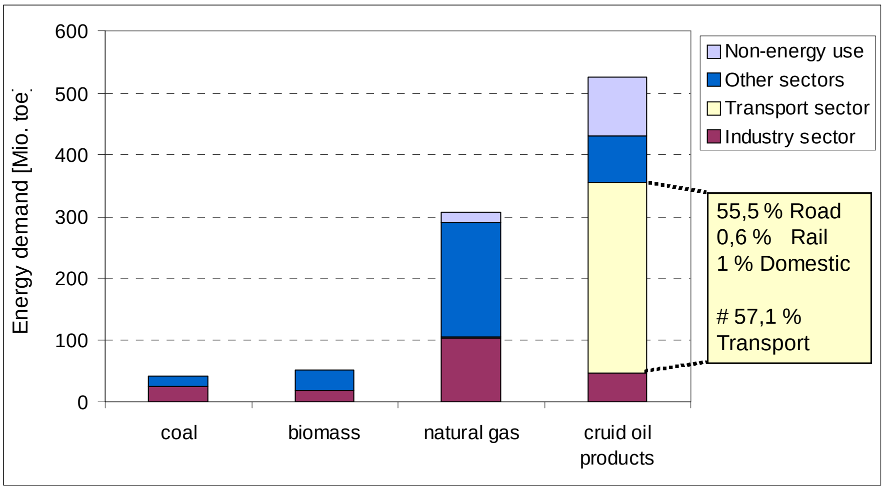

Figure 1: Share of transport in energy demand (Source: ERTRAC, built out of figures provided by IEA website (http://www.iea.org/). EU27, 2007)

More than half of the crude oil is consumed by road transport. Oil is also expected to stay the main energy source for transport in the short to medium term. Strong efforts are therefore required to substitute oil on a time scale consistent with the availability of finite oil resources.

The transport dependence on oil needs to be differentiated. The air transport sector is most dependent on oil; more than 99.9% of jet fuel is petroleum-based. For road and marine applications many possible alternatives exist, such as other fossil resources, biomass, renewable energies and nuclear power (via electricity and hydrogen production). They could all be used in the form of different types of fuel for different types of vehicles, including vehicles powered by the most common internal combustion engines, by hybrid propulsion in a combination of internal combustion engines and electric motors, fuel cells combined with an electric motor, and battery supplied electric vehicles.

Figure 2 shows the results on transport fuels of an extensive modelling IEA study for different technology scenarios including all main fossil and alternative fuel options.

For the Baseline scenario, oil derived products will provide 75% of the energy demand in 2050. For the five different alternative scenarios (representing different shares of dominant transport technologies including fossil fuels, biofuels, EVs and FCVs) the expected total contribution of oil products in 2050 stays over 50% in all cases.

The total increase of demand for oil products in 2050 is 37% above the 2005 level in the first alternative scenario and 5% above to 38% below the 2005 level in the other four alternative scenarios.

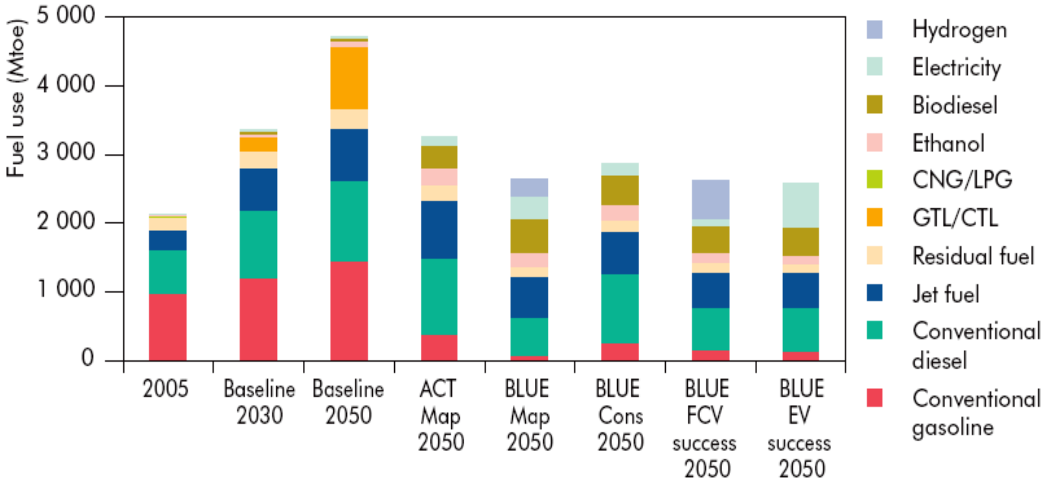

Figure 2 Transport energy use for different technology scenarios (Source: International Energy Agency. Energy Technology Perspectives 2008: Scenarios & Strategies to 2050)

Demand for road transport is expected to grow dramatically in Emerging Economies. While EU demand is not expected to increase significantly, developing countries, including population rich countries like China and India, are entering their most energy-intensive phase of economic growth as they industrialise, build infrastructure, and increase their use of transportation. These demand pressures will stimulate more efficiency in energy use and alternative supply, but these alone may not be enough to offset growing demand tensions completely.

Growth in the production of easily accessible oil will not match the projected rate of demand growth. Cost for exploration and production and environmental risks will increase with opening unconventional resources, as shown in Figure 3.

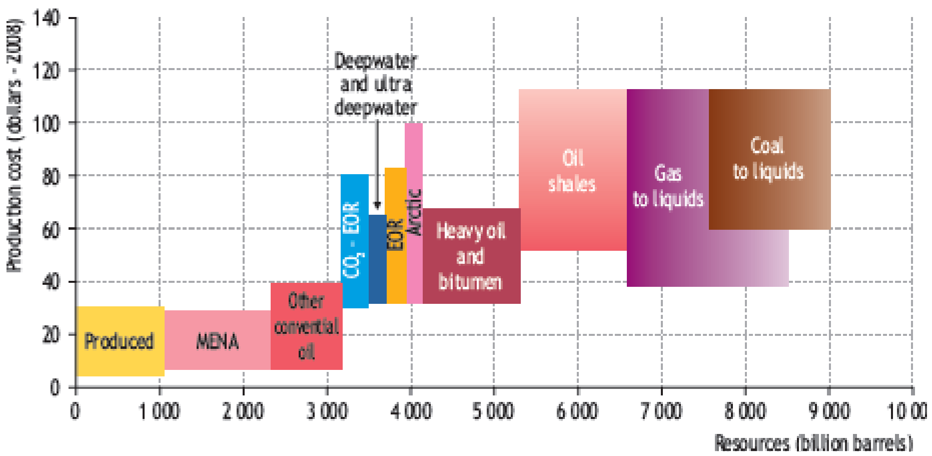

Figure 3: Cost-supply curve for oil of different sources (Source: IEA, WEO 2008, Figure 9.10)

Even if it were possible for fossil fuels, from the supply side, to increase production to maintain their current share of the energy mix and respond to rising demand, increasing pressure on CO_2 emissions would not favour this solution. But also with a moderation of fossil fuel use and effective CO_2 management, the path forward is still highly challenging. Remaining within desirable levels of CO_2 concentration in the atmosphere will become increasingly difficult.

Over the coming decades, all cost-competitive opportunities should also be deployed to moderate energy use. These opportunities could include the improvement of energy efficiency in all modes of transport, the use of intelligent transport systems to manage traffic and freight logistics, optimised air and waterway traffic, improved vehicle efficiency, spatial planning, driver behaviour assisted by vehicle guidance, and similar measures.

3. Alternative fuel options

Energy supply for transport could take a large number of different pathways as shown in Figure 4. Competing sectors on the same primary energy sources, such as industry and households, are also shown in Figure 4. The assessment of future transport energy needs and potential supplies therefore has to be embedded into a more general consideration of total energy consumption and total global potentials.

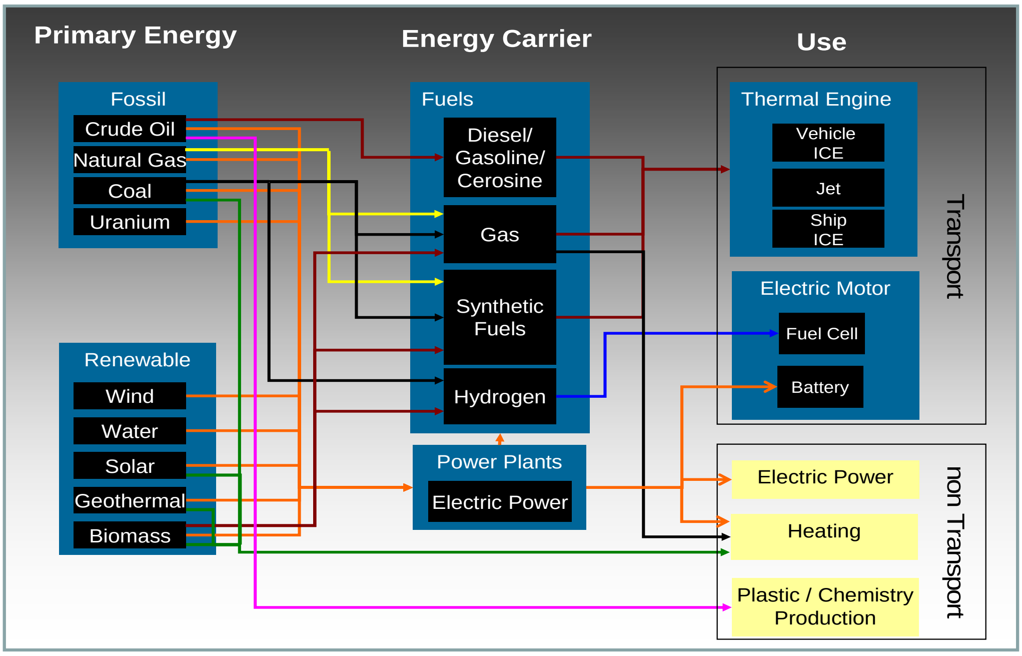

Figure 4: Energy pathways in transport and other sectors (Source: ERTRAC)

Alternative fuels such as electricity, hydrogen, biofuels, synthetic fuels, methane or LPG will gradually become a much more significant part of the energy mix. No single substitution candidate, however, is seen. Fuel demand and greenhouse gas challenges will most likely require the use of a great variety of primary energies. There is rather broad agreement that all sustainable fuels will be needed to resolve the expected supply-demand tensions.

Technical and economic viability, efficient use of primary energy sources and market acceptance, however, will be decisive for a competitive acquisition of market shares by the different fuels and vehicle technologies. Any new fuels should demonstrate their availability, affordability and reliability. Compatibility with existing fuels and vehicle technologies would facilitate a smooth market transition and optimise the total system cost and customer acceptance.

Political and regulatory support will be decisive in the first phase to support the development and market entry of alternative fuels able to respond to the decarbonisation objectives.

Liquid hydrocarbon fuels are expected to remain predominant over the next decades. But the use of electricity, hydrogen, biofuels, synthetic fuels, methane and LPG will steadily increase.

During the transition period to 2050, it will also be important to actively manage the change in demand from traditional refineries and to channel fossil fuel products to those transport modes and petrochemical production having the greatest needs. Research will be needed to develop plants and process technologies to utilise biomass for applications that have traditionally been supplied by fossil fuel refineries.

3.1 Electricity

Electricity as a transport fuel could:

- decrease the EU's oil dependence, as electricity is a widely-available energy vector that is produced all over the EU from several primary energy carriers;
- improve energy efficiency through the higher efficiency of an electric drive train;
- decrease the CO_2 emissions of the transport sector along with the expected continuing increase in the share of renewable energy sources in the EU power generation mix, supported by emission capping through the EU Emissions Trading Scheme.
- provide for innovative vehicle solutions requiring less resources and allowing better vehicle utility optimisation.

Electricity as power source for vehicle propulsion allows a radical change in energy supply to transport, from a single energy source, such as oil, to a universal energy carrier, which can be produced from all primary energy sources.

Electricity as fuel also changes the core of a transport carrier, the propulsion technology. It requires power trains and fuel infrastructure completely different from those for liquid fuel powered internal combustion engine vehicles.

In 2005, 14% (460TWh) of the EU Gross Electricity Generation (3,300 TWh) came from renewable energy sources. It is estimated that 35 to 40% of the total electricity (3,200-3,500 TWh) has to come from renewable energy sources in 2020 to meet the so-called "20-20-20" target [9].

With the share of renewables rising in electricity production, battery driven technologies together with smart grids could also help to balance the intermittent supply of wind and solar power working as storage facilities, in the longer-term, with sufficient vehicles in the market. The logistic issues for vehicle charging management will be a key issue for the power system optimisation and the CO_2 emission reduction expected from EV deployment. Smart charging aiming at the integration of renewable electricity can help maximising the CO_2 reductions achievable with the deployment of electric vehicles.

Local emission of pollutants from transport is completely suppressed when using electricity for propulsion. Electrical vehicles therefore are ideally suited for densely populated urban areas, which still have difficulties to meet air quality obligations.

Electricity for propulsion of a transport carrier can be supplied externally, with or without intermediate storage on board, or produced on board.

External electricity supply is most common for railways in all forms (tram, metro, passenger train, freight train). In road transport, electricity supply by wire has been used for a long time on trolley buses.

Intermediate storage of electricity in externally chargeable batteries on board road transport vehicles has been the dominant technology in the second half of 19th century. Performance of these vehicles, however, was restricted by the low energy density of batteries. Electric road vehicles were then outperformed in the market in the beginning of the 20th century by internal combustion engine vehicles using high energy density, cheap and plentiful liquid fuels. Novel battery technologies give electric road vehicles a new chance today. The autonomy/range of electric vehicles, however, is still strongly limited with today's technology. Present high battery cost is another important hurdle to broad market penetration. However, large efforts and investments are being made to improve the performance and reduce costs for future electric vehicles.

On-board generation of electricity for propulsion has been applied in ships powered by diesel and electro motors. Following this principle, so-called range-extender models have recently been developed for Battery Electric Vehicles to increase their driving range. These vehicles are equipped with two engines. Electricity is generated on board by an internal combustion engine (ICE) burning liquid fuels. Plug-in to the grid allows also external electricity supply. An electric motor is used for propulsion.

Another approach, long under development, is the use of a fuel cell as energy converter, which produces electricity as output from the chemical reaction of hydrogen and oxygen recombining to water. The electricity then drives directly an electric motor, or is stored in a battery.

Electric propulsion of road vehicles is used in different configurations:

- Hybrid Electric Vehicle (HEV), using a combination of an ICE and an electric motor. The battery is charged from braking energy recuperation. The external energy input comes only through the fuel for the internal combustion engine.

- Plug-in Hybrid Electric Vehicle (PHEV), using the same power train as a HEV, but with the additional option of charging the battery also by plugging to the electricity grid.

- Range-extender vehicle (REV), representing another type of HEV, with propulsion from an electric motor, and charging of the battery by plug-in to the electricity grid or by petrol fuelled ICE. When the battery is depleted, a small ICE working as generator provides the electricity for propulsion and for sustaining the battery state of charge.

- Battery Electric Vehicle (BEV), with electric propulsion only, and external energy input only through charging of the battery from the electricity grid.

- Hydrogen/Fuel Cell Vehicle (HFCV), with electric propulsion only, and external energy input through refilling an on-board hydrogen tank.

- On-board reformer, where the car is fuelled with either bioethanol or biomethanol and the reformer converts the biofuel to hydrogen. This may provide extended operational range.

- Trolleybuses with overhead wires.

Hybrid configurations without the external charging possibilities do not contribute to oil substitution. They can, however, save oil and reduce CO_2 emissions by improving the overall energy efficiency of a vehicle.

Only configurations with additional external energy input in form of electricity (PHEV, Plug-in REV, and BEV) or hydrogen (HFCV) offer routes to oil substitution and full decarbonisation. Battery-and fuel cell driven technologies currently seem to be a mid-term or long-term solution for sustainable mobility. The bottleneck is the development of efficient batteries and fuel cells available at affordable prices, which will depend on mass production and economies of scale.

As long as batteries alone can not meet the customers' expectations for range, reliability and price, hybrid solutions, including range extenders, could be adequate bridging technologies from ICE to battery driven power trains.

Many key elements, such as batteries, motors, and power electronics, are similar for all types of electric road vehicles. Fundamentally different, however, are fuel infrastructure and energy converters for the different approaches.

The two main classes, battery electric vehicles, and hydrogen/fuel cell powered vehicles, are therefore discussed in two separate chapters.

3.1.1 Battery electric vehicles

Technology

Electric motors replacing internal combustion engines can considerably improve the energy efficiency of light-duty road transport vehicles, by a factor of about 3. The improvement for heavy-duty vehicles is closer to a factor 2, compared to a diesel ICE drive train.

Electric motors are standard industrial products in all sizes required for road vehicles. Batteries, on the other hand, are the main issue for a broad market introduction of electric vehicles due to their low energy density and high cost.

The energy density in vehicle batteries of the latest technology (Lithium-ion) is about a factor 50 lower than in conventional liquid fuels. Even with a factor 3 higher energy efficiency, still a factor 15 larger weight would be required for onboard storage of the electric energy required to meet the same range with an electric vehicle as with an internal combustion engine vehicle.

High cost and punitive payload constrain the maximum amount of energy storage and thereby the vehicle range. The electricity charge-out capacity of a battery has also to be limited to ensure durability. Electric on-board ancillaries, such as air-conditioning further limit the effective driving range. Battery cars therefore are presently suited mostly for short distance (urban) deployment.

However, adding a small combustion engine as electricity generator or a fuel cell to the electric drive train of a pure battery electric vehicle (range extender), offers the potential to overcome the range limitations of pure battery electric vehicles and therefore could be a perfect bridging strategy towards future electro mobility

Infrastructure

A great advantage of **electric vehicles**, compared to other alternative transportation technologies, is that a large part of the infrastructure, i.e. the electricity grid already exists. Initially only the last bits of infrastructure, i.e. the charging stations remain to be developed. In this way, the infrastructure hurdles to the further spreading of electric vehicles are relatively small, notably if we assume availability of home/office charging. However in urban areas with limited parking lots this might be a challenge.

However in order to exploit the maximum of the benefits of electric vehicles, the electricity grid will need to be reinforced in the long run. Hence it is indispensable to create and set an encouraging climate to develop electric vehicle infrastructure. Finding business models that foster these infrastructure developments is essential.

The existing electricity supply systems are still dominated by large, controllable generators connected to an inelastic demand side by transmission and distribution networks. However, future electricity networks will be required to connect generators of many different technologies and sizes, at all voltage levels, some of them highly controllable and others with their output dependent on the instantaneous physical availability of their primary energy resource. Further, patterns on the electricity demand side may change as well. Therefore the control and the management of the charging pattern (i.e. demand side management) of the electric vehicles will be essential to streamline the demand for electricity with the supply of electricity.

Hence a mass market of electric vehicles will require an intelligent connection between the electric vehicle and the electricity grid. In this context, the roll-out of electric vehicles on a large scale will have to be accompanied by a targeted or national roll out of "*smart*" electricity metering systems (depending on the economic evaluation foreseen) and the development of a "*smart*" electricity grid.

In essence the "*Smart grid"* will be rather similar to today's conventional grid, including a feature that will enable communication flows within the electricity network which will allow the intelligent control of generation and demand as well as the configuration of the network and recovery after faults.

These technological developments will require significant investments, and to become commercial viable for volume deployment, standards will need to be set.

Regarding electric vehicle infrastructure, a standardized grid-vehicle connection is necessary. A common hardware solution between socket, connector and charging point should ensure consumer convenience, enabling the electric vehicle user to plug its car to electricity supply at any place in Europe. It is important to standardise the technology, as this would provide a secure investment climate and remove market hurdles.

This will also support the automobile manufacturers with a future oriented hardware solution. There is also a need for communication software standards based on standardised metering protocols for communication between the vehicle and the grid.

Potential

Electricity as an energy carrier can be produced from all primary energy sources. Supply potential therefore is not an issue of availability of primary energy sources but of production capacity from power generation plants, and of power distribution infrastructure, with renewables also increasingly more an issue of energy storage capacity.

The annual energy consumption of a mid-size electric vehicle is of order 3 MWh (assuming 15,000 km/year and an energy consumption of 20 kWh/100 km). The consumption of 1 million electric vehicles is then of order 3 TWh/year, corresponding to 0.1 % of present total annual EU electricity production (3362 TWh in 2007 [10]). The sum of the different national and regional targets set out today would result in about 5 million electric vehicles in the EU by 2020, with a total electricity consumption of about 0.5 % of present EU electricity production.

Expectations on the market share and ramp-up of the sales of electric vehicles vary widely, in the range of 3 to 10% by 2020 to 2025, and higher beyond. Based on today's new vehicle sales of about 15 million vehicles in the EU-27 in 2009 (passenger cars and commercial vehicles), this would result in new registrations of electrically chargeable vehicles of 450,000 to 1,500,000 units by 2020 to 2025.

The energy needs for electric vehicles, with these prospects, can be covered by the existing electricity generation system for a long time of market build-up. No new generating capacity is therefore required for the electric vehicle fleet expected on the road for the next 15-20 years.

Charging periods of batteries, however, may need to be controlled in order to prevent excessive power demand and destabilising fluctuations on the grid. The build-up of a smart grid and of smart metering systems should provide the tools for that.

Reductions of CO_2 emissions of order 30% are obtained when replacing an internal combustion engine vehicle by an electric vehicle (powered by the overall EU electricity mix). The total saving from 1 million electric cars would then amount to about 1 Mt CO_2 /year. A projected 5 million electric vehicles in the EU by 2020 (total sum of presently formulated national and regional targets) could then provide a saving of 5 Mt CO_2 /year (total CO_2 emissions from road transport in the EU stands at 920 Mt CO_2 /year at present).

The market penetration will depend on the developments of battery and vehicle technology, infrastructure availability, cost, market incentive systems, and customer acceptance.

Limitations to the ultimate number of electric vehicles by limited raw material reserves have been discussed. Lithium has been considered particularly critical, as it is the key material for the type of batteries presently favoured. But also other materials used in motors and magnets, such as the rare earth metals neodymium, dysprosium, and others might imply limits to growth. Known reserves of all key materials, however, would be largely sufficient to build up a significant market share of electric vehicles and probably cover the whole market segment accessible for electric vehicles, with present day technology. Recycling can then preserve the industrialised stock in circulation. Future technological developments will also most likely shift to other materials, whilst optimising product performance in a mature stage of market penetration, as it has happened with all innovative technologies.

Security of supply of rare raw materials, however, may be of concern if only few suppliers dominate the market [11]. Particular attention is therefore required that with a technology change, insecurity on energy supply is not exchanged for insecurity in raw material supply.

3.1.2 Hydrogen

Hydrogen is a universal energy carrier, like electricity, which can be used as fuel for transport. Hydrogen can be produced from all primary resources and therefore offers diversity of supply of energy.

It is supposed that Hydrogen could be produced cost-effectively on both small and large scale from centralised and decentralised production. It is currently used to supply energy to a wide variety of industrial applications.

The use of hydrogen in a fuel cell with an electric motor is an alternative and a complementary solution to the storage of electricity in batteries for EV or hybrids. It provides longer range and faster recharging compared to the storage of electricity in batteries for EV. In the long term, it may be also possible to use hydrogen to fuel internal combustion engines, either directly or blended with natural gas (up to 30%).

Technology

Hydrogen is combined with oxygen in a fuel cell on board a vehicle. The resulting electro-chemical reaction produces electricity and heat and water vapour as exhaust gas – in a process inverse to the electrolysis of water. The energy, which first had to be invested to produce hydrogen, is recovered in this recombination process. Energy losses, however, occur in the several energy conversion processes, from the primary energy source to the final electricity production on board a vehicle, and its use for propulsion through an electric motor. Nevertheless the energy efficiency of the final stage on board a vehicle can be at least a factor 2 higher than with thermal internal combustion engines, as shown in the European HyFLEET:CUTE hydrogen bus project [12].

HFCVs have similar performance as ICE vehicles and hybrid solutions in terms of range, speed, refuelling time and size of the car.

The technology is ready for market entry: To date over 400 HFCVs, ranging from the small A-segment to the large J-class segment (SUV), have driven more than 15 million km with over 80.000 fuelling procedures. All technological hurdles have been resolved (heat management, efficiency, storage, platinum size…), and a study [13] shows that further production could reduce the cost of fuel cells by 90% by 2020, by innovations in design, different use of materials (e.g. reduced platinum use), further innovations in production technology and economies of scale.

Infrastructure

Hydrogen as an alternative fuel for transport needs building up the necessary refuelling infrastructure, in order to reach a sufficient geographical coverage to accompany vehicles' market entry. The storage and distribution part of the infrastructure can, for the market introduction phase, build on existing facilities for large scale industrial use of hydrogen.

Infrastructure build-up for hydrogen and a comparison to the needs for battery electric vehicles (BEVs) has been assessed in the recent hydrogen study [13]. Costs for electrical and hydrogen infrastructure are comparable and affordable. It may not be wise to pick one or the other since they both are complementary. Battery cars are more suited for the small size segment and shorter range, whereas fuel cell cars can serve larger cars and longer range.

Due to its modular nature, electric infrastructure is easier to build up in the beginning. However, infrastructure costs for HFCVs are expected to be less than those for BEVs in a later phase, after 2020. In a first hydrogen market build-up phase, €3-5 billion would need to be invested annually in infrastructure until 2020, based on an estimated number of one million HFCVs. The investment should be concentrated in areas of high population density (large cities) and should build on existing infrastructure.

Additional cars decrease the infrastructure cost per unit. In a mature market phase, an annual investment of €2.5 billion per year (70 million cars) is estimated to be needed for HFCVs, compared to some €13 billion per year required for BEVs (200 million cars) until 2050.

Up to 2020 the focus should be on reducing the technological risk and building up an initial network and fleet. An economic gap of about €25 billion would need to be overcome by leveraging financial support and close coordination at EU, national and regional level.

Between 2020 and 2030 the first steps are taken and the commercialisation can firm up. The investment risks decrease as the fleet increases and the technology further tested. The learning rate will go down. The cost for this initial build up is estimated at about €75 billion. Whilst a supportive funding mechanism may still be required, investment risks should become acceptable for private investors. After 2030, to achieve 25% market share in 2050, €100 billion would be needed for extra production, distribution and retail infrastructure. This amount can be absorbed in the cost-price of new cars and a real competitive market with minimal public support can take off.

In terms of geographical coverage, territorial spread is key and a gradual and coordinated build up of infrastructure across Europe would be needed.

A reasonable approach is to start in one or several geographical areas in order to de-risk the technology then develop a roll out plan for Europe.

One should combine national and European longer term interests and allow smaller scale demonstration and deployment projects to de-risk the technology and absorb the learning costs, reducing these for subsequent roll-out projects. In this way private and public stakeholders can together build up a European infrastructure network in a cost efficient way.

In the past, Europe has built a number of times parallel fuel infrastructures, such as the full size area covering distribution systems for several quality grades of gasoline and diesel, and in a smaller scale also for LPG and methane.

Potential

The Hydrogen Fuel Cell Vehicle has the greatest potential in the medium to larger car-segment including buses that drive a longer range. This segment represents more than 70% of the current car fleet.

For hydrogen, as an energy carrier like electricity, the same arguments as for electricity hold with regards to the potential of primary supply, production and distribution capacities.

Hydrogen has been produced for industrial applications in large quantities for about a century. At global level, oil refining is the most hydrogen-intensive sector (51%), due to fossil fuel quality requirements followed by the manufacture of ammonia (34%), and the production of other specialty chemicals (14%). The energy sector is a growing area of importance. Fuel cells are used in back-up power systems (e.g. in manufacturing and telecoms industry) and could play an important role as a storage mechanism for excess wind power and for balancing the electricity grids in case of intermittence issues. Furthermore fuel cells and hydrogen are already commercially available in Combined Heat and Power (CHP) applications in industry, as well as in mobile applications.

In transport, hydrogen as a fuel is already commercially used in early markets like the logistics industry (e.g. forklifts). Areas of development are the urban public transport sector (buses, taxis), for which large scale demonstration projects have been under way uninterrupted since 2003 to further develop the technology for commercial deployment.

Steam reforming of natural gas is the technology most commonly used today to produce large quantities of hydrogen at low cost. The conversion of biomass to produce hydrogen offers a route to renewables in future. The development of this process to industrial maturity will benefit from the current programme to scale up production of biofuels using gasification (see section 3.2). The preferred pathway for producing hydrogen from non-fossil sources is the electrolysis of water. Cost, however, is high with present technology, and efficiency mediocre. With increasing use of fluctuating renewable energy sources, hydrogen is more and more also seen as a possible option for high capacity long-term (seasonal) energy storage. High-temperature thermo-chemical production of hydrogen, with solar or nuclear energy input could be another option for sustainable hydrogen production at zero-CO_2 emission.

Resources for hydrogen production are not a limitation, as long as all primary energy sources could be used. Resource constraints on the total amount of energy available, however, require efforts on energy efficiency for a hydrogen economy, as for all energy consumers. Cost of hydrogen production also needs to be reduced. Depending on the process, production costs of hydrogen are expected to be reduced by 30% to 50% over the next 40 years, together with an increasing diversification of the energy resource mix for production. Electricity, one of the main resources for hydrogen production, will increasingly come from renewable and low-carbon technologies thus giving hydrogen a perspective as low-CO_2 alternative fuel, contributing to decarbonising transport.

Electric vehicles have the advantage of zero emissions of pollutants and of CO_2 locally. However, their overall carbon footprint depends on the technologies and sources used to produce electricity and hydrogen. Using existing production technologies for electricity or hydrogen, the CO2 emissions could already be reduced by at least 30%. In order to fully decarbonise hydrogen production in the long term, both the development of CO2 capture and storage and increase of renewable electricity production are needed.

Major OEMs worldwide are envisaging in their company strategies to introduce commercially fuel cell powered vehicles around 2015, scaling up to mass-production volumes by 2020 [13]. Cost reduction, however, would be necessary to ensure a broad market take up.

The fuel cell car technology is ready for market roll-out by 2020-2025. Actual deployment, however, is interrelated to the existence of an adequate retail fuelling network.

Fuel cell cars are comparable to conventional cars in terms of use with respect to range, speed or refuelling patterns.

Optimisation of fuel cell components and manufacturing processes in research, technological development and demonstration programmes have priority over the coming years.

3.1.3 Electricity from the grid

Technology

There is long technological and operational experience with vehicles fed directly from the grid via over-head line or third rail technology. Current technological research and development aims at improving the already high energy efficiency of electric traction and auxiliaries.

Infrastructure

Technological and operational experience with transport infrastructure providing energy via over-head line or third rail in different power classes for urban and long distance traffic has been refined over decades of development and application. There are no technical obstacles to future expansion, only political and financial ones.

Potential

Shifting traffic onto electrified direct-fed transport infrastructure could lead to substantial and near-zero substitution of oil products. Infrastructure spatial planning in line with active management of transport demand, as outlined by the 2010 report for the Commission "EU Transport GHG: Routes to 2050?" could significantly support decarbonisation of transport.

3.2 Biofuels (liquid)

Technology

Biofuels can be produced from a wide range of biomass feedstock. Liquid biofuels technically can be used for propulsion in all transport modes and can be used with existing power train technologies, for certain biofuels with minor technical modifications, and existing re-fuelling infrastructures in various blending ratios depending on biofuel types. Biofuels are also the primary route for the decarbonisation of synthetic fuels, methane and LPG.

Biomass can be processed to biofuels on several conversion paths. Figure 5 illustrates the different biomass conversion pathways.

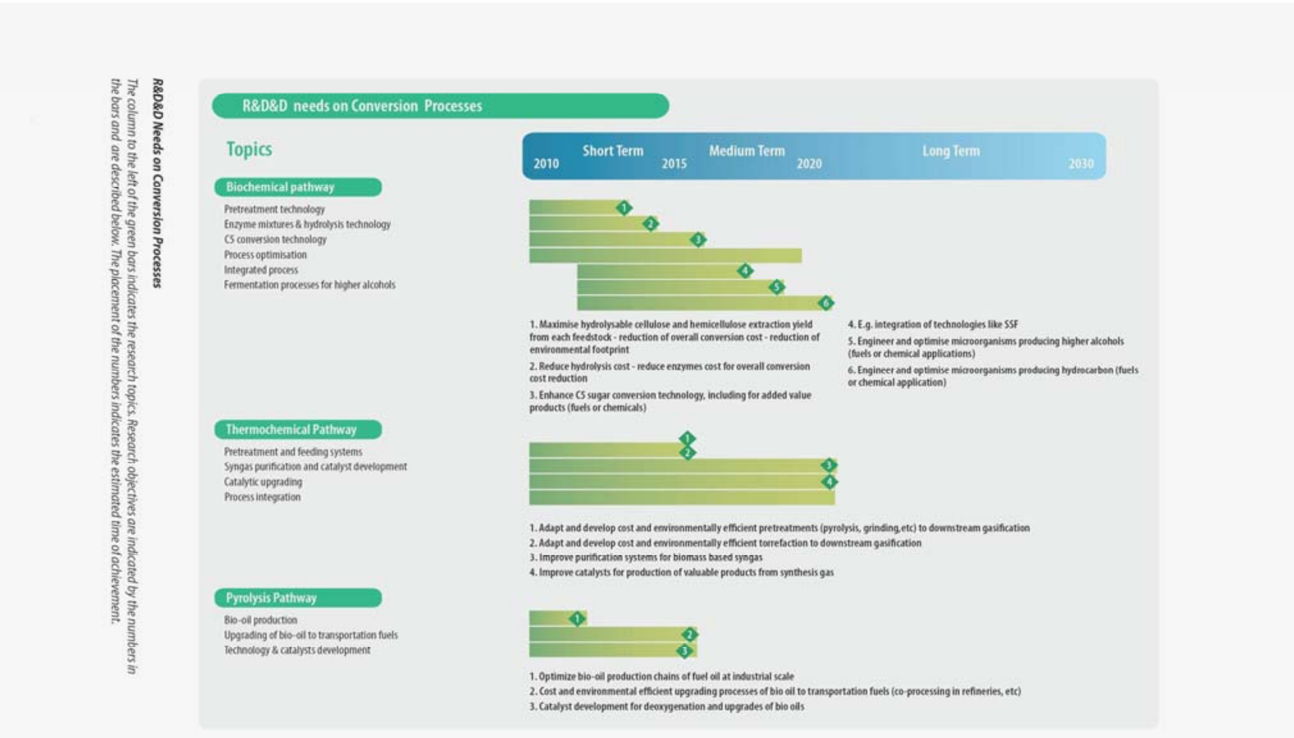

Figure 5: Biomass RD&D needs on Conversion Processes. (Source: Biofuels Platform SRA 2010. http://www.biofuelstp.eu/srasdd/SRA_2010_update_web.pdf)

Currently dominant commercial biofuels are on the market with two principal pathways:

- Bioethanol as a blending component in petrol and in the form of ETBE (Ethyl *tert*-butyl ether), made from sugar-producing plants, such as sugar cane and sugar beets, or starch-producing plants like wheat and corn, and used in gasoline engines.
- Biodiesel (esters, FAME) as a blending component in diesel, made from vegetable or animal oils in the chemical form of fatty acid methyl esters and used in diesel engines.

During the last decade also non-esterified pure vegetable oil has been in use to a limited extent, especially based on rapeseed oil. Contrary to biodiesel due to specific physical and biochemical properties, the use of pure vegetable oil requires some adaptations of the diesel engines.

Advanced conversion paths based on thermo-chemical processes:

- Bioethanol and higher alcohols from biomass via gasification.

- Hydrotreated vegetable and animal oils (HVO) produced by oil refining type catalysts and processes that can be stand alone units or co-processing of bio and fossil feed in an oil refinery. Paraffinic diesel fuels and minor amounts of bio-gasoline are commercial HVO products. Aviation jet fuel (HRJ) and bio-LPG can be produced, too.

- Synthetic fuels / hydrocarbons from biomass via gasification (BTL, main markets: renewable transportation fuels for diesel and aviation engines).

- Bio-methane and other gaseous fuels from biomass via gasification (substituting natural gas and other gaseous fuels), which could also be liquefied.

- Bio-energy carriers from biomass via other thermo-chemical processes like pyrolysis, torrefaction etc. (main markets: fuels for heating, power generation or intermediate for further upgrading into transportation fuels.)

Advanced conversion paths based on biological and chemical processes:

- Ethanol and higher alcohols from ligno-cellulosic biomass (main market: fuels as gasoline substitutes)

- Renewable hydrocarbons from sugars containing biomass via biological and/or chemical process (main markets: fuels for jet and diesel engines)

- Bio-energy carriers from CO_2 & sunlight through micro-organism based production (algae, bacteria etc.) and further upgrading to transportation fuels and valuable bio-products (main market: fuels for jet and diesel engines)

In the HVO process, vegetable oils and animal fats are treated with hydrogen and isomerisated. The HVO process yields paraffinic hydrocarbons with excellent combustion properties and good storage stability.

Extensive research programs are being developed to explore both the thermo-chemical and bio-chemical conversion of ligno-cellulosic biomass and wastes to biofuels:

– In the thermo-chemical route, ligno-cellulosic biomass and solid waste go through a series of common steps including preliminary processing, gasification and purification to give synthesis gas (a mixture of hydrogen and carbon monoxide). The synthesis gas is then processed using different catalyst systems to give ethanol, higher alcohols, methanol, hydrocarbons/middle distillates, methane, ammonia or hydrogen.

– In the biochemical route, ethanol or higher alcohols (e.g. butanol) are produced by hydrolysis of cellulose and hemi-cellulose followed by fermentation of resulting sugars.

Around both route~~s~~ the general concept of a bio-refinery including chemicals production is to be considered.

In the long term, other options could be considered, such as marine biomass (algae) to produce biofuels for transportation activities. At present, researchers are concentrating on producing biodiesel or jet fuel from microalgae oils. The main issues are cost, energy consumption, and yield.

New routes based on biotechnology (genomic research) are under research in order to indentify enzymes and modified yeast for producing directly hydrocarbons (or hydrogen) from various sources (e.g. saccharides).

Major advantages of liquid biofuels are:

- high energy density, especially in the case of synthetic / paraffinic fuels (HVO, BTL)

- compatibility with existing ICE vehicles and fuels, subject to appropriate quality standards for the biofuel and the final biofuel blend

- distribution via the existing refuelling infrastructure system, subject to the type of biofuel and the final biofuel blend

The maximum blending ratio may be limited for vehicles in operation. For new vehicles, upgrading to higher biofuel ratios is possible, given enough lead time for adaptive development. Some synthetic/paraffinic BTL fuels have no "blending walls" since they can be used neat with current vehicle technologies. They may also provide possibilities for increasing engine efficiency. Their properties are similar to other current synthetic fuels (GTL). HVO is already used commercially in 10-30 volume % blending ratios in diesel fuel and neat by large test fleets. There is no need for disruptive technology changes in the area of engine design for higher blending ratios of such biofuels.

Blending ratios above those presently mandated by the Fuel Quality Directive may require some adaptations to existing engine/vehicle designs. The blending of advanced biofuels (i.e. those produced from residues, wastes etc) could overcome some of these difficulties as would the use of bio-ETBE.

The production of first and second generation biofuels from both traditional crops and ligno-cellulosic crops requires efficient land use, and compliance with strict sustainability criteria is important. All biofuels that are used in the EU to fulfil its climate and energy targets need to comply with the sustainability criteria as laid down in Directives 28/2009/EC and 30/2009/EC. Research into liquid and gaseous biofuels is still needed to reduce the carbon footprint and increase the efficiency of land use. Non-food feedstock (such as algae, jatropha,) and waste biomass are alternatives. Furthermore, the problem of high production costs of advanced biofuels needs to be tackled.

Infrastructure

Blending biofuels with fossil fuels not exceeding the limits specified by the Fuel Quality Directive (10% ethanol in E10, and 7% biodiesel in B7) has the advantage that neither new engines nor new infrastructure are necessary. Increasing ethanol and biodiesel content in the blends may require some adaptations to certain exhaust treatment designs. This would not apply to HVO and BTL.

Potential

The potential of biofuel production from both traditional crops and energy crops is determined by the area of land, which can be made available, the yield of that land, and the use of biomass and co-products in other sectors. The production of second generation biofuels from wastes and residues is limited by the availability of these materials.

Sustainability considerations, including life cycle aspects constrain the technical potential in all cases.

The extent of the greenhouse gas emissions saving with biofuels depends on the biofuel pathway. According to Directives 2009/28/EC and 2009/30/EC, the CO_2 saved from the use of biofuels must be at least 35% of that produced from using fossil fuels. However, this does not include the impact of indirect land use change, which has to be addressed according to the legislative mandates in the Directives.

Biofuels are expected to provide the main contribution for achieving the targets of 10% renewable energy use and 6% greenhouse gas reductions in transport sector by 2020, as mandated by the Renewable Energy and Fuel Quality Directives.

Pure vegetable oil use as diesel engine fuel can be ecologically and economically beneficial. The production involves few process steps and is economically possible with small units. The production process requires only low energy input, because no thermal or chemical process steps are involved. It can be implemented in decentralised small units. The non-toxicity and the low flammability are advantages from a logistics point of view. Possible impacts on exhaust emissions and exhaust after-treatment systems, however, need to be considered.

Increase of first generation bioethanol production is readily available, within the constraints set by the sustainability criteria of the Renewable Energy and Fuel Quality Directives. This should be supplemented increasingly by second generation bioethanol from waste, residues or lignocellulosic non-food crops. The product will be identical to current bioethanol production and will not require any further changes to bioethanol supply or vehicle infrastructure.

First generation bioethanol production in the EU could increase to about 25 Mtoe by 2020, 50 Mtoe by 2030 and 100 Mtoe by 2050 according to biofuel industry estimations [14]. The majority would come from cereals and sugar beet.

The transition to fuels blended with 5% bioethanol has already been made in some EU Member States. This can contribute to the decarbonisation of transport. An assessment of the possible gains should, however, also include life cycle aspects such as emissions from land use change related to the production of biofuels, and similarly for all other fuels.

A transition to a 10% bioethanol blend has been made in France and Spain, and more Member States of the EU will follow in 2011. This could enable a doubling of the decarbonisation potential.

Further transitions to 20% and increased use of 85% bioethanol blends could enable even larger decarbonisation of most of the spark ignition driven light duty vehicle fleet. The impact of such high blending ratios on engine performance and possible adaptation measures, however, need to remain cost-competitive with other biofuel pathways.

The use of E85 in a flex fuel vehicle offers some specific environmental and technological benefits, compared to a gasoline vehicle [15]:

- Carbon monoxide emissions are 20% lower and NO_x emissions 18% lower

- Benzene emissions are 70% lower and butadiene emissions 62% lower

- Particulate emissions are 34% lower

- Energy efficiency with high ethanol blends can be improved by using a higher compression ratio engine.

Market developments of biofuels also should take into account the existing and still growing preponderance of diesel over gasoline in the European fuel market, with a split of 65% diesel and 35% gasoline. The resulting strong imbalance of refinery output and market demand in Europe presently is compensated by exporting large amounts of gasoline from Europe, and importing the missing quantities of diesel into Europe. Additional production of gasoline equivalent bioethanol products in Europe exacerbates this imbalance in the fuel market. This imbalance may be reduced by equalising the excise duty on petrol and diesel fuels and by modifications to refineries to increase the diesel/petrol production ratio.

In future, new feedstock (ligno-cellulosic resources from dedicated energy crops to residues/waste) and new products should become available, offering the possibility of increasing biomass use in the transport sector. A potential of 290 Mtoe/year of biofuel from energy crops, ligno-cellulosic resources and waste in Europe by 2030 is identified in the European Environment Agency report No.7 (2006).

The industrial viability and environmental impacts of producing biofuels from ligno-cellulosic biomass has yet to be demonstrated. Taking this process to industrial scale would raise a number of questions pertaining to the optimization of each step (preliminary processing, hydrolysis and fermentation, or gasification, purification and synthesis gas conversion), especially from the economic point of view. A dozen of pilot and demonstration units are now operating in the US, and six pilot projects have been announced in Europe. Most of these plants are to demonstrate the biochemical route to bioethanol, but plants are also being built to demonstrate production of bioethanol and hydrocarbons from gasification

First generation bioethanol from sugar and starch crops is economically viable at present only within current MS incentive schemes. Future technology developments, however, are expected to reduce costs and improve the market prospects... Second generation processes to produce biofuels are under development along several technology routes, but still more costly.

<u>Biodiesel</u> could come from significant EU potential of feedstock and land available for oilseed crops production. According to present forecasts for EU diesel demand by 2020, a 10% share in total diesel consumption would represent the production of at least 20 Mtoe of biodiesel (probably FAME type). This production could theoretically be obtained from about 4% of the total EU agricultural area.

In volume terms, more biodiesel (8.2 Mtoe in 2008) is consumed in Europe than bioethanol (2.2 Mtoe), which is different with regard to the world's major biofuel consumers, the US and Brazil, where the domination of spark ignition engine cars supports a larger share of bioethanol substituting gasoline.

HVO capacity will be 2 Mtoe in 2011. Currently the feedstock is the same as for FAME. Somewhat larger volumes, however, are available for HVO since the HVO process yields good final products (stability, cold properties) from a wide range of vegetable oils and animal fats. Volume potentials of non-food vegetable oils and algae oils are promising and can be a sustainable source of high volumes already by early 2020s. It has been estimated that the HVO process is more suitable for algae oils than the esterification process.

With rapidly growing supply of algal oil, or similar feedstock supply, HVO could provide a significant share in transport fuels by 2030, with production of order 25 Mtoe/y, and of order 60 Mtoe/y by 2050. In addition, the use of agricultural by-products and wastes for microbial processes can also add considerably to the total feedstock potential. The fully fungible HVO properties also allow the use of high concentration or pure biofuel without compromising increasingly stringent fuel specifications and tailpipe emission limits, both in diesel and aviation jet engines.

BTL can be produced from a wide range of biomass feedstock by applying the same advanced synthesis processes developed for GTL. Plants are being scaled up to commercial scale in concept designs.

The BTL pathway relies on the indirect thermo-chemical conversion of biomass to produce synthetic fuels (through a Fischer-Tropsch process or equivalent), which is also true of the technologies based on DME (dimethyl ether), methanol, syngas or ethanol obtained using gasification. BTL technology enables the conversion of renewable feedstocks into high-quality synthetic hydrocarbon transport fuels that are fully fungible with today’s liquid fuel infrastructure.

Reducing investment cost is critical, as current plants are challenged by relatively high capital costs. This can be achieved by optimizing the collection, preliminary processing and gasification of biomass, as well as the purification of synthesis gas.

BTL demonstration plants, however, are still awaiting start up, and reliable data on costs is currently unavailable.

Biofuel resource potential

To increase biofuel production overall, future developments should focus on maximising biomass output, while limiting any negative environmental impact of its production. Production of food and biofuel may take place also hand-in-hand since many plants produce material for food and biofuel at the same time.

The relation between biofuel supply potential and cost has been assessed for EU-27 plus Ukraine in the EU-funded project REFUEL (supported by the EU programme *Intelligent Energy Europe*), on the time horizon 2030 [16].

According to the results of this study, 1st generation biofuels could provide up to about 4 EJ/year at cost up to about 10 €/GJ, as shown in Figure 6. With 2nd generation biofuels, a potential of up to about 15 EJ/y would become accessible at cost of up to about 6 €/GJ. This potential of biofuel supply is comparable to the total present consumption of oil in transport of about 15 EJ/y (350 Mtoe/y).

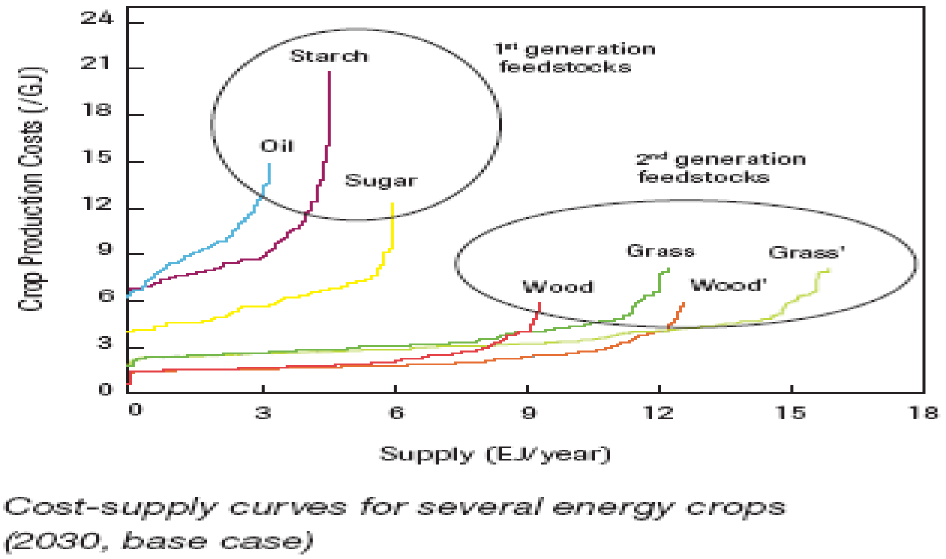

Figure 6: Cost-supply curves for biofuel feedstock in Europe (Source: REFUEL project [16])

Biofuels can be considered a global commodity, and they are already traded globally. The potential of biofuels should therefore be assessed on a global basis, and compared with global energy demand overall, and the sectoral demand of transport, in order to see which part of future energy supply to transport could in principle be covered by biofuels, and which part of global biofuel supply may be expected to reach Europe based on cost and global sustainability considerations. Global trading of biofuels would be essential to take full profit of the substitution potential of biofuels. Life cycle aspects such as land use change and related greenhouse gas emissions should be considered in this wider frame as well. This could be addressed through appropriate carbon accounting rules at EU and global level, and land management at national, regional and global level.

Global potentials of biomass liquid fuel have been assessed in a study on global and regional potential of renewable energy sources for different scenarios [17]. Cost-supply curves on global level from this study are shown in Figure 7.

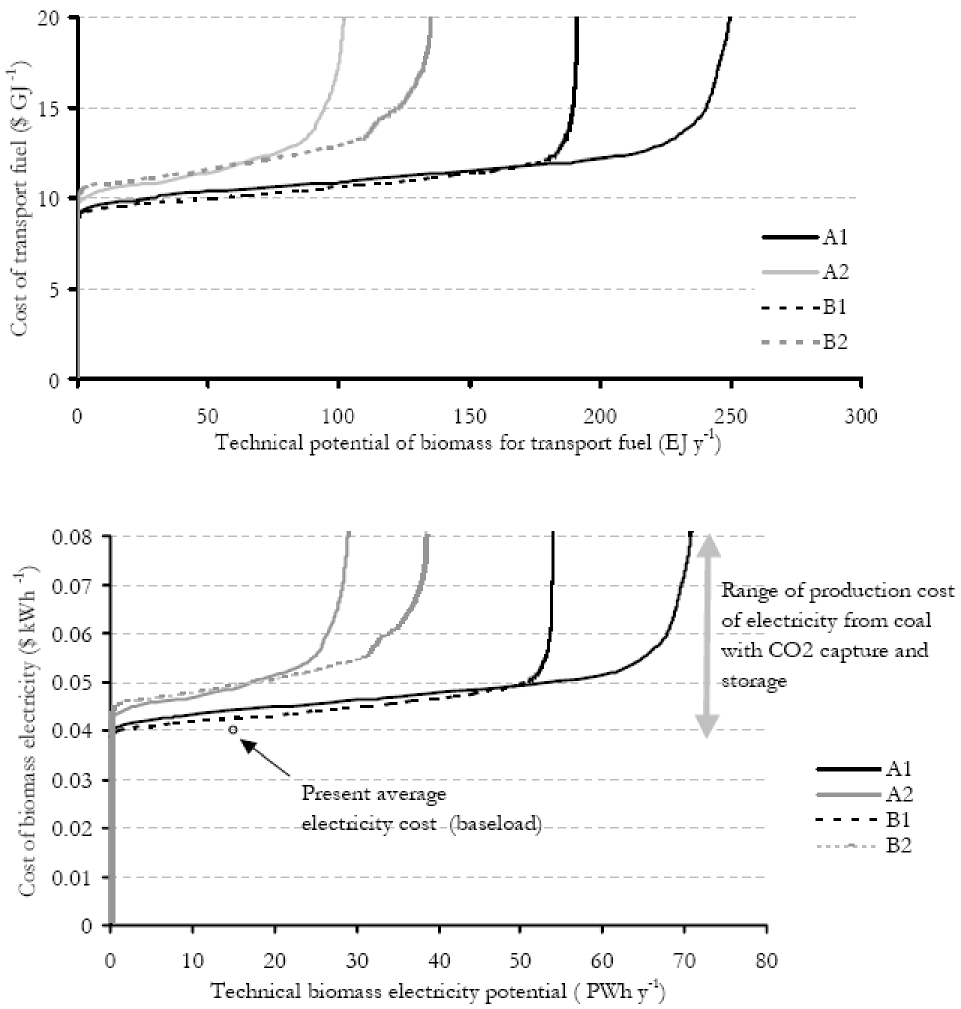

Fig. 7: Cost-supply curve for biomass based liquid fuel (synthetic FT diesel), using energy crop produced on abandoned agricultural land and rest land as feedstock, globally for 2050.

The availability of biomass from crops for conversion to transport fuels is limited by sustainability criteria. The availability of biomass from ligno-cellulosic crops for all biofuels (including bioethanol, BTL, biomethane and hydrogen) is limited by competition between biofuels and the use of biomass for other sectors. While bioethanol and FAME biodiesel are used primarily as transport biofuels, ligno-cellulosic biomass and biogas are currently used mainly for power generation; Fischer-Tropsch products are mainly used in the chemical industry. Constraints on biofuel availability might require measures to prioritise the supply to the sectors most in need of high-energy density fuel: aviation, long-distance road transport, freight transport. Market based measures, such as cap and trading mechanisms, would be preferable over regulatory sectoral allocations.

3.3 Synthetic fuels

Synthetic fuels pathways

Synthetic fuels pathways potentially include a broad range of pathways from different feedstocks to products, achieved via a process with selective control of the molecular structures of the end product.

- Feedstocks can include any carbon-based chemical energy source suitable for gasification to synthesis gas: Ligno-cellulosic biomass, natural gas, coal, oil residues, municipal solid waste (MSW) etc…
- Products that can be synthesised vary broadly: Hydrocarbons (aromatic and paraffinic), ethanol or other oxygenated fuels, such as methanol/DME, synthetic methane, hydrogen, hydrotreated renewable jet fuel (HRJ).

Synthetic fuels chemistry

While many different "synthetic fuels" are possible, once full control on the molecular design of the synthesis product is achieved, the focus for the synthetic fuels industry has been development of processes to produce high quality liquid fuels and non-fuel products which can be seamlessly integrated into the current energy system. This avoids the need for investment in new vehicles/infrastructures.

In practice, the preference is to synthesise paraffinic distillates for the following reasons:

- Paraffinic distillate fuels (kerosene, diesel) are compatible with today's diesel and jet engines and with today's existing fuel infrastructure.
- Paraffinic distillate fuels can directly be used as clean-burning fuels or used as high-quality blend components in conventional fuel products, delivering high combustion quality with reduced emissions compared to diesel.
- Beyond the kerosene/diesel fuel range, the lighter components (LPG/Naphtha) are ideal feedstocks for petrochemicals, and the heavier co-products can be tailored to production of high-quality base oils used in energy efficient lubricants.

Process Technology - Gasification

The production of BTL, GTL, and CTL (general: XTL) involves two steps to reach the desired paraffinic fuels from feedstocks that are otherwise difficult to deploy as fuels without massive changes in vehicles and infrastructure. The steps are the same irrespective of the feedstock used.

In the first step, the raw material is converted to synthesis gas (hydrogen and carbon monoxide), where the precise pre-treatments and technologies will depend on the chemical and physical properties of the feedstock.

In the second step, a low-temperature Fischer-Tropsch process is used to obtain crude paraffinic liquids, largely independent of the original feedstock. The intermediate crude stream is then further refined and separated into products, yielding mainly diesel and jet fuels, of very high quality (cetane number > 70, no aromatics, no sulphur, and tuned to deliver the desired cold-flow properties). Naphtha and base oils are the other principal products.

The experience and processes developed for current fossil XTL technology can be applied in adapted form to new, renewable feedstocks (such as cellulosic biomass in BTL) for producing renewable synthetic fuels.

Process Technology – HVO

More direct pathways exist to paraffinic distillate fuels from lipids (plant oils and tallows). Here, the desired fuel chemistries can be reached using hydrotreating and isomerisation techniques as a milder process, to deliver the desired high-quality fuels product arriving at an almost identical composition as for BTL. The following Figure 8 summarizes the characteristics of main fuel types and technology pathways for future implementation.

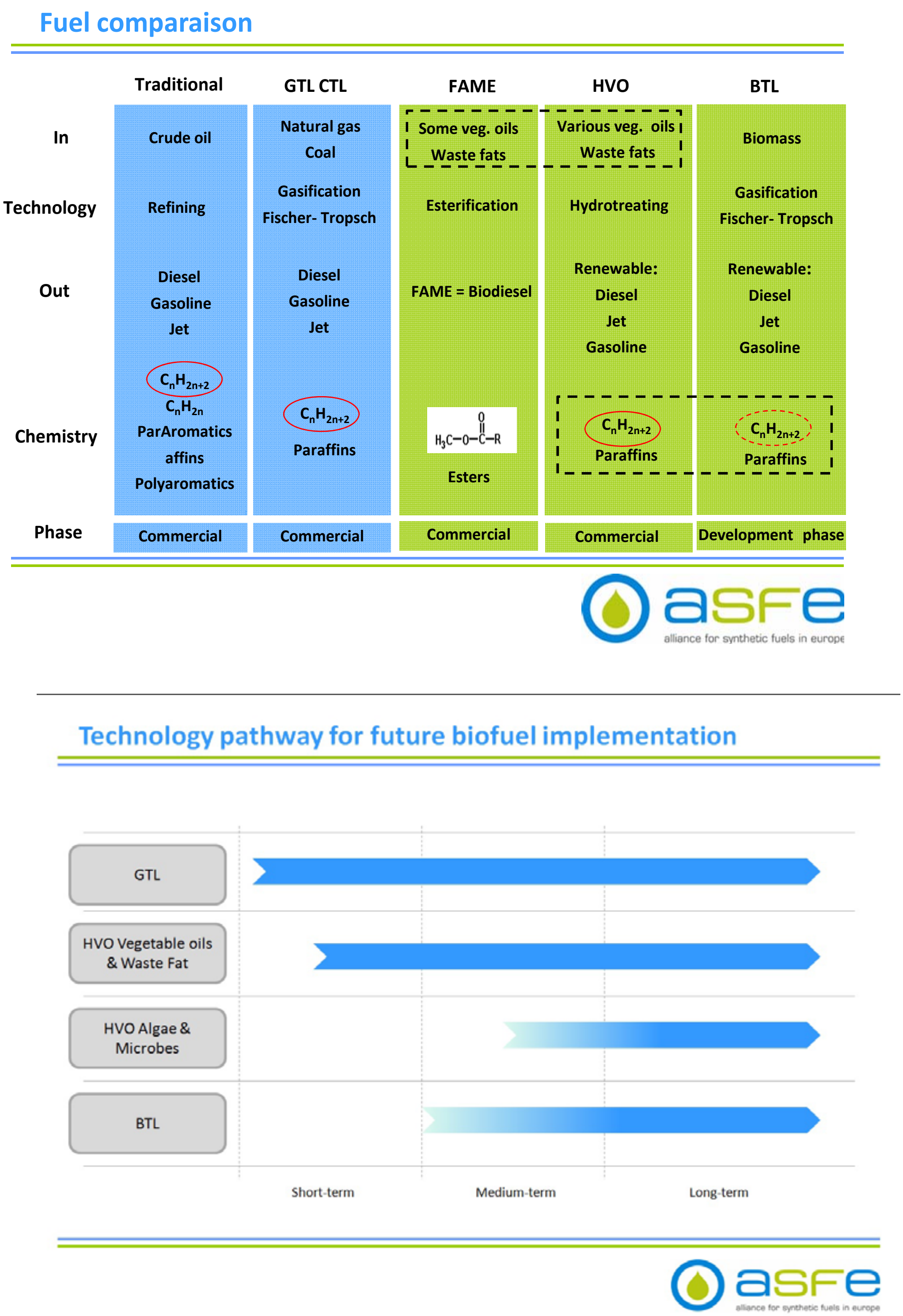

Fig. 8: Fuel comparison and technology pathways for future biofuel implementation (Source: ASFE)

Product applications and experience

GTL and HVO have already been used extensively in road applications. Fleet trials have been conducted with heavy duty applications as well as passenger cars using both, neat form (100% synthetic fuels) or high blending ratios (25-30% blending in diesel) in all climatic conditions, including extreme cold conditions. Synthetic fuels especially when used in a neat form can significantly reduce PM and NOx emissions.

GTL fuels have been tested in air transport by Shell, Airbus and US military.

Synthetic fuels corresponding to paraffinic hydrocarbon diesel fuel are produced already today on a commercial scale from natural gas (GTL), hydro-treating vegetable oils and animal fats (HVO), and at demonstration scale from biomass gasification (BTL). Synthetic fuels have high energy contents in MJ/kg, but have slightly lower volumetric energy content than conventional diesel. Properties are specified in detail in CEN CWA 15940.

Synthetic diesel fuels are fully fungible and can be blended into fossil diesel fuel at any blending ratio, or can be used neat as clean burning hydrocarbon in all existing or future diesel vehicles. Synthetic fuels have high cetane number which enhances the combustion property of the fuel. When used neat, better fuel efficiency than with standard diesel fuels can be achieved. These characteristics allow seamless compatibility and durability of engines, fuel systems, exhaust after-treatment device, and engine oil.

Larger market shares of synthetic fuels could further allow an optimisation of the fuel-engine system, with the perspective of higher energy efficiency and lower pollutant emissions at reduced after-treatment cost.

Preferred pathways

The advantages of each pathway and its associated costs, whether environmental or economic, largely depend on the type of feedstock involved.

BTL can be produced from a wide range of biomass feedstock by applying the same advanced synthesis processes developed for GTL, and previously for CTL. Plants are being scaled up to commercial scale in concept design studies.

HVO is commercially available today, and is expected to increase its market volume rapidly..

GTL is commercially available today, and is economically competitive with conventional oil products. With the recent technology advances allowing economic production of natural gas from shale and tight formations, current technically recoverable gas is estimated at 250 years supply at current rates of production. This makes GTL an attractive option to bring gas to market, providing high quality products that can be used as direct substitutes for oil-based products.

Major advances in process performance and significant increases in realizable project sizes have improved the outlook for GTL through the last decade. Historically, most of the projects undertaken or under development have been located in Qatar and Nigeria. However, with the rapidly evolving supply potential for abundant and affordable natural gas, new perspectives are appearing for GTL becoming a main future fuel option substituting oil.

CTL as pathway to synthetic fuels from coal is of interest to countries with substantial coal resources, such as India or China, which anticipate an upsurge in energy consumption in the decades to come, but the CTL option has two significant disadvantages. Secondly, it turns in a poor performance regarding CO_2 emissions. It is therefore difficult to envisage CTL playing a role in the European transport fuels mix.

China has announced its intention to build a number of projects by 2020 for a total capacity of 700,000 bbld. At least six coal liquefaction projects are planned in the United States (aggregate capacity: nearly 150,000 bbld). Some are already at the stage of applying for a permit from the competent authorities, others still at the feasibility stage.

Infrastructure

The preferred paraffinic synthetic fuels can – by design – be used neat or be blended at any mixing ratio with conventional mineral oil based fuels. The existing re-fuelling networks can therefore be used. No specific infrastructure is required. The same applies for HVO.

Potential

Energy security: By 2012 around 8 million tonnes/y of GTL will be produced and 2 million tonnes/y of HVO, along with around 15,000 tonnes/y of BTL. Synthetic fuels therefore are already available now. They offer the potential to reduce the current EU diesel/gasoline imbalance. The BTL pathway reduces competition with food production, as BTL fuels can be produced from many non-food biomass products, and also from the residual biomass of plants cultivated for food production (e.g. crops, with cereals used for food and straw for BTL fuels).

Synthetic fuels can play a unique role in diversifying the transport energy supply, as they can be produced from a wide range of feedstock, distributed by existing infrastructure and deployed in the existing vehicle fleet. They also support advanced diesel-engine technologies, with higher energy efficiency and better environmental performance.

Air quality: Synthetic fuels can contribute to better air quality, particularly in urban environments. Extensive road tests have shown significant reductions in NOx and particulate matter emissions, compared to standard diesel fuels, when using neat paraffinic fuels (GTL/ HVO) in existing vehicles.

Decarbonisation of transport: All synthetic fuels enable advanced engine technology and therefore enable a reduction in the consumption of fuel. According to the JEC Well-to-Wheels Study the GTL pathway has slightly higher CO_2 emissions, the CTL pathway significantly higher CO_2 emissions than conventional pathways, but this could be improved by CO_2 capturing in the plant, once this becomes available. Only HVO and BTL fuels provide scope for CO_2 emissions reduction, with HVO offering -40 to -80% and BTL -60 to -90%, compared to conventional oil derived fuels.

3.4 Methane

Technology

Methane can be used in established combustion engines. Natural gas/bio-methane vehicles offer today a well developed technology, with performances fully equivalent to petrol or diesel units and with very clean exhaust emissions. Methane can also be used in diesel/gas mix compression ignition engines. Advances in technology allow present natural gas engines with minor modifications to reach EURO 6/VI emission level values.

Methane could be also used in the form of Liquefied Natural Gas (LNG) for fuelling combustion engines in boats and ships and heavy duty road transport vehicles, up to now mainly through dual fuel systems (engines burning together diesel and methane). Many OEMs are working on LNG, testing and improving different vehicle approaches, in both dual fuel and dedicated gas engines. Dual-fuel technology in converted diesel engines can have several benefits:

- It allows for a large substitution rate of diesel fuel by NG/biomethane. Research has shown that a replacement of 75-85 % of diesel with NG/biomethane is feasible in some working conditions of the engines.
- It maintains the engine configuration and similar power and torque performance of a compression ignition engine. The CO_2 reduction is particularly noticeable when diesel engine efficiency is still maintained in dual fuel operation, because of the high degree of replacement of diesel oil by gas.
- The dual fuel system allows maintaining the same level of vehicle autonomy as with diesel, subject to the availability of LNG filling stations.
- The dual fuel system allows running with 100% diesel fuel if no LNG is available.

Dedicated stoichiometric gas engines provide:

- low pollutant emission levels (mainly NOx), allowing for low-cost after-treatment
- low CO_2 emission, 5-7% less than Euro 5 diesel and 20-24 % less than petrol.

Range and payload of methane fuelled vehicles may, however, be constrained by on-board fuel storage.

Infrastructure

Infrastructure partially exists, since Europe is covered with an extensive natural gas distribution grid for residential, industrial and power plant applications. The gas grid could be made available also for bio-methane feed-in to allow for a smooth change-over from fossil to renewable methane gas sources.

The infrastructure of CNG fuelling stations, gas upgrading plants and gas injection exists or is rapidly expanding in a few countries like Germany, Sweden, Switzerland, Austria, Italy etc. In other countries, infrastructure is rudimentary and has to be improved or still created. In some countries, like France and Spain, there is practically no public network of methane filling stations. Both countries have pushed the use of this fuel in urban trucks and buses, with infrastructure accessible only to these fleets.

EU-wide area covering fuel infrastructure, with refuelling stations along all major highways and also in urban areas, would be crucial for a broad market uptake of methane fuelled vehicles. The absence of refuelling possibilities in a particular European country will present a major problem for the transit traffic. Denmark, yet without a single methane refuelling station, is thus a barrier for methane vehicles travelling between Germany and Sweden, both strongly expanding natural gas and biomethane use as transport fuel. This illustrates the need for a European infrastructure development plan. Until the problem has been solved, the cars must be built as bi-fuel vehicles able to run on petrol when no gas refuelling is possible.

To ensure free circulation of methane powered vehicles across Europe, a more homogeneous, area covering infrastructure would need to be created. Larger gaps, in particular, must be closed to bring out the advantage of modern methane vehicles, which can be used also for medium and long-distance travelling. Co-ordinated European action would be necessary to create a really European methane infrastructure. Infrastructure gaps for private customers using small or medium-sized CNG vehicles could be closed by home refuelling facilities using own gas connections.

Wider use of methane in ships requires building up the necessary re-fuelling infrastructure in ports.

The infrastructure needs for LNG (with potential application in ships and heavy duty trucks) and CNG (for cars and urban short-range applications) are fundamentally different, leveraging different parts of the existing gas infrastructure. For CNG, the methane needs to be compressed and dispensed from the current grid. For LNG, the methane needs to be handled through the supply chain as a cryogenic liquid, and could be sourced from LNG terminals or produced in liquefaction facilities in other locations. In remote areas lacking access to the gas grid, LNG could be supplied via trucks to filling stations able to supply both LNG and CNG.

Biomethane should preferentially be fed into the general natural gas grid. Methane powered vehicles should then be supplied from the gas grid. This can balance regional differences in biogas production and natural gas consumption by vehicles, and avoid double investment into a parallel bio-methane distribution network. Blending biogas with fossil natural gas, allows a gradual increase of non-fossil fuels without major investments in new infrastructure. However, where logistics and economics permit, captive fleets could be fuelled from closed-coupled bio-methane facilities such as sewage treatment plants.

Potential

The consumption of methane as motor fuel is still quite low. In 2010, it amounted to 3,000 Mm^3 per year, equivalent to 2.7 million tonnes oil equivalent (Mtoe) in European OECD countries. Italy, which began to develop this pathway in the 1930s, is the leading market.

A methane vehicle presently offers several environmental and technological benefits, compared to a gasoline or a diesel vehicle:

- CO_2 emissions are up to 24 % lower than for a comparable gasoline vehicle and could be up to 7% lower than with a diesel Euro 5 vehicle.
- Particulate emissions are close to zero.
- Energy efficiency can be improved with turbo supercharging due to low engine knocking.

In the long term, however, these differences may diminish, with exhaust emission requirements for gasoline, diesel and natural gas vehicles, as regulated by EURO standards, further converging.

Natural gas reserves had been estimated to last around 30-40 years more than those of oil. New drilling techniques have considerably increased the available resources, by up to a factor 3 in recent years. Methane therefore contributes to the diversification of transport fuels and improves security of energy supply to transport, with a long-term perspective.

Recent publications of the International Energy Agency (Energy Outlook 2009) and of the World Watch Institute (April 2010) show that natural gas reserves are far higher than previously estimated. According to new data, only 14% of the world’s ultimately recoverable conventional resources have been extracted. At current global rates of production, the remaining conventional gas resources could last up to 130 years. Range estimates are presently further updated towards higher values in short intervals, following the very active exploration activities. The possibilities for recovering these newly discovered reserves, however, are still subject to considerable uncertainties. Recovery of so-called unconventional resources (shale gas) has recently started in the US. With the last estimations related to shale gas, experts have estimated the total gas reserves as for 250 to 350 years.

Bio-methane from biomass offers an extension and gradually increasing substitution for fossil natural gas. The larger part of bio-methane is still produced from waste and waste water at present and provides significant CO_2 savings. However, bio-methane from agricultural crops and food industry waste produced in dedicated digesters are soon taking over according the Biogas Barometer. Bio-methane, as long as it undergoes a purification process to comply with the methane grid specifications, can be mixed at any ratio with natural gas.

A potential of 60 Mtoe/year of biogas from energy crops in Europe by 2030 is identified in the European Environment Agency report No.7 (2006). A study of the Leipzig Institute for Energy and Environment (2007) indicates even an availability of 410 Mtoe/year of biomethane by 2020, half of it covered by biogas from animal and municipal waste and from energy crop, the other half from gasification (assuming the full potential being available for biomethane production).

In a 2030-2050 perspective, bio-methane could account for a considerable part of the total volume of methane used in Europe. Including the potential of CIS countries, the total potential of bio-methane supply is comparable to the total present natural gas consumption of the EU.

Bio-methane versus liquid biofuel production from the same biomass source has to be assessed under various aspects: optimisation of biomass yield per area of land, optimisation of energy yield, optimisation of CO_2 savings, and optimisation of economics. By-products from the same biomass may be considered as well. Large differences in yield have been identified in the case of maize [18]: The bioethanol yield alone is 81 GJ/ha, about half of the yield achievable for bio-methane of 176 GJ/ha. A quantitative analysis by NGVA Europe comes to a similar result (Annex 2a). When taking into account co-products of the bioethanol production process, substantially higher values for the total yields are obtained, at 270 GJ/ha, and with additional use of the corn stover 461 GJ/ha (Annex 2b). This wider co-product consideration, however, provides only a theoretical framework for the whole product chain, comparable to an assessment of petrol and oil production from a refinery, together with all petrochemical products of the crude oil pathways.

Where bio-methane and liquid biofuels can be produced from the same biomass feedstock, the optimum use therefore depends on the possibility of fully exploiting all co-products. Bio-methane would be the preferential product, however, from sewage, manure, and landfill sources.

Liquefied natural gas (LNG) offers the great advantage of a much higher energy density because of its liquid status, and this characteristic enables it to be used for medium and long distance road transport. The other interesting point is the price, because being the same in terms of cost per unit of energy as for the gaseous form, by saving the compression the final price could be lower. For liquefaction, however, natural gas must be cooled down to - 160 °C and then kept insulated against temperature loss to keep it in liquid state. This energy intensive process must be balanced against the effort to compress the gas.

LNG recently has started to attract the attention of the maritime sector, as possible substitution for high-sulphur bunker fuel, following the requirements for cleaner fuels, as agreed by the International Maritime Organisation (IMO).

Methane gas vehicles can play an important role in urban and medium distance transport in the mid term (2020). A 5% market share for CNG/LNG vehicles could be possible by 2020, with some 15 million vehicles. A higher market share could be reached towards 2030 and beyond. In the city, all types of vehicles can be operated: passenger cars, light duty vehicles, taxis or buses for public transport and trucks, substantially reducing pollutant emissions. Heavy duty trucks could in the medium range start to replace compressed methane by liquid methane, as the first new engines are currently appearing on the market. In 2050, these vehicles could still take an important share. In urban transport, passenger cars would shift from gas to electricity, while in the medium transport range gas would be more suitable.

Various countries in other parts of the world have already demonstrated that methane can become a major automotive fuel and be used on most kinds of motorised vehicles. Natural gas is already the largest fuel in Pakistan, used in 70 % of all cars. Several countries in Latin America have reached 20-25 % market shares. Within the EU, Bulgaria is leading with a 3 % market share, followed by Italy with a 1.5 % market share, whereas the EU average is only 0,4 %.

The methane vehicle fleet development within the EU is very different from country to country: Italy, Germany, Austria, the Czech Republic, Slovakia, the Netherlands, and Sweden have a reasonably good coverage of their territories with public methane filling stations allowing the development of the private use of light duty vehicles powered by methane. Sweden is leading in the use of biomethane, which is now accounting for 65 % of all the methane gas used in some 28.000 vehicles (as of June 2010). In Italy new passenger cars sold as methane vehicles in 2009 reached 7 % of all new registrations, and Sweden is close to a 5 % share.

A market share of 20 % of natural gas in transport fuels would allow a 5 % reduction of the CO_2 emissions from all European vehicles. Assuming that 20 % of the gas used would be made up of bio-methane, the CO_2 reduction would increase to 7 %. Over time, the share of biomethane in the overall natural gas supply could increase gradually and ensure further decarbonisation of methane powered vehicles.

Methane use in buses and trucks substitutes for diesel fuel, and therefore can alleviate the imbalance in the European fuel market between gasoline and diesel. Decreasing pressure on diesel demand would then improve the overall energy efficiency of fossil fuel production.

3.5 LPG

Technology

Liquefied Petroleum Gas (LPG) was the first true alternative motor fuel. A mix of butane and propane, LPG is derived from oil refining (40% of the world total; 75% of LPG in Europe) and natural gas processing (60% worldwide; 25% in Europe). LPG can be burned in a slightly modified spark ignited internal combustion engine. Though retrofitted systems have traditionally dominated the automotive LPG market, both supply and demand for new, manufacturer-equipped LPG-powered vehicles is emerging in a series of EU markets.

When LPG motor fuel is used in a properly equipped vehicle, it has advantages over conventional motor fuels, particularly environmental benefits:

- On a well-to-wheel basis LPG’s CO_2 emissions are 14% and 10% lower than those of petrol and diesel respectively.
- NOx emissions are lower than for gasoline vehicles and much lower than for diesel vehicles.
- No soot particles are emitted.
- The octane number is high, which should improve engine efficiency.

In the long term, however, these differences may diminish, with exhaust emission requirements for the different engine technologies converging.

A major advantage of using LPG as a transport fuel is better efficiency in the exploitation of mineral oil, and natural gas wells and thereby improving the energy and greenhouse gas emission balances of those. But this only holds if no other use would exist, which is not the case. The amount of LPG channelled to transport therefore has to be balanced also against its deployment in other sectors.

Infrastructure

The core infrastructure is already established, as LPG is used, in addition to the transport sector, also in domestic, industrial, and other sectors. More than 27,000 public filling stations for LPG were in service in the EU-27 as of end 2009. The cost of individual filling station installations ranges from about €20,000 for a basic unit with dispenser to €125,000 for a station with remote underground tanks and a dispenser incorporated in a petrol forecourt.

Potential

In 2006, LPG consumption for European OECD countries stood at 5.7 Mtoe, up 6% year-on-year. As for the other alternative fuels, spot developments are currently supported by fiscal incentives.

LPG supply is expected to increase as a result of increasing natural gas production worldwide. This could lead to an oversupply situation in the LPG market, as less than 10% of the available total is being consumed at present (21 million tons out of a total of 240 million tons available). This supply situation could allow an increase of the current fuel share of LPG in Europe, from about 3% to 10% by 2020 [19].

Bio-LPG derived from various biomass sources is expected to emerge as a viable technology in the medium to long term as a by-product in the biofuel production process in bio-refineries. Bio-LPG would then serve the same purpose as now fossil based LPG, namely improve the efficiency and economics of the whole fuel chain.

The current HVO plants are designed to yield mainly paraffinic diesel fuel but they produce also some bio-LPG as side product. Low-CO_2 LPG could therefore already be delivered for niche markets. LPG can also be blended with DME produced via synthesis gas.

3.6 Fuel mix outlook

Major resource constraints as well as technological and economic issues exist for all main fuel options at present. These issues are not expected to be all overcome in foreseeable future.

It is therefore unlikely that there will be a single solution for the fuel for future mobility. The precautionary principle would then already advise to base projections on future mobility on several options. This would require developing both existing and **disruptive solutions**. For those technologies, which require new system solutions, specific policy actions should be combined and mutually interlinked with research and demonstration projects.

A mix of several different complementary fuels, with possibly increasing complexity, will therefore most likely determine the energy supply to transport for the foreseeable future.

The main options for alternative fuels for oil substitution are:

- electricity, via battery or hydrogen/fuel cells
- liquid biofuels, in different forms
- methane (natural gas of fossil origin or bio-methane produced from biomass), in compressed gaseous form or in liquefied form as LNG
- synthetic fuels, bridging the gap from fossil (coal, natural gas) to renewables (biomass)
- LPG,   up to possibly 10%, possibly also bio-LPG in future

Electricity and hydrogen are universal energy carriers and can be produced from a wide range of primary energy resources.

All these alternative fuel options can be produced from low- CO_2, and finally from CO_2 -free sources. Substitution of oil in transport by these main alternative fuels leads then inherently to a decarbonisation of transport if the energy system is decarbonised.

Decarbonisation of transport and decarbonisation of the energy system can therefore be considered as two complementary strategic lines. They are closely related, but can be decoupled, and require different technical approaches. Decarbonisation of the energy carriers used in transport should progress at least with the rate of their introduction into the transport fuel mix.

4. Fuels of choice by transport mode

Not all alternative fuels are equally suited for all modes of transport, and also not for all sectors within a specific mode. The needs of the different modes and the possibilities of the different fuels therefore need to be analysed for each mode separately.

The suitability of a fuel for a specific transport mode will depend on a number of factors:

- Energy density of the fuel
- Vehicle compatibility and emissions performance
- Cost and market availability
- Safety during production, distribution, storage, vehicle refuelling, and use

As shown in Figure 9, the energy density is especially important for fuels that must be stored on the vehicle for consumption because it directly impacts on the distance the vehicle can travel before refuelling. For this reason, fuels having higher mass and volumetric energy density will generally be most suited for longer-distance operations, including aviation, on-road freight transport and long distance passenger vehicle travel.

4.1 Road

Urban transport is particularly suited to be powered by zero local emission electricity (small battery electric vehicles, buses, urban freight vehicles, or electric trolleys) and hydrogen/fuel cells. It could also use neat synthetic or paraffinic fuels, methane, or LPG. Possible risks of market fragmentation and resulting limitations in economies of scale in case of competition between fuels need to be clarified.

Unlike trucks, agricultural transport is characterised by short distances and by vehicles returning to home base daily. At the same time renewable energies based on energy carriage by electricity will mainly be produced in rural areas in partially small scale grids. Here, battery-electric agricultural vehicles and mobile off-road machinery can be integral and stabilising part of small scale grids supporting more local use of renewable electricity in such areas. Applications with inherent storage systems, e.g. with electric vehicles, can reduce the need for quick and strong grid extensions and improve the overall economy of enhanced renewable energy use.

Medium distance transport could be covered by synthetic and paraffinic fuels, methane and possibly hydrogen. Possible competition also needs to be clarified, as hydrogen and methane require the build-up of new dedicated infrastructure and different vehicle technologies.

Long distance transport could be supplied by biofuels and synthetic fuels and also by liquefied natural gas (LNG) and LPG.

All sectors of road transport both for passengers and freight, could be covered by biofuels in liquid form, in all molecular compositions, if sufficient feedstock for sourcing can be made available. For vehicle owners it is essential that fuels and vehicles operate in all climatic conditions, including temperatures as low as -40°C.

4.2 Rail

The rail sector accounts for just 0.6% of total CO_2 transport emissions. In terms of the share of utilisation, rail accounts for 10.7% of the freight market and 6.1% of the passenger transport market.

Railways are already largely running on alternative fuels, as railway tracks are already electrified to about 50% of their total length in the EU. But in traffic volume, the present fuel mix of railways at EU level is even more advanced: around 80% electric traction and 20% diesel traction. Full electrification is an option, but may not be economic or operationally viable in many cases: the main question is which is the best diesel train proportion to be electrified economically, considering energy consumption, and which are the most appropriate measures to promote electric trains.

Diesel locomotives could also use biofuels, or possibly LNG, and thereby substitute oil where electrification is difficult or not economic.

Fuel cells operated with hydrogen could also be deployed to replace diesel engines. No infrastructure changes along the tracks would be necessary in this case.

Urban rail systems (tramways, metros, suburban railways) are nearly 100 % electrified – in many cases since more than 100 years. The objective should be to use carbon-free electricity in future and to promote the use of such largely oil-independent and energy-efficient transport modes. At the same time it should be prevented that urban rail systems are abandoned for e.g. economic reasons especially in some Central and Eastern European Member States. The capture of breaking energy in new energy storage technologies (batteries or super capacitors) will not only further reduce energy consumption, but also enable to run urban rail systems partly without overhead wires in areas where such installations are difficult to realise in the urban environment/architecture.

4.3 Aviation

Aviation has the most severe payload constraints and needs fuels with high energy density. It therefore will continue to rely on liquid hydrocarbon fuels.

Due to the flight environment, the fuel has also to present extremely good cold flow properties. More generally, for safety and reliability reasons, aviation fuel has to match very stringent specifications including among others energy density, freezing point and thermal stability. It must also be compatible with the materials used in the aircraft and engine fuel systems.

In 2009, synthetic paraffinic kerosene produced via the Fischer-Tropsch process (FT-SPK) with coal (CTL), natural gas (GTL) or biomass (BTL) has been approved for use in civil applications for blending up to 50% with conventional jet fuel. Today, CTL and GTL are at the industrial stage while BTL is close to the demonstration level. Synthetic paraffinic kerosene can also be produced from plant oils or animal fats through hydro-processing (Bio-SPK or HVO or HRJ). This second pathway is currently undergoing the approval process also for blending up to 50% with conventional jet fuel. Although technically mature, it is still at an early stage of commercial production. The use of fully synthetic kerosene from both processes is foreseen in near future.

Both HRJ and BTL are "drop-in" fuels with the potential of significantly reducing greenhouse gas emissions, BTL being from this point of view the more promising of the two pathways. Life cycle emissions will depend strongly on feedstock production conditions, with a wide scope of resources under consideration including agricultural crops, forestry resources, residues and new advanced feedstocks like algae. Availability of these feedstocks and the associated logistics are major issues for the deployment of these fuels. They have to be addressed along with the environmental impacts in order to ensure a sustainable deployment of biofuels in aviation.

Efficiency over the complete fuel cycle and economical viability will also need to be improved to help for a suitable commercial scale application in aircraft fleets.

Other alternative fuels may appear for aviation in the future, but in order to have any significant impact by 2050, they will need to be "drop-in", i.e. compatible with existing engines, airframes and fuel supply systems and infrastructures.

In the longer term, hydrogen or other "non drop-in" alternatives could offer a potential if they succeed in demonstrating a significant environmental and economical advantage that overcome the cost required to adapt aircraft and infrastructures.

4.4 Waterborne

Waterborne transport has a number of options for substituting oil by alternative fuels. Ships and boats of all types could be supplied by synthetic fuels; inland waterways vessels by hydrogen, methane and LPG; maritime ships by biofuels, LPG, LNG. The opportunity to use nuclear propulsion for seagoing ships is being increasingly voiced by the sector.

Regulatory pressure for cleaner marine fuels is increasing gradually and is therefore expected to trigger major technical changes. The 2008 amendments to Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) lay down significantly more stringent sulphur content limits in marine fuels internationally. Moreover, specific areas designated as Sulphur Emission Control Areas (SECAs) require ships to use fuel with no more than 0.1% sulphur. Achievement of these standards can be via purchase and use of low sulphur fuels, and also through alternatives.

The requirements of Annex VI as amended have seen an increased interest in LNG as a fuel – especially for those ships carrying cargo across short distances (short sea shipping). Using LNG would enable such ships to comply with the requirements of MARPOL and also remain competitive with other modes of transport.

LNG remains a viable alternative for maritime transport – however, there is much to be done in terms of infrastructure and bunkering support.

In addition to LNG, research into the use of nuclear and hydrogen fuel is ongoing. Nuclear technology has been used for a number of years on board naval and also commercial ships and a legal framework also exists for these kinds of ships – such as the IMO Code of Safety for Nuclear Merchant Ships. The capital costs of nuclear fuel can, however, be prohibitive – while social acceptance would need to be gained.

4.5 Modal fuelling outlook

A strategy for the use of energy and energy carriers in transport needs first to look at the main energy carriers and at the demand on energy density for the different transport sectors. The main fuels are categorized in Table 1.

	Energy per volume [kWh/l]	Energy per weight [kWh/kg]
Battery electricity	Low	Low
Gaseous Hydrocarbon, H2	Low	High
Liquid Hydrocarbon	High	High

Table 1: Energy density of main energy carriers

All these possible solutions have quite different potentials of application for future mobility, depending on market competition and future requirements of passenger cars and freight vehicles for traffic in urban areas and long distance travel. Possibly a combination of technologies, including biofuels and battery-driven or fuel-cell technologies (“hybrid solutions”) may fulfil mobility requirements in the future.

The main fuel options with the potential for full oil substitution in the long term, possibly on the time perspective 2050, can be classified as follows:

- Energy dense liquid fuels fully compatible with current infrastructures will be needed for aviation, long distance freight and road transport. Only bio based feedstocks can provide such liquid transport fuels, in complement with fossil based hydrocarbon fuels. To maximize decarbonisation of fuel mix, the bio based share should be blendable at high rates and offer high energy density.
- Liquid and gaseous fuels for fleets and short distance freight/travelling. In urban areas, the market potential could become large for these fuels in addition to/competition with electricity.
- Electromobility would be prevalent for short distance and fleets in road transport. For long distance, liquid fuels, supplemented by hybrid solutions should prevail.

The coverage of the different transport modes by the different alternative fuels is summarised in Table 2. The modes are differentiated by travel distance where a single fuel can not meet all needs of a specific mode, such as short/medium/long distance travel on road, and inland navigation/short sea shipping/maritime shipping for waterborne transport.

		Road/passengers			Road/freight			Rail	Water			Air
		short	med	long	short	med	long		inland	short-sea shipping	maritime	
Electric	BEV	■			■			■				
	HFC	■	■		■			■	■			
	Grid	■			■			■				
Biofuels (liquid)		■	■	■	■	■	■	■	■	■	■	■
Synthetic fuels		■	■	■	■	■	■	■	■	■	■	■
Methane	CNG	■	■	■	■	■						
	CBG	■	■	■	■	■						
	LNG	■	■	■	■	■	■	■	■	■	■	
LPG		■	■	■	■	■	■		■	■		

Table 2: Coverage of transport modes and travel range by different alternative fuels

5. System analysis: fuels-vehicles-infrastructure

A comparative assessment of the different fuel options needs to take account of CO_2 and GHG emissions, energy consumption, energy efficiency and macro-economic cost elements for the 3 system components:

- **fuels**, integrating the impacts along the whole pathway from the primary energy source to the final use for propulsion of a transport carrier, in a Well-To-Wheels (WTW) analysis;

- **vehicles**, including purchase and maintenance, comprising in the analysis life cycle aspects for production and disposal;

- **fuelling and distribution infrastructure(s)**, including creation and maintenance as well as macro-economic cost elements for single fuel and multiple fuel fuelling and distribution infrastructure(s).

Consistent, transparent and rigorous methodologies, based on common and mutually accepted data-sets, have not been developed the same way for all transport modes nor for the three system components as a basis to assess the energy efficiency, environmental acceptability and economic viability of technological options.

Most studies have been carried out for the road sector and here in particular for the fuel chain. The part of fuel production from the energy source to the supply to the energy carrier, Well-To-Tank (WTT), from this work can largely be used as a basis for the analysis of other modes as well. The consumption on board a vehicle, from Tank-To-Wheels (TTW) however, needs specific analysis for each mode, which is not available to the same extent for all.

5.1 Well-To-Wheels analysis

A consensual and robust European Well-To-Wheels (WTW) analysis of all main alternative fuels and power-trains for passenger cars was jointly developed and presented first in 2003 by the European Commission's **J**oint Research Centre, **E**UCAR, and **C**ONCAWE, the so-called **JEC research collaboration**. The assumptions made were clearly documented; a robust database and a transparent methodology were used, and the results were peer reviewed. Main parameters included in the study were energy consumption and efficiency, greenhouse gas emissions, cost (without externalities), market potential and 2010 as time horizon.

The JEC Well-To-Tank analysis considers conventional fossil fuels (gasoline, diesel and naphta) as references, but also compressed natural gas, liquefied petroleum gas (LPG), biofuels (including synthetic fuels) and biogas, as well as hydrogen. To facilitate comparison of pathways of different nature, actual processes are re-grouped into 5 standard stages, namely: production and conditioning at source; transformation at source; Transportation to the EU; Transformation in the EU; Conditioning and Distribution.

All fuel options are subsequently considered based on an analysis of primary energy sources, i.e. crude oil, coal, natural gas, biomass, wind and nuclear. Life cycle aspects, such as indirect land use change for biofuels production, are not part of a well-to-wheels analysis, as the scope of analysis between WTW and LCA clearly differs, also with regard to cost analysis. Such very relevant steps have to be treated separately and then linked to the WTW analytical approach. Some fossil fuel feedstocks, such as tar sands and oil shale, were excluded from the analysis as having a very marginal impact but may be further analysed in the future. Electricity was included for the pathway from the power station through the grid to mid-voltage supply.

JEC Tank-To-Wheel analysis uses a mid-range European car platform as reference vehicle, complying with Euro 3 emission standards, with different power-train options analysed, e.g. spark ignition engine for gasoline, LPG, CNG, Ethanol and Hydrogen; compression ignition engine for diesel, DME and Biodiesel; fuel cell engines; hybrids; hybrids with reformer types.

5.1.1 Well-to-wheels energy consumption and CO_2 emission of cars

An overview of energy consumption and CO_2 emissions on a well-to-wheels basis shows that alternative fuels can in some cases significantly contribute to reducing CO_2 emissions, but are generally less energy-efficient than fossil fuels (both, oil and natural gas derived fuels). In general terms, no single fuel pathway offers a short term route to high volumes of "low carbon" fuel. This implies that contributions from a number of technologies/routes are needed; a wider variety of fuels is to be expected in the market; blends with conventional fuels and niche applications should be considered if they can produce significant GHG reductions at reasonable cost.

Large scale production of synthetic fuels or hydrogen from coal or gas offers the potential for GHG emissions reduction via CO_2 capture and storage. The largest CO_2 emissions reductions, up to full decarbonisation, at highest energy efficiency can be achieved with hydrogen, and electricity when used in a fuel cell vehicle, as seen from Figure 9. Carbon capture and storage is likely to play a role (an industrial initiative at European level is indeed devoted to this), although high costs and deployment efficiency are likely to be major hurdles for the large scale development of these processes.

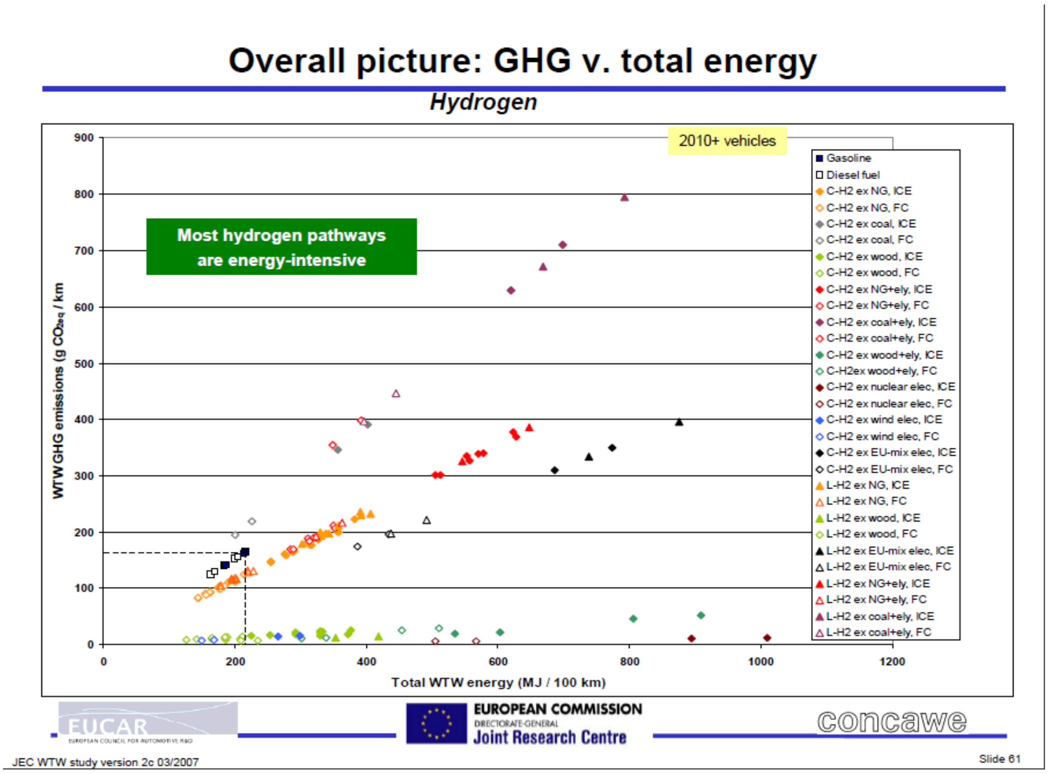

Fig. 9: CO_2 emissions versus energy consumption for hydrogen powered vehicles over the whole fuel chain for different hydrogen production pathways (JEC Well-To-Wheels study, Version 2c, March 2007)

The JEC WTW analysis has investigated 75 different pathways from primary energy sources. In general, biomass fuels derived produce less CO_2 emissions but with a wide variation. Potential volumes of ethanol and biodiesel are limited. Cost of CO_2 avoidance and fossil fuel substitution crucially depend on the specific pathway, by-product usage and N_2O emissions.

Advanced biofuels and hydrogen have a higher potential for substituting fossil fuels than conventional biofuels. It is also appreciated that advanced renewable fuels, including BTL fuels, give lower emissions than conventional biofuels. Therefore, BTL processes have the potential to save substantially more GHG emissions than current bio-fuel options at comparable cost although issues not included in the “stages” of the WTW analysis such as land and biomass resources to name but a few.

Next updating of the JEC WTW analysis will include revised data on biofuels, as well as on electric vehicles and electricity pathways.

Other points discussed were the following:

- The high diversity of alternative biofuels needs a comparative analysis. The biofuels pathway should be updated where new relevant results have been obtained from the dedicated specific line of activity (JEC Biofuels Programme) analysing technically feasible scenarios to reach the 10% RED target for 2020 [20].
- Electricity considered should include pathways for coal, natural gas, biomass, wind, solar and nuclear as primary energy sources, as well as the current EU-mix. Vehicles with different systems for batteries recharging may be also analysed.
- Passenger car can be used as a reference for benchmarking the complete range of vehicles.

The comparison of Well-to-Wheels CO_2 emissions of different power trains before 2020 shows that the Well-to-Wheels efficiency of HFCV is comparable to ICE gasoline and diesel although these have the highest carbon footprint, respectively in 2010 189 and 165g CO_2/km compared to Plug-in hybrid, battery electric with 58g CO_2 /km and fuel cell electric engines with 119g CO_2 /km which have no CO_2 emissions from tank to wheel.

In 2020, the carbon footprint of ICE gasoline and ICE Diesel is reduced respectively to 121 and 116g CO_2/km due to 6% decarbonised gas/diesel, compared to 83g CO_2/km for the HFCV, 49 g CO_2/km for the PHEVs and 29 g CO_2/km for BEVs.

In 2050, electric vehicles have nearly suppressed all emissions, assuming a fully decarbonised electric sector via renewables, nuclear and CCS.

As regards well to wheel efficiency, fuel cell power drives are better than ICE whereas battery electric vehicles remain the most efficient power drive.

The energy consumption of electric and internal combustion engine vehicles is compared in a detailed Well-to-Wheels analysis in Annex 2c.

Among the other alternative fuel pathways, DME from wood, synthetic diesel from wood, cellulosic ethanol, and bio-methane allow the highest CO_2 emissions reductions, also up to full decarbonisation, at highest energy efficiency, as shown in Figure 10. HVO was not yet included into that figure but according to the values published in the annex of the RED Directive, the HVO values are equal or slightly better than those of biodiesel (FAME).

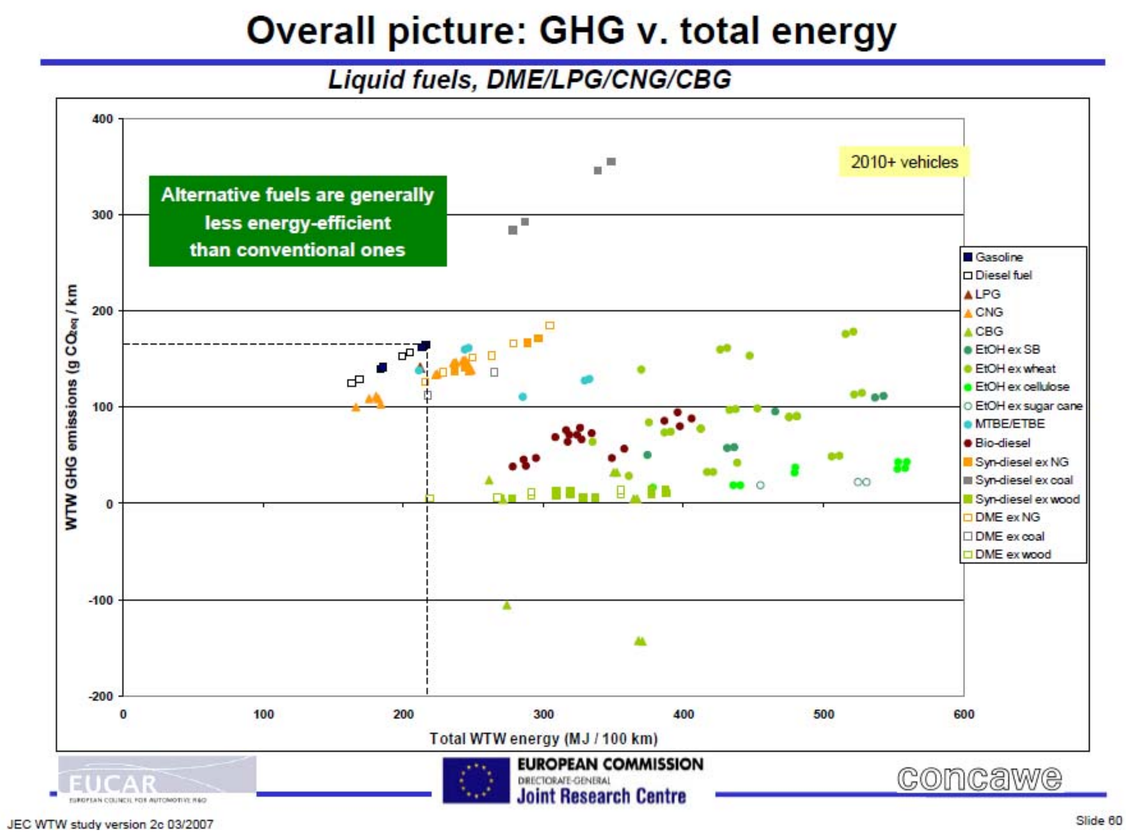

Fig. 10: CO_2 emissions versus energy consumption over the whole fuel chain for different alternative fuel pathways (JEC Well-To-Wheels study, Version 2c, March 2007)

5.2 Life cycle aspects

The processes for the development of energy sources, the production of transport carriers and their disposal, and the greenhouse gas emissions associated with direct and indirect land use change need also to be considered in an overall assessment of energy consumption, CO_2 and pollutant emissions, and cost. These one-off impacts have to be converted into running charges linked to the operation of the transport carriers, quantified by km, tonne-km, passenger-km, or time. A life cycle analysis provides for this conversion and can integrate life cycle quantities into well-to-wheels quantities.

Examples of life cycle aspects for the different fuels are:

- Exploration and installation of oil and gas production, distribution, and storage facilities
- Construction of power plants and infrastructure for electricity generation and distribution
- Construction of alternative fuel production, distribution and storage systems
- Direct and indirect land-use change for biomass production
- Manufacturing of transport carriers and infrastructure
- Disposal of facilities for fuel production, distribution and storage
- Disposal of transport carriers and infrastructure

Very few of these elements have been analysed so far in comparative quantitative studies, with transparent documentation of assumptions, input data, and assessment methodology.

A rather exceptional case is the inclusion of the impact of indirect land-use change, in addition to the sustainability criteria for biofuels, following the Renewable Energy Directive. This approach combines a life cycle element with the well-to-wheels pathway. An objective comparison of the different fuels would require the same approach for other energy pathways, including an assessment of the production facilities of fuels, vehicles, their different components, and the infrastructure into an overall energy and greenhouse gas balance.

Further extension of a combined life cycle / WTW analysis to other fuels is important and urgent to provide a solid basis for a better informed assessment of system changes required in the long term for the fuel supply to transport.

5.3 Infrastructure overview

Infrastructure requirements of the different alternative fuels are very different, in technological challenges, cost, complexity, coordination requirements and administrative implications. Alternative energy sources requiring dedicated infrastructures would need to prove their advantages over fungible fuels and biofuels which require only minor infrastructure changes. Development of fungible and biofuel products to industrial volumes might be the more economic way. Technical and resource limitations of the different alternative fuels may require, however, taking both approaches.   .

Electricity is readily available in Europe from a dense electricity grid. But additional infrastructure is still required for charging on-board batteries as intermediate storage in road transport vehicles or stationary batteries in charging ("filling") stations. Infrastructure build-up is also required for any further electrification of railways. Ensuring stability of the grid requires also the build-up of communication and control systems for the power transfer between the grid and the vehicles.

Hydrogen is produced and distributed in large quantities in petrochemical plants. It is widely used in industry, which can be leveraged for a public infrastructure. Hydrogen for fuel cell operation, however, requires additional purification in those plants where today's purity levels do not yet meet fuel cell vehicle requirements and requires a step-by-step build-up of the refuelling station infrastructure. Hydrogen needs completely new infrastructure throughout the whole chain from production over distribution and storage in filling stations and on-board the vehicles.

Biofuels can be blended and distributed through the existing oil and gas infrastructure, as long as the blend-in concentration is compatible with the blends mandated by the Fuel Quality Directive and existing standard vehicle technologies. Higher blending (e.g. E85: 85% ethanol / 15% petrol) requires some modifications to existing infrastructure and a dedicated distribution system.

Synthetic fuels can be made fully fungible and use the existing petrol/diesel infrastructure.

Methane can be distributed through the existing dense natural gas infrastructure in Europe. or can be delivered in form of LNG. Additional infrastructure, however, is required for supply and storage at filling stations and for possible filling from home filling stations.

LNG is available in a growing number of terminals on the European coast. Additional re-fuelling infrastructure in ports and along roads ("Blue Corridors") would be required to make LNG a real option for maritime and long-distance road transport.

LPG is available from an area covering infrastructure in Europe. Some supplementary filling stations could possibly close a few geographical gaps,

Building up and maintaining several infrastructure systems in parallel is not an insurmountable obstacle. In the past, parallel fuel infrastructures have been built a number of times, such as the full size area covering distribution systems for several quality grades of gasoline and diesel, and in smaller scale also for LPG and methane. This parallel full roll-out of several systems has been carried out by industry alone, without public support. The more it should be possible to undertake the creation of new infrastructure essential for future security of energy supply and mobility, also in the interest of all sectors of economy, those active in the fuel and vehicle sectors first.

5.4 Economics

Alternative fuels are currently more costly than conventional fossil fuels. The economics under present market conditions, however, does not include security of supply aspects, damage costs from pollutant emissions, and it includes only partially costs for CO_2 emissions and product disposal. A comparison of the different alternative fuel options, even under the conditions of these market failures, is still useful to clarify the cost-effectiveness of the different solutions, and to identify possible support measures to compensate for existing market failures.

Most important is the identification of the options with the lowest total system CO_2 abatement cost and the highest energy efficiency for each transport mode. The orthogonal approach of assessing for optimum use of the different energy sources across the different sectors of economy is only of limited value, because energy demand can not be shifted between the sectors along to the criteria of consumption and emission minimisation. Projected energy demand in transport therefore should be taken as fixed, and the fuel mix required for meeting it, optimised with respect to energy efficiency, CO_2 emissions, and cost.

Estimates for vehicle costs, infrastructure and fuel lifetime costs are presented in the following for the main alternative fuels.

Electricity

Electric cars presently cost about 10,000-15,000 € more than a comparable ICE car. The difference for light duty and heavy duty vehicles would be larger due to larger batteries required at high cost.

Electricity supply to vehicles needs grid connection points for charging at different power (slow or fast charging – with technical characteristics still to be agreed by industry).

Infrastructure for slow-charging will not be very expensive, as most of the charging points will be at home (concept of "home-refuelling"), where the cost of charging points shall be much lower. Only a small number of additional fast-charging points will be required, according to the expectations of most industrial actors in the field.

Electricity consumption cost, on the basis of commodity cost without taxes, is comparable to fuel cost for petrol/diesel vehicles, as the overall energy consumption is the same. Real cost to the consumer, however, may be different, depending on the level of taxation.

Electrification of railway infrastructure as well as purchasing and operation of electric railway vehicles can be done with proven technology and predictable prices.

Hydrogen

Hydrogen vehicles have been estimated 4-5 times more expensive than petrol/diesel ICE vehicles [13]. For a medium size car, the difference would then amount to 150,000- 200,000 € in a pre commercial phase.

After 2025, the total cost of ownership (TCO) of all power trains is expected to converge and by 2050, BEV, HFCVs and PHEVs could become all cost competitive with ICEs and then be viable alternatives. HFCVs have then a TCO advantage over BEV and PHEVs in the heavy/long distance car segments; by 2030 they are almost comparable to ICEs for larger cars and by 2050 considerably less expensive.

With incentives, BEVs and HFCVs could be cost competitive with ICEs as early as 2020.

Infrastructure costs of hydrogen are estimated, in a recent study presented to the Future Transport Fuels Expert Group, to drop significantly from 12.000 € per vehicle to 3.000 € in 2020. After 2020, the infrastructure costs for FC vehicles are expected to be less than for battery electric vehicles.

The same recent study presented investment costs of at least 500,000 € - 1,000,000 € for a hydrogen filling station under conditions of mass deployment (cost based on average proprietary industry data)). Assuming a smaller number of hydrogen outlets in Europe as filling stations (40,000) results in a total cost of 30 b€ for area covering build-up. A smaller number is sufficient as a new network allows optimizing the sites.

Hydrogen production costs are expected to be reduced by 40% to 50% over the next 40 years. Currently production costs of hydrogen for transport amount to 16.6 €/kg delivered at pump (1 kg allows around 100 km driving range), with high retail costs (2/3). This cost is projected to decrease by 70% in 15 years (2010-2025) to 5.5 €/kg with the development of large plants and stations.

Biofuels

No additional investment is required for vehicles as long as low-blend and fully fungible biofuels are used. High-blend biofuels (above E10 and B7) will require limited additional infrastructure for distribution, storage and re-fuelling, and possibly some engine modifications.

Railway experience in blending diesel with biodiesel varies; while evidence suggests blends of up to 20% biodiesel operate well, significant losses of operational performance can occur at higher biodiesel blends. This could be avoided by using paraffinic type fuels HVO and BTL.

Additional infrastructure for distribution and storage has already been installed for current low blend biofuels.

No new infrastructure is required for low-blend biofuels or for using synthetic fuels. Higher-blend traditional biofuels, such as ethanol and biodiesel will require limited additional infrastructure for distribution, storage and re-fuelling. Paraffinic type fuels HVO, GTL and BTL are fit for the current infrastructure also in high blending ratios or as such.

Biofuel production costs vary over a wide range. The cheapest bioethanol (from sugar cane) could be competitive in the market or even cheaper than petrol but this analysis is directly linked to the relative evolution of the food crop commodities market and the oil market (from 50 up to 130 $/bbl); synthetic biofuels are up to a factor 2 more expensive than the commodity price for petrol/oil, in present conditions.

As regards costs for HVO and BTL, according to a recent Bloomberg study [21], feedstock costs represent about 70 - 75 %, conversion costs about 10 %, and capital costs about 15 - 20 % of the total costs of HVO, as shown in Figure 12. This means that HVO costs are feedstock dominated as is the case with FAME. Today HVO’s feedstock is practically the same as for FAME. However, somewhat more feedstock is available for HVO since the HVO process is able to yield good final product quality (stability, cold properties) from various kinds of vegetable oils and animal fats, reducing costs compared to FAME. In the future, non-food vegetable oils and algae oils are expected to become available for HVO production in significant cost effective volumes.

BTL technology is available in pilot scale at this moment, and scaling up to commercial scale is anticipated before 2020. The Bloomberg study shows an estimate where capital costs have the major effect (about 60 %), but feedstock costs are clearly lower than for HVO and FAME.

For fuel refiners, HVO and BTL are valuable blending components in high blending ratios since they enhance properties of the fossil diesel fuel part (increasing cetane number, reducing density and aromatics, suitable for winter conditions).

Synthetic fuels

According to an earlier study by the California Energy Commission [22], a GTL blend with diesel was found to be the most cost effective solution to replace oil based fuels. GTL is still a cost-competitive alternative to conventional oil products today. With rapidly increasing natural gas reserves, following the recent discoveries of large amounts of shale gas, the favourable market prospects for GTL as a main option for a universal future transport fuel are only growing. Cost reduction of future GTL plants might also be expected as a result of economies of scale and experience with recently commissioning of large commercial plants.

Figure 11 shows the resulting operating cost estimates for different biofuel pathways.

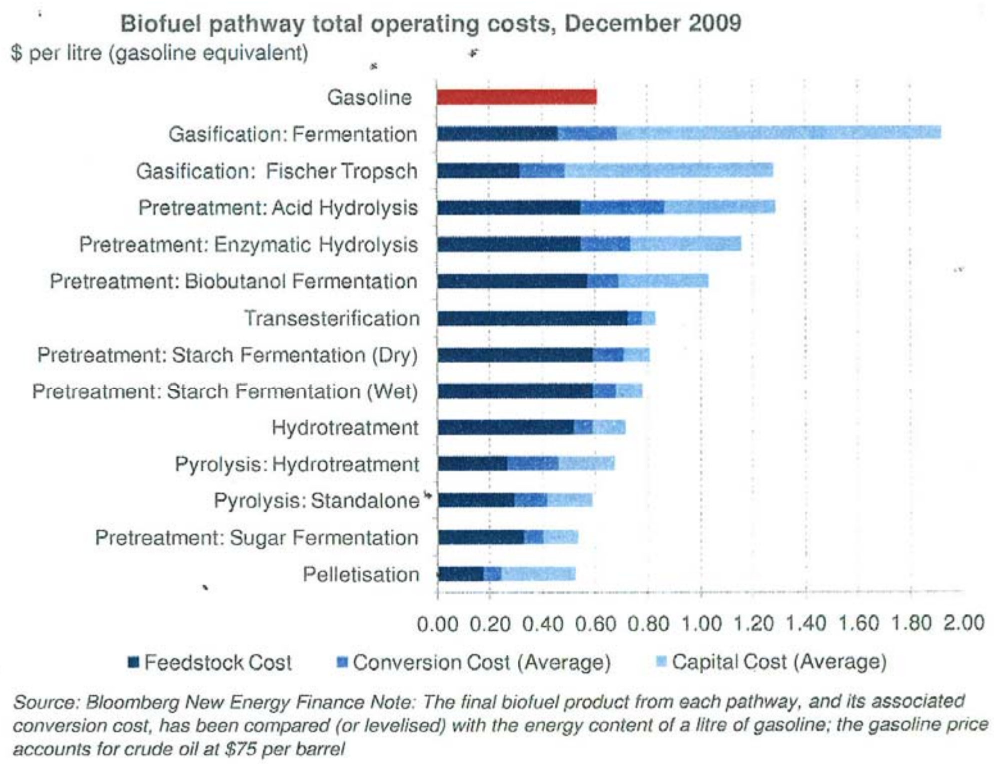

Figure 11: Cost estimates of biofuel pathways. Source: Bioenergy Research Note, Bloomberg New Energy Finance, January 25, 2010.

Methane

Methane cars are in the same price range as diesel cars. Heavy duty trucks and buses are 10,000-20,000 € more expensive than the comparable diesel vehicles, mostly because of the higher cost of gas combustion engines fabricated at much smaller number than diesel engines. Certain niche markets, such as urban public transport or garbage collection, however, offer larger consumption and can be cost-effective in terms of infrastructure and re-fuelling. These urban captive fleets could therefore guarantee profit even with higher cost of vehicles.

Infrastructure for methane distribution has to be extended, with a new outlet in a filling station at a cost of the order 250,000 €. Assuming the same number of methane outlets in Europe as filling stations (100,000) results in a total cost of 25 b€ for area covering build-up. Cost would be significantly lower by choosing strategically located points providing a sufficient coverage.

Cost for methane as a fuel could be lower than for petrol/diesel, as methane as natural gas comes directly from the well and does not need to pass through refineries. Bio-methane could have comparable cost at fabrication in industrial quantities.

LPG

LPG vehicles are being offered as bi-fuelled vehicles at an additional price of about 2,000€ cost, which can be dramatically reduced as demonstrated in some countries. As the LPG core infrastructure is already established, however, the additional price of LPG vehicles could be reduced with greater market penetration developing.

No major investment into additional infrastructure for LPG is needed.

LPG as a fuel has about the same commodity price as petrol/diesel.

System costs for alternative fuels in road transport

The additional costs for alternative fuel vehicles have been assessed in the European well-to-wheels study. An overview is given in Figure 12.

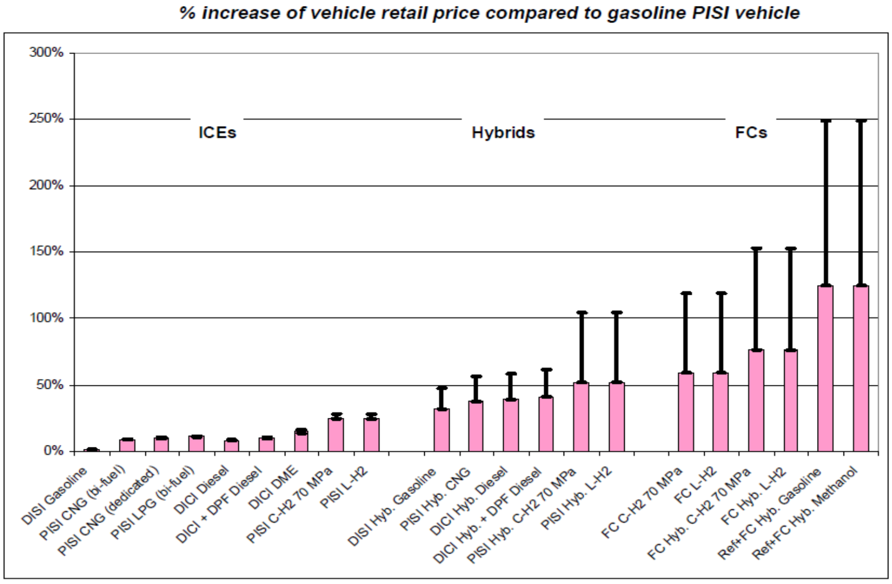

Figure 12: Relative increase of the vehicle retail price for different fuel and vehicle technologies, compared to a gasoline powered vehicle (JEC Well-To-Wheels study 2008)

Cost of oil substitution and cost of CO_2 emissions reduction have been determined in the JEC Well-To-Wheels study for the different alternative fuel pathways. A summary is shown in Figure 13 for a scenario based on an assumed oil price of 50 €/bbl. The most cost-effective solutions are wood-sourced DME, synthetic diesel from wood (BTL), bioethanol from crops, and biodiesel.

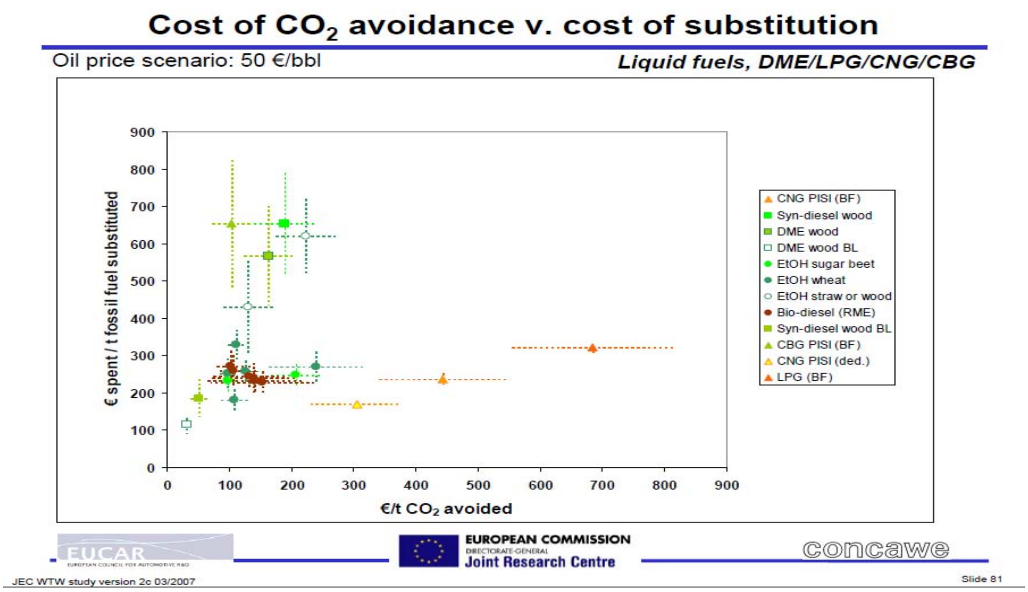

Fig. 13: Cost of oil substitution versus cost of CO_2 emissions reduction for different alternative fuel pathways, over the whole fuel chain (JEC Well-To-Wheels study)

6. Strategy 2050

A long-term view and a stable policy environment are required to provide clear, consistent and unwavering signals to industry and investors on the necessary actions to substitute fossil fuels and decarbonise transport. A long-term trajectory should therefore be defined for Europe within a predictable regulatory framework. Within this trajectory, managing the transition from a predominantly fossil fuel to a predominantly alternative fuel transport system will be an ongoing challenge.

Policy and regulation should be technology neutral, founded on a scientific assessment of the well-to-wheels CO_2 emissions, energy efficiency, and cost associated with competing technology pathways. The incentives for alternative fuels should be based on their CO_2 footprint and their general sustainability. This should include recognition of all alternative fuel pathways and all CO_2 abatement measures available, including application of carbon capture and storage (CCS).

Separate regulations on the energy system and on the transport system ensure more efficient implementation and leave flexibility for adopting the most cost-effective solutions. However, these regulations need to be developed in parallel to ensure that they are complementary and that they provide consistent message to industry.

In consideration of EU dependence on energy imports, sustainability standards at the global level and EU standards that apply to domestic production as well as imports, are key elements of alternative fuels policy to ensure that potential issues on bringing land into cultivation, protection of rare habitats and species (biodiversity), soil and water issues are managed. Safeguards are also needed in areas including migrant labour, the protection of human rights, and local communities. These sustainability standards should be applied similarly and in a non-discriminatory way to all pathways of energy and raw material.

The energy supply to transport is summarised in Figure 14, showing on the left side the most important primary energy sources, from crude oil and natural gas to renewable. Of these, the energy carriers (shown in the middle) are produced. On the right side of the figure, the main fuel systems are presented.

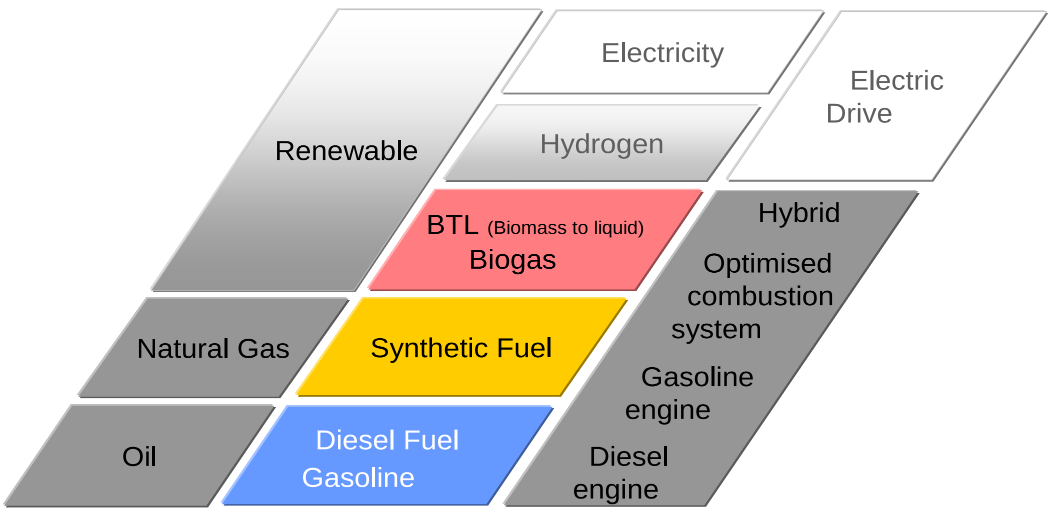

Figure 14: Fuel and vehicle propulsion strategy (Source: ERTRAC)

The first element of a long-term fuel strategy should be a continuous strive for increasing the energy efficiency of all transport operations as well as vehicles, by means of rigorous, consistent implementation of the downsizing concept, direct injection, charging and engine displacement reduction and the utilisation of new efficient combustion systems of all diesel and petrol engines. This stretches the availability of fossil resources and facilitates full substitution of oil by CO_2–free energy sources in the long term. The main guidelines for this strategy are the following:

- **Energy efficiency** policies in the end-use transport sectors allow energy savings and reduction of CO_2 emissions. They will not provide for oil substitution, as required in the longer term. But energy savings through efficiency policies are an important prerequisite for replacing oil-based fuels, meeting increasing demand with limited supply from alternative energy sources.

- **Future transport technologies** and measures designed to promote them, need to deliver both on efficiency and on replacing oil-based energy with renewable energy. Past developments have shown that energy efficiency standards have indeed the potential to deliver on both. As an example, the inclusion of a 95 g CO_2/km target for 2020 in Regulation 443/2009 has boosted electric cars in their various forms.

- **Allocation of fuels** to the different sectors of transport might better be achieved through market competition than through regulatory measures. Some sectors could also afford higher fuel prices, supporting early market development of initially more expensive alternative fuels.

- **Electric drive technology** has the greatest potential for sustainable short to medium distance road transport over the long term, although it is not yet decided whether the electricity used will be stored in a battery or generated in a fuel cell using hydrogen. In case of vehicles fed by overhead line/third rail there is no significant need to store energy.

- **Liquid and gaseous biofuels** are other priority candidates for oil substitution in the long term strategy, within the time horizon of 2050. They are primarily needed in those sectors where no alternatives exist, such as aviation, parts of maritime transport, and long-distance freight transport. Fungibility of biofuels would be of advantage for their long-term market expansion. The option of alternative biofuels blending standards should be compared with fungible biofuels, both for liquid and gaseous pathways, with fully flexible blending ratios between fossil and biomass based products in order to allow a smooth transition in the fuel mix and to keep and valorise the achievements of internal combustion engine technology.

- Any decision to expand the use of biofuels should take into account the impact on life-cycle GHG emissions and biodiversity. The **sustainability safeguards for biofuels** should be reviewed to prevent i.a. unwanted effects on indirect land use change.

- **Bioethanol** expansion would need additional standards for higher blending ratios, going from E5 to E10 in 2011 and then possibly to E20. Before introducing higher blends into the market, their compatibility with vehicle and infrastructure technologies needs to be ensured. The 2020 RED target could be supported by a wider deployment of flex-fuel vehicles using E85 blends. Blending potential and associated costs should be analysed.

- Expansion of diesel alternatives can be supported by **blending paraffinic fuels** (HVO, GTL, BTL) that are fully fungible with existing vehicle technology and distribution infrastructures in any blending ratios.

- The technical and economic complications of several different **biofuel blending standards** for fuel supply infrastructure and vehicle technology need to be assessed against the option of fully fungible (synthetic) biofuels complying with one single standard.

- There should be clear and stable guidelines on the **injection of bio-methane into the grid**, including possible favourable tax treatment supporting market build-up. This can balance regional differences in biogas production and natural gas consumption by vehicles, and avoid double investment into a parallel bio-methane distribution network.

- The approach with **tailored fuels versus a multi-segment approach** should be analysed in depth. R&D activities and a possible pilot project could be proposed for adequate testing of these technologies.

All these principal alternative fuel candidates can be produced from low-carbon technologies. Substitution of oil in transport by them leads inherently to a decarbonisation of transport if the energy system is decarbonised. Life-cycle aspects have to be included in this assessment.

Decarbonisation of transport and decarbonisation of the energy system can therefore be considered as two complementary strategic lines. They are closely related, but can be decoupled and require different technical approaches. Decarbonisation of the energy carriers used in transport should progress at least with the rate of their introduction into the transport fuel mix. However, the decarbonisation of the two systems needs to be undertaken in a complementary manner in order to ensure that approaches are consistent.

Harmonised standards should be developed for all fuels recognised as "EU fuels", i.e. fuels of EU-wide coverage, to allow economies of scale for the market roll-out and free movement of all vehicles using these principal alternative fuels.

The following additional issues should be taken into consideration for the different transport sectors:

- Road transport:

  - Urban transport can be powered by several alternative fuel options, namely electricity (battery electric small vehicles or electric trolleys) and hydrogen; also by biofuel blends, neat synthetic fuels or paraffinic, methane or LPG. Possible risks of market fragmentation and resulting limitations in economies of scale in case of competition between the two fuels need to be clarified.

  - Medium distance transport could be covered by synthetic or paraffinic fuels, hydrogen, biofuel blends and methane. For methane, a gas grid already exists. Possible competition also needs to be clarified, as hydrogen and methane require the build-up of new dedicated infrastructure. Methane gas vehicles are mature technology where as hydrogen driven engines have to be further developed.

  - Long distance transport can be supplied by biofuels or synthetic or paraffinic fuels, for freight possibly also by liquefied methane gas (LNG, LBG or LPG).

  - In all cases (urban, medium and long-distance), there will continue to be a significant role to play for the internal combustion engine and advancements in ICE technology can be expected and certainly not disregarded in future scenarios

- Railways and urban rail systems can further contribute to decarbonising transport, since power generation is on a path of decarbonisation through the EU ETS and renewable energy targets. Additional electrification should be undertaken. For those few lines where electrification is not feasible or economically viable, engine technology from heavy duty road vehicles could be adapted for rail. Possible standards for diesel engines and potential use of biofuels, and possibly LNG should be explored.

- Aviation will be reliant on liquid kerosene. Therefore, for aviation the most promising sustainable alternative is to adopt synthetic biomass derived fuels.

- Waterborne transport could be supplied by synthetic or paraffinic fuels for all types of vessels, by hydrogen on inland waterways, biofuels, LPG, and LNG on short sea shipping, and nuclear on long distance.

Diversification of primary energy sources, with the aim of reducing dependence from fossil reserves, decarbonising energy sources, and maximising the use of electricity from low-carbon sources and globally sustainable liquid and gaseous biofuels and for mobility, are therefore the objectives of this fuel strategy.

Finally, a policy that acts on demand patterns should be developed, reflecting the importance of investing in infrastructure that favours low carbon development. The strong relationship between the provision of infrastructure spatial planning and transport speed on the one hand, and transport demand on the other hand, as stated by the 2010 report to the Commission “EU Transport GHG: Route to 2050?”, needs to be taken into account.

7. Road map 2010-2050

Transitions in fuel supply infrastructure and vehicles will be needed for all new transport fuels. These transitions may need to be encouraged or mandated throughout all EU Member States and coordinated at the EU level in order to drive the market forward.

The timing and priority of these transitions must be driven by:

- Cost of the transition to a new energy carrier in terms of infrastructure and vehicle cost
- Potential carbon savings of the transition, taking into account the time that will be needed to decarbonise the energy stream
- Cost of decarbonising the energy sources which will feed into the energy stream
- Availability of feedstock for decarbonising the energy sources taking into account life cycle aspects for the different fuel pathways e.g. land use change

Assuming that targets for CO_2 reductions of transport continue increasing steadily to almost 100% by 2050, improvements in the energy efficiency of transport operations and vehicles will provide a period of several years to evaluate and develop the technologies for alternative fuel systems that will require major transitions in infrastructure and vehicle design. Timely decision on these major transitions can therefore be taken to ensure a cost effective solution that is commensurate with adequate industrial lead-time.

A transition strategy will be necessary for the short and medium term. The following points could be used as guidelines to this aim:

- During the next decade, gasoline and diesel will remain the main fuels for transport and are expected to stay at a similar level to today.
- Electricity is expected to increase its market share in the short to medium term, starting over the next years. But for road transport, it may remain confined to short-distance transport. To overcome this limitation, fast-charging or battery exchange infrastructure could be built up along TEN-T corridors. In addition, rail offers a readily available low-carbon, low-oil option. Rail should be further electrified wherever technically feasible and economically reasonable.
- Hydrogen could enter the broader market in the medium to long term, starting around 2015, and would then require strategic integration of hydrogen production and distribution facilities in current transport infrastructure planning (TEN-T).
- Liquid biofuels that fulfil all sustainability criteria and effectively reduce greenhouse gas emissions, compared to the fossil fuels they are replacing, should be developed, meaning further improving current technologies and developing new ones. The option of standards for additional biofuel blends should be compared with fungible fuel types, such as synthetic fuels, which allow for a wide range in the blending ratio with mineral oil fuels, in order to provide a smooth transition from fossil to renewable fuels. The potential of alternative sources of biomass such as algae should be unlocked.
- Methane, from fossil natural gas and biomass derived bio-methane, can serve as an additional option in the short, medium and long term. Bio-methane is particularly attractive as this path provides the highest energy yield per agricultural area used. Methane gas vehicle technology is mature for the broad market, and the existing dense natural gas distribution network in Europe could supply rapidly expanding natural gas filling stations. Additionally, synthetic

natural gas derived fuels (GTL) can contribute to the substitution of oil without modifications to the existing vehicle fleet and refuelling infrastructure.

- Liquefied methane gas (liquefied natural gas LNG and liquefied biogas LBG) could substitute oil for long-distance transport. Strategic freight transport corridors should therefore be equipped with LNG/LBG filling stations. LNG/LBG supply infrastructure should also be built up for ships.
- LPG, currently the alternative fuel with the largest market share, is expected to keep its position as fuel primarily used in passenger cars and vans, with the potential, however, of possibly increasing from its current market share of around 3% to around 10% by 2020. In the long-term perspective, beyond oil, biomass could be available for producing bio-LPG in bio-refining processes.
- There is also a need to take a global perspective here, especially for aviation and maritime applications. Equally, the European car manufacturing industry must be competitive on a global scale. Eco-innovation can certainly contribute to this competitive position. On the other hand, emerging markets will gain in absolute and relative importance. The EU cannot afford to ignore technology choices beyond its borders. This suggests that some advanced fuel technologies (fuel cells, electric motors) may be confined to certain niches.

8. Actions 2010-2020

8.1 Policy approach

General

- **Maintain focus on "systems solutions" for sustainable transport. Fuel** providers, **vehicle** providers and **users** must all contribute to a sustainable transport future, and policy should promote consistent and complementary action across all participants in order to foster the co-evolution of the transport and energy systems.

- **Maintain a portfolio approach** when allocating priorities in funding in the Eighth Community R&D Framework Programme (2014-2020). All sustainable transport solutions, including demand management, are needed. The span of the R&D programme should include a fair allocation of funding for the main alternative fuel options identified in this report.

- **Set a certain / stable policy environment that delivers a clear and consistent signal to industry on the actions required to decarbonise transport.** Defining a long-term trajectory for Europe within a predictable regulatory framework, creates certainty in the market that investments in sustainable transport pathways will have value over time, encouraging an investment approach rather than a simple focus on short-term compliance.

- In order to stimulate all sustainable transport solutions, **a wide range of complementary policy instruments, from regulation to marked-based instruments, are needed**.

- **Policy and regulation should be technology neutral,** founded on a scientific assessment of the **well-to-wheels GHG emissions** associated with competing transport pathways and the relevant life cycle aspects.

- **All fuel options will be required**; hence a level playing field will provide the most effective mix of transport fuels to address the energy challenge. This is a key criterion to consider during reformation of the energy tax directive and in future reassessments of border tariffs imposed on sustainable biofuels.

- Regulation should **avoid "double burdens" imposed on fuel suppliers by overlapping policies** that favour specific solutions, such as fuel mandates, additional CO_2 taxation levies on transport fuel, and emissions covered under the EU Emissions Trading Scheme (ETS).

- **Sustainability standards** are a key element of alternative fuels policy to ensure that potential issues with bringing land into cultivation, protection of rare habitats and species (biodiversity) and soil and water issues are managed. Of fundamental importance is that the alternative fuels deliver reductions in CO_2 emissions when these are measured across the life cycles of the fuel. Social safeguards are also needed.

- Solutions should be such that they can be used widely in Europe **in all climatic conditions.**

Well-to-wheels and life cycle aspects

- The well-to-wheels analysis established by the JEC research collaboration (European Commission's **J**oint Research Centre, **E**UCAR, and **C**ONCAWE) should be further developed to include all fuels and different vehicle classes, at current technology, and future projections to full market maturity of all main alternative fuels. Regular updates should be foreseen, in line with the expected technological developments.

- The well-to-wheels analysis should be extended and differentiated to cover all main types of fossil fuels, including oil products derived from tar sands, oil shale and deep-sea drilling, and shale natural gas. The analysis of fossil fuel life-cycle aspects should be based on the same approach used for biofuels.

- The well-to-wheels (WTW) methodology should be used to broaden the basis for analysis by all stakeholders on the main alternative fuels whilst adhering to the rigorous technical evaluation of emissions inventories for transport fuels.

- Life-cycle analyses on important aspects of alternative fuels and vehicle technologies, such as feedstock, raw materials, land use changes, manufacturing and disposal processes should be linked to the well-to-wheels analysis.

- Sustainability criteria should be applied consistently among the different fuels on the basis of well-to-wheels and life-cycle aspects, including indirect impacts.

8.2 Legislation

General

- All sectors should internalise the cost of CO_2 emissions. All sectors have to play a role in reducing emissions. To avoid market distortions, policy makers should set up mechanisms requiring sectors across the whole economy to internalise the cost of their emissions.

- Policies aimed at reducing the carbon intensity of fuels and, more in general, reducing emissions in transport, should use a wide range of instruments, including internalising the external cost of transport for all modes and setting the right pricing signals, to stimulate the uptake of options that deliver CO_2 emissions reductions in transport and ensure a level playing field between transport modes.

- A CO_2 emissions reduction target for transport fuels should be considered instead of volume targets for renewables or specific alternative fuels, such as biofuels. Setting a CO_2 reduction target for transport fuels is an efficient approach to decarbonising the sector, as it allows fuel suppliers a wide range of reduction options, such as reducing flaring at refineries, using less-dirty crudes, deploying low-carbon alternative fuels and electricity. Thereby it can ensure significant CO_2 emission cuts. At the same time, however, it is crucial that the emissions from all different fuels are properly accounted, using the same approach for all fuel pathways.

- A policy framework that supports the deployment of alternative energy carriers in order to meet such targets is needed, in parallel to an appropriate infrastructure that would help customers make use of alternatives to oil.

- Regulation aimed at fuel characteristics should be coordinated with parallel regulation aimed at improving the fuel efficiency of vehicles (for all modes) and regulation on the share of renewables and the CO_2 intensity of the energy system in order to ensure that consistent and coherent requirements and incentives are provided.

- Regulation of the carbon content of fuels should be reviewed and revised towards setting progressively more stringent targets for the full fuel mix, consistent with the long-term objective of decarbonisation of transport. This regulation should be aligned with legislation on renewables and CO_2 in the energy mix in general, and the requirement for regulation on renewables in transport fuels should be re-examined in the wider context. Implementing provisions should ensure that the higher carbon content of unconventional fuels derived from tar sands and oil shale is duly reflected, and imports of such fuels effectively discouraged

- Regulation on fuel efficiency, or CO_2 emissions of vehicles should be revised towards setting progressively more stringent energy efficiency targets beyond 2020, whilst recognizing the importance of a systems solution with the transfer of emissions burdens between vehicles and fuels supply chains that can occur when moving from conventional to alternative fuels pathways.

- Efficiency standards should be introduced as a matter of urgency for all types of vehicles, including trucks, ships and air planes

- Low carbon fuel and vehicle policy, as well as the relevant technical developments, must be kept under regular review in order to ensure that policy is giving the right signals to all stakeholders, whilst maintaining sufficient stability and confidence to deliver an environment suitable for investment.

- Regulation should be based on an impact assessment of the various policy options to ensure that the principles of better regulation are followed and legislative measures aimed at achieving these ambitious objectives of transport decarbonisation are taken, based on the overall cost-effectiveness of the measures.

- EU policies should be better aligned, e.g. the EU Emission Trading System with the Renewable Energy Directive, and the various waste Directives between themselves.

<u>Electricity</u>

- Harmonised standards for plugs, batteries, power transfer, and information exchange between electric vehicles and electricity grid should be established and implemented EU-wide. The goal should be to establish worldwide standards in order to avoid market fragmentation and to reduce costs (economies of scale).

- Infrastructure for charging electric vehicles could be built up EU-wide to encourage the market take-up of electric vehicles and allow their free circulation in Europe.

- Proper framework conditions to make further railway electrification economically viable need to be set.

Hydrogen

- A basic EU hydrogen supply infrastructure could be built upon the existing demonstration filling stations and extended to an EU intercity network refuelling infrastructure, with support from EU, national and regional hydrogen development programmes.
- Harmonised authorisation procedures for hydrogen installations should be established as well as harmonised standards for refuelling pipes.

Biofuels

- Harmonised standards should be timely developed for biofuels, allowing the possibility of higher incorporation rates of biofuels into fossil fuel blends. Member States and the Commission should coordinate implementation of new standards and identical biofuel blending EU-wide to provide consumer and industry a proper common market. The goal should be to establish worldwide standards in order to avoid market fragmentation and to reduce costs by economies of scale.
- A review should be undertaken in the near future to consider the merits of moving to higher levels of low blend biofuels in general market fuels (i.e. beyond E10 and B7). Mid-level blends of ethanol (e.g. E20) might be needed in the mid-term to achieve the EU's climate and energy targets. This has been confirmed by the JEC-consortium in its recent biofuels study where E20 is considered to be part of the European fuel mix as soon as 2015. Since work on fuel specifications, adoption of infrastructure and cars takes a couple of years, an impact assessment should start immediately to assess the economic, technical and societal impacts of a rapid move to E20. If appropriate, standardization work should start as soon as possible.
- Periodical reviews, in particular of evolutions in feedstock are required on a regular basis, to support the technological developments for advanced biofuels with a clear and long term framework for the economic value of end products.
- A common approach should be taken across the EU on future biofuel blends. Countries outside the EU through which commercial transport moves, should be encouraged to provide the same quality fuels along those commercial routes.
- The EU should assess the impact of indirect land-use change due to biofuels on CO2 emissions and take appropriate action to reflect this in the Renewable Energy and Fuel Quality Directives.
- The Renewable Energy Directive should be reviewed in view of greater flexibility in sourcing strategies, such as co-processing and blending of various feedstocks.

Methane

- Build-up of an EU-wide area covering methane gas re-fuelling infrastructure should be considered, to ensure free circulation of methane-powered vehicles in Europe.
- Harmonised standards for biomethane injection into the gas grid should be developed.
- NG/biomethane should be promoted as one of the main fuels in heavy urban transport.

LPG

- Gaps in the refuelling network should be filled, with a view to ensuring free circulation of LPG powered vehicles in Europe.
- Feasibility and benefits of support for harmonised LPG filling unit design should be assessed.

8.3 Incentives

- Support schemes, such as purchase incentives and favourable taxation, should be provided, with the perspective that the main alternative fuels will become economically viable. These support schemes should be established with the perspective of long-term stability in order to assure industry and customers in fragile start-up markets, but should be time-limited so that they do not become subsidies. Support schemes should also be co-ordinated between the Commission and the Member States to ensure maximum harmonisation EU-wide in order to avoid market fragmentation on the expense of economies of scale. Possible implicit impacts of incentives on modal choices should be taken into account.

  Market incentives could include:

  - Tax incentives and direct purchase subsidy
  - Taxation based on a polluter-pays principle
  - Faster depreciation
  - Incentives for commercial customers and public fleets
  - Favourable “benefit-in-kind” taxation for company cars, whilst avoiding loopholes for increasing demand for cars, as is currently the case in several Member States
  - Subsidies for home/office charging infrastructure
  - Incentives for industry for R&D and production
  - Purchase incentives for clean and energy efficient vehicles
  - Access privileges (e.g. entry to low emission zones) for clean and energy efficient vehicles
  - Administrative simplifications for the build-up of new fuel infrastructure
  - Encouragement of new user models
  - Encouragement to switch to less energy-intensive modes
  - Encouragement to reduce commuting distances
  - Encouragement of teleworking to reduce transport

- The CO_2 emissions performance of fuels should be a key guiding principle for incentives.

- The forthcoming revision of Directive 2003/96/EC on the taxation of energy products and electricity and of Directive 2006/112/EC on the harmonised value-added tax scheme should provide a long-term perspective on favourable tax treatment of the main alternative fuels to ensure a stable framework and economic viability for the necessary investment by all stakeholders concerned. A new taxation structure should be set up so that energy content and CO_2 emissions related to the energy carrier are taxed separately.

- Low emission requirements on urban traffic could give regulatory advantages for electric/hydrogen vehicles, and to a certain extent also to vehicles powered by methane and clean burning synthetic fuels.

- Electricity infrastructure extension to supply ships in port should be supported by public funds.

- Use of clean energy in ports, in particular electricity, could be encouraged by differentiated charging for ships and boats in port. The charging scheme should be harmonised EU-wide to prevent market distortions at the expense of the environment.

- Increasing electrification of railways could be encouraged by harmonised differentiated charging.

- Incentives should be provided for the continued development of new, highly sustainable biomass feedstocks.

- The European Commission should ensure that agricultural/forest materials and biofuels imported into the EU do not receive public subsidies twice. The European Commission should use trade defence mechanisms to ensure fair competition between imported and EU-produced biofuels.

- Methane should be promoted as one of the main alternative fuels for Heavy Duty Vehicles (including buses) in urban transport.

- In WTO negotiations, export and import taxes on transport fuels and feedstocks (including oilseeds, vegetable oils and biodiesel) should be discussed and regulated to maintain a global level playing field consistent with EU trade policy.

- European Blue Corridors should be investigated for the build-up of Liquefied Natural Gas (LNG) infrastructure to support the use of liquefied methane gas in medium and long distance freight transport.

- Current distributors of diesel and gasoline could be encouraged to offer refuelling with alternative fuels.

- Biofuel development for sectors relying on high energy-density carriers (aviation and shipping) should be stimulated by community action, whilst recognising the global nature of regulation required for implementation within these sectors.

- EU ETS should be strengthened to support the introduction of biofuels in aviation.

- Local and regional authorities, being among the first customers of electric and fuel cell hydrogen cars, including buses, should be actively involved in the development of local infrastructures for battery cars and fuel cell hydrogen cars. A regional platform for electric transport to support the deployment of these vehicles, as exists now for hydrogen and fuel cells (HyRaMP) could be very effective in leveraging the complementary aspects of battery and fuel cell hydrogen car technologies with regard to the build up of a local industrial value chains and infrastructure, the efficient use of (local) primary energy sources, including renewable energy, for electricity and hydrogen production and to enhance the dissemination of best practice among key decision makers.

8.4 R&D support

- Within the R&D schemes (e.g. EU Framework Programme), the funding should be equally shared between new, advanced technologies (electric vehicle, HFC, advanced biofuels) and conventional technologies, as also the continuous improvement of conventional ICE vehicles is an essential part of decarbonising transport and reducing fossil fuel consumption.

- Research and technological development of the main alternative fuels should receive priority funding under the 8th EU Framework Programme.

- The strategic research agendas prepared by the Technology Platforms should be implemented.

- Key components of electric vehicles, in particular batteries, on-board power management, and systems for vehicle-grid interaction and infrastructure impacts should be supported in research and integrated demonstration projects.

- Support for hydrogen and fuel cell technologies should be continued, with increased funding, through the recently created JTI. Synergies with activities under the Green Car Initiative and the future Smart Cities Initiative as well as with other European Industrial Initiatives under the SET Plan should be identified to leverage funding and coordinate infrastructure build-up.

- Support for the continuous improvement of gaseous fuel components (fuel tank, mono-fuelled vehicles engine mapping, new injection strategies,..) should be given backing from the EU and the authorities.

- In the development of biofuels, priority support should be given i.a. to integrated bio-refineries for optimum exploitation of the biomass potential.

- Biotechnology research and development should be supported in the field of bio-energy and plant chemistry.

- Applied research for crops designated specifically for biomass and for average-wattage or large poly-combustible equipment should be supported. This will allow industrial or collective heating needs to be met, whilst at the same time preserving a balance in the supply of straw and other agricultural by-products.

- Production of bio-energy carriers from CO_2 and sunlight through micro-organism based production (algae, bacteria etc.) and further upgrading into transportation fuels and valuable bio-products (main market: renewable transport fuels for jet and diesel engines).

- The potential to increase productivity from degraded and abandoned land should be studied more closely.

- Pilot projects for heavy duty vehicles running on methane gas, and projects on synthetic fuels for long distance passenger and freight transport, should be supported.

- Support for multi-modal technologies and for technologies that promote the most oil-efficient and carbon-efficient transport modes, e.g. in terms of ticketing, information systems, coordination with other transport modes, for instance multi-modal route planners.

References

[1] European Commission, EU Energy and Transport in Figures, 2010 http://ec.europa.eu/transport/publications/statistics/statistics_en.htm

[2] BP Statistical Review of World Energy, June 2010

[3] Conclusions of Council, October 2009

[4] Communication from the Commission: Europe 2020. A strategy for smart, sustainable and inclusive growth. COM (2010)2020, Brussels, 3.3.2010

[5] Communication from the Commission: A sustainable future for transport: Towards an integrated, technology-led and user friendly system, COM (2009)279, Brussels, 17.6.2009

[6] Communication from the Commission: A European strategic energy technology plan (SET-plan), COM (2007)273, Brussels, 22.11.2007

[7] Intelligent Transport Systems and New Technologies within the Framework of TEN-T http://ec.europa.eu/transport/infrastructure/tent_policy_review/expert_groups/expert_group_3_en.htm

[8] Market Development of Alternative Fuels http://ec.europa.eu/transport/urban/vehicles/road/road_en.htm

[9] Renewable Energy Snapshots 2009, JRC Report (March 2009) http://re.jrc.ec.europa.eu/refsys/pdf/RE%20Snapshots%202009.pdf

[10] European Commission, EU Energy and Transport in Figures, 2010 http://ec.europa.eu/energy/publications/doc/statistics/part_2_energy_pocket_book_2010.pdf

[11] http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

[12] http://hyfleetcute.com/data/HyFLEETCUTE_Brochure_Web.pdf

[13] McKinsey study 2010

[14] European Bioethanol Fuel Association (eBIO)

[15] RED, Yanowitz & McCormick, 2009

[16] REFUEL project: http://www.refuel.eu/fileadmin/refuel/user/docs/REFUEL_D19a_flyer_feedstock_potentials.pdf

[17] http://igitur-archive.library.uu.nl/dissertations/2004-0309-123617/full.pdf

[18] Fachagentur Nachwachsende Rohstoffe eV (FNR) 2008

[19] Study on the impacts of LPG cars penetration in EU31 on the exhaust air emissions reduction http://www.tmleuven.be/project/tremoveaegpl/2009_12_05_AEGPL%20report_Final_110209.pdf

[20] A general description of the JEC Biofuels Programme is available at http://ies.jrc.ec.europa.eu/jec-research-collaboration/activities-jec/jec-biofuels-programme.html and the standard presentation of results can be downloaded from http://ies.jrc.ec.europa.eu/uploads/jec/JEC%20Biofuels%20Programme.pdf

[21] Bioenergy Research Note, Bloomberg New Energy Finance, January 25, 2010

[22] http://www.energy.ca.gov/reports/2003-08-14_600-03-005.PDF

ANNEX 1a: Commission Expert Group FTF : Member Organisations

	Road	Rail	Airborne	Waterborne
Mineral oil products	EUROPIA CONCAWE ASFE UPEI	EUROPIA CONCAWE ASFE UPEI	EUROPIA CONCAWE ASFE UPEI	EUROPIA CONCAWE ASFE UPEI
Biofuels (liquid, gas)	EBTP EBB eBIO EBA ePURE UEPA ASFE EFOA	EBTP EUBIA EBB eBIO ePURE UEPA EFOA	EBTP EBB eBIO ASFE ePURE UEPA EFOA	EBTP EBB eBIO EBA ePURE UEPA ASFE EFOA
Natural gas	NGVA Europe			NGVA Europe
Electricity	EURELECTRIC CEDEC EUROBAT AVERE	EURELECTRIC CEDEC	EURELECTRIC CEDEC	EURELECTRIC CEDEC
Hydrogen	FHC-JTI NEW IG N.ERGHY EHA AVERE	FHC-JTI NEW IG N.ERGHY EHA	FHC-JTI NEW IG N.ERGHY EHA	FHC-JTI NEW IG N.ERGHY EHA
LPG	AEGPL			AEGPL
Manufacturers	ACEA EUCAR		Clean sky JTI	CESA
Suppliers	CLEPA	UNIFE	Clean sky JTI	
Research	ERTRAC EPOSS EARPA		ACARE Clean sky JTI	
Operators, users	UITP IRU FIA EUROCHAMBERS EUROCOMMERCE CEDEC	UITP CER UIC EUROCHAMBERS EUROCOMMERCE CEDEC	AEA ACI Clean sky JTI EUROCHAMBERS EUROCOMMERCE CEDEC	UITP EBU EUROCHAMBERS EUROCOMMERCE CEDEC
Civil society	T&E WWF GREENPEACE IEEP COPA-COPEGA	T&E WWF GREENPEACE IEEP COPA-COPEGA	T&E WWF GREENPEACE IEEP COPA-COPEGA	T&E WWF GREENPEACE IEEP COPA-COPEGA

Commission Expert Group FTF: ACRONYMS OF MEMBER ORGANISATIONS

ACARE	Advisory Council for Aeronautics Research in Europe
ACEA	European Automobile Manufacturers' Association
ACI	Airports Council International
AEA	Association of European Airlines
AEGPL	European LPG Association
ASFE	Alliance for Synthetic Fuels in Europe
AVERE	European Association for Battery, Hybrid and Fuel Cell Electric Vehicles
CEDEC	European Federation of Local Energy Companies
CER	Community of European Railway and Infrastructure Companies
CESA	Community of European Shipyards' Associations
Clean Sky JTI	Joint Technology Initiative for Aeronautics & Air Transport
CLEPA	European Association of Automotive Suppliers
CONCAWE	The oil companies' European association for environment, health and safety in refining and distribution
COPA-COGECA	European Farmers; European Agri-Cooperatives
EARPA	European Automotive Research Partners Association
EBA	European Biogas Association
EBB	European Biodiesel Board
eBIO	European Bioethanol Fuel Association
EBTP	European Biofuels Technology Platform
EBU	European Barge Union (inland navigation)
EFOA	European Fuel Oxygenates Association
EHA	European Hydrogen Association
EPOSS	European Technology Platform on Smart Systems Integration
ePURE	European Producers Union of Renewable Ethanol
ERTRAC	European Road Transport Research Advisory Council
EUCAR	European Council for Automotive R&D
EURELECTRIC	Union of the Electricity Industry
EUROBAT	Association of European Storage Battery Manufacturers
EUROCHAMBERS	Association of European Chambers of Commerce and Industry
EUROCOMMERCE	Retail, Wholesale and International Trade sectors in Europe
EUROPIA	European Petroleum Industry Association
FCH-JTI	Fuel Cells and Hydrogen Joint Technology Initiative
FIA	Federation Internationale de l'Automobile
GREENPEACE	Greenpeace
IEEP	Institute for European Environmental Policy
IRU	International Road Transport Union
N.ERGHY	European Research Grouping on Fuel Cells and Hydrogen
NEW IG	European Industry Grouping for a Fuel Cell and Hydrogen Joint Technology Initiative
NGVA Europe	Natural Gas Vehicle Association Europe
T&E	Transport & Environment (European environmental organisation)
UEPA	European Union of Ethanol Producers
UIC	International Union of Railways
UITP	International Association of Public Transport
UNIFE	European Railway Industry
UPEI	Union Pétrolière Européenne Indépendante
WWF	World Wildlife Fund

ANNEX 1b: Commission Expert Group FTF. Stakeholder Participants.

MEMBER ORGANIZATION	REPRESENTATIVE	BACK-UP
ACARE		
ACEA	**Paul GREENING**	Anders ROJ
ACI		
AEA	**Araceli CAL**	Jean-Francois GRUSON
AEGPL	**Arnaud DUVIELGUERBIGNY**	
ASFE	**Nigel DICKENS**	Seppo MIKKONEN
AVERE	**Robert STUSSI**	
CEDEC	**Jorn HANSEN**	Marc MALBRANCKE
CER	**Steffen JANK**	Jerome LABARRE
CESA	**Lanfranco BENEDETTI**	
CLEAN SKY JTI		
CLEPA	**Richard AUMAYER**	Tim VINK
CONCAWE	**Ken ROSE**	
COPA-COGECA	**Dietrich KLEIN**	
EARPA	**Peter PRENNINGER**	
EBA	**Arthur WELLINGER**	
EBB	**Raffaello GAROFALO**	Amandine LACOURT Adrian O'CONNELL
EBIO	**Warwick LYWOOD**	Robert VIERHOUT
EBTP	**Birger KERCKOW**	Jean-Francois GRUSON
EBU	**Robert TIEMAN**	
EFOA	**Sunanda BANERJEE**	Walter Mirabella

MEMBER ORGANIZATION	REPRESENTATIVE	BACK-UP
EHA	Ian WILLIAMSON	
EPOSS	Sebastian LANGE	
ePURE	Robert VIERHOUT	
ERTRAC	Wolfgang STEIGER	
EUCAR	Anders ROJ	
EURELECTRIC	Thomas THEISEN	Gunnar LORENZ
EUROBAT		
EUROCHAMBER	Dieter KREIKENBAUM	
EUROCOMMERCE	Fatma SAHIN	
EUROPIA	Isabelle MULLER	Harald SCHNIEDER
FHC-JTI	Carlos NAVAS	Claire CASTEL
FIA	Wilfried KLANNER	
GREENPEACE	Franziska ACHTERBERG	
IEEP	Ian SKINNER	Catherine BOWYER
IRU	Marc BILLIET	
N.ERGHY		
NEW IG	Gijs VAN BREDA VRIESMAN	Ilse VAN HARTEVELT
NGVA Europe	Manuel LAGE	Matthias MAEDGE
T&E	Jos DINGS	
UEPA	Valérie CORRE	
UIC		
UITP	Ulrich WEBER	Paul ARENTS
UNIFE		
UPEI	Bernard SCHNITTLER	Anahita ARYAN
WWF		

ANNEX 1c: Commission Expert Group FTF: COMMISSION PARTICIPANTS

EC / DG	REPRESENTATIVE	BACK-UP
MOVE	Franz SÖLDNER (Chairman) Carlos GARCIA BARQUERO (Technical Coordinator) Antonio TRICAS AIZPUN Hugues VAN HONACKER Aneta CIUPEK Piotr RAPACZ Hoang VU DUC Felix LEINEMANN Victoria BUTLER	
AGRI	Mauro POINELLI	
CLIM	Wojciech WINKLER	Marek STURC
ENER	Paul HODSON Ewout DEURWAARDER	Malcolm McDOWELL Maniatis KYRIAKOS Marcus LIPPOLD
ENTR	J. BARREIRO HURLE	
ESTAT	Monika WRZESINSKA	
INFSO	Cosmin CODREA	Wolfgang HOEFS
REGIO	P BERNARD-BRUNET Enrique BUATAS COSTA	
RTD	Daniel CHIRON	Maurizio MAGGIORE
SG	Marcel HAAG	
SANCO	Kyriakos GIALOGLOU	Sara TROIANO, Marta GAZZOLA
JRC-ISPRA	Laura LONZA	
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JRC-PETTEN	Jean-Pierre SCHOSGER	Christian THIEL
EEA	Peder JENSEN	David CLUBB

ANNEX 1d: ACRONYMS AND ABBREVIATIONS

BEV: Battery Electric Vehicle
BTL: Biomass-To-Liquid
CEN: European Committee for Standardization
CHP: Combined Heat and Power
CNG: Compressed Natural Gas
CTL: Coal-To-Liquid
CWA: CEN Workshop Agreement
DME: Di-Methyl Ether
ETBE: Ethyl Tertiary Butyl Ether
ETS: European Trading Scheme
EV: Electric Vehicle
FAME: Fatty Acid Methyl Ester
FQD: Fuel Quality Directive
GHG: Greenhouse Gas
GTL: Gas-To-Liquid
HEV: Hybrid Electric Vehicle
HFC: Hydrogen Fuel Cell
HFCV: Hydrogen Fuel Cell Vehicle
HRJ: Hydrotreated Renewable Jet
HVO: Hydrotreated Vegetable and animal Oils
IEA: International Energy Agency
ICE: Internal Combustion Engine
ILUC: Indirect Land Use Change
JTI: Joint Technology Initiative
LNG: Liquefied Natural Gas
LPG: Liquefied Petrol Gas
MSW: Municipal Solid Waste
OEM: Original Equipment Manufacturer
PHEV: Plug-in Hybrid Electric Vehicle
RED: Renewable Energy Directive
REV: Range Extender Electric Vehicle
TCO: Total Cost of Ownership
TTW: Tank-To-Wheels
WTO: World Trade Organisation
WTT: Well-To-Tank
WTW: Well-To-Wheels

ANNEX 2a: NGVA Europe assessment of liquid biofuel / biomethane potential

Fact Sheet: Biomethane production potential in the EU-27+EFTA countries, compared with other biofuels.

Data used in this Fact Sheet come from the NGVA Europe's Position Paper "Biomethane", prepared by Mattias Svensson, MSc Chem. Eng., PhD Env. Biotechnology, Research Manager at the Swedish Gas Center, in June 2010.

Note about units:
1 EJ (exaJoule) = 10^{18} Joule
1 PJ (petaJoule) = 10^{15} Joule
1 EJ ~ 24 Mtoe

BIOMETHANE PRODUCTION POTENTIAL
Some basic data at world level:

- Current global energy utilization in 2007 amounted to 347 exajoules (EJ, corresponding to 8.286 Mtoe, or 96,4 petawatthours, PWh) (*IEA 2009*).
- Theoretical energy potential of the global annual primary production of biomatter is enormous, 4.500 exajoules (EJ)
- Out of the 2.900EJ theoretically harvestable biomass, approximately a tenth is considered technically available on a sustainable basis, 270EJ (75PWh) (*WEA 2000*)
- Other research indicates an upper limit of 1.135EJ in 2050 for a sustainable global bioenergy production not interfering with the supply of food crops (*Ladanai and Vinterbäck 2009*)

European level

- It is reported that the sustainable primary biomass potential, waste streams included, will increase from 8 EJ (2,2PWh) in 2010 to 12EJ (3,3PWh) in 2030 (*EEA 2006*).
- Higher total estimations are also reported, for example a technical potential of biomass of 17EJ (4,7PWh) for EU-27 (*Ericsson and Nilsson 2009*).
- **A large share of this may come from agriculture, increasing from 2EJ (547TWh) in 2010 to 5,9EJ (1,6PWh) in 2030 (*EEA 2007*).**
- **With a conservative land utilization (5% of the arable land), estimations on the biogas potential of energy crops from anaerobic digestion in EU-27 show yields ranging between 0,9 to 2,7EJ (252-758TWh) with harvest yields of 10-30 tonnes dry solids per hectare (*Holm-Nielsen 2008*).** This value is coherent with the previous estimation of 2 EJ for 2010.
- A coarse estimate for the 500 million inhabitants of EU-27 indicates a biogas potential of 68TWh (0,24EJ) from wastewater sludge. In agriculture, animal manure represents a very large biogas potential.
  Estimates for EU-27 show a theoretical potential of 205TWh (0,72EJ) (*Holm-Nielsen 2008*). Summing up, as much as 453TWh (1,6EJ), not including landfills, could come annually from waste streams.
  Energy crops could optimistically add to that figure up to 1.500TWh (5,4EJ), depending on share of arable land and crop yields.

- Most European countries have extensive grid coverage, enabling a large share of the biomethane potential of Europe to be realized through injection schemes. A German biomethane injection study (*Thrän et al. 2007*) shows that the biomethane potential of anaerobic digestion and thermal gasification from residual products and a sustainable production of energy crops in the vicinity of the European gas grid (EU-28) may in 2020 be in the range of 2.000-3.500TWh (7-12,4EJ).

  If including the potential of the CIS countries, the potential increase to 4.000-6.000TWh (14,1-21,2EJ), large enough to cover the current EU-28 natural gas utilization.

Additional data from other sources, confirming the estimates

Other studies (Möglichkeiten einer europäischen Biogaseinspeisungsstrategie. Institut für Energetik und Umwelt, Leipzig, 2007 and Biomethane in the transport sector. An appraisal of the forgotten option, Max Ahman, 2009) estimate for the EU 27 the biomethane potential to be approx. 5,47 – 8,9EJ (**131 – 214Mtoe**) in 2020. The given numbers can be taken as a theoretical maximum reference based on available biomass resources in Europe (energy crops, ligneous waste, wet biomass without urban waste, etc.). Taking into account current infrastructure conditions and different biomethane interests in the various European countries, reaching 10% of the mentioned total biomethane potential could be feasible for the EU 27 and EFTA countries in 2020. This potential includes biomethane produced though biological and the thermo chemical conversion process.

This figure of 5.47-8.9EJ in 2020 is quite well aligned with the other previously indicated forecast of 8EJ in 2010 to 12EJ in 2030 (*EEA 2006*).

COMPARISON WITH OTHER BIOFUELS

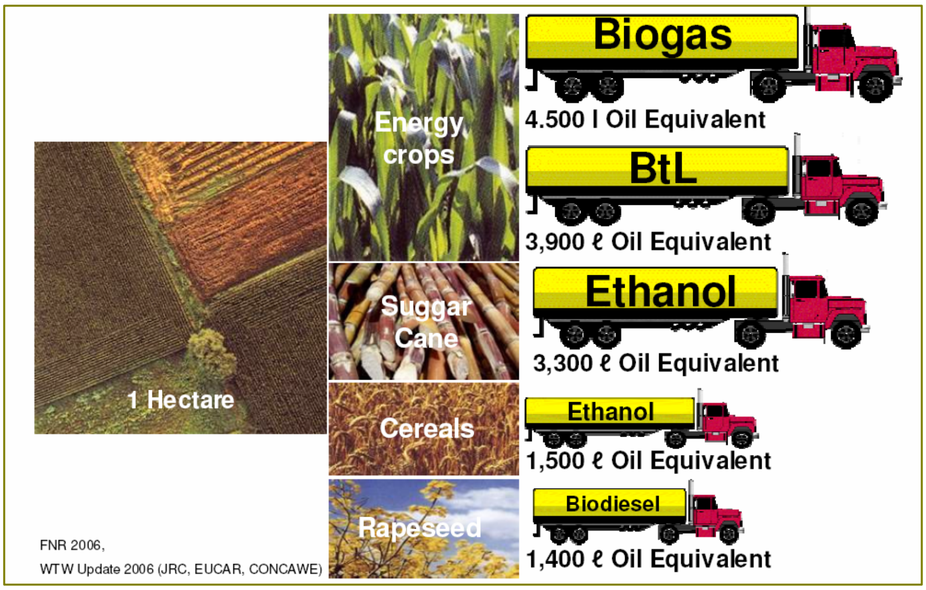
The production of other (liquid) biofuels is based only in crops, and its land surface efficiency is clearly lower than in the case of biogas. See illustrations below.

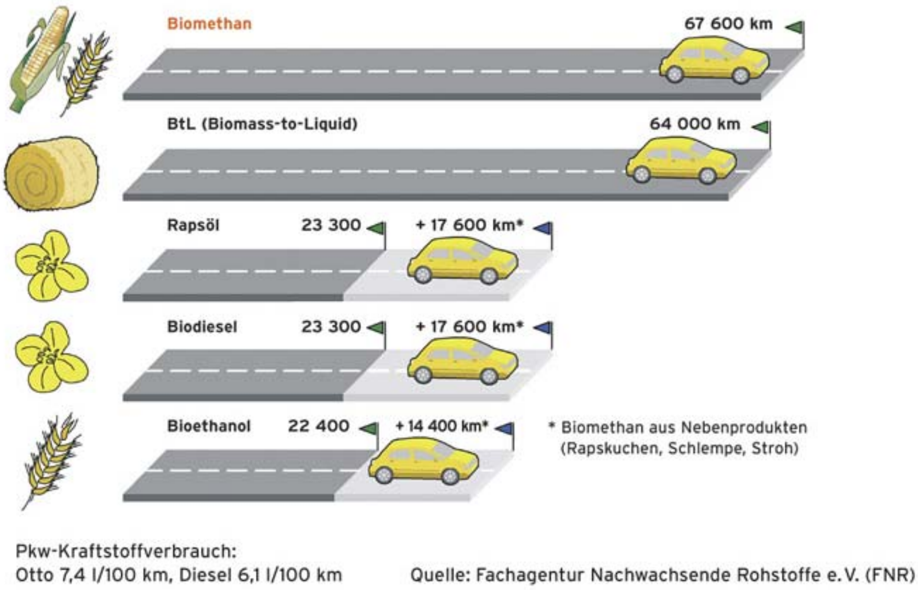
The efficiency of the land devoted to ethanol production, as an average of cereals and sugar cane crops, would be 2.400 litre of oil equivalent per hectare. In the same conditions the biogas production reaches 4.500 litre of oil equivalent, which is roughly double.

If we apply this 53% land efficiency of bioethanol against biogas production, both coming from crops, the total 1.500 TWh (**5,4EJ= 130Mtoe**) estimated potential for biogas, would be reduced to some 800 TWh (**2,9EJ= 70Mtoe**) in the case of ethanol.

If we now take the global estimation of 2.750 TWh (**9,9EJ**= **238Mtoe**) (as an average between 2.000 and 3.500 TWh), this quantity is made out of 1.500 TWh (**5,4 EJ= 130Mtoe**) coming from crops plus another 1.250TWh (**4,5EJ= 1.108Mtoe**) coming from other sources: sewage, manure, landfills, etc.

If we choose bioethanol instead of biogas we would loose the potential of the waste, sewages, etc (1.250TWh, **4,5EJ= 108Mtoe**) and we would also reduce the efficiency of the crops by 47%. In other words we would obtain 800TWh (**2,9EJ= 70Mtoe**) instead of 2.750TWh (**9,9EJ= 238Mtoe**).





CONCLUSIONS

It is clear that among all biofuels, biogas/biomethane **offers the best results in terms of energy production potential and land efficiency**, and it is also the only one able to be efficiently produced from several different sources.

Additionally we have to keep in mind that **biomethane is the only biofuel in which the composition of the renewable fuel is exactly the same as in the gas coming from well**. This characteristic allows biomethane to be mixed with natural gas at any percentage and without any problem for the vehicle engines.

ANNEX 2b: eBIO assessment of the yields of biofuels and biomethane

Comparative Energy Efficiency and Biofuel Yields
Many comparisons have been done on the yield per unit area of biofuels from different feedstocks and using different technologies, either to show the benefits or alternative crops or alternative biofuels. A common error in these comparisons is to ignore the animal feed co-products obtained together with the biofuels, which give substantial land use credits from cereals and oilseed crops. The omission of co-products gives a misleading comparison of biofuel yields.
It has been shown that when co-products and utilisation of the corn stover are ignored (ref 1), the bioethanol yield from maize of 81 GJ/ha is only about half of that for biomethane yield of 176 GJ/ha. However, when taking into account the effects of co-products, the net bioethanol yield is substantially higher than for biomethane production with a net yield of 270 GJ/ha and if the corn stover is used for bioethanol generation, this rises to 461 GJ/ha.

Feedstock energy efficiency
A key determinant of the biofuel energy that can be obtained from any crop is the energy efficiency of the technology to produce biofuel from the crop. i.e.

(Biofuel energy + useful co-product energy) / crop energy

The production of bioethanol from cereals and sugar beet is intrinsically a highly efficient process. Starch and sugar are converted to ethanol with the following reactions.

	Starch			Ethanol		Efficiency
	C6H10O5	+ H2O	->	2 x C2H6O	+ 2 x CO2	
Mass	162	18		92	88	
LHV kJ/kg	16.14			26.8		
Energy MJ	2615			2466		94.3%
	Sucrose			**Ethanol**		**Efficiency**
	C12H22O11	+ H2O	->	4 x C2H6O	+ 4 x CO2	
Mass	342	18		184	176	
LHV kJ/kg	15.08			26.8		
Energy kJ	5159			4931		95.6%

These reactions give energy efficiencies of 95%. Typically about 91% of the starch in cereal crops is converted to bioethanol, while the remainder is unconverted or reacts with similar energy efficiencies to give yeast and glycerol. All the other components of the cereal: proteins, fats, minerals and cellulose pass through the process with no loss of energy and together with the yeast and glycerol, are used as animal feed. Thus the total feedstock energy efficiency of the process is about 97%.
In the production of biomethane from biomass, the process can utilise the protein and fat components of the biomass, but the co-product sludge and digestate are not used for animal feed, so the energy value of these streams is lost. The AD process thus has several inefficiencies:

- The energy value of inactive components such as cellulose is lost in the sludge.
- Some carbohydrate is used to grow the bugs and is lost in the sludge.
- Some of the active components are left unconverted in the digestate.
- The energy conversion efficiency of carbohydrates to methane is about 2.5% lower than the ethanol.

The energy losses will vary depending on the design of plant. For the case used by FNR for the gross production of biogas from whole crop maize (ref 1), the energy efficiency is 70%. This is also the typical efficiency given by JEC.
About 21% (ref 1) of the gross biogas production is normally used to supply the heat and power to the biogas plant, which further reduces the energy efficiency. However for this comparison, it is assumed that process heat and power is supplied externally. Some biomethane is also lost through during purification of biogas to biomethane.
Clearly for waste materials, which cannot be used as animal feed, the ability of anaerobic digestion to utilise other components such as proteins and fats outweighs the intrinsic efficiencies of the AD process and AD may well be the most appropriate technology for these cases.

Land Use Efficiency
The bio-refining of cereals and sugar beet to bioethanol, also produces a co-product in which the nutrients other than sugar and starch are concentrated and is used as animal feed. In the case of cereals the animal feed co-product is known as distillers dried grain and solubles (DDGS) and has protein levels comparable with oilseed meals. DDGS produced in the EU will therefore displace a mixture of EU cereal crops and imported soy meal. Since soy is a low yielding crop, compared to EU cereals, the replacement of soy meal by DDGS gives a substantial land use credit.
The table below shows the detailed comparison of land use efficiencies for German maize, taking into account the DDGS co-product. The co-product digestate and sludge from the AD process can be used as fertiliser to replace artificial fertilisers, but this does not provide any land use credit.

Land Usage for biofuel production					
Crop		**Maize whole crop**	**Maize - mature crop**		
			Grain	**Stover**	**Total**
Biofuel		Biomethane	Bioethanol	Bioethanol	Bioethanol
Fresh crop yield	fresh t/ha	45	9		
Solid content		33%	87%		
Dry mass yield	t/ha	14.9	7.8	7.0	14.9
Biogas	m3/ fresh te	202			
Methane in biogas		54%			
Biofuel yield	t/fresh t	0.078	0.33		
Biofuel yield	t/dry t	0.237	0.38	0.27	
Biofuel yield	t/ha	3.5	3.0	1.9	
Biofuel LHV	MJ/kg	50.1	26.8	26.8	
Biofuel yield	GJ/ha	176	81	51	131
Co-product yield	t/t fresh grain		0.32		0.32
Co-product land credit	ha/ha		0.73		0.73
Net land area	ha/ha maize		0.27		0.27
Net biofuel yield	GJ/ha	**176**	**270**		**461**

It may be seen that when co-products and utilisation of the corn stover are ignored, the bioethanol yield from maize of 81 GJ/ha is only about half of that for biomethane yield of 176 GJ/ha. However, when taking into account the effects of co-products, the net bioethanol yield increases to 270 GJ/ha and if the corn stover is used for bioethanol generation, this rises to 461 GJ/ha.

Using a similar approach as in ref 2 with updated data, the net biofuel yield from other crops including co-products is:

Crop	Crop Yield t/ha	Net Biofuel yield GJ/ha
Feed Wheat	7.8	399
Maize	8.7	239
Sugar Beet	67	336
Rape	3.5	108

Data

Maize yields and biomethane production is taken from ref 1
Bioethanol from grain and co-product substitution is from ref 2.
Bioethanol from corn stover is from ref 3.

The calculation of the land area for co-product credit is explained in ref 2 and is shown below.

		Maize grain
Co-product yield	t/t fresh grain	0.32
Co-product yield	t/ha	2.88
Wheat displacement	t/t DDGS	0.494
Soy meal displacement	t/t DDGS	0.395
Wheat yield	t/ha	7.75
Wheat area credit	ha/ha	0.18
Soy yield	t/ha	2.63
Soy meal content	t/t soy	0.79
Soy area credit	ha/ha	0.55
Soy oil content	t/t soy	0.18
Soy oil loss	t/ha maize	0.25
Biodiesel loss	GJ/ha maize	9.0
Net biofuel yield	GJ/ha maize	71.6
Co-product land credit	ha/ha	0.73
Net land area	ha/ha maize	0.27
Net biofuel yield	GJ/ha	270

References

1) Fachagentur Nachwachsende Rohstoffe eV" (*FNR*) (*2008*)
2) Impact of protein concentrate co-products on the net land requirement for biofuel production in Europe, Lywood et al, GCB Bioenergy Dec 2009"
3) Well-to-Tank Report Version 2c, CONCAWE, EUCAR & ECJRC Mar 2007"

ANNEX 2c: Well-to-Wheels comparison electric / internal combustion engine vehicles

Energy consumption

Electric vehicles have high efficiency in converting electric energy to mechanical energy for the propulsion of the vehicle, with values of order 80% for the battery-to-wheels energy transfer (corresponding to the tank-to-wheels pathway for the internal combustion engine). Electricity production and distribution, however, have low energy efficiency. The JEC well-to-wheels analysis gives a value of 35% for the European grid. This includes the conversion efficiency in power plants and the distribution losses from the power plant output to the medium voltage level. Not included are the "well-to-tank" losses on the pathway from the primary energy source to the power plant input, which should be added in an update of the JEC study to allow full comparison with the well-to-tank pathway of liquid and gaseous motor fuels.

Fuel cell electric vehicles have a good efficiency in converting hydrogen to mechanical energy for the propulsion of the vehicle, with values of up to 56% for the tank-to-wheels energy transfer by 2020. Hydrogen production and distribution, however, have low energy efficiency. A recent industry consortium study [13], which is in line with the JEC well-to-wheel analysis gives values for biomass to hydrogen of 25% well-to-tank efficiency, coal to hydrogen 33%, oil to hydrogen 41% and gas to hydrogen 56%. This includes the conversion efficiency in hydrogen production plants and the distribution and retail losses. Not included are the well-to-tank losses of the pathway from the primary energy source to the hydrogen production plant, which should be added in an update to allow full comparison with well-to-tank pathway of liquid and gaseous motor fuels.

Internal combustion engine vehicles, on the other hand, have low efficiency in converting energy from combustion to propulsion (tank-to-wheels transfer), of order 25% for diesel, and 20% for petrol cars, on average. The well-to-tank fuel supply pathway, however, is highly efficient, with only about 15% of the fuel energy content needed for the whole chain, from the oil field to the vehicle tank.

Energy consumption of electric and internal combustion engine vehicles therefore have to be compared for the full energy pathway from source to final consumption:

Electric vehicle: (based on JEC well-to-wheels study, vehicle data from MIT study):

Vehicle energy consumption ("battery-to-wheels"): 0.58 MJ/km (0.16 kWh/km)

Vehicle efficiency: 72%
(battery charging/discharging: 90%; battery to wheels: 80%)

Energy efficiency of EU electricity production to the battery charger output: 30%
(Power station-to-medium voltage 35%; medium-to-low voltage 95%; low voltage-to-charger output 90%)

Total energy consumption ("well-to-wheels"):
0.58 MJ/km / 0.3 / 0.9 = 2.14MJ/km (***0.6 kWh/km***)

Internal combustion engine (European well-to-wheels study; reference low mid-size car):

Vehicle energy consumption ("tank-to-wheels"): 1.83 MJ/km (0.51 kWh/km)

Fuel production/distribution consumption ("well-to-tank"): 0.16 MJ per MJ fuel

Total energy consumption ("well-to-wheels"):
1.83 MJ/km x 1.16 = 2.12 MJ/km (***0.6 kWh/km***)

This comparison shows that the **total energy consumption is the same with internal combustion engine vehicles and comparable electric vehicles**. Electric vehicles therefore do not save energy overall. They allow, however, a diversification of primary energy supply and therefore contribute to improving security of supply.

CO_2 emissions

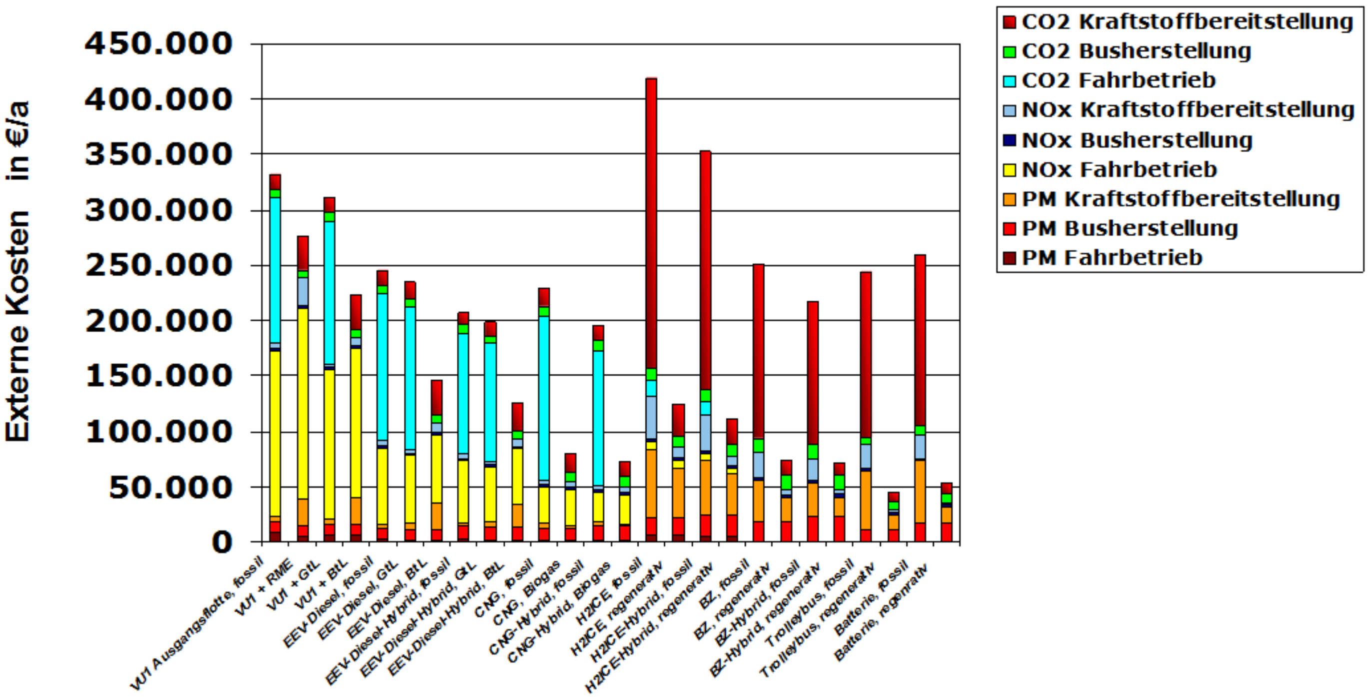
CO_2 emissions can be significantly reduced by replacing internal combustion engine vehicles using petrol or diesel by electric vehicles. On the basis of the CO_2 intensity of the European electricity grid of 430 g CO_2 /kWh (JEC study), CO_2 emissions are reduced by 30%.

It should be noted that 50% of the vehicles in the fleet are small/compact and contribute to 1/3 of CO2 emissions; the other 50% of the vehicles are mid sized to large and account for 2/3 of CO_2 emissions.

ANNEX 2d: Model of an ecological and economical analysis on the strategic optimisation of public transport bus fleets

In order to further improve air quality in Europe on the one hand and climate protection on the other hand it is necessary to persistently reduce the emissions caused by traffic. On the question of a sustainable relationship between mobility and responsibility, the expansion of an attractive, environmentally-friendly public transport (PT) is increasingly propagated as an answer. In the context of an integrated ecological sustainability, the operation of PT service bus systems with lowest local and global emissions along with high energy efficiency and reduced noise emissions is indispensable. The realization of this objective, in view of increasing economical compulsions, requires careful analysis and systematical optimization. Therefore a comprehensive ecological and economical model has been developed, with which a bus operator can individually carry out a coherently comprehensive ecological and economical system analysis for its current bus fleet, related to its operational characteristic, to determine the status quo. Based on that, the influence of variations through the potential use of alternative drive technologies and fuels can be quantified with concrete action recommendations for the strategic optimization of the vehicle fleet.

The modularly constructed comprehensive ecological and economical model is based on the life cycle analysis of the essential subsystems of the overall system “bus fleet”, such as vehicle production and disposal, fuel provision, operation and maintenance. In the ecological analysis, the nitrogen oxide and particulate mass emissions (as main local criteria) as well as CO_2 emissions (GHG / CO_2 Equivalent) and energy consumption (as main global criteria) with the resulting external cost of the fleets are the focus. The economical analysis quantifies both the vehicle cost which are strongly influenced by the drive technology (capital service, maintenance cost and fuel cost) and the vehicle related full cost of the entire transport company. Only a limited selection of basic data which is normally well known by the transport operators is required for the ecological and economical analysis. Additionally, this permits, in connection with evident scenario and standardization capacities of the model, inter-company comparisons of transport operators.



Graph: System-related external costs as environmental profile of a public transport company (64 buses, 17 years operational service life, existing fleet “VU1 Ausgangsflotte, fossil”) taking into account local and global emissions from fuel provision, vehicle production and disposal, operation and maintenance

The following example shows the application of the model on a public transport company which exists in reality and operates bus services in “light urban” traffic. The bus fleet is already entirely equipped with particle filters.

As the ecological analysis of single local and global indicators of the different scenarios can have partially contrary impacts it makes sense to carry out a comprehensive analysis of all external system costs in order to get an overview on the ecological performance of each scenario:

The comprehensive ecological analysis of all scenarios taking into account all system related emissions shows that regenerative scenarios for

- Trolleybuses with electric energy from wind power
- Electric buses with batteries powered with electricity from wind power
- Fuel cell hybrid buses (and fuel cell buses) with hydrogen from electrolysis with wind energy as well as
- EEV CNG hybrid buses (and EEV CNG buses) with biogas

have the largest ecological potential under the framework conditions of the chosen public transport company. Hybrid buses with regenerative hydrogen (from wind power) combustion engines as well as diesel hybrid buses with BtL do not reach this potential due to higher emissions from fuel provision.

Due to the lack of serial production and/or the lack of sufficient regenerative fuel provision today the best ranking technologies are not yet available - except the trolleybus and the latter being limited due its dependence on overhead wires which can not be realized everywhere.
Therefore in short and medium term public transport companies still have to rely on fossil fuels. Under this assumption the following fossil-based scenarios offer the best options which are already available today:

- EEV diesel hybrid technology, particularly in combination with GtL, followed by
- EEV CNG technology and
- EEV diesel technology, particularly in combination with GtL

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Further information: Pütz, R.: Modell zur ökologischen und ökonomischen Analyse und strategischen Optimierung von Linienbusflotten; ALBA-Fachverlag, Düsseldorf; 2010

http://www.alba-publikation.de/oxid.php/sid/792972f6f9a29a95f1804899e1d605cb/cl/details/cnid/290/anid/8644b8d108bb4ffa4.79529865/Strategische-Optimierung-von-Linienbusflotten/