EHA EUROPEAN HYDROGEN ASSOCIATION 10

DWV Deutscher Wasserstoff- und Brennstoffzellen-Verband

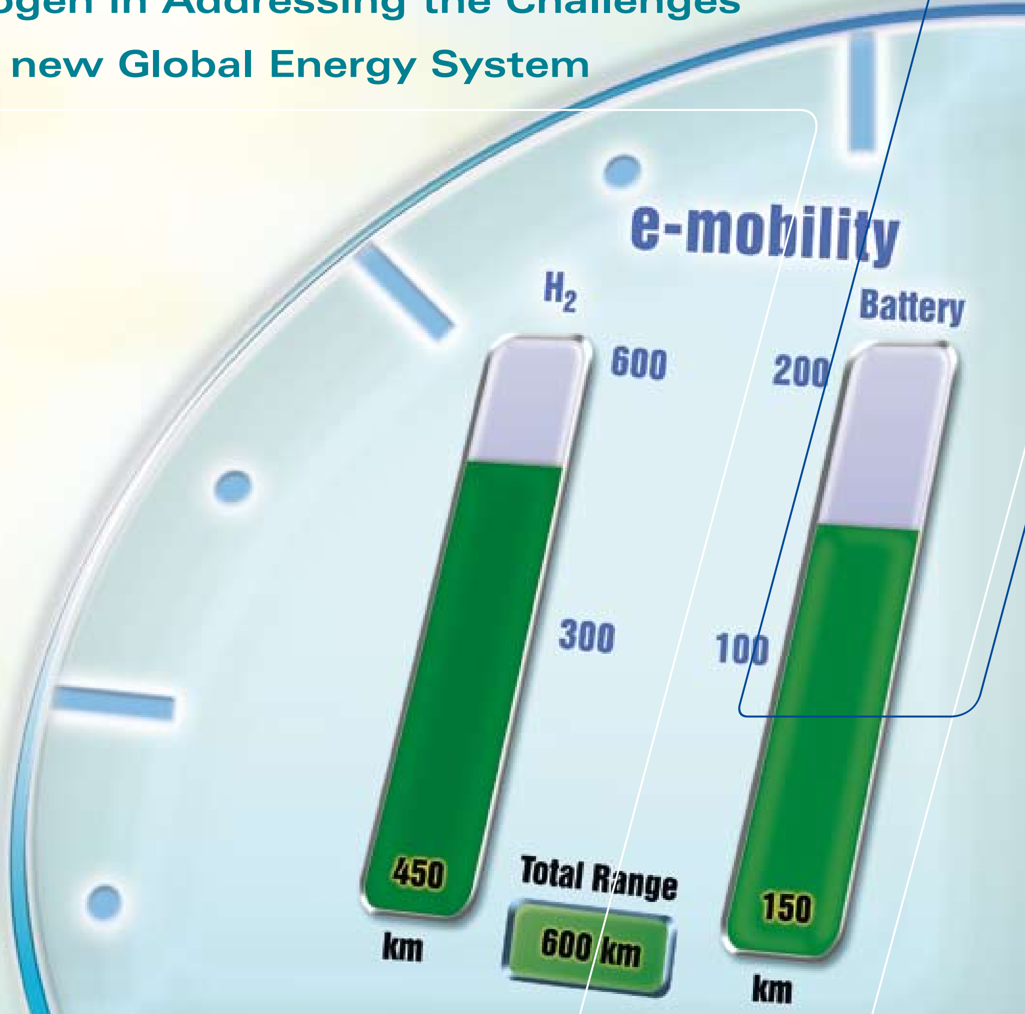
AeH2 Asociación Española del Hidrógeno

AFH2

Hydrogen Sweden

Energy Infrastructure 21

Role of Hydrogen in Addressing the Challenges in the new Global Energy System



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Foreword

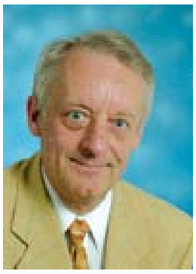
We are happy to present the third publication of the EHA/DWV series of strategy papers on the role of hydrogen as an energy carrier in a changing energy and climate landscape. The first paper dealt with the status of supply of different primary energy sources for hydrogen production, clearly indicating that renewable energy sources will be the most secure and sustainable source for future hydrogen production. The second paper demonstrated the role of hydrogen and fuel cells to facilitate large scale renewable energy deployment. This third paper explains the role of hydrogen in developing an intelligent and efficient infrastructure for electric mobility as we will need to gradually replace depleting fossil fuels with more renewable sources.

Since the year 2000 the European Hydrogen Association, EHA, representing 15 national associations and the main hydrogen infrastructure development companies (SHELL, StatoilHydro, ENI, Linde, Air Liquide, Air Products) has promoted the role of hydrogen to key decision makers in Europe. Monitoring the consequences of relevant EU policy dossiers on hydrogen infrastructure development, the EHA has become a reference point for information on industrial, national, and local developments as well as a link to international progress in the field of hydrogen applications. The EHA in this way has facilitated increasing visibility of the role of hydrogen in defining EU's response to the current energy and climate challenges. Together with its national member associations the EHA is supporting an intelligent and efficient hydrogen infrastructure build-up in Europe involving European industries and making the best use of primary energy sources. The EHA is hosting the secretariat of the European Regions and Municipalities Partnership for Hydrogen and Fuel Cells, HyRaMP, representing 30 regions and cities. By linking national and regional organisations with EU developments the EHA hopes to facilitate the leveraging of funding and activities at EU, national and local level to accelerate the transition to a commercial hydrogen infrastructure.

Since 1996, the German Hydrogen and Fuel Cell Association, DWV, supports hydrogen producers, suppliers and end users in German speaking countries in their endeavours to implement hydrogen in the energy economy and the transport sector. DWV has about 80 corporate members, among them 5 auto manufacturers, 7 energy and infrastructure companies, 15 component manufacturers and suppliers, 22 research and educational organizations and 16 engineering and planning experts. As the largest national member organization within the EHA it strongly supports EHA's efforts to bring clean, renewable and energy efficient energy and transport technologies to Europe.

Brussels, Berlin, November 2009

Lars Sjunnesson, Chair, EHA



Johannes Töpler, Chair, DWV

Our global energy system faces the following challenges:

- We are facing an energy crisis and a noticeable drastic climate change. And we are not prepared.
- We urgently have to reduce GHG emissions in order to limit climate change effects.
- Renewable electricity will need to substitute declining fossil fuels.
- New energy storage capacity will be required.
- Our future energy system will be structurally different from today's.
- Uncertainties with regard to forecasts will grow (e. g. World Energy Outlook, International Energy Outlook).
- Merely extrapolating existing technology paths is unlikely to provide solutions; paradigm changes are not only to be expected, but also necessary.

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Introduction

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Climate change, economic crisis, and energy paradigm change are all interlinked

"The world does not face separate global crises – the "environment crisis", "development crisis", and the "energy crisis" are all one." Brundtland Commission, 1987

Economic growth is based on three main factors: capital, labour, and the *potential to perform physical work*, also known as "energy"[1]. Since the system is irreversible, energy continuously needs to be infused into the system to ensure that it remains in a stable condition.

Over the past two centuries we have been using fossil energy to keep this system stable. Fossil availability is limited and accessibility and quality of resources vary globally. As high-quality, easily-accessible resources have been used first, over time it takes more and more capital, labour, and energy to exploit what is left (e. g. tar sands, deep-sea oil, low quality coal). This continuous downward spiral will increasingly limit our economic capabilities. We can only escape this development by shifting towards different and more abundant energy sources early enough. Renewables are the ideal candidate here, and technological development has made the shift possible. Not only will renewable energy assist in keeping our energy system and economy running at a certain level, but it will also reduce emissions (GHG, pollutants, heat). However, the later we start moving towards different energy sources, the more drastic measures and consequences will be.

"We need a signal for a different future before the investments which have been postponed will be caught up. According to our calculations the total cost will grow by 500 billion US$ per year by which the agreement [Kyoto successor agreement] will be delayed". Fatih Birol, Chief Economist of the IEA[2]

It is important to recognise that no patchwork solutions are needed, but a comprehensive approach. Peak oil, climate change, and its consequences offer the opportunity to solve energy, economic, and environmental problems at once.

[1] Robert U. Ayres and Benjamin Warr, Accounting for growth: the role of physical work, Structural Change and Economic Dynamics, 16(2005) 181-209

[2] Interview "2030 most new cars will have hybrid and electric engines" ["2030 haben die meisten Neuwagen Hybrid- und Elektromotoren] given to Süddeutsche Zeitung, 07 October 2009

IPCC – limitation of global warming is needed

The scientific community agrees on the need to limit global warming to a maximum of 2 °C above the pre-industrial temperature level which seems to be the maximum tolerable. The IPCC calls for a stabilization of the global carbon dioxide concentrations at 400 ppm by 2100. From 2015 the concentration will have to decrease. In order to achieve this goal industrial countries will have to reduce their CO_2 emissions by 40 % until 2020 and by at least 80 % (potentially 90 %) until 2050. This means in average all countries will have to reduce their CO_2 emissions by at least 50 % until 2050.

The need to reduce carbon dioxide emissions from oil, gas, and coal in order to fulfil the requirements of climate gas emission reductions can well go in line with the introduction of new renewable primary energy sources in order to substitute fossil energy sources gradually reaching peak ("the point where supply cannot cover demand anymore – not where all resources are gone"). Renewable energy sources and thereof derived clean zero emission fuels like electricity and hydrogen can solve both issues in one effort and transform the energy and transport systems into more sustainable ones.

The International Energy Agency (IEA) warns that ongoing trends in energy supply are not sustainable. The IEA reference scenario presented in the World Energy Outlook 2008 and 2009 would result in a doubling of the aggregated concentration in CO_2 equivalents and a global average temperature increase up to 6°C until 2100.

"Preventing catastrophic and irreversible damage to the global climate ultimately requires a major decarbonisation of the world energy sources."

Source: International Energy Agency, World Energy Outlook 2008 and 2009

CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

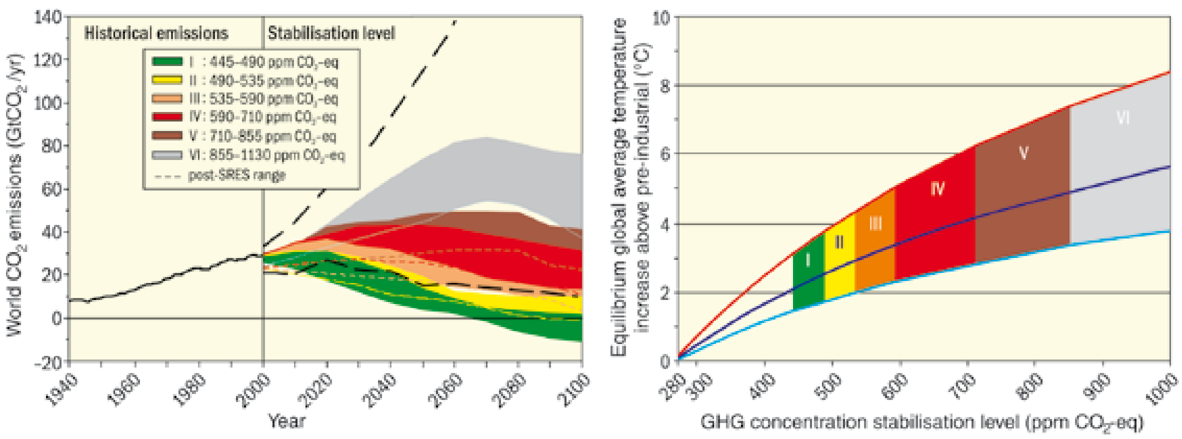
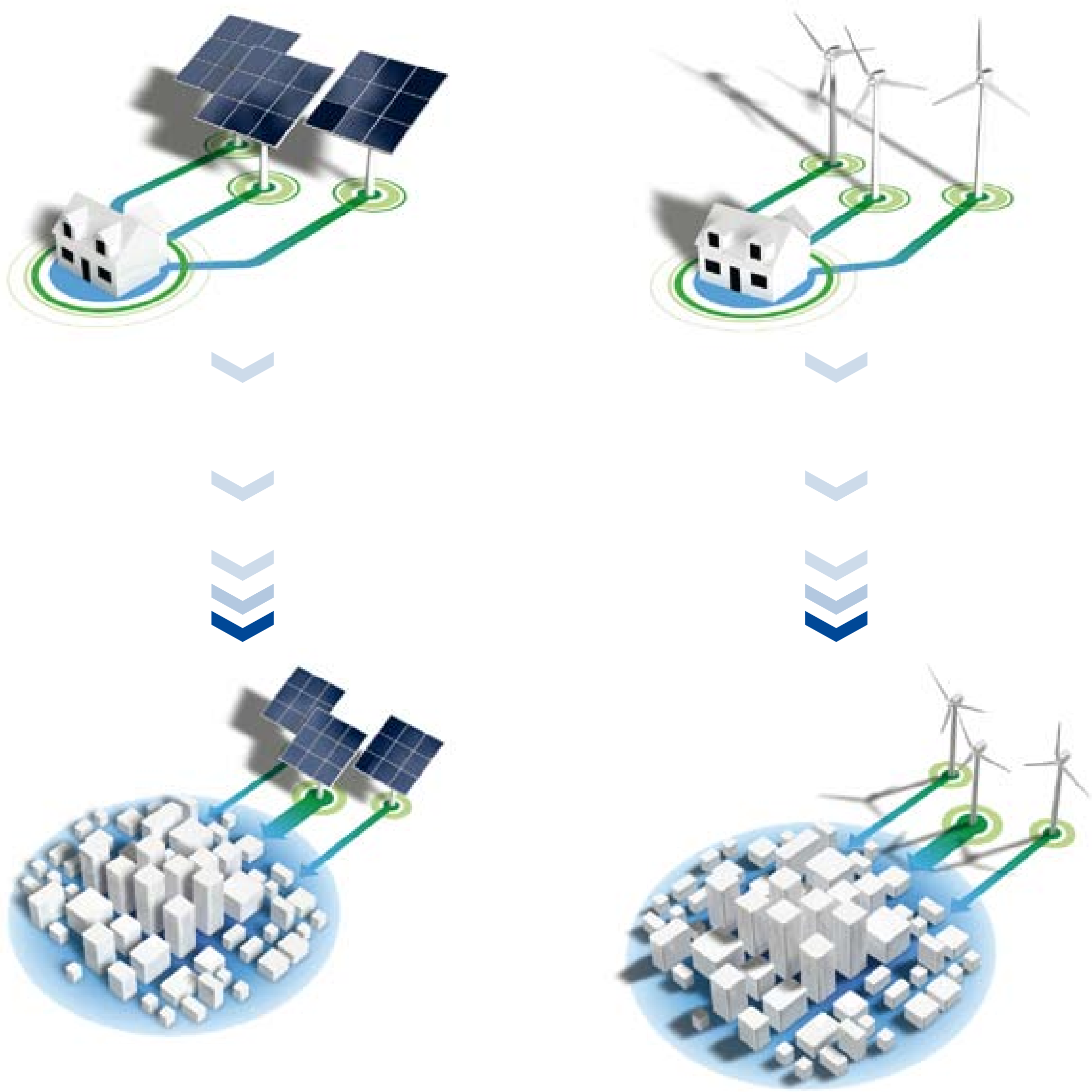


Figure: Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely equilibrium global average temperature increase above pre-industrial (right hand panel).

Source: Climate Change 2007, Synthesis Report, Valencia, Spain, 12-17 November 2007

In the following we present eight statements on our energy supply and infrastructure

- to provide the reader with insight into and awareness of the most imminent issues and for the expected trends related to our energy supply and infrastructure;
- to highlight the most important elements of the expected paradigm change;
- to identify major needs and options for indispensable action;
- to provide a path towards successfully adapting to these changing conditions;
- to show opportunities and directions for sustainable developments and investments;
- to explain the contribution of hydrogen and fuel cells, especially in the transport sector.



International Energy Agency

"What is needed is nothing short of an energy revolution."

"The world's energy system is at a crossroads. Current global trends in energy supply and consumption are patently unsustainable – environmentally, economically, socially. But that can – and must – be altered: there's still time to change the road we're on."

"The scale and breath of the energy challenge is enormous - far greater than many people recognise. But it can and must be met"

"Continuing on today's energy path, ... would mean rapidly increasing dependency on fossil fuels, with alarming consequences for climate change and energy security."

Source: International Energy Agency, World Energy Outlook 2008 and 2009

A sustainable future for transport in Europe

"Transport is a complex system that depends on multiple factors, including the pattern of human settlements and consumption, the organisation of production, and the availability of infrastructure. Owing to this complexity, any intervention on the transport sector must be based on a long-term vision for the sustainable mobility of people and goods, not least because policies of structural character take long to implement and must be planned well in advance."

Source: EC COM(2009) 279/4

Climate change – global warming due to burning of fossil fuels

Greenhouse gas (GHG) emissions have serious impacts on the climate and on our life.

If current fossil fuels consumption trends continue, GHG emission will rise with catastrophic consequences.

"Together these impacts will have very large consequences for food security, water availability, and health. However, it is possible to avoid these dangerous levels of temperature rise by cutting greenhouse gas emissions. If global emissions peak within the next decade and then decrease rapidly it may be possible to avoid at least half of the forecasted four degrees of warming." statement by Dr. Betts of the Met Office

Source: UK Hadley Met Office, 28 September 2009
(http://www.metoffice.gov.uk/climatechange/news/latest/four-degrees.html)


STATOIL
HYDROGEN

Eight statements on our changing energy supply

A reality check on what is happening with our current energy supply and demand system

1 Peak-Oil is now

It is most likely that the global production of crude oil has already peaked and will start to decline soon. We have to adopt the appropriate measures to prepare for new energy sources and fuels as soon as possible.

The European oil supply is expected to decline rapidly in the next 20 years

During the next years the easy-to-produce conventional oil from currently existing fields is expected to decline fast (see also the box "IEA warns that oil supplies are running out fast" opposite). Even more critical is the European supply, as domestic oil production has already been declining since 2000, and, consequentially, European dependency on oil imports is continuously and ever faster rising.

Rising competition of declining oil supplies

In parallel to the decline of global oil production, the number of oil exporting countries will likely shrink as well, making Europe dependent on fewer sources. In 2006 oil production in non-OPEC countries has already peaked[3]. Soon, import-export balances will shift on a global scale, and importing oil will become more difficult. Demand growth in non-OECD countries such as China and India will further exacerbate the situation. A thorough assessment of global oil production and import-export balances clearly points towards quickly declining oil imports to Europe within the next years (see box "Europe's crude oil supply will decline").

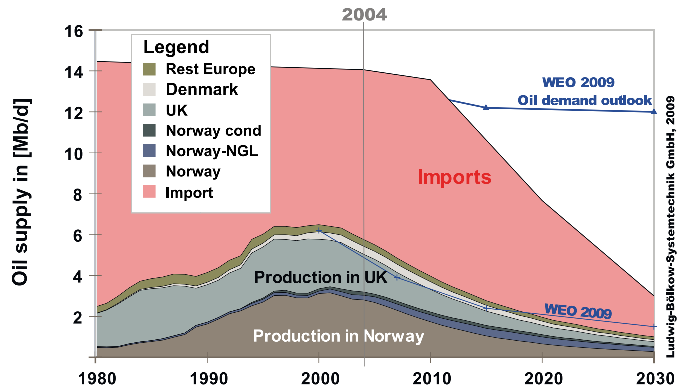
It is very important to recognize that oil, beyond its main applications in energy and transport, is also an important and essential resource for other industries where its substitution is difficult. Its value as a base material for chemistry (plastics, fertilizer, textiles, and pharmacy) and construction (insulation materials, structural materials, etc.) will increase.

Rising oil prices

With increasing demand for stalling or declining supplies oil prices will invariably rise. The International Energy Agency as well as the U.S. Energy Information Administration (see box on "Rising oil prices" opposite) point to this fact with increasing intensity. This represents a fundamental change in their official information policy and therefore should be taken quite seriously. Without exogeneous pressure caused by facts both institutions would not conceed existing supply problems. The current economic crisis has somewhat eased price pressure short term, but, going forward, will actually worsen the situation due to postponement of investments in new oil exploration and production capacities.

As a consequence, not only for addressing the imminent fact of climate change reasons but also dictated by economy and availability, Europe will need to quickly reduce its oil consumption by introducing alternative fuels for transport.

Europe's crude oil supply will decline

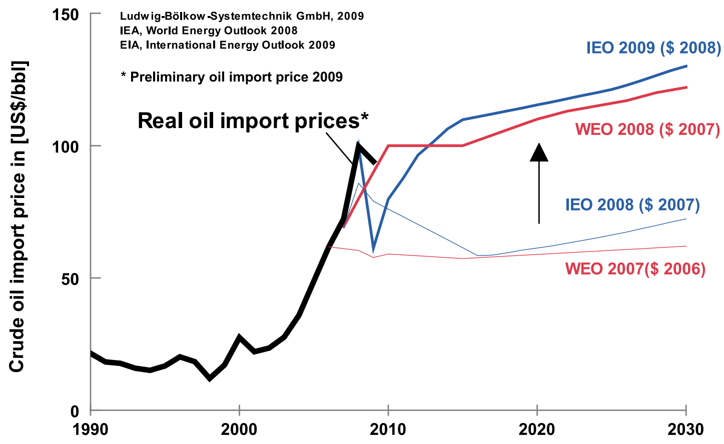


Facts 2004 (IEA data)	***LBST Outlook 2030***
Total supply: 14.1 Mb/d	Total supply: 3 Mb/d
Production: 5.8 Mb/d	Production: 1 Mb/d
Imports: 8.3 Mb/d	Imports: 2 Mb/d

[3] Crude Oil – The Supply Outlook, Report to the Energy Watch Group, October 2007, EWG-Series No 3/2007

Rising oil prices – changing assumptions for economic development and new conditions for future investments and strategies

During the last year, the International Energy Agency (IEA) as well as the US Energy Information Administration (EIA) have changed their forecasts for oil price development drastically. These changes will have significant impacts on the economy and our society.



IEA warns that oil supplies are running out fast

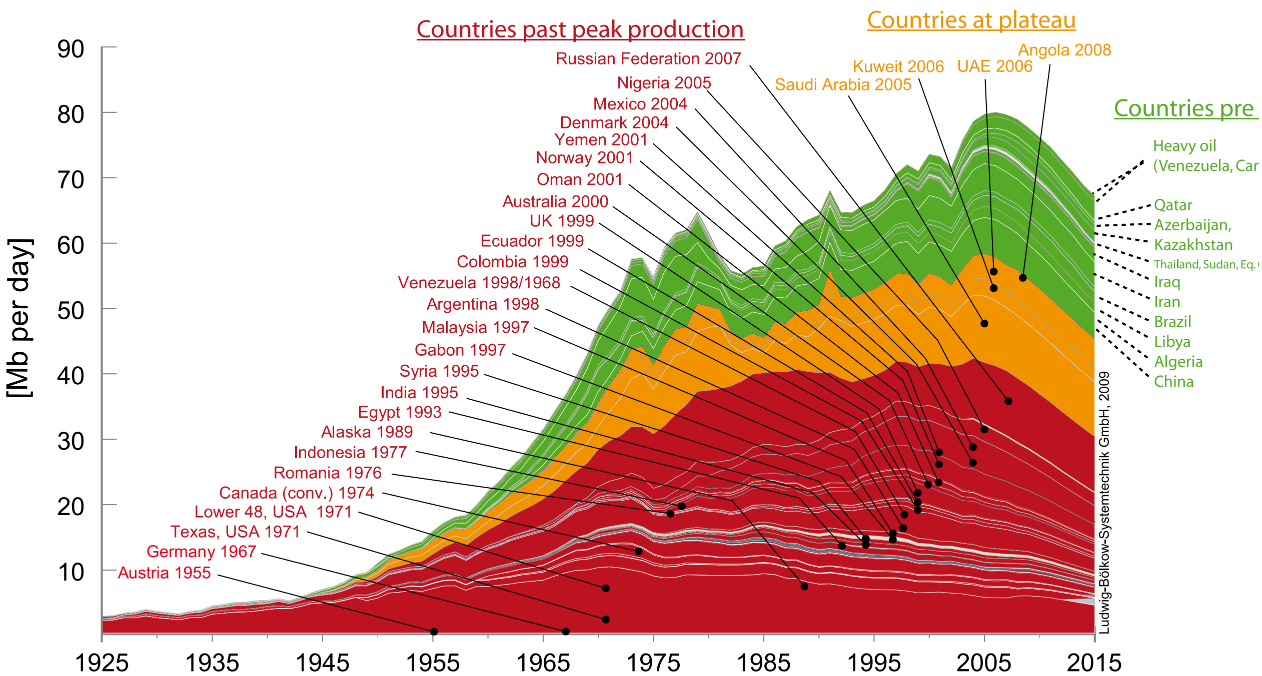
This summer, Fatih Birol has warned in an interview that chronic under-investment of oil production facilities could result in an "oil crunch" within the next five years that will jeopardise any hope of a recovery from the present global economy recession.

"There is now a real risk of a crunch in the oil supply after next year…"

"We have to leave oil before oil leaves us".

"I'm not very optimistic about governments being aware of the difficulties we may face in the oil supply."

Source: Fatih Birol, Chef Economist, IEA, Interview 3 August 2009, The Independent, "WARNING: Oil supplies are running out fast"



History: IHS-Energy 2006; PEMEX; Petrobras ; NPD; DTI; ENS(Dk); NEB; RRC; US-EIA; Saudi-Aramco; data for small countries are estimated by LBST, Juli 2008
Forecast: LBST 2009

2 Gas, coal, and nuclear will *not* be able to substitute oil equally

Europe imports more than 53 % of its energy[4]. European production is declining – dependency on imports of fossil and nuclear fuels is rising. At the same time, the availability of gas, coal, and uranium will decline during the next decades. Increasing consumption of fossil and nuclear fuels in other regions such as China and India will gradually lead to reduced amounts available for imports to Europe.

Natural gas

Europe's natural gas (NG) production has already peaked in 2003. Major NG producers in Europe are the Netherlands (peak in 1996), the UK (peak in 2000), and Norway (peak expected by 2015). Today, the EU-27 needs to import more than 60 % of its natural gas (largest suppliers are Russia, Norway, and Algeria)[5].

It is expected that the total supply (domestic production plus imports) will start to decline after 2020 when Russian natural gas supply is expected to peak and Norwegian production will already have peaked. (See box: "Europe's natural gas supply will decline" below).

Whether shale gas production will be able to slow down this decline for some time will have to be proven.

Coal

Statistics on the coal reserve data are very unreliable and uncertain. In the past, global coal reserves have been systematically overestimated, and, thus, during the last years the global coal statistics have been reassessed and partly drastically adjusted downwards. Today, more than 90 % of existing coal reserves are concentrated in only eight countries (USA, Russia, China, India, South Africa, Australia, Ukraine and Kazakhstan), the largest of these (China, USA and India) having already become coal importing countries[6]. As a result, only a small share of coal is available on world markets.

A country-by-country assessment of reserves and production indicates that the coal production will start to decline once the largest producer, China (producing 45 % of the world production), will reach its production peak. This can be expected between 2020 and 2030.

As a result, increasing price pressures are expected. The possible introduction of carbon capture and storage (CCS) technologies as a bridging means to address elevating climate change concerns in the current fossil based energy production particularly for coal will further add to this development.

Europe's natural gas supply will decline

Facts 2004 (IEA data)

Total supply: 503 Bm³

Production: 287 Bm³

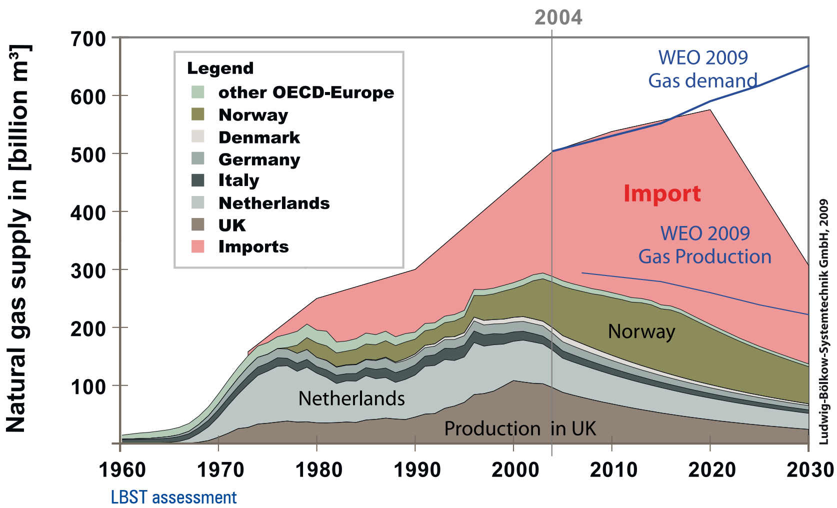
Imports: 216 Bm³

LBST Outlook 2030

Total supply: 307 Bm³

Production: 137 Bm³

Imports: 170 Bm³



[4] www.energy.eu

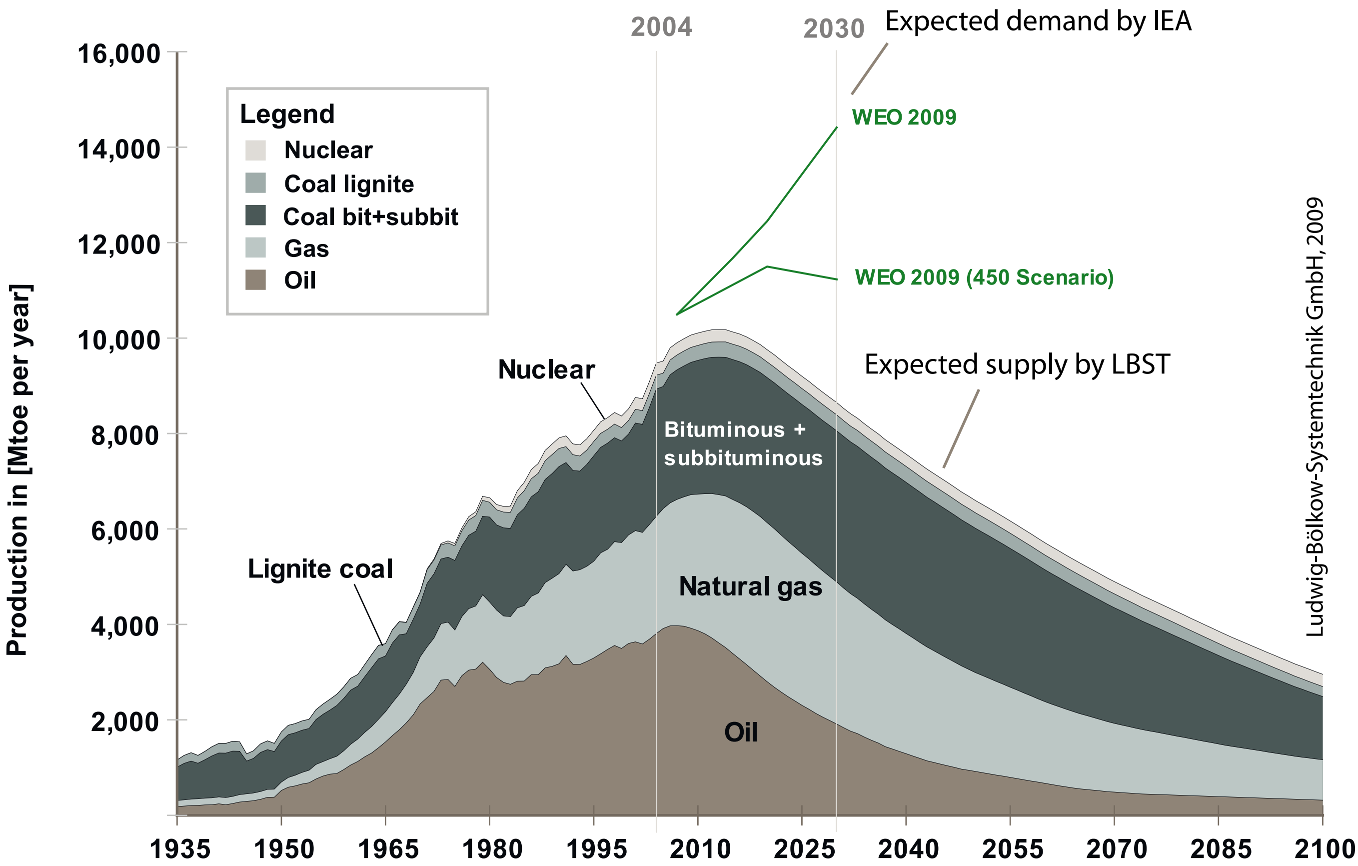
[5] http://ec.europa.eu/energy/energy_policy/doc/02_eu_energy_policy_data_en.pdf

[6] www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Coal_10-07-2007ms.pdf

Nuclear energy

Nuclear energy can by no means substitute declining oil supplies. Today, just a very small share of 2 % of the global energy supply is provided by nuclear energy. Existing nuclear power plants are aging and due to the long lead times for the construction of new power plants it will require significant efforts to even keep the number of operating nuclear reactors at the present level in the coming years.

As with other energy sources, Europe is strongly depending on imports (about 98 % of the uranium used in Europe is imported to Europe). In addition, uranium used in Europe reserves are limited. At present, 60 % of the uranium supply is covered by mining and 40 % is supplied from stocks. Within the next 5-10 years these uranium stocks will be exhausted. For the existing power plants it is of considerable importance that global uranium production will be able to close the emerging gap. Whether beyond this sufficient uranium can be mined for new power plants remains completely open[7].



Outlook – fossil and nuclear fuel demand

LBST expects that the global supply of fossil and nuclear energy could start to decline between 2015 and 2020. Thus, the future demand as projected by the International Energy Agency (IEA) will not be covered.

[7] http://www.lbst.de/ressources/docs2006/EWG-paper_1-06_Uranium-Resources-Nuclear-Energy_03DEC2006.pdf

3 Biomass potentials are limited and their use presumably is in competition to other uses

Biomass over generations has been the main commodity used for energetic uses besides the flow of water and the movement of air. Biomass also provides the most basic feedstock for humans: food. As the available land area and the sustainably obtainable area yields are limited by nature, an ever growing demand of energy cannot be covered at significant shares for an ever growing population.

Insufficient biomass potentials to cover European road transport demand

Under the hypothetic assumption that all available biomass for energetic uses would go into transport fuels (4.5 EJ) at best only 35 % of the European road transport demand could be covered by European biomass in 2020[8]. The highest coverage is only achieved if the biomass is converted to compressed gaseous hydrogen (CGH_2).

Assuming that 50 % of the energetic biomass potential would be available for the production of transportation fuel, a maximum of 17 % of the fuel demand expected for 2020 could be met by biomass derived fuels. In case biomass to liquids (BtL) processes are used, only abou 12 % of the fuel demand could be met.

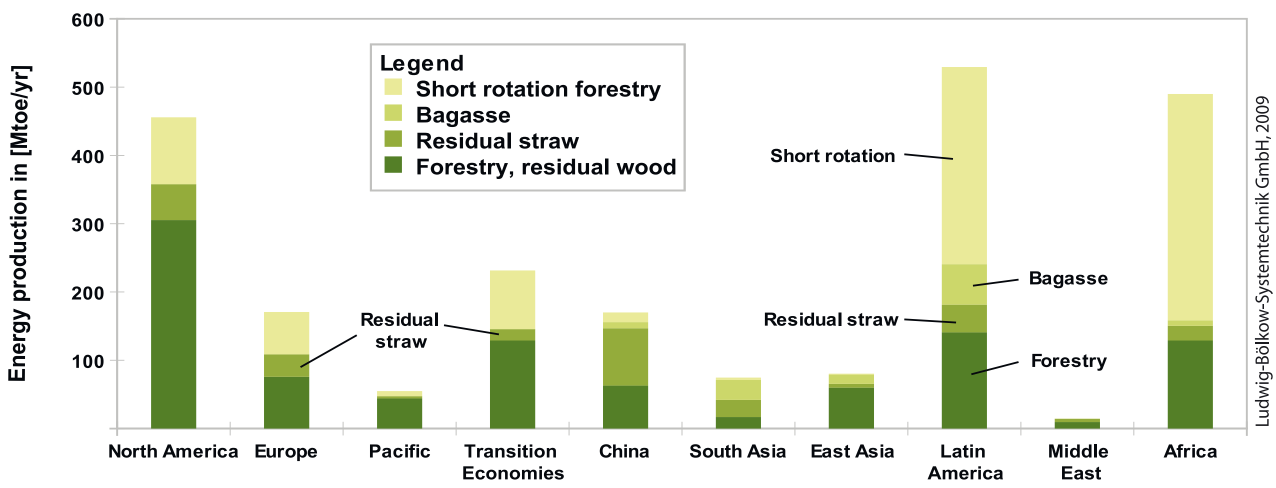
In Concawe/EUCAR/JRC (CEJ) 2007[9] various scenarios have been modelled to assess the potential of biomass derived fuels. For the calculation of biomass availability competing uses of the biomass for heat and electricity generation have been considered. In this case only a maximum of 1.6 EJ via CGH_2 (12.5 %) can be covered. In case of BtL about 7 % of the fuel demand could be met.

Other sources conclude that the biofuel goal by the European Commission of 10% renewables in transport by 2020 with significant efforts could be met[10].

Land requirements for food production have been taken into account in all scenarios.

Technical potential of lignocellulosic biomass by region and type

The figure shows the worldwide energy potential for biomass from residues and from plantation based on the lower heating value (LHV). The largest potential is identified for energy crops (short rotation forestry) in Africa, Latin America and OECD North America.



Source: LBST

[8] LBST scenario calculations for GermanHy, 2008, (not published)

[9] Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, WELL-TO-TANK Report, Version 2c, March 2007, CONCAWE/EUCAR/JRC, 01 March 2007 [http://ies.jrc.ec.europa.eu/uploads/media/WTT_Report_010307.pdf]

[10] M. Kaltschmitt et al., Biomass potentials for biofuels production, Biofuels Conference, Berlin, 30th September 2009

Rising competition for biomass use

Biomass and the available land area is facing increasing demand from a broad range of possible uses: raw material for the chemical and pharmaceutical industry, raw material for construction and manufacture, production of energy for stationary and mobile fuels, food cultivation, and nature preservation (by non-commercial use). As the declining availability of cheap oil will increase the attractiveness of using biomass derived fuels as a complement in the transport sector, pressure on suitable agricultural land in Europe and worldwide will rise.

Infrastructure vs yield

Liquid biofuels (biodiesel, BtL, butanol, ethanol etc.) in principle allow admixture to fossil liquid hydrocarbons or direct use in existing supply and refueling infrastructure. This and the continued use of internal combustion engines (ICEs) for propulsion make them attractive for the transport sector. On the other hand, obtainable yields per hectare of land can differ significantly between biofuels, easily by a factor of two.

Using biomass to produce gaseous fuels, be it compressed methane (CNG) obtained through biogas or compressed hydrogen (CGH_2) obtained through bio-gasification and purification, results in markedly higher areal yields.

Even higher areal yields by a factor of about 4-8 for hydrogen fuel cell vehicles (FCVs) or about 10-15 for battery electric vehicles (BEVs) are achieved by producing renewable electricity on the same area by wind or solar power. However, gaseous fuels (CNG as well as hydrogen) as well as BEVs require a dedicated supply and refueling infrastructure different from today's.

Effort to classify 2nd generation biofuels

There is no unique definition, but in simple terms, in 1st generation biofuels only the sugar or starch content of a plant is turned into a combustible fuel, whereas 2nd generation biofuels result from converting the cellulosic plant content through a chemical or biological process. In principle, 2nd generation biofuels thus use a higher fraction of the biomass, and avail themselves of a broader range of potential feedstock. However, other non-cellulosic biofuel processes which are less advanced at present are often also filed under 2nd generation.

Overview of different "types" of "2nd generation" biofuels:

- Biomass to liquid (BtL)
- Lignocellulosic ethanol and butanol
- Algae-based biofuels
- Upgraded biogas (bio-methane)
- Hydro-treated vegetable oil (e.g. NExBtL™)
- Synthetic natural gas (SNG) via gasification and methanization
- DME via gasification and synthesis
- H_2 from gasification
- H_2 from reforming of biogas

4 Renewables will become the dominating energy source

Renewable energy potentials exceed the global energy demand by far. During the next years and decades the growth of renewable energies will provide the basis for our future energy supply as well as for our economic growth and development. In the long run, renewables will replace fossil and nuclear fuels.

Sufficient potentials

Renewable energy potentials which are technically, economically and also sustainably recoverable lie far above the present world energy consumption.

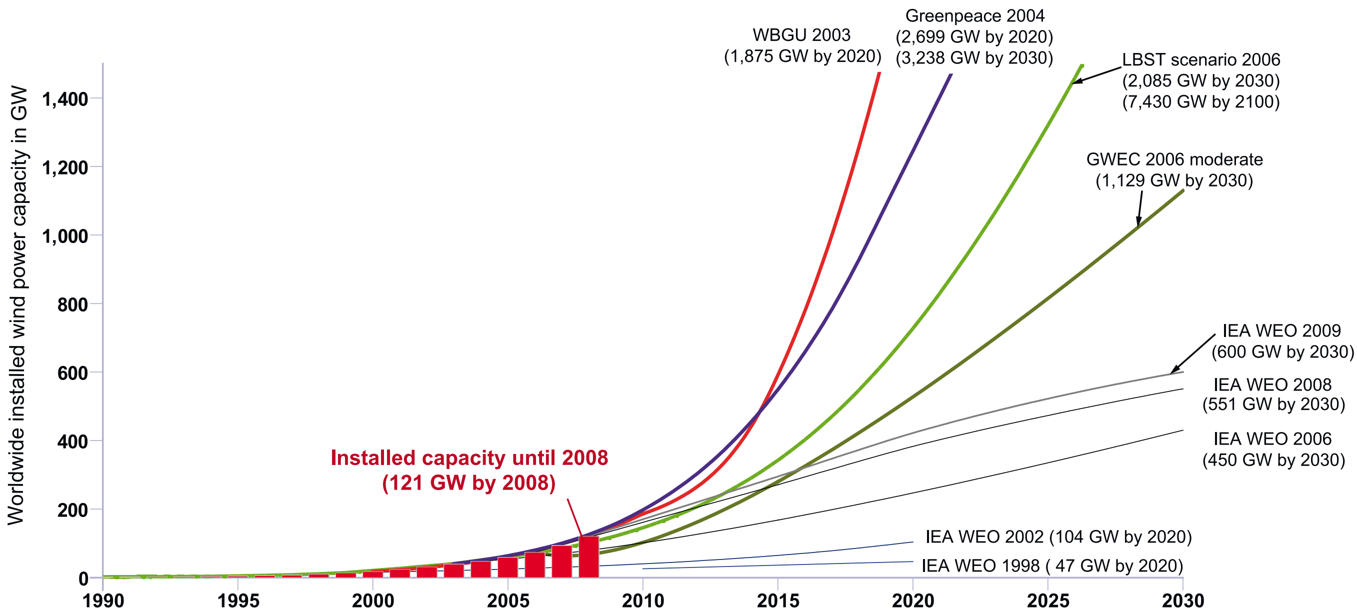
Especially photovoltaics, concentrating solar thermal power, wind power, and maritime power offer huge potentials for renewable electricity generation and fast growth rates. They have a sufficiently large potential to cover the world's energy needs more than once.

From niche market to economic growth factor

Renewable energies have been growing faster than expected and predicted in optimistic scenarios. Especially the share of renewable electricity has increased strongly during the last decade. (See below: growth of wind power).

In 2007, the share of renewable energy sources for electricity production has amounted to 15 % in the EU-27 and to 14 % in Germany[11].

Renewable energy technologies allow a fast ramp-up of power generation capacity. Wind power plants and photovoltaic installations can be completed in 1 to 2 years, quicker than typical conventional fossil and nuclear energy production plants.



Ludwig-Bölkow-Systemtechnik GmbH, 2009
Sources: GWEC 2008 Report: Worldwide wind capacity 1997-2008, Report, 2009
International Energy Agency: World Energy Outlook (WEO) 1998, 2002, 2004, 2006, 2008
Greenpeace: Windstaerke 12 (Windforce 12), May 2004
WBGU 2003: German Advisory Council on Global Change (WBGU), World in Transition – Towards Sustainable Energy Systems, Report 2003

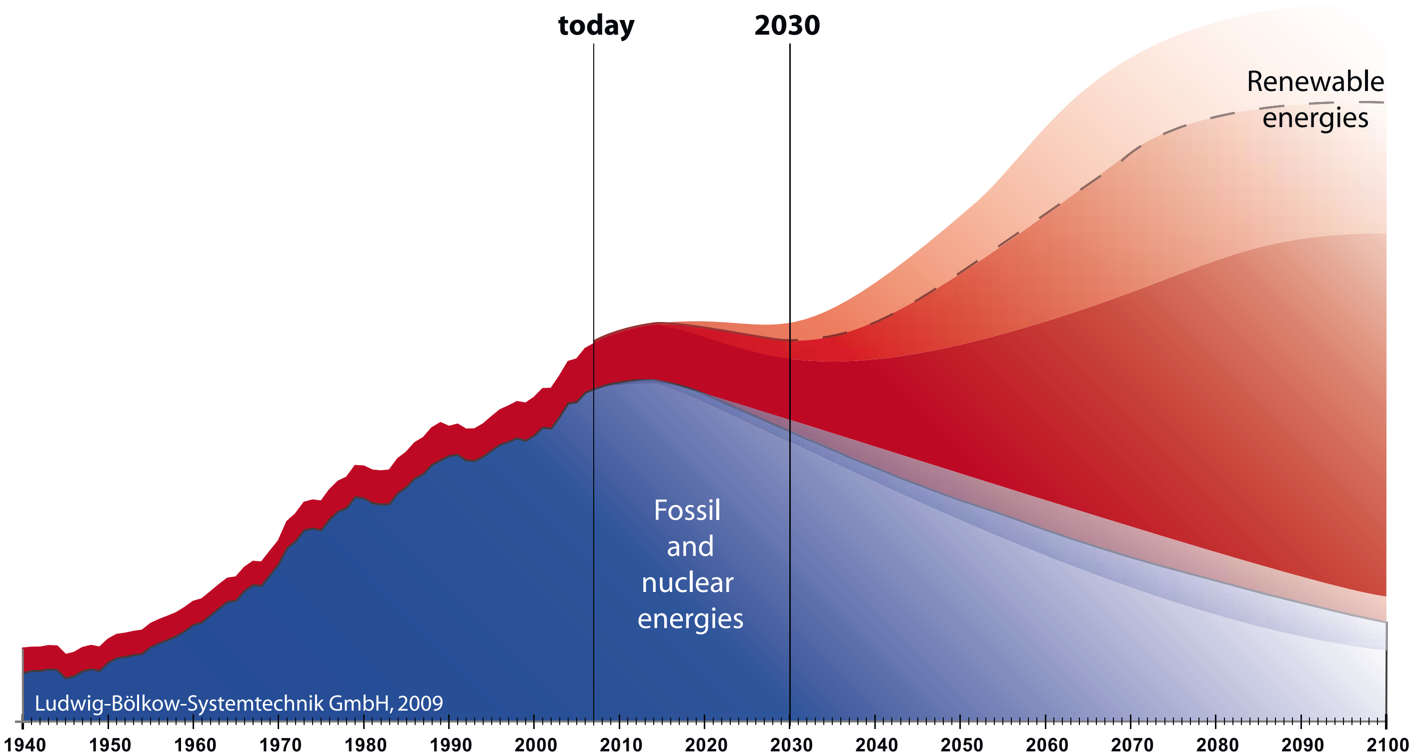
Growth of wind power: history and scenarios

[11] http://www.energy.eu/#renewable

Transition towards a renewable energy system

During the next years and decades the renewable energy generation capacity has to be expanded at least at the current rate in order to manage the required transition towards a post-fossil era. As shown below, renewable energies can substitute declining oil, gas, coal, and nuclear power reserves, and renewable electricity will become the pillar of our energy supply base.

With the target of limiting global warming to 2 °C and declining fossil fuel supplies already becoming a reality, there is no real alternative to this transition, which will need to take place over the next 2 to 3 decades. Only the switch to a sustainable energy system may ensure our economic and social welfare.



Build-up of renewable energies has to be facilitated now

The global supply of fossil and nuclear energy could start to decline between 2015 and 2020. Thus, the future demand as projected by the International Energy Agency (IEA) will not be covered.

Source: Ludwig-Bölkow-Systemtechnik GmbH, 2009

5 Renewable electricity will require new energy storage capacities

Electricity will become the new "leading energy vector". However, the complexities associated with storing electricity (unlike fossil energies) require new storage mechanisms and capacity. The need for energy storage will increase. Due to the intermittent nature of most renewable energy source, the future energy system furthermore will require intelligent approaches for energy management.

Renewable electricity will become the major pillar of our energy supply system

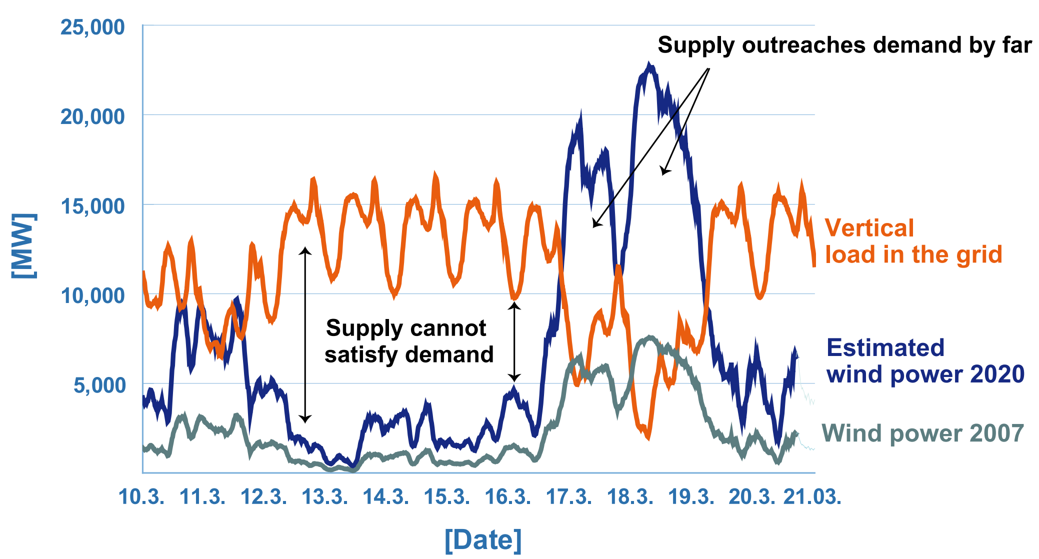
Renewable energy generation cost is on its way to become competitive with fossil energy technologies[12]. After 2015, the cost of renewable electricity from wind power and from solar thermal power plants is expected to be at par with fossil energies like natural gas and coal[13] including cost for either emission trading or carbon capture and storage technologies (expected costs are about 0.08€/kWh). As a result, electricity generation from fossil energy will gradually move from the provision of firm energy to dispatchable generation, being replaced by renewable electricity (solar, wind, maritime, hydro, geothermal).

The need for energy storage will increase

Many of the high-potential renewables are intermittent (wind, photovoltaics) or have limited dispatchability. Hence, the anticipated transition from a fuel dominated energy economy to an electricity based one will create the need to produce "fuel" from electricity, not only electricity from fuel as is prevalent today. In other words, there is a need to store electricity, not only for short periods (in order to smooth sudden demand and supply fluctuations) but also seasonally to match variations of demand and supply (see box below: energy storage).

Need for energy storage

Vertical load curve and feed-in of wind power in the E.ON grid



Ludwig-Bölkow-Systemtechnik GmbH, 2008
Source: E.ON Netze, February 2008, www.eon-netz.com

[12] Langfristszenarien und Strategien für den Ausbau erneuerbarer Energien in Deutschland, Leitszenarion 2009, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), August 2009

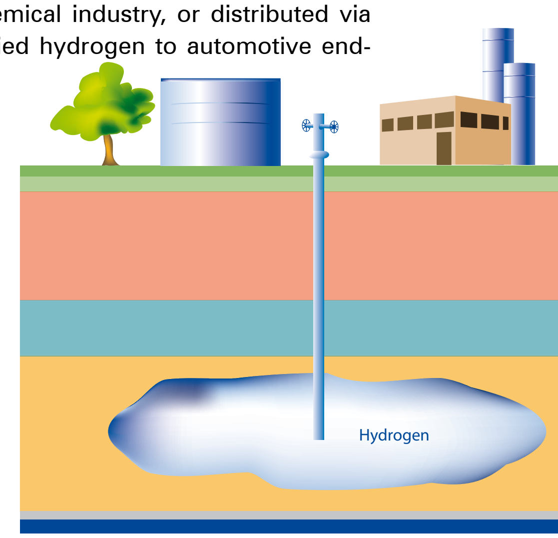
[13] „Leitstudie 2008" - Weiterentwicklung der „Ausbaustrategie Erneuerbare Energien" vor dem Hintergrund der aktuellen Klimaschutzziele Deutschlands und Europas., Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit (BMU), October 2008

Long-term storage of renewable electricity

In general, electricity is difficult and costly to store, in particular in larger quantities (GWh) over longer periods of time (beyond 48 hours). Various options exist, each addressing different capacity and storage time requirements, such as pumped hydro storage, adiabatic compressed air storage, redox flow battery storage systems, battery systems (NaNiCl, NaS), and electrolytic hydrogen production with underground cavern storage. The latter provides a particularly cost effective way for long-term storage of intermittent renewable electricity, for which only few other options exist.[14] Although electrolytic hydrogen stored in underground salt caverns (cycle efficiency 30… 40 %) incurs higher losses than competing technologies such as pumped hydro (cycle efficiency 80 %) and adiabatic compressed air (cycle efficiency 70 %) these are limited in their implementation potential as well as in their capacity levels compared to hydrogen underground storage.

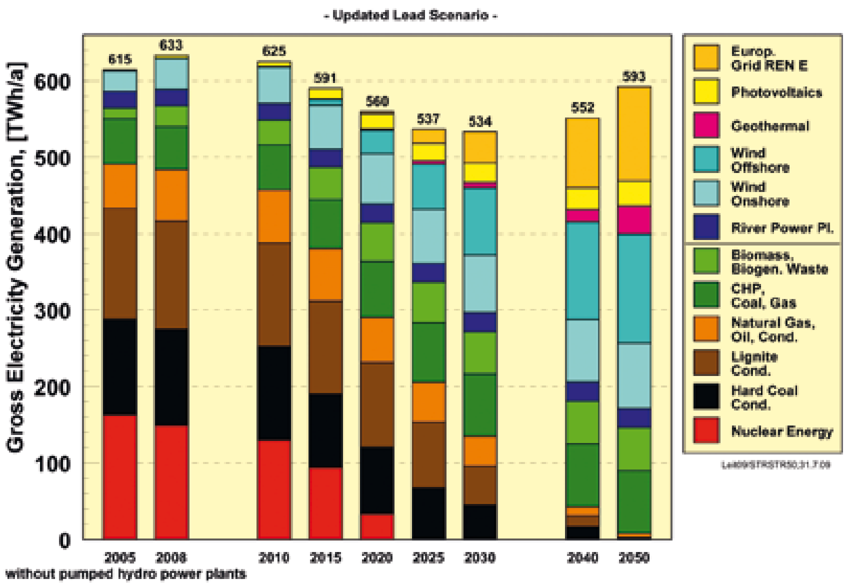
Stand und Entwicklungspotenzial der Speichertechniken für Elektroenergie – Ableitung von Anfoderungen an und Auswirkungen auf die Investitionsgüterindustrie, FhG-ISE, FhG-AST, VK Partner, 30.06.2009, Auftragsstudie 08/28 für das BMWi

Salt cavern hydrogen storage is a proven technology and can accommodate about 60 times the electricity equivalent in the same volume as adiabatic compressed air storages[15]. Hydrogen stored in such large storage systems can either be re-electrified with large combined cycle gas turbines, used directly as feedstock in the chemical industry, or distributed via pipeline or as liquefied hydrogen to automotive end-users.



Hydrogen storage in underground salt cavernes

Power generation in Germany until 2050



Structure oft the gross national electricity generation in the updated BMU 2009 Lead Scenario broken down into energy sources and types of power plants.

Source: "Leitszenario 2009" - Langfristszenarien und Strategien für den Ausbau erneuerbarer Energien in Deutschland unter Berücksichtung der europäischen und globalen Entwicklung, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), August 2009

[14] Stand und Entwicklungspotenzial der Speichertechniken für Elektroenergie – Ableitung von Anfoderungen an und Auswirkungen auf die Investitionsgüterindustrie, FhG-ISE, FhG-AST, VK Partner, 30.06.2009, Auftragsstudie 08/28 für das BMWi

[15] Leonhard W. et al. (2008), Energy storage in power supply systems with high share of renewable energy sources – Significance, state of the art, need for action, ETG Energy Storage Task Force, VDE Association for Electrical, Electronic & Information Technologies, Frankfurt, December 2008

6 Infrastructures will need to adapt

During the transition from a carbon based energy system to an electricty dominated one, not the potential to generate renewable electricty will be the biggest challenge but rather the infrastructure requirements as electricity as a "leading energy vector" implies profound consequences. With society unlikely to be willing to accept major changes in lifestyle, our infrastructures for mobility and logistics will need to adapt.

Energy distribution patterns will change

As the portfolio of energy sources changes (e.g. towards a higher share of renewable electricity), traditional long-distance energy transport (pipeline, tanker) loses physical capabilities and thus importance, and new long-distance energy transport for electricity (HVDC transmission) may partly complement. Additionally, efficient use of energy will gain further importance.

The more distributed nature of most renewable energy sources and along with increasing attractiveness of other distributed power generation systems (like CHP) may reduce the need for long distance energy transportation. The more distributed generation will be managed by smart grid structures, able to bundle different sources into 'virtual power stations', the better supply and demand can be balanced in an more intelligent and efficient way. These smart grids will be embedded into the regional or national grids via overlay grids and innovative new storage systems. Smart grid technology will also allow to include electricity storage capacities from battery electric vehicles (BEVs) as a means of grid balancing.

Furthermore, demand side management, combined heat and power (CHP) production with grid feed-in, residential or office-based photovoltaic electricity generation with grid feed-in, district heating, district gas supply (e.g. biogas, biomethane or hydrogen), and other local energy supply and production concepts will benefit and assist in balancing supply and demand peaks.

Mobility and logistics patterns will change

With electricity entering into the transport sector as a 'fuel', mobility, logistics, and means of transportation will gradually change. Potential developments include a broader portfolio of vehicles for personal mobility e.g. the advent of dedicated BEVs for shorter range or inner city trips. We may also see changing customer attitudes in densely populated agglomerations (falling number of holders of a drivers licence, car sharing on the rise, eco taxis, scooters, electric personal transport devices etc.) influencing the type of service and the fuel used, and thus the infrastructures required to operate the urban transport system. Traditional public transport concepts with improved modern zero emission propulsion technologies will gain acceptance. In more rural areas sub-centers may flourish and innovative public and/or individual transport concepts will have to serve scattered settlements more efficiently than today. Similar changes are expected to influence the movement of goods.

In general, however, society is unlikely to be willing to drastically change its way of living to adapt to a changing environment. It will rather seek for solutions in order to continue and improve existing lifestyles.

The more important seems the perception that a fast, successful and above all politically motivated adaptation to the changing conditions for Europe possibly will be the only chance for a path towards regional and independent energy production and use, the reduction of environmental emissions and costs[16], as well as a basis for economic development for European industry and society.

[16] By 2020, the environment costs (air pollution, CO_2 emissions) of all transport modes could reach €210 billion. [EC communication on Strategy of the internalisation of external costs (COM 2008/435)]

Message from the European Commission

"The transport sector in Europe still depends to 97 % on fossil fuels, which has negative implications on the environment, the security of energy supply and the economic development."

"Transport is an essential component of the European economy. The transport at large accounts for about 7 % of GDP and for over 5 % of total employment in the EU.")

Source: EC COM (2009) 279/4

Infrastructure challenges for energy transport

Compared with fossil energies, existing electricity grids and power transmission lines have a small energy transport capacity. Future electricity grids and large HVDC power lines (today 3-6 GW with 500-800 kV DC) must be installed at a much larger scale than today otherwise they will not be able to provide the same energy transport capacity as large oil pipelines (~75 GWh/h) or gas pipelines (~40 GWh/h) (see table below). Different to the transmission of electricity, hydrogen pipelines offer a much higher power transmission capacity (~30 GWh/h).

Thus, a future energy system based on renewable electricity faces big challenges: to expand existing power transmission infrastructure on the one hand, and to reduce power demand on the other hand in order to arrive at an economic optimum.

Energy transportation infrastructure (typcial sizes installed)	Energy transmission capacity
Oil pipeline (1 million barrel per day)	73 GWh/h (thermal)
Natural gas pipeline (30 billion Nm^3/yr)	38 GWh/h (thermal)
High voltage direct current transmission lines (HVDC) (53 TWh/y)	6 GWh/h (electric)
Hydrogen pipeline (with the diameter of a natural gas pipeline) (79 billion Nm^3/yr)	27 GWh/h (thermal)
Hard coal transport per ship from South Africa to Germany (4 TWh/yr)	0.5 GWh/h (thermal)

Table: Options for energy transport (LBST)

7 Electric-mobility will replace internal combustion engines

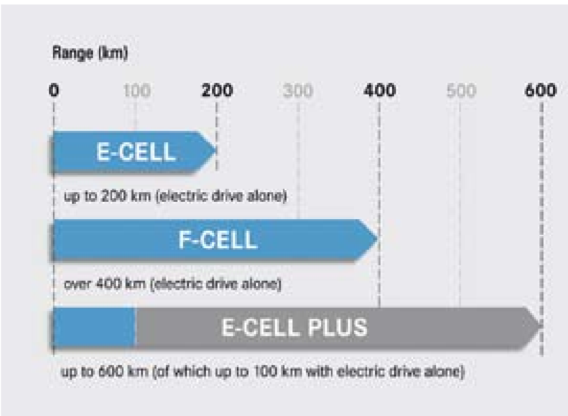
Climate change, energy supply limitations, and the resulting financial strains may influence the choice of energy and transportation services in the future more than in the past. Cleaner and more efficient powertrains will be preferred. Furthermore, societal or lifestyle changes may influence these choices as well, probably as profoundly as exogenous factors.

Emerging powertrains

Car concepts have diversified considerably during the last years in order to better serve changing user requirements. This trend will continue further over the next years by including a larger variety of new efficient powertrains and cleaner and more sustainable fuels. Additionally, downsizing and lightweight construction concepts will become more relevant.

The currently emerging trend towards the electrification of the propulsion system clearly benefits from the increasing share of renewable electricity. Available technologies range from hybrid powertrains, over plug-in hybrids to battery electric and fuel cell hybrid vehicles.

Example: Daimler e-cell, f-cell and hybrid



Fuel cells and batteries will bring renewables on the road

The automotive industry is in transition from from the internal combustion engine to the electric motor. The transformation process towards a new transport system has already started.

A great advantage of both electricity and hydrogen is that they can be produced from any primary energy carrier at high efficiency. This offers the opportunity to use different primary energy sources, and especially renewables, in road transport.

Hydrogen and fuel cells are key technologies for the transport sector, as they enable almost the same personal freedom, flexibility, and ease-of-use as we are accustomed to from today’s vehicles with internal combustion engines. Only hydrogen will have the capability to bring larger volumes of renewable electricity into the market of individual transport within the next years and decades. Hydrogen fuel cell electric vehicles (FCVs) for longer-range (>400 km), heavy goods, and public bus transport, complemented by battery electric vehicles (BEVs) for short distances (up to max. 200 km) and lightweight applications will be able to offer new efficient options for European transport markets.

Likewise, both BEVs and FCVs complement the required evolution in the electricity grid infrastructure very well: BEV in large numbers can provide buffering and reserve capacity within a smart grid with associated demand management; FCVs tie in ideally with using hydrogen for long-term or seasonal energy storage.

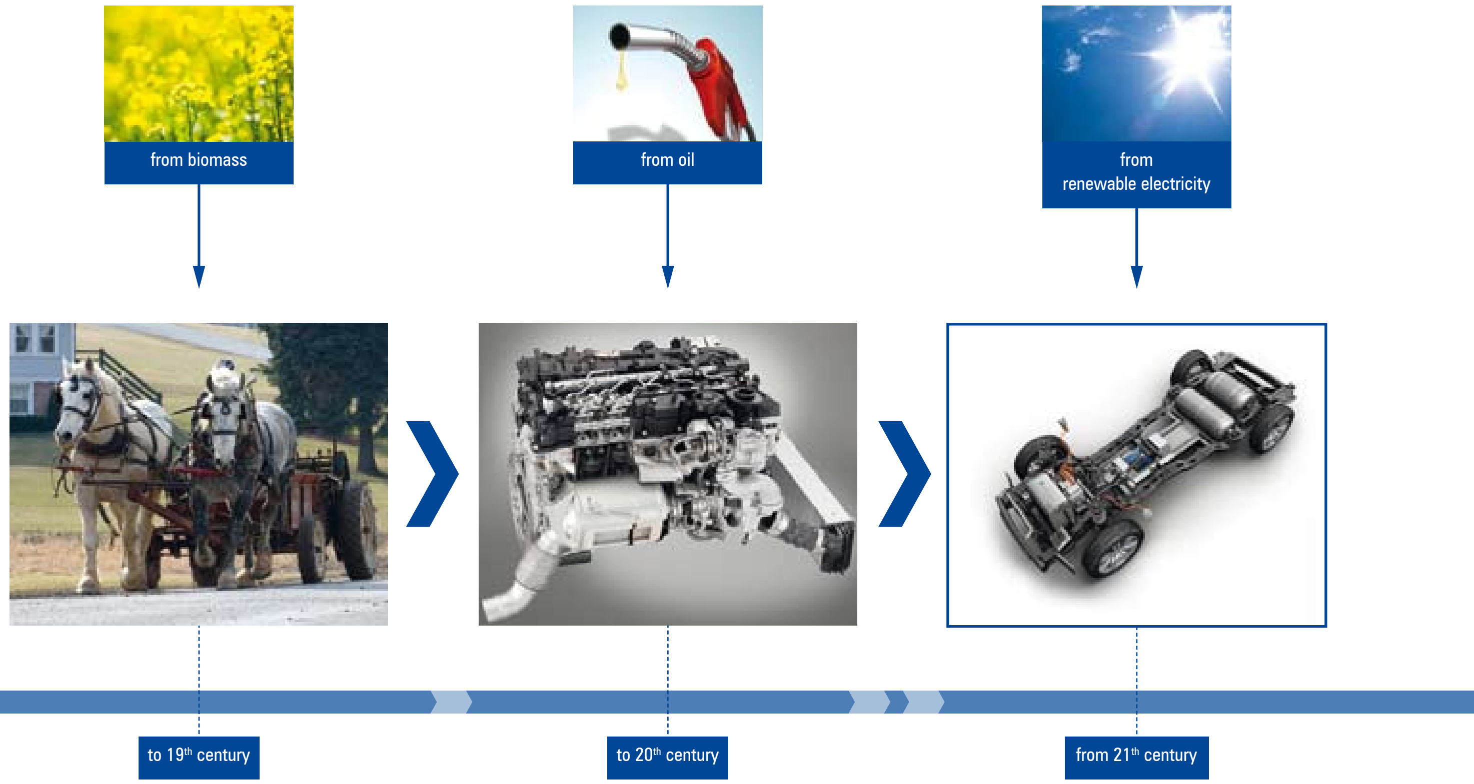
Transformation to hydrogen mobility – the German H_2 Mobility initiative

In September 2009, leading automobile manufacturers announced a joint statement on the development and market introduction of electric vehicles with fuel cell. From 2015 onwards they anticipate several hundred thousand units over life cycle on a worldwide basis. The MoU goes back to a joint initiative by Daimler and Linde aimed at providing sufficient hydrogen fuelling station infrastructure, which is the key to establishing electric vehicles with fuel cell on the market.

Besides Daimler, Linde, OMV, Shell, Total, and Vattenfall Europe, a 2nd utility has joined, EnBW. According to a communication[17] around the disclosure of the MoU, EnBW is convinced that fuel cell and battery electric vehicles can have a significant contribution to a climate preserving mobility based on clean primary energies. Furthermore, hydrogen is attributed a potentially important role as energy storage in distributed energy systems and as means for the integration of renewable energies.

Source: http://www.bmvbs.de/Anlage/original_1096793/Memorandum-of-Understanding-mehr-Informationen.pdf:

[17] „Faktenblatt“ der EnBW Energie Baden-Württemberg, Newsletter Wasserstoff + Brennstoffzelle, VWEW Energieverlag GmbH, 06.10.2009



Definition of "e-mobility"

E-mobility is a means of propelling vehicles by the use of electric motors. These electric motors are fed by electrons which are provided either from a battery or from a generator like a fuel cell or from both in conjunction (i.e. hybridisation). This type of e-mobility with battery or fuel cells is the only true zero emission propulsion technology not requiring continuous contact to an electricity supply system (as e.g. tramways or trolley buses) and still ensuring most efficient use of energy, also by brake energy recovery.

Efficiencies of BEVs and HFCVs in comparison

Assuming a hybridized fuel cell vehicle (HFCV) and a BEV, each with an operating range close to 500 km, then the primary energy requirements are about the same when natural gas is the primary energy source (natural gas steam reforming for hydrogen and combined cycle power plant for electricity generation). If electricity is the energy "source" (e. g. electricity produced from wind power), then energy demand of the HFCV per km-driven is somewhat more than 50 % higher than that of the BEV with the same driving range. If the battery-electric vehicle realistically is calculated at a much lower operating range of 150-300 km (only then allowing an operating weight which is acceptable for a four or five seat car) then its energetic advantage is gradually approaching a factor of 2.0, based on electricity as "energy source", and a factor of about 1.3 based on natural gas as source for either hydrogen or electricity. In the latter case, though, we are not anymore talking about the same vehicle with regard to customer needs as the assumed autonomy has been reduced to about half. Eventually, the customer has to decide which technology, thereto related characteristics and costs are acceptable.[18][19][20]

Large-scale market introduction programs

Two prominent examples on government support for pure battery electric individual mobility and for hydrogen mobility are France (véhicules électriques) and Germany (H_2-Mobility), respectively. In each case the mass roll-out of electric vehicles (BEVs and FCVs), each supported by their dedicated fuel supply infrastructure, is foreseen by 2020. In both cases the number of 1 million vehicles on the road shall be reached or surpassed by 2020.

[18] Thomas CE., Fuel cell and battery electric vehicles compared, International Journal of Hydrogen Energy (2009), doi:10.1016/j.ijhydene.2009.06.003

[19] M. Ball, M. Wietschel (editors), The Hydrogen Economy: Opportunities and Challenges, Cambridge, 2009

[20] C. Stiller, R. Wurster, Build-up strategies for a hydrogen supply and refuelling infrastructure including a comparative outlook on battery-electric vehicles and their infrastructure requirements, Proceedings of the 2. International Conference on Sustainable Automotive Technologies, Springer, 2010

8 New mobility concepts imply new fuel supply networks

Customer requirements demand a simplification in number and type of clean fuels offered. As long-term storage of renewable electricity implies hydrogen, it can play a prominent role in new mobility concepts, especially in co-existence with electric transmission. Required investments are comparable to other, less flexible solutions.

Customer requirements

The fuel supply infrastructure is the interface to the customer, and must be simple and safe to use, and located reasonably convenient to ensure customer acceptance.

Already today it can be perceived that users of energy services prefer to have a limited number of fuels of defined quality and energy providers to choose from, as well as a limited number of supply channels in order to minimize logistical and infrastructure efforts. However, electricity for batteries and hydrogen for fuel cells supply complementary mobility concepts, and therefore a co-existence is beneficial from a customers' point of view. Both electricity and hydrogen have defined qualities and are both efficient and simple to use, providing zero emission capabilities at the point of use and over the entire production and supply chain if produced from clean primary sources.

Production and distribution of transport fuels

Both hydrogen and electricity can be produced from a broad variety of energy feedstock, and therefore mitigate the upcoming resource problem today's petroleum-dominated mobility is facing. Furthermore, hydrogen can be converted to and from electricity at acceptable efficiency, allowing for cross-linking of the two energy vectors. Renewable electricity will be distributed over existing or reinforced electric power lines. Hydrogen can be produced from renewable electricity at any stage and scale; from large-scale central production with connected underground storage to small-scale, on-demand production at refuelling stations. Existing gas pipelines may be used for hydrogen transport in many cases with only limited alteration necessary.

Vehicle charging/refuelling

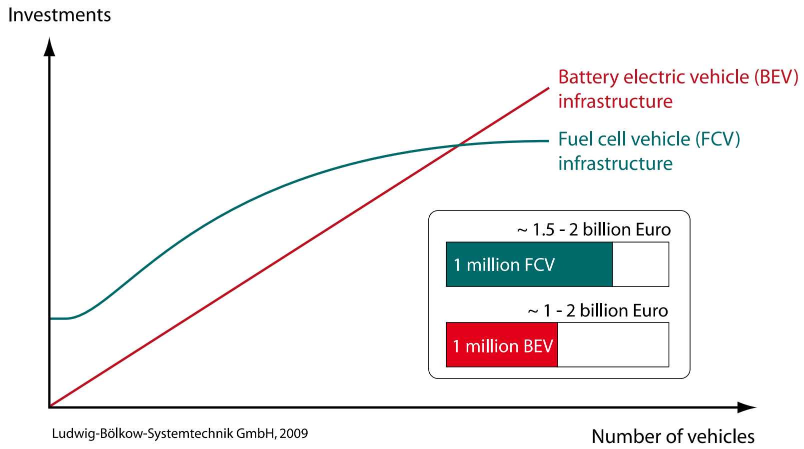
	Charging / refuelling points	Charging / refuelling time
Battery vehicle	Private charging points (at home, company)	8-10 hours – regular charging
	Public charging (e.g. parking lots)	0.5-4 hours – fast charge
	Battery swapping station	3 – 15 minutes – battery swapping
Fuel cell vehicle	Hydrogen refuelling station (public)	< 3-5 minutes

Contrary to the requirements for a hydrogen refuelling station infrastructure, BEV and plug-in hybrid vehicle charging initially can be facilitated at home or in parking areas with comparatively simple charging posts. As the vehicle population grows fast charging or battery swap stations will become essential for a wide-area coverage electric fuel supply system.

While the hydrogen refuelling process will typically not take longer than 3 minutes, electric refuelling will take significantly longer (between several hours down to several tens of minutes). Only battery swapping stations would if economically and technically feasible help to avoid that.

Infrastructure costs for hydrogen refuelling and battery recharging are comparable.

Refuelling infrastructure costs for hydrogen and battery charging are comparable



Build-up of hydrogen infrastructure in Germany

First evaluations by industry have shown that the build-up of a full coverage refuelling infrastructure with 1,000 hydrogen refuelling stations (HRS) in Germany would cost in the order of 1.5 – 2 billion Euro. Such an infrastructure can support about 1 million FCVs.

The cost of one small HRS providing about 1,000 cars with fuel lies between 1.2 and 1.5 M€. For larger HRSs following larger vehicle populations and providing fuel to at least 5,000 cars cost reach about 3.5 M€ for each station.[18 19 20]

Build-up of electricity charging infrastructure in Germany

The build-up of a charging infrastructure supporting about 1 million battery electric vehicles (BEVs) would cost between one and two billion Euro depending on the share of fast charging equipment.

As the vehicle quantities increase further, the infrastructure investment for BEVs (scaling almost proportionally with the number of BEVs) can even overshoot the hydrogen infrastructure investment (scaling disproportionately with the number of vehicles once an area-wide infrastructure is established).[20 22]

Required investments

Obviously, the creation of a new end-user infrastructure implies a significant investment. For hydrogen a relatively high upfront investment in refuelling infrastructure is mandatory, whereas in the case of directly electricity-fuelled vehicles these substantial investments can be postponed somewhat, since home refuelling points and slow fill charging posts may be sufficient in the beginning.

However, as soon as a mass market builds up, the economy-of-scale effect is much larger for the hydrogen infrastructure, and the specific hydrogen infrastructure costs can even fall below the electric charging infrastructure costs at a market volume of between 1 and 10 million cars (see box "Refuelling infrastructure costs" above).

In any case, as soon as we leave liquid hydrocarbons as automotive fuels and switch to battery vehicles or hydrogen vehicles, new infrastructures will be needed which require considerable investments. However, in comparison, these investments for the infrastructure are minor compared to the efforts of developing and purchasing the "rolling stock", i.e. the new vehicles. Furthermore, also today's fuel distribution and refueling is capital intensive, and there will be some savings once renovation and replacement of conventional refuelling equipment can be discontinued.

[21] Jörg Wind, Elektrifizierung des Automobils, F-Cell Symposium. Stuttgart 29.09.2009

[22] Ulrich Eberle, The Electrification of the Automobile - Fascinating Technologies vs. Technology Challenges, Hessisches Brennstoffzellenforum -9. November 2009, Darmstadt

Conclusions

- The upcoming decline of fossil fuel availability, and unsustainable rise of CO_2 emissions is a fact. Development and investment cycles in energy and infrastructure are long. Action needs to be taken now to prepare for the changes to come.
- Renewable electricity will take over a dominating role in the energy sector and in transportation, whereas biofuels will only have a limited role.
- Actions include adapting the electricity network and management system as well as preparing for the introduction of new transportation fuels.
- Electricity needs to be complemented by a more densely storable energy carrier. Hydrogen is an ideal energy carrier given its established and efficient conversion path to and from electricity. Hydrogen is storable electricity.
- Hydrogen will pave the way to new harmonised and economical structures and markets. New and more diverse players will appear.
- Electricity and hydrogen as leading new fuels in transport will force the electrification of the powertrain and the gradual replacement of the international combustion engine and conventional fuels.
- A strategic synergy exists between the need of heavily increasing the role of renewable energy sources in the primary energy mix and the goal to introduce clean climate neutral energy carriers in the transport sector: both require the storage of “clean energy“. This storage capability from several days onward can be best achieved through hydrogen storage and use.

Policy Recommendations

- EU, national and local energy development needs a coordinated approach, i.e. clean urban mobility can only be created by taking into consideration the efficient use of primary energy sources as well as their delivery to the point of use. This implies that transport and energy policies needs to be closely coordinated to ensure a positive effect of incentives, fiscal, and financial measures.
- The politically monitored and coordinated integration of different clean energy technologies is crucial to avoid inefficient solutions and not to miss industrial development opportunities.
- Horizontal programming between the European Industrial Initiatives and Joint Undertakings as for Fuel Cells and Hydrogen (FCH JU) proposed by the EU Strategic Energy Technology Plan (SET Plan) should develop joint energy production and distribution pathways with regard to electric transport development.
- Creation of a Europan Industrial Initiative on Efficient Electric Mobility covering fuel cell, batteries, and hybrid vehicles as joint collaboration between FCH JU and Green Car Initiative.
- A broadly conceived aggressive information strategy on clean transport technologies and their consequences for transport planning and infrastructure development should be an integral part of the new EU Transport policy for 2010-2020.

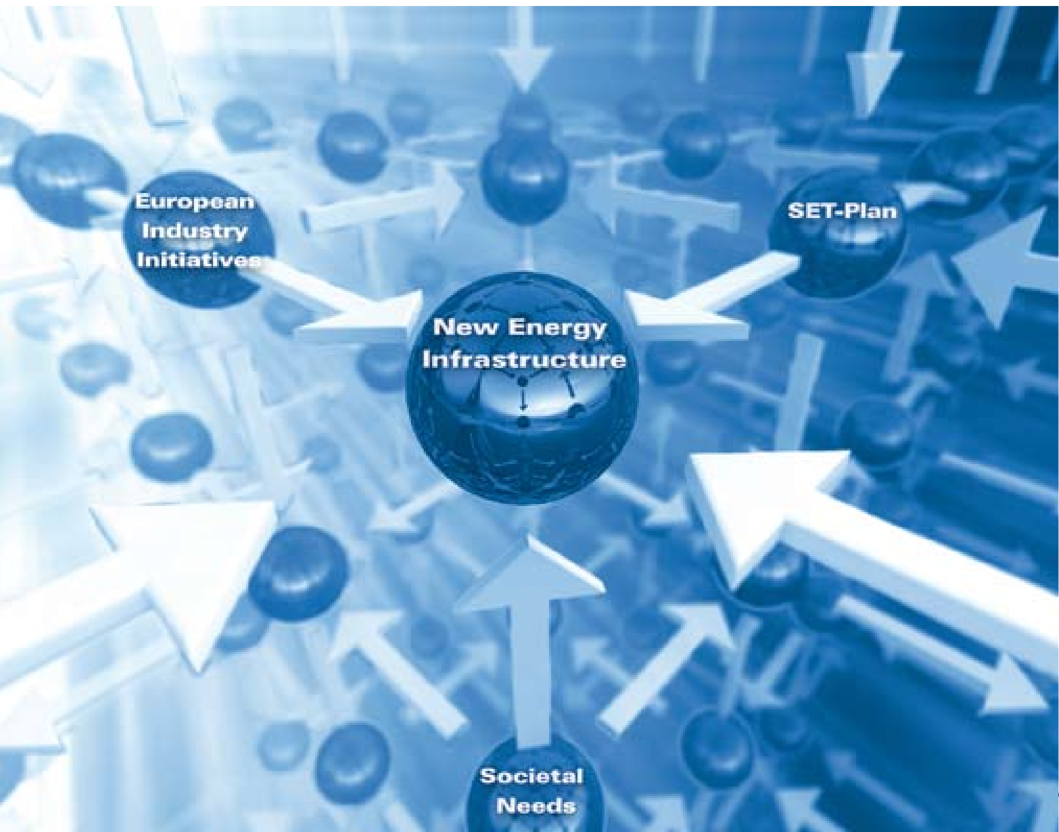
Further items for consideration

EU wide information campaign for public procurement officials on the impact of electric mobility on infrastructure requirements.

Standardisation of new energy vectors (electricity and hydrogen) to successfully prepare for post-fossil fuels.

Suggestions for required funding schemes, topics and demonstration programs (policy needs to put forward things that the markets cannot bring up alone).

Raise public awareness to provide guidance to a changing society. Planning of a new Trans European Network for Transport.



Abbreviations

BtL	Biomass-to-Liquid (fuel)
BEV	Battery Electric Vehicle
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DWV	Deutscher Wasserstoff- und Brennstoffzellen-Verband (German Hydrogen and Fuel Cell Association)
e-mobility	Electric mobility (electric propulsion)
EC	European Commission
EHA	European Hydrogen Association
EIA	US Energy Information Administration
EJ	Exa-Joule (= 10^{18} Joule)
FCV	Fuel Cell Vehicle
GHG	Greenhouse Gas (emissions)
HRS	Hydrogen Refuelling Station
HVDC	High Voltage Direct Current (transmission)
IEA	International Energy Agency
IEO	International Enery Outlook
LBST	Ludwig-Bölkow-Systemtechnik GmbH
MPa	Mega Pascal (= 10 bar)
Mtoe	Million Tons of Oil Equivalent
N_2O	Nitrous Oxide
NG	Natural Gas
Nm^3	Norm (standard) Cubic Meter
PFCs	Perfluorocarbons
PJ	Peta-Joule (= 10^{15} Joule)
PV	Photovoltaics
WEO	World Energy Outlook

In the year 2000 five national hydrogen organisations established the European Hydrogen Association (EHA) and started a close collaboration to promote the use of hydrogen as an energy vector in Europe. In 2005 major European industries active in the development of hydrogen and fuel cell technologies joined the EHA and enforced this effort to create a commercial market for stationary and transport applications and a role as market leader for the European hydrogen and fuel cell sector.

In 2005 the EHA opened its office in Brussels and established itself in a relatively short time as an active and recognized point of reference for European institutions. The EHA currently represents 14 national hydrogen and fuel cell organisations and the main European companies active in the hydrogen infrastucture development.

This unique membership structure has enabled the EHA to have up-close insight in national and local development and to communicate important issues regarding industrial and regulatory needs to key decision makers at EU level. By participating actively in important meetings of the Commisison, European Parliament and other European organisations the EHA has been able to create more visibility of the contribution of the use hydrogen and fuel cells to EU policy to key decison makers in Brussels. In addition the EHA, in collaboration with its national member associations supports and promotes important developments in European Regions and Municipalities.

Link: www.H2EURO.org

The German Hydrogen and Fuel Cell Association (DWV) promotes and prepares the general introduction of hydrogen as an energy carrier and of fuel cells as efficient energy conversion technology into the market.

DWV brings the interested parties (companies, institutes, private persons) together, keeps them informed, informs the general public and the deciders in economy and politics and advises the process of regulation and standardisation. In a nutshell: DWV is the German hydrogen and fuel cell lobby.

DWV works in close cooperation with the European Hydrogen Association and other national partner organisations all over the world.

Link: www.H2DE.org

Ludwig-Bölkow-Systemtechnik GmbH (LBST) is a leading European consulting company for business and society focussed on the sustainable use of natural resources and energy as well as sustainable mobility.

Since 1982, LBST has been supporting leading national and international companies and other stakeholders in society in establishing and developing sustainable structures, products and services.

Link: www.LBST.de

Based on long-standing appropriate industrial experience on innovative technology, innovation management and strategy flow-advice is consultative and executive dealing with solutions for the application of renewable energies and related infrastructure.

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