OFFICE OF TECHNOLOGY ASSESSMENT
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Reinhard Grünwald

Prospects for low CO2 and pollutant emissions transportation

Summary

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SUMMARY

Contrary to the general trend, transport is the only sector which has shown an increase in CO_2 emissions over the last decade. In the meantime the necessity of reducing CO_2 and pollutant emissions in transport is indisputable. The starting points for this are on the one hand the introduction of new fuels and energy sources to substitute petrol and diesel, and on the other hand an improvement in the efficiency of drive systems.

As the transport sector will have an important role to play in climate and resource protection as well as in the achievement of air pollution control goals, the Committee on Education, Research and Technology Assessment of the German Parliament commissioned the Office of Technology Assessment at the German Parliament (TAB) to undertake a preliminary study on the subject of the »Prospects for Low CO_2 and Pollutant Emissions Transportation – an Overview of Fuels and Drive Systems«.

The aim of the preliminary study is to look through and appraise the literature currently available, and to provide an overview of the main issues investigated to date. In addition, more detailed calculations were made for the quantification of the potential for reductions in emissions and on the land requirements for biofuels. On this basis gaps in research are to be identified and topics proposed which TAB assesses as meriting particular attention for further in-depth analysis.

POTENTIAL FOR INCREASING EFFICIENCY AND REDUCING EMISSIONS OF THE TRANSPORT SYSTEMS

Road Traffic

Road traffic, not only due to its share of the total transport volume, but rather also in view of the level of development it has reached thus far, shows the greatest potential for improved efficiency and for a reduction in greenhouse gases emitted. For this reason it usually finds itself in the spotlight of every transport technology discussion. This is also reflected in the focal themes taken up in the literature; the vast majority of the studies inspected dealt with technologies for improvements in the efficiency and reductions in emissions in transport from the road traffic point of view. For the reasons given the present report will broadly follow this approach.

Rail Traffic

Rail vehicles are nowadays normally powered by an electric motor or a diesel engine. This said, today's electric motors already have a relatively high level of development with limited potential for further savings. Even the (large) diesel engines used in rail vehicles have already reached a high level of development according to efficiency criteria. It can be seen that manufacturers in the railway sector see little incentive for the rail-specific development of new traction system technologies as a result of the comparatively small numbers of engines required. For this reason there is a tendency to carry technologies which have been tried and tested in road traffic over to rail traffic.

All that will remain in future, between very efficient diesel generator sets and electric drives with external power supplies for rail vehicles, will probably be extremely small niches for alternative drive system technologies such as fuel cells. Potential for further technical savings lies above all in the driving resistance sector (rolling and acceleration resistance, aerodynamic drag) and brake energy recovery in diesel vehicles.

Air Traffic

For several years, air traffic has shown by far the highest transport volume growth rates for all types of traffic. This trend will continue in future according to all forecasts. That is why measures to reduce both consumption and emissions in air traffic are of high priority. At the same time, however, the spectrum of technologies which can be used for this is limited, further adding to the urgency of the problems in this sector.

Established engines have a conflict of objectives between raising the efficiency of the turbines and reducing nitric oxide emissions. Fuel cells are not predestined to become an alternative drive system technology in air traffic due to their relatively heavy weight. In addition, the predominant reaction product in fuel cells is water, which in itself is not unproblematic. The reason for this is that certain emissions (including water) display different reaction mechanisms at high altitudes than when they are on the earth's surface. The significance of these so-called »non-permanent greenhouse gases« for the greenhouse effect has not yet been fully clarified scientifically. The evaluation of the environmental characteristics of alternative fuels (e.g. hydrogen) in air traffic will depend considerably upon this.

Lightweight construction and aerodynamics have been and remain in the foreground of aircraft fuel savings. Further advances in lightweight design are primarily dependent upon the development of new materials.

Shipping Traffic

The (large) diesel engine has become accepted as the dominant engine technology in the shipping business. Transport vessels in inland navigation are fuelled with diesel and in deep-sea shipping with heavy oil, which due to its high level of pollutant emissions is not the best solution from an environmental point of view. On the basis of the typical, quasi-stationary operation of shipping traffic, engines can be designed to be fuel-efficient and operated at close to optimum efficiency.

As measures are introduced to improve existing or develop new drive systems, the same technologies come into question in principle as those used for road and railway vehicles. Fuel cells are already used for ship drives in the military sector today. However their widespread application in civilian shipping in the years to come is doubtful for financial reasons.

POWERTRAIN TECHNOLOGIES AND SYSTEMS

Despite their high level of development, the conventional drive systems – especially petrol and diesel engines – still have considerable potential for further development. Additional potential is expected from more advanced technologies such as hybrid and fuel cell systems.

Petrol engine

There technical opportunities for reducing specific fuel consumption in conventional petrol engines are very diverse. Petrol engines demonstrate a relatively low level of efficiency at partial load. Many of the enhancements are therefore aimed at optimising or else avoiding this unfavourable operating condition.

Serviceable technologies in the short to medium term are, for example, downsizing in conjunction with turbocharging; direct fuel injection, as well as variable valve control, cylinder cutout and compression. Each of these technical measures has the potential to contribute to a reduction in fuel consumption, some by up to more than 15% (depending on the size and type of vehicle). The values of individual measures may not be simply added together however, as they partly exploit the same reduction capacities in different ways.

In addition to conventional »petrol-driven cars«, Otto-cycle engines powered by natural gas, ethanol or hydrogen are already in use today. The technology for this therefore exists in principle; however significant improvements are expected in the future. The introduction of these engine concepts also depends upon the availability of the respective fuels. The introduction of natural gas and/or hydrogen vehicles would have to be accompanied by the build-up of an appropriate filling station infrastructure. An extensive area wide infrastructure for natural gas as a fuel is currently under construction.

Diesel engine

The diesel engine has had its fuel consumption favourably optimised in the past and has reached a relatively high level of development in this regard. Considerable improvements in efficiency were achieved primarily through electronic direct injection. The development of this system has to a great extent been completed. Only minor additional fuel savings can be expected in diesel engines in the near future through the further optimisation of technologies which are already in use (for example, reductions in engine friction, improved exhaust gas recirculation).

Even more than with petrol engines, there is a conflict of objectives in the construction of diesel engines between raising the energy efficiency and complying-with growing legal requirements to reduce emissions of air pollutants such as carbon monoxide, hydrocarbons, nitric oxides and particulates.

Convergence of petrol and diesel engines

Conventional combustion engines, whether petrol or diesel, have one fundamental problem: A flame front separates the combustion chamber into relatively hot and cold areas which has negative effects on the emissions of nitric oxide and unburned carbon. One objective therefore is the self-ignition and burning of a homogenous air-fuel mixture simultaneously at several places in the cylinder avoiding the flame front and shock wave in the cylinder. This would combine the advantages of the homogenous air-fuel mixture of petrol engines with the self-ignition properties of diesel engines. This procedure is called homogenised combustion (Homogeneous Compression Combustion Ignition, HCCI). The development of this technology is currently in the test bench phase.

Interaction between CO_2 reduction measures and pollutant emissions

Automotive engineering measures designed to reduce fuel consumption or CO_2 emissions could be counterproductive with regard to the emissions of human and ecotoxic pollutants. Conversely the reduction of pollutants (e.g. by equipping diesel vehicles with a particulate filter) could lead to increased fuel consumption and higher CO_2 emissions. Quantifying the interaction of CO_2 and pollutant reduction measures is in part however methodologically demanding. Further research is required here.

Hybrid vehicles

Hybrid vehicles combine multiple energy converters and storage systems in the vehicle. These are typically combustion engines and electric motors with fuel tanks and batteries. The reduction in consumption in comparison with conventional vehicles at a similar development level essentially results from the following properties of the powertrain or operational mode:

> *energy recuperation*, i.e. the partial recovery of brake energy (particularly frequent in city traffic),
> *optimal operating range for combustion engines*, i.e. avoiding low efficiency in the partial load range and making use of the higher efficiency in the medium to full load range,
> *»downsizing«*, i.e. use of smaller internal combustion engines.

The weaknesses of the hybrid concept can be characterised as follows:

> Complexity: The costs for production and maintenance are higher due to the larger number of components. In addition the losses caused by additional energy conversion steps reduce the savings in consumption.
> *Weight*: The additional weight of the hybrid-specific components limits reductions in consumption compared with monovalent vehicles.

Overall, the efficiency of hybrid vehicles is thus *heavily dependent on the operational profile*: It is true that comparatively high savings can be achieved in city traffic. However out of town the effects are significantly smaller; at high speeds consumption may even be higher as a result of the additional weight.

Nevertheless it is evident that the hybrid concept is already able to make a contribution to reducing emissions today and has considerable potential for even further development. An important additional advantage which all hybrids have is the possibility of being able to run entirely emission-free (limited by battery capacity) in heavily polluted areas such as the inner-cities for instance.

Fuel Cell Vehicles

Fuel cell vehicles are regarded as a forward-looking vehicle concept. They are currently in the development phase; series-production vehicles do not yet exist. A differentiation can be made between *Three concepts* depending on the fuel used:

> Pure hydrogen (stored as liquid or compressed hydrogen),
> the creation of a hydrogenous fuel gas on-board from methanol or hydrocarbons (»on-board reforming«) and
> the direct use of methanol in dedicatedfuel cells.

Hydrogen is the fuel of choice from the point of view of efficiency; however the on-board storage and the lack of an H2-infrastructure are problematic. Hydrogen storage systems are substantially heavier and many times more expensive than tanks for methanol or petrol.

Further development is required for all components, particularly in terms of cost cutting. The R&D of fuel cells takes place to a large extent in the field of material science (e.g. developing new membrane materials for polymer electrolyte fuel cells). A noteworthy market penetration of fuel cell vehicles is – now that the euphoria of the 1990s has clearly cooled down – currently expected in 15 to 20 years at the earliest.

TECHNOLOGICAL POTENTIAL FOR LOWERING CONSUMPTION AND REDUCING EMISSIONS

In order to be able better to illustrate the technological potential for lowering consumption, i.e. the effects of vehicle-sided measures, technology packages were defined and combined into six model configurations, and their reductions quantified:

> *Conventional*: This refers to a vehicle which, in addition to a significant reduction in resistance (weight, rolling resistance, and aerodynamic drag), has had a range of further drive-side developments of a more conventional nature implemented.

> *Mild hybrid*: This vehicle is driven by a hybrid engine with a small electric power unit.
> *Full hybrid*: This model differs from the mild hybrid in that it has a larger electric drive.
> *Concept*: This is a visionary vehicle which combines the extreme reduction of resistance with optimised drive systems.
> *Concept hybrid*: This is a concept vehicle (as above) with an additional hybrid drive system.
> *H_2FC*: This is a vehicle driven by a hydrogen fuel cell.

The results in the following chart show that considerable efficiency potential can be exploited using »conventional« measures alone. The largest reductions among the configurations close to the market result from the hybrid concepts and among these for full hybrids in particular. The concept car and fuel cell car are projected as having significantly lower consumption when they become available for registration approval in 2020 than conventional and hybrid cars.

The influence which the different optimised technology configurations will be able to exert on the overall consumption of the vehicle fleet is however decisively determined by their market penetration. This means that for significant reductions to be achieved – above all the high potential of what are still rather visionary concepts is required and/or a substantially quicker market penetration of relatively mature measures.

TECHNOLOGISCHE POTENZIALE ZUR VERBRAUCHSSENKUNG VON BEISPIELKONFIGURATIONEN

Konfiguration	Otto-PKW			Diesel-PKW			BZ[2]
	Verbrauch	Änderung[1]		Verbrauch	Änderung[1]		
	2004	2010	2020	2004	2010	2020	2020
PKW-Mix[3]	236			223			
konventionell	–	-54	-61	–	-43	-51	–
milder Hybrid	–	-50	-55	–	-47	-54	–
Vollhybrid	–	-74	-79	–	-68	-74	–
Konzept	–	–	-95	–	–	-92	–
Konzepthybrid	–	–	-116	–	–	-111	–
H_2-BZ	–	–	–	–	–	–	-124

alle Angaben in MJ/100 km
1 Neuzulassung in 2010 bzw. 2020 bezogen auf den PKW-Mix 2004
2 BZ: Brennstoffzellen-PKW; Reduktion bezogen auf Otto-PKW
3 gesamte PKW-Flotte nach Fahrleistungsanteilen der Größenklassen gewichtet

ALTERNATIVE FUELS: ECOLOGICAL AND ECONOMIC CONSIDERATIONS

About ten different alternative fuels are currently under discussion from an international and a national viewpoint with regard to their potential contributions to a more sustainable mobility. They can be introduced with a multitude of possible methods of production in combination with various drive system technologies (such as optimised conventional combustion engines or fuel cells). Besides the conventional marketable biofuels (biodiesel, ethanol from sugar/ starch as well as biogas) the focus of the discussion lies in particular on the biofuels currently under development (primarily biomass-to-liquid (BTL) fuels, ethanol from wood, straw or the like) and hydrogen.

Conventional biofuels

Production technologies are more or less fully developed for the conventional biofuels biodiesel (in Germany predominantly made from rapeseed), bioethanol from grain, maize and sugar beet, and biogas; there is potential for optimisation particularly in the reduction of the use of fertilisers, the increase in yield per hectare and the use of the by-products created during fuel production.

Data situation: The energy and greenhouse gas balances and the costs vary greatly in the literature, above all as a result of the assumptions made concerning agricultural production and the consideration of the by-products produced. There are only a few publications which assess the production of biogas as a fuel. Energy, greenhouse gas and cost balances can vary considerably depending on whether residue or cultivated biomass is used as input raw material.

Greenhouse gas balance: In principle it can be said that the greenhouse gas balances of rapeseed methyl ester and ethanol from wheat or sugar beet are significantly more favourable, comparing the direct combustion of the fuel with diesel and petrol as reference fuels, assuming the by-products are usable. With an optimised use of by-products, the greenhouse gas emissions can be further significantly reduced. Despite the rather sketchy data availability, the balance for biogas from waste can be judged as being very favourable.

Costs: The production of biodiesel and ethanol is clearly more cost-intensive than of fossil fuels and even in 2010 is not expected to be achievable for less than 20 to 40 Euros/GJ. Biogas from waste is comparatively less expensive at about 15 to 34 Euros/GJ. Concerning energy crops, 2-culture systems (moist matter fermentation) seem to perform particularly favourably.

Biofuels under development

What is particularly interesting in a prospective perspective is the production of bioethanol from woodlike source materials (cellulose) and synthetic fuels through biomass gasification (biomass to liquid, BTL). It is true that an appreciable penetration of the fuel market with these synthetic fuels cannot be reckoned with in the next 10 to 15 years. However they do offer considerable potential for the future compared with conventional biofuels due to their non-specific source materials as well as the opportunity of using the entire plant. Demonstration projects indicate that further development in process engineering is required before this path towards the supply of fuel can be profitably trodden. Attention should be paid to the fact that an economically and ecologically meaningful biomass logistics system needs to be built up for the supply of raw materials.

Data situation: Hardly any publications are available on balancing energy and greenhouse gas emissions for these biofuel pathways which are still in their development phase.

Greenhouse gas balance: On the basis of available concept studies and demonstration projects it is expected that both energy consumption and also greenhouse gas emissions caused by conventional biofuels can be considerably reduced in principle.

Costs: The costs quoted in the various publications differ greatly, so that no consistent picture can be inferred. It is however in general expected that the costs will sink substantially in future. Costs of around 9 Euros/GJ by the year 2010 have on occasion been considered possible.

Hydrogen

The production of hydrogen as a fuel in cryogenic liquid form or as a compressed gas is possible on the basis of almost all primary energy carriers. In most cases the necessary technologies have already been developed or are commercially available. Production can take place both in centralised large-scale plants as well as in decentralised filling stations.

Data situation: The production paths for hydrogen have been comparatively well investigated with regard to energy requirements and greenhouse gas emissions. Further environmental effects on the other hand (e.g. acidification and ozone formation potential) have been barely or not at all investigated. Existing cost data relating to the individual fuel pathways are not as yet very reliable.

Greenhouse gas balance: The greenhouse gas balance of hydrogen depends crucially upon the primary energy used. The potential for CO_2 and low-emission fuel pathways in hydrogen production is primarily based upon renewable energy sources. The (potentially large) greenhouse gas reduction potential during steam reforming of natural gas and coal gasification is dependent on the technical and economic viability of CO_2 separation and storage. In general, the production of cryogenic liquid hydrogen, encouraged primarily for economic reasons, has disadvantages from a climatic point of view when compared to its compressed form due to the high energetic costs of liquefaction.

Costs: Despite all the uncertainty, higher costs are indicated according to information available at the current state of knowledge in comparison with numerous biofuels. The most economical variant with a high emission reduction potential is direct biomass gasification. Its potential is comparable to that of electrolytic hydrogen production with renewably generated electricity, which is however more expensive.

Infrastructure requirements: If hydrogen is to be used as a fuel, an important prerequisite for the diffusion of appropriate vehicles is an extensive network of hydrogen filling stations. By today's standards, there is no ideal solution to the problem as to whether filling stations need to be provided in order to stimulate the demand for hydrogen, or whether demand for hydrogen can induce the supply of filling stations. It is therefore most likely to be solved in practice by investment behaviour, which is closely linked chronologically and adapted to the market phases, and supporting instruments until a marketable equilibrium is reached for the given situation. In general, it is assumed that fleet operators could play a key role in the pilot and introductory phases.

The development of a hydrogen infrastructure would be premature at this time, as a number of technological decisions of key importance either have not been, or could not yet be made, such as the method of storing hydrogen in the vehicle for example. That is why more intensified international co-operation in research and development and the further development of infrastructure concepts, as well as of norms and standards, is absolutely essential.

POTENTIAL REDUCTIONS IN WELL-TO-WHEELS EMISSIONS

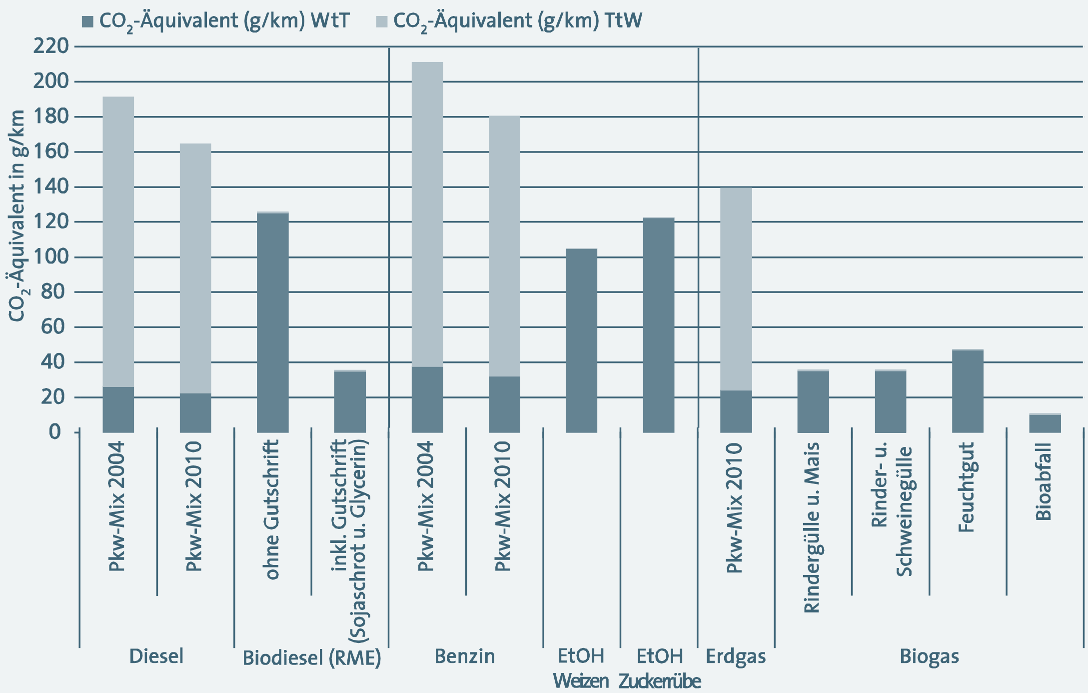
In order to quantify the technological potential for emissions reductions in the transport sector, an analysis is required that integrates the potential implicit in fuel provision (Well-to-Tank, WtT) with that in the vehicle itself (Tank-to-Wheels, TtW) to provide a Well-to-Wheels (WtW) perspective. In contrast to the literature, in which this discussion is usually conducted on the basis of a randomly selected reference vehicle, the present report maps the complete car fleet in the years 2010 and 2020.

WtW analysis 2010

Some of the findings of the WtW analysis for the year 2010 are shown in the chart, which portrays the emissions of CO_2 equivalents per vehicle kilometre driven for a range of engine/fuel combinations.

It can be seen that as a result of the efficiency measures assumed by the trend, the greenhouse gas emissions of conventionally driven cars will decrease by about 14% compared with the base year 2004. As mentioned above, the strong dependence of greenhouse gas emissions from biofuels on the method in which credits from upstream processes are accounted for is also shown. This is of particular note in the case of biodiesel (rapeseed methyl ester, RME), where the reduction potential can vary from 20 to 80% in comparison to the use of fossil diesel fuel depending on the use made of the by-products. Overall it can be seen that even the conventional biofuels (RME and bioethanol based on wheat or sugar beet) have an advantage over the fossil fuels regarding greenhouse gas emissions at any rate.

WTW-DARSTELLUNG FÜR PKW MIT DIESEL- UND OTTOMOTOR 2010



Biogas appears to be very interesting in terms of greenhouse gas reduction. It can be produced from semi-liquid manure, a mixture of semi-liquid manure and maize or else even from biological waste or moist matter (2-culture systems). Compared to natural gas of fossil origin for example, methane-rich gas produced from biological waste can reduce greenhouse gas emissions by around 90%.

WtW analysis 2020

Under the basic conditions considered and assumptions of technological development made here, there will be a reduction of greenhouse gas emissions by the average car solely through improvements in efficiency of about 25% in the year 2020 in relation to the base year 2004. Using a concept hybrid car optimised for minimal consumption, the reduction of greenhouse gas emissions can be increased by a further 25%.

Due to learning curve effects in the production of biofuels, the greenhouse gas emissions (WtW) when using conventional biofuels in 2020 will also be lower than in 2010. The biofuels of the so-called »second generation«, which are currently still under development, perform particularly well. They are expected to make a contribution to the fuel market in Germany in 2020. These fuels will make reductions in greenhouse gas emissions of more than 80% possible compared to fossil fuels. When by-products are added, e.g. the surplus power generated producing FT diesel, negative greenhouse gas emissions will even be possible in a few cases. Also in 2020, several manufacturing paths for biogas appear interesting leading to greenhouse gas reductions of 65 to 90% compared to natural gas.

The WtW balancing for hydrogen operated fuel cell vehicles depends crucially upon the origin of the hydrogen. It seems that – as a result of the high level of emissions in the upstream processes – the hydrogen provided from natural gas does not display a significant greenhouse gas advantage over traditional fossil fuels. If hydrogen is produced through electrolysis on the basis of the European power mix and then used in fuel cell vehicles, then its balance compared to the use of fossil fuels and conventional combustion engines turns out to be clearly negative. If however the hydrogen is produced from renewable electricity by electrolysis, then it has comparatively low greenhouse gas emissions. It should however be noted here, as is explained below, that the use of renewably generated electricity to power vehicles is in competition with the stationary sector.

If CO_2 separation is technically optimised so that it is also economically competitive, and there is sufficient storage capacity available, the »reforming natural gas« and »coal gasification « hydrogen pathways may also become interesting for achieving climate protection goals in the transport sector.

BIOFUELS – POTENTIAL VOLUMES AND LAND REQUIREMENTS

In addition to technological operability, specific potential for reductions in emissions and the costs of biofuels, the question of what volume of biofuels can be produced on the land available is of considerable importance for the overall evaluation of the relevance of biofuels as substitutes for fossil fuels and the achievement of climate protection goals.

Beginning with basic assumptions on agricultural yield and efficiency of the individual production processes, including enhancements as a result of learning curve effects, land requirements are calculated for several scenarios arising from the substitution of a certain volume of fossil fuels.

A maximum consideration highlights the fact that an area of more than 18 m ha will be required to cover the total fuel requirements of the car sector in 2010 with conventional biofuels (RME, bioethanol from wheat). This is clearly not going to be brought about by domestic production. The maximum acreage available for the cultivation of energy crops in Germany in 2010 according to environmental policy restrictions is given as about 1.6 m ha according to the literature.

The land required in order to meet the provisional EU target share of biofuels of 10% in 2020, would be 1.6 m ha using RME and bioethanol from wheat. Greenhouse gas reductions of about 7 m t/a would thereby be achieved. If the EU target were to be met using so-called second generation biofuels, the land required to substitute diesel fuel would be 1.1m ha assuming the use of BTL made out of wood from short rotation plantations. The area required by bioethanol from lignocellulose can not be quantified here as the necessary data is not available. The greenhouse gas reductions would be approx: 12.3m t/a.

EXTENDING THE RESOURCE BASE THROUGH IMPORTS

It is clear from the analyses of the potential volumes of biofuels that considerable land requirements result from ambitious target volumes. Consequently the option, of using the exogenous potential for providing biomass for energetic use, through the import of bioenergy sources in addition to the use of domestic potential seems interesting.

In Europe there is for example, considerable and as yet unexploited potential in Poland and Rumania. Potential imports from threshold and developing countries appear considerably more extensive still. As a result of climatic conditions and land availability, the global potential of bioenergy lies to a considerable extent – at least 50% – in today's threshold and developing countries.

From the aspect of sustainability, it is essential that potential exports of biofuels do not lead to environmental drawbacks (e.g. virgin forest clearance, the conversion of extensive acreage into bioenergy plantations) or social problems (e.g. expropriation or expulsion) and that food security is not unfavourably affected.

Initial study results from the World Food Organisation (FAO) for example, point towards the fact that there is no direct connection between potential bioenergy imports from developing countries and nutrition security. However the development of binding criteria for the »sustainability« of biofuel exports from developing countries would be desirable.

COMPETING USES

In studies on the usage of biofuels, assessments of potential often occur with 100% of the available biomass being assigned to the fuel sector. Such a way of proceeding does not take account of competing uses, which are effective on different levels. Competing uses are characterised by conflicting targets and partially contradictory restrictions on the one hand, and by the relationship between – limited – resources (potential) and demand on the other hand.

Purposes of land use

A fundamental competition situation lies in the fact that different types of use – e.g. agriculture and forestry, settlement and traffic as well as nature conservation and landscape protection or recovery – are in competition for the land available. If new claims are then added – such as the cultivation of energy crops for biofuels – or the models of use change, the competition between these uses could be aggravated. The determination of the land available for the cultivation of biomass is thus methodically difficult in so far as considerations have to be made concerning the priority of the various claims for use (e.g. biomass vs. nature conservation).

Mobile or stationary?

An additional fundamental competitive situation lies in the question as to which use the biomass gained or the electricity generated should be put: Is use in the transport sector or in the stationary sector preferable? The achievable CO_2 reduction and avoidance costs are appropriate criteria for an environmental economic evaluation here.

It is undisputable that in the case of biomass, priority should be given to its use as a raw material, as this can effectively be connected upstream in the chain of materials use. Provided that materials can be registered and collected in a logistically affordable form following their material use phase, they are subsequently usable either as fuel or energetically.

The majority of current studies when it comes to evaluating whether mobile or stationary use should have priority (thus e.g. conversion of wood to BTL diesel or the combustion of wood pellets for the generation of heat and electricity), tend to conclude that stationary use is more effective than biomass use in the mobile sector from the viewpoint of greenhouse gas avoidance costs. Similarly, the feeding in of renewable electricity into the grid is rated as more efficient than the production of hydrogen through electrolysis for mobile use. However a reliable statement on future greenhouse gas avoidance costs caused by »stationary« or »mobile« use cannot be made without a detailed modelling of consistent scenarios using appropriate volume frames, cost trends and the consideration of saturation effects.

PRIORITY NEED OF INVESTIGATION FOR TECHNOLOGY ASSESSMENT

A number of questions were identified from the overall view of the current state of knowledge and discussion elaborated in this report in the subject areas of transport systems and drive system technologies as well as fuels, which are in need of investigation. TAB assesses these as meriting particular attention on the one hand because of their central importance for the achievement of reductions in emissions in the transport sector, and on the other hand because there are considerable gaps in research in these fields. The priority need for investigation was seen in the following fields:

Transport systems and drive system technologies

> Potential for reducing emissions in rail, water, and air transport systems
> Problem sector goods traffic – technological potential

Fuels

> Biofuels of the so-called second generation (Well-to-Wheels analyses)
> CO_2 separation and storage in the production of fuels
> Imports of biofuels
> Global biomass potential and competing uses
> Strategies for introducing alternative fuels

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TAB

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BÜRO FÜR TECHNIKFOLGEN-ABSCHÄTZUNG
BEIM DEUTSCHEN BUNDESTAG

KARLSRUHER INSTITUT FÜR TECHNOLOGIE (KIT)

Neue Schönhauser Straße 10
10178 Berlin

Fon +49 30 28491-0
Fax +49 30 28491-119

buero@tab-beim-bundestag.de
www.tab-beim-bundestag.de