Renewable Energies for Climate Benign Fuel Production – Powering Fuel Cell Vehicles

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Transportation contributes to energy consumption and greenhouse gas emissions, sustainable mobility requires reductions in both areas. Alternative fuels from natural gas and from renewable resources can contribute in the mid and long term to the fuel market for mobile as well as stationary applications. The lack of reliable data on emissions, energy chain efficiencies and costs demonstrates the need for field tests and demonstration projects. Fuel cells offer the technology to use "new fuels" in a highly efficient way.

Why Renewable Fuels for the Transportation Sector?

1. Situation of Energy Supply and Environmental Issues

In the future, the global energy demand is expected to rise considerably, resulting in increasing CO_2-emissions. A significant share of energy consumption is due to rising transportation activities. Today, the mobility sector is almost completely dependent on crude oil derivatives. Figure 1 shows the global energy and CO_2-emission situation and an outlook through 2020.

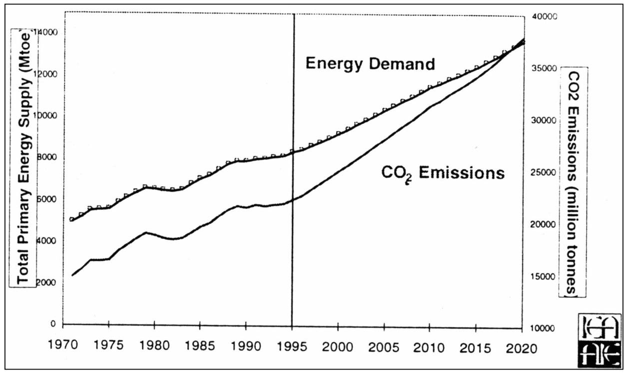

Fig. 1: Global Energy- and CO_2-Emission Situation
Source: Robert Priddle, International Energy Agency, Challenges of World Energy Supply, p. 11. Conference Proceedings „Energy Supply and Climate Protection", Munich, November 11, 1999.

70% of proved crude oil reserves are located in the OPEC area (mainly in the Middle East region). Global production of low-cost conventional crude oil is expected to peak within the coming decade. The gap between increasing demand and economically available crude oil will be covered by using deep sea oil as well as oil sands and tars. Natural gas liquids are an additional option for closing the supply-demand gap, as illustrated in figure 2.

The production of non-conventional oil causes considerably higher CO_2-emissions and higher cost. Canada estimates greenhouse gas emission increases of a factor of 3.5 for heavy oil and a factor of 3.65 for oil sand resources.

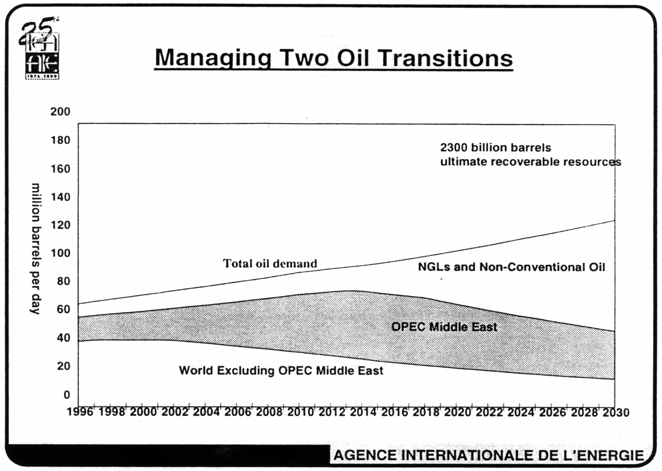

Fig. 2: Global Crude Oil Supply and Demand – Outlook
Source: Robert Priddle, International Energy Agency, Challenges of World Energy Supply, p. 11. Conference Proceedings „Energy Supply and Climate Protection", Munich, November 11, 1999.

Due to strong increases in energy demand, the future fuel supply will face instabilities in ecological, economic, and political respect (price increases, volatile prices, distribution conflicts, augmenting greenhouse gas emissions etc.).

In the past years, the major energy consuming sectors have succeeded in stabilizing or reducing energy consumption and emissions, except for the mobility sector. Transportation faces high growth rates and expects a doubling of fuel consumption through 2020, connected with growing greenhouse gas emissions. Therefore, the climate discussion will more directly address the mobility sector as a major potential contributor to climate issues.

Sustainable mobility requires emission and consumption reduction and therefore a re-orientation of today's fuel production and supply system:

- A secure, economic and environmentally sound fuel supply is a key factor for maintaining mobility and economic development.
- The geostrategic imbalance of crude oil consumption (approx. 80% in industrialized countries) and crude oil reserves (approx. 75% located in the OPEC area, esp. in the Middle East region) reveals the proneness of industrialized economies and mobility to political or logistic disturbances of fuel supply. Distribution conflicts are likely; currently 60% of Middle East crude oil is exported East, i.e. to the Asian nations. The global production share of OPEC oil will augment to more than 50%.
- Peak crude oil production of Western Non-OPEC countries, especially North Sea, will probably be reached within this decade; the USA have surpassed peak production in the 1990s. Increasing fuel demand in Western industrialized countries has to be met by augmenting imports from OPEC-countries (delivering mainly to Asia even today), by enhancing the use of Unconventional Oil, or by introducing alternative fuels such as hydrogen, ethanol and methanol. These fuels can be principally derived from natural gas, in the future from renewable energies.
- Transportation plays a key role in the discussion of the anthropogenic greenhouse gas effect. The self-commitment of the European automotive industry association (ACEA) on CO_2-reduction as well as the approaches of the German Federal Goverment target a mid-term stabilization and long-term reduction of CO_2-emissions caused by the transportation sector.

Conclusion

Increasing fuel prices due to either political reasons or as a consequence of decreasing low-cost crude oil resources as well as emission and consumption reduction legislation will amplify the pressure on the mobility sector (e.g. Climate Protection Program of the German Federal Government; EU Green Paper). This is mainly due to the following reasons:

- Improving air quality (local situation: reduction of air pollution, e.g. Clean Air Initiative of the World Bank)
- Mitigating global warming (global situation: CO_2-reduction, e.g. ACEA Self Commitment)
- Relaxation of dependence on crude oil (diversification of fuel supply through enlarging our supply basis by alternative fuels, in the long term from renewable resources).

The automotive industry focuses on a variety of solution approaches:

1. Enhancing efficiency of drive train systems:

- Improving conventional engines, e.g. direct injection systems, light weight design, hybrid propulsion systems (improvement >20% within the next 10 years feasible)
- Development of new propulsion systems, e.g. fuel cell electric drive systems (see fig. 10: DaimlerChrysler Fuel Cell Vehicle R&D Program with hydrogen and methanol powered vehicles)

2. Market introduction of CO_2-free fuels (e.g. hydrogen from renewable electricity) or CO_2-neutral fuels (e.g. methanol and ethanol from biomass), i.e. introduction of renewable fuels to the transport and mobility sector. Examples: Ethanol program in Brazil and USA; Biodiesel program in Germany.

Renewable Energies already contribute a considerable share to the current energy consumption:

- World: 6%
  (including non-commercial biomass: up to 14%; e.g. Sub-Sahara: 47% biomass)
- EU: 6% (Biofuels in EU: 0.15%)
  (Sweden: 28,5%; Austria: 23,3%; Finnland; 21,8%)
- Germany: 2%
- USA: 8% (thereof 44% biomass)

2. Renewable Energies for Transportation: Potentials and Approaches

In the mid- and long-term perspective, alternative fuels from natural gas and from renewable resources have to be introduced to the fuel market in order to

- enlarge our energy basis and increasing security for political and economic crises (loosen the dependence on crude oil, especially by using renewable and hence partly regional energy carriers)
- reduce transportation emissions by CO_2-free, CO_2-neutral and CO_2-reduced fuels.

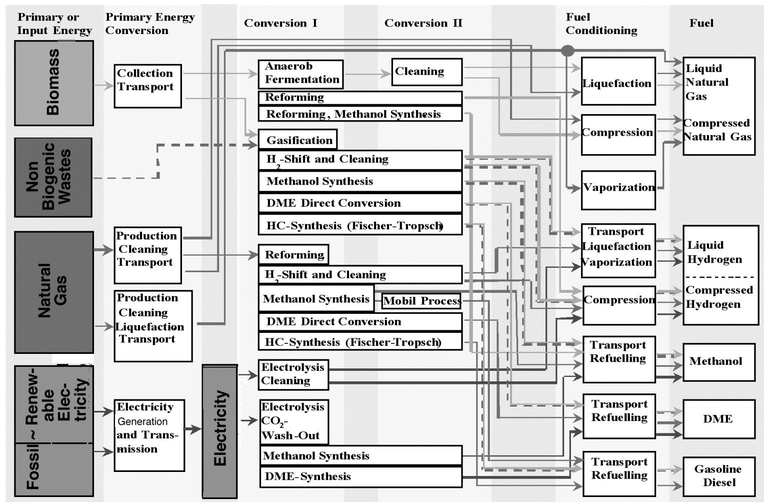

Fig. 3. TES Fuel Production Paths

For this approach, feasible energy sources are wind/hydro/solar power (electrolysis and hydrogen generation) as well as biomass (gasification and fermentation of biomass and wastes for producing methanol, ethanol, synthetic fuels; production of natural oils by pressing biomass with high oil content; biodiesel etc.). Figure 3 shows an overview of fuel production paths.

A variety of technological options exist for producing fuels from renewable energies that have to be adapted according to local and regional conditions (availability of different natural resources and renewable energies).

In Germany, the industry initiative Transport Energy Strategy (TES) was created to assess the potentials of alternative fuels on the basis of renewable resources and select one or two alternative fuels for mass market introduction.

In total, more than 70 fuel production paths were assessed on technology issues, energy efficiency, cost, CO_2-emissions and resource availability. The TES analysis is mainly based on available scientific examinations and publications as well as industry information.

Figure 4 presents TES results "Potentials of Alternative Fuels in the EU". In the case of biomass, only residual and waste biomass was considered. Comparable analyses are available for Germany.

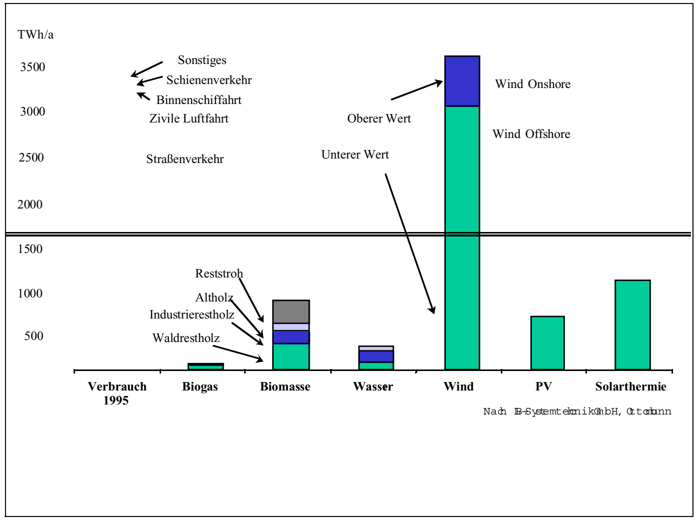

Fig. 4. Availability of Renewable Resources in Europe
Source: TES

Figure 5 shows the resource availability of renewable methanol in Germany (assumption: 50% of renewable resources are used for stationary application, 50% for the mobility sector); the corresponding values for hydrogen from renewable resources were evaluated as well.

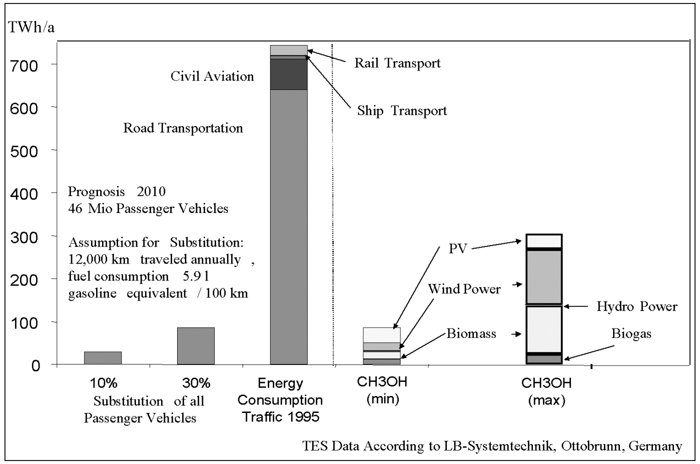

Fig. 5. Availability of Methanol from Renewable Resources to German Road Transport
Source: TES

The analyses indicated that approximately 6-8% of German fuel demand can be provided by using biogenic wastes and residues, and an additional 5-7% can be contributed by reactivating non-used agricultural areas partly for non-food production. Totally, some 15% of fuel demand can be provided from today's view. Corresponding values for Europe are higher than 30% (see figure 6).

Referring to EU Green Paper biofuels are very attractive emitting between 40 and 80% less greenhouse gases than other fuels.

Selected examples:
1. Available biomass resources
- Sweden: residual wood, approx. 125 TWh/a
- Finnland: residual wood, approx. 100 TWh/a
- Germany: residual biomass, approx. 128 TWh/a
2. Offshore wind power resources
- UK: 307% of national electricity consumption
- DK: 1.708%
- FRG: 55%
- NL: 180%

Considerable additional resources can be made available in the context of the Kyoto Clean Development Mechanism (CDM) by recultivating eroded soils, but also by using agricultural surplus areas in Eastern Europe in the case of extending the EU East to the future joining candidates.

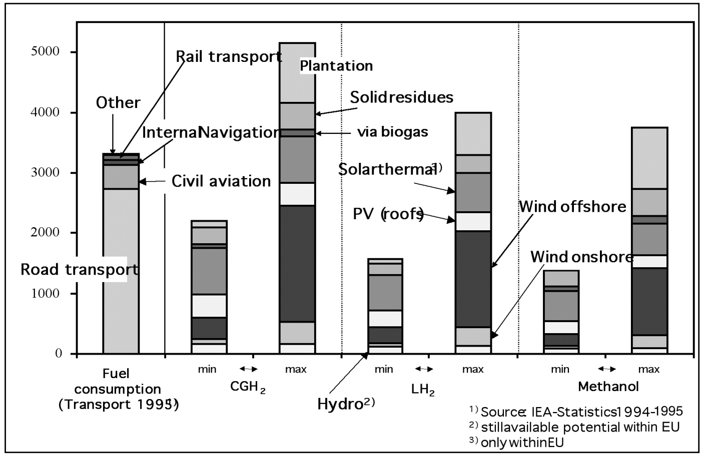

Fig. 6. Availability of Renewably Generated Hydrogen and Methanol in EU
Source: Ludwig Bölkow Foundation, Ottobrunn, Germany

Important to note is that the production of biofuels must not be in conflict with food production.

The technical feasibility of mass producing fuels from renewable resources has to be assessed in demonstration plants and field tests in order to gain reliable data on emissions and total cycle energy chains (input/output analyses) as well as cost data.

Selected efficiency values for the production of renewably produced fuels (source: TU Munich, IfE):

1. Compressed hydrogen from
- gasification of biomass eta ~ 56%
- electrolysis (PV and solarthermal electricity) 47-54%

2. Methanol from
- Gasification of biomass 40-55%
- Fermentation of biomass ~ 46%

Examples for specific fuel yield from renewable sources
- RME 1-1.4 t/ha/a
- Ethanol 4-5.000 l/ha/a (equals up to 2.6 t OE/ha)

- Fast growing wood 10-15 t/ha/a (equals 3-5 t OE/ha)
- Annual crops 12-18 t/ha/a (equals 4-6 t OE/ha)

Current political approaches for intensifying the use of renewable resources for transportation:

- EU Green Paper (11/2000)
  "Required Commitment for 7% biofuels in 2010"

- EU Council (Transportation, 03/2001) on transport policy: "Accelerated introduction of alternative fuels from renewable resources"

- National Climate Protection Program of the German Federal Government (10/2000): "Use of alternative fuels such as natural gas, hydrogen, and methanol"

Figure 7 shows the global potentials for producing biofuels. Noteworthy is the large share of secondary biomass resources.

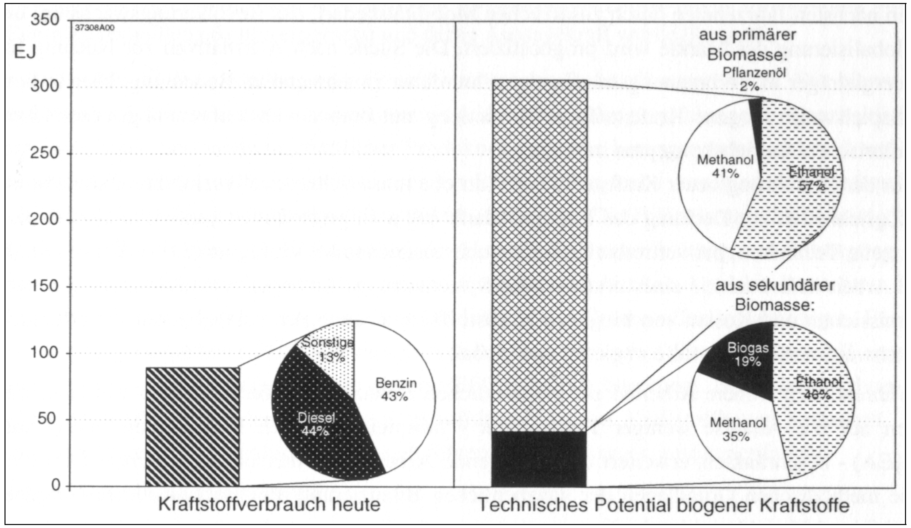

Fig. 7. Global Resources for Renewable Fuels
Source: Dreier, Thomas, "Ganzheitliche Systemanalyse und Potenziale biogener Kraftstoffe. TU Munich, 2000, p. 115.

Figure 8 illustrates climate relevant CO_2-emissons for fuel cell vehicles and internal combustion vehicles (total cycle: fuel production and vehicle operation). Alternative fuels such as methanol and hydrogen can be derived from both fossil and renewable resources. Bio-methanol and renewably generated hydrogen feature lowest CO_2-values when used in fuel cell vehicles.

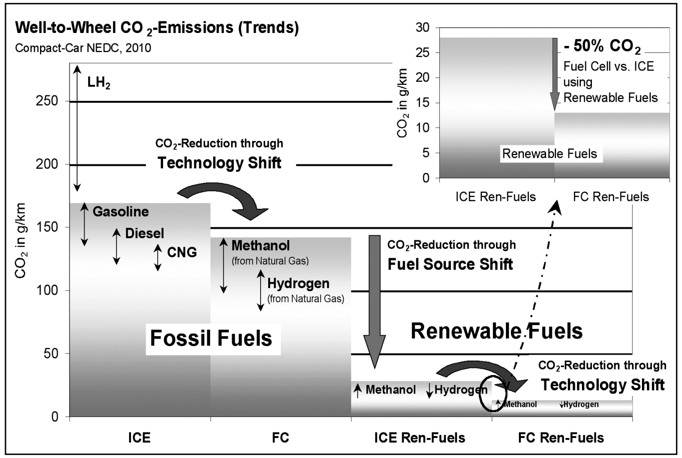

Fig. 8. Total Cycle Emissions for Internal Combustion Engines and Fuel Cell Electric Vehicles
Source: DaimlerChrysler and TES.

Remark: Range of expected vehicle efficiencies for market penetration (after 2010).

For the transition to unconventional oil, gasoline and diesel, production will feature lower efficiencies and higher CO_2-emissions.

Significant CO_2-reductions will be achieved with the market penetration of renewably produced fuels in combination with fuel cell vehicles: the fuel cell benefits from its efficiency advantage of 30-50% since both propulsion technologies then utilize the same fuel sources with identical fuel production efficiencies. This leads to well-to-wheel efficiency improvements of up to 50% for fuel cell vehicles powered by renewable fuels compared to internal combustion engines run with renewables.

Conclusion
Renewable resources for fuel production in combination with fuel cell drive systems can contribute:

- to reduce Europe's dependence on crude oil imports (today 75%, expected increase up to approx. 90% through 2020) and enhance supply security

- to reduce emissions from the mobility sector and thus approach a sustainable transportation system

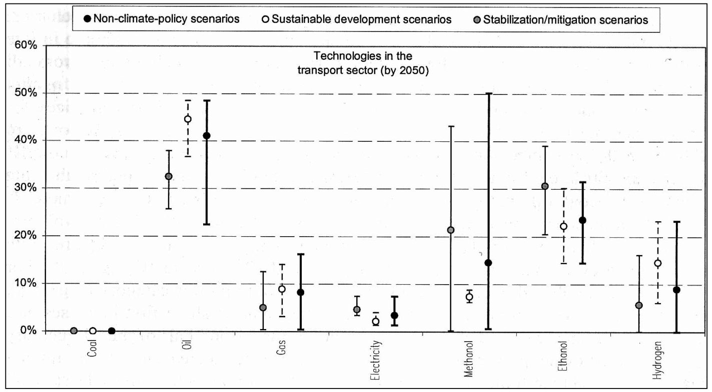

Fig. 9. Outlook of Market Share for Global Transportation Sector (Ranges for 2050)
Source: Keywan Riahi and R. Alexander Roehrl, „Energy Technology Strategies for Carbon Dioxide Mitigation and Sustainable Development". Environmental Economics and Policy Studies (6/7, 2000)

Figure 9 presents a feasible fuel scenery characterized by a diversification of fuels (Source: IIASA).

However, there is no unique and ideal solution to the challenges mentioned above. Renewable resources such as photovoltaics, wind and hydropower, biomass etc. have to be regarded in their variety and regional availability, contributing together a significant share to energy consumption.

3. NECAR Fuel Cell Cars

DaimlerChrysler's commitment to FC technology is evident considering the different demonstration vehicles that were developed and introduced in recent years. As early as in 1994, Daimler-Benz demonstrated the feasibility of using fuel cells for vehicle propulsion with the introduction of the New Electric Car (NECAR) I. Just two years later, in 1996, Daimler-Benz presented NECAR II, a six-seat minivan, also fueled with compressed hydrogen, and demonstrated that FCVs have the potential to reach production maturity in the mid term.

NECAR 3 (1997), a compact car based on the A-Class of Mercedes-Benz, was the first FC car worldwide that runs on a liquid fuel: methanol. Hydrogen is generated on board by methanol reforming.

NECAR 4, presented in 1999 in Washington, uses liquid hydrogen as a fuel, reaches a top speed of 145 km/h and can travel more than 400 km before refueling. The fuel cell systems fits in the vehicle floor for the first time, allowing room for up to five passengers and cargo space

NECAR 5 (2000) finally demonstrated on board reforming of Methanol in a compact car with nearly no restrictions for passenger, again integrating the complete fuel processor and fuel cell system in the vehicle floor.

4. Fuel Cell Bus Solutions

Commercial vehicles operated in densely populated areas, like buses, delivery vans etc. are the largest group for an early market introduction of FC vehicles, using their environmental advantages. The first DaimlerChrysler commercial vehicle was presented in 1997. The NeBus (New Electric Bus) was built as a prototype of a hydrogen powered fuel cell bus and was designed for city and regional transportation of up to 58 passengers.

The amount of compressed hydrogen stored allows an operating range of approximately 250 km which is sufficient for a standard city bus tour. In comparison with conventional diesel and natural gas buses, the NeBus shows a good acceleration characteristics with low noise behavior and low energy consumption.

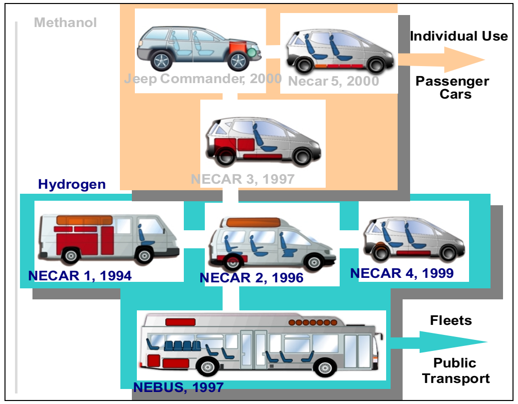

Fig. 10. Development Lines: Fuels for fc-vehicles: hydrogen, methanol and gasoline

DaimlerChrysler is in a fuel neutral way working on fuel cell concepts with three different fuels – hydrogen, methanol and gasoline. Each fuel has its specific liabilities and assets, unique strengths and weaknesses.

Fuel cell electric power generated from hydrogen is the easiest to produce, eliminates all carbon dioxide emissions during vehicle operation, and produces greater efficiencies than using gasoline or methanol. A hydrogen powered fuel cell is a way to achieve a true zero emission vehicle without the range limitations of a battery.

The key challenges for hydrogen-powered fuel cells are the storage system on board of the vehicle and the lack of fuel infrastructure. Consequently, we see chances for hydrogen as fuel for mass transit, company fleets, and car pools that operate within a limited region and can return to centrally located hydrogen filling stations.

Methanol is pointing the way toward a fuel cell technology for mass production and general use in private passenger vehicles. DaimlerChrysler engineers have developed a process that obtains hydrogen from methanol, using an on-board reformer. Fuel cell vehicles powered by methanol from fossil resources are locally virtually pollution-free and have the potential to reduce carbon dioxide emission by 30 percent compared to today's conventional vehicles. Furthermore, methanol has long-term environmental benefits because like hydrogen, it could be produced from renewable resources (e.g. from biomass).

Additionally, DaimlerChrysler pursues direct methanol fuel cell technologies as a much simpler successor technology with advanced research and development.

Gasoline fuel cell vehicles would not be dependent upon significant fuel infrastructure changes. However, gasoline is much more difficult to convert to hydrogen. For gasoline-based fuel cell systems, a more complicated reforming technology using much higher operating temperatures needs to be developed in order to change the liquid gasoline into a gas with a large proportion of hydrogen. In addition, a much cleaner gasoline is needed for operating the reformer properly. Naphtha, for example, with no sulfur, a higher hydrogen content and fewer aromatics could be the fuel for such a system.

Nevertheless, on-board gasoline-to-hydrogen reforming for fuel cell drive systems is yet a technological challenge.

5. DaimlerChrysler European Bus Fleet Program

To significantly enhance the development of clean urban transport, transit authorities of ten European metropolitan areas will participate in a joint fleet test with DaimlerChrysler and its bus subsidiary Evobus.

In each of these cities three buses shall be operated and a hydrogen refueling station will be erected. During the project the buses will be operated in public transport under normal traffic conditions for a period of two years. While these first real scale field tests of fuel cell buses will deliver significant amounts of data to support the development process towards commercially viable fuel cell buses it is at the same time the transport companies participating in these tests of emission-free vehicles that will become global pioneers and gain considerable experience in this technology of the future.

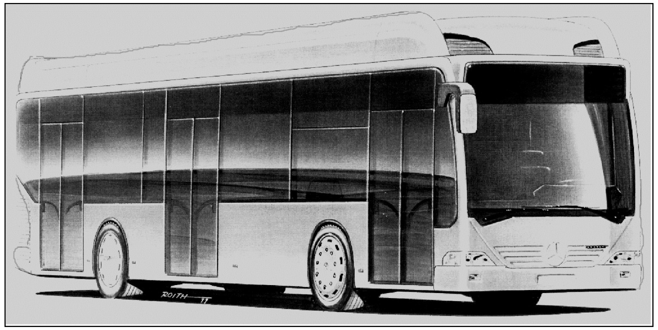

Fig. 11. European Bus Project NEFLEET

The Fuel cell buses will be based on the Mercedes-Benz Citaro low-floor buses and will be specifically modified to accommodate the fuel cell drivetrain. While the hydrogen supply infrastructure is being set up, the transport operators will receive guidance, knowledge and expertise for the operational phase of the buses.

Apart from technical aspects influencing the future fuel cell bus design the issues of hydrogen production and distribution will be a central point in this project. Different productions paths for hydrogen will be demonstrated, including fossil and renewable options.

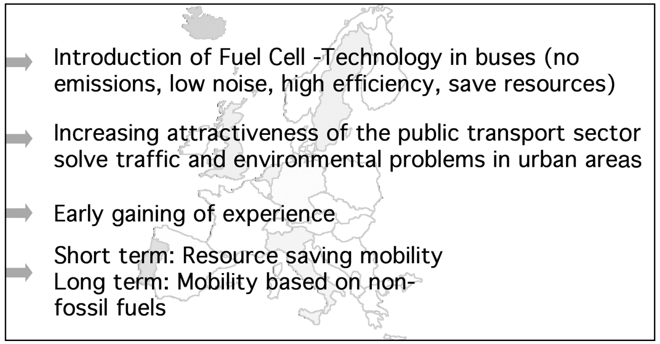

Fig. 12. Goals of NEFLEET

6. Conclusion

Fuel Cell systems seem to be the world's most promising alternative drive concept for the future. They are highly efficient, have extremely low emissions and good driving performance. Additionally, fuel cells could run on a variety of alternative fuels, including fuels from renewables.

The market ultimately has to decide what the best technology is. While fuel cells are progressing at fast pace, the traditional gasoline-powered combustion engine continues to improve as well.