

題目：ダイムラー・ベンツ社の燃料電池自動車開発戦略

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Fuel-Cell Vehicles as the Model for Future Modes of Transport

With the Fuel Cell Technology, Daimler-Benz is opening the door to an automotive future without emissions and increasing energy costs: Fuel cells, which process hydrogen as "fuel", provide an ideal range for municipal and shuttle traffic — at airports, for example. The electric drive is clean, quiet and comfortable. With internal-combustion engines, utilization of the fuel is meeting natural limits. In fuel cells, by contrast, the chemical reaction between air and hydrogen produces electric energy, water vapor and heat without such restrictions.

Buses, trucks and cars roll silently down the road, the air is clear and pure. Air quality in the cities has improved so much that people are returning to urban areas from the surroundings: This is the kind of future environment-compatible traffic desired by inhabitants in conurbation in particular.

A decisive step in this direction is the NEBUS (Fig.: 1) from Daimler-Benz. It obtains its energy from hydrogen; it does not emit any pollutants such as nitrous oxides, sulfur dioxide or soot particles, but only water vapor. This vehicle is thus a real "zero-emission vehicle", a veritable ecological bus. Its electric drive makes it extremely quiet; all that can be heard is the quiet hum of its electric motors and compressor and the tire sounds.

A lot of automobile manufacturers now agree: Fuel-cell vehicles offer the best opportunities of making traffic more environmentally compatible in the medium term — without sacrificing the driving comfort people have become accustomed to with conventional vehicles. Precisely the opposite is true: Fuel-cell powered vehicles utilize energy better than other solutions.

Long range, great comfort

The NEBUS has a range of 250 kilometers with a full tank and can thus easily be driven the 140 to 170 kilometers usually required of municipal-service buses. A further advantage: The powerful electric motors make gear changing unnecessary. The continuous but very gentle acceleration even makes the NEBUS superior to an average diesel vehicle. Electric power output is very dynamic: Reaction times of the fuel cells are less than one second and thus comparable with those of a good diesel engine. Drivers and passengers in regional public traffic will appreciate this.

Furthermore, the compact design of the fuel cell opens up completely new possibilities for design engineers in vehicle construction: Many technical constraints, such as the arrangement of the drivetrain and auxiliary equipment in conventional vehicles, are now a thing of the past. Secondary equipment such as air-compressors and air-conditioning compressors can now be installed in any position where they save space, e.g. protected by covers underneath the seats. The design of the NEBUS was based on the standard municipal-service bus O4050N with a new driver workplace. The vehicle is 2.50 meters wide, 3.50 meters high and 12 meters long and can seat up to 42 people with the seat configuration shown. The stepless entry points are only 32 to 34 centimeters above the ground.

This low-floor concept was made possible by the electric wheel-hub drive. This eliminates the need for the transmission and universal shafts required in a mechanical drive system. Instead, electric motors located near the wheels transmit the electric power of the fuel cell directly to the wheels. Three-phase asynchronous motors, each with a peak output of 75 kW, are located at the right and left axles. Their combined output of 150 kW, or more than 200 HP, corresponds to that

of a good diesel drive. Also included are additional supply systems and reserves for the vehicle's electrical system with steering assistants, compressed air, brakes and door control. Another environmental-friendly detail is the solar roof hatches: When the bus is stationary, current from the independent solar cells is used to maintain a pleasant climate and good ventilation.

Safety and performance

In the NEBUS, tens stacks of 150 fuel cells each provide a total output of around 250 kW and a voltage of 720 V. They power the fuel cells themselves, the wheel-hub motors and other proven components. Seven glass fiber-reinforced aluminum tanks on the roof of the bus store the hydrogen gas used to operate the fuel cells (Fig.: 4). They are pressurized to 300 bar.

The vehicle, which is still around 2.5 metric tons heavier than a bus with gas motor and weighs around 3.5 tons more than a diesel-engine bus, has a relatively high center of gravity. In order to prevent the roof load of 1900 kilograms from amplifying every pitching and rolling motion in curves, a special shock-absorber technology was developed for driving comfort and safety: The adaptive shock-absorber control system suppresses this pitching and rolling by adapting the tension and pressure stages of the shock absorbers to the various driving loads. Sensors indicate the body tilt in curves, for example, and the shock absorbers will then have a harder reaction where they are under greater load.

An important safety feature is hidden underneath the cover panels: The 380-volt compressor driving the main power-steering pump. If the 720-volt driving system and the 380-volt system of the power-steering pump drive should fail, the vehicle can still be steered with the 24-volt power-steering pump, which is powered by the standard vehicle battery. And if the electrical system should ever fail completely, the

bus can nevertheless be handled safely thanks to the direct-action steering gear with its high transmission ratio. Similar safety reserves are also built into the braking system: It always stores enough compressed air so that the driver can safely brake several times, even if the electrical system should fail.

Fuel cell and gas

The fuel cell (Fig.: 2) forms the heart of the new technology. It has been used in aerospace applications for decades, is regarded as robust and reliable, but has always been too technically complex for automobiles until now. In fuel cell vehicles, chemically bound energy is obtained at a low operating temperature of around 80°C. The electrochemical reaction between gaseous hydrogen and atmospheric oxygen supplies electricity, which is obtained from the separation of positively and negatively charged particles by an electrolytic film or membrane (proton exchange membrane, PEM for short). Tightly packed collections of such films produce a kind of generator battery (stack) that produces current at its location.

The materials used are relatively inexpensive; production costs are comparatively low. In the long term, therefore, the system costs can also be reduced to a low level. An important basis for this is the years of experience with gas-powered vehicles: The Daimler-Benz subsidiary EvoBus has delivered 150 natural-gas buses in the past four years alone, for example. Moreover, hybrid and battery-powered vehicles are being successfully tested so that all these components can come together in the NEBUS.

Wealth of ideas and team spirit

The breakthrough came in the early 90s, when researchers from Dornier were specifically integrated in the automotive research of Daimler-Benz. They had already gathered much valuable experience

in the development of fuel cells within the framework of several space programs and could now put this experience to use for ground vehicles.

The technology itself was developed together with the Canadian company Ballard Power Systems Inc., in which Daimler-Benz holds a 20 percent stake. Daimler-Benz, Ballard and Ford Motor Company formed a global alliance aimed at becoming the world's leading commercial producer of fuel cell powered vehicles and components for cars, truck and buses. This collaboration gave rise to two new subsidiaries dbb Fuel Cell Engines GmbH, which is responsible for the fuel cell system, and Ecostar for the electric drivetrain. This co-operation underscores the earnest with which the development of the fuel cell is being pursued as an alternative drive system for passenger cars.

Hydrogen has a lower energy content than natural gas, is still more expensive and, with the poor filling-station infrastructure in Europe, is also not readily available. This is not a great obstacle for buses in regional public transport, however: For fleet operation, it is always worthwhile to establish a central filling station where buses are fueled by trained personnel. Daimler-Benz already proved the practicality of this concept in a long-term test carried out in the 80s. With further development and testing, therefore, the NEBUS would be as good as ready for practical use today.

At present, hydrogen is obtained mainly from natural gas or as a by-product of processes in the chemical industry. The simplest method is electrolysis, in which water is decomposed into hydrogen and oxygen with the help of electricity. Processes of this kind are very energy-intensive, however. In order to make full use of the environmental advantage of hydrogen, it is necessary to produce the gas in larger quantities at acceptable cost. Therefore, the necessary electricity can be obtained only from regenerative sources such as hydropower or

solar energy in the long term. It will take years until this is realized, however.

Hydrogen from methanol

In the late 80s, initial system analyses of the fuel-cell project demonstrated that methanol possesses the best properties as an alternative fuel in this system. This finding was subsequently strengthened, despite the lower energy density of methanol, so that a basic decision was made in 1991 to continue along this path. The Daimler-Benz's involvement in fuel-cell technology (Fig.: 3) actually began in 1994 with the NECAR I test vehicle. The NECAR II followed in 1996, then the NEBUS and finally the NECAR 3. With a value of 5.6 kilograms per kilowatt, the power density in the NEBUS is four times greater than in the NECAR I, for which the energy density was still 21 kilograms per kilowatt. In other words: The stacks producing electrical power were as heavy as 1,050 kilograms for 50 kW in the NECAR I (power density: 21 kg/kW); the fuel cells powering NEBUS weighed only 1,400 kilograms for an output of 250 kW (power density: 5.6 kg/kW).

Pole position in the 1997 race for technical highlights undoubtedly goes to NECAR 3 (Fig.: 5). To the casual onlooker, the only visible difference between this A-Class model from Daimler-Benz and its conventional counterpart is the paintwork. On the inside, however, NECAR 3 still bears striking resemblance to a mobile laboratory, with the rear bench seat having given way to the miniature chemical factory needed to process the methanol to the necessary hydrogen.

This process is based on methanol, which is evaporated in a mixture with salt-free water and converted to hydrogen in a reformer. As methanol is liquid at room temperature, it could therefore be filled into vehicles at a "normal" service station, just like conventional gasoline and diesel fuels. With a tank filling of 38 liters, the prototype has a

range of around 400 km and an artificially limited top speed of 120 km/h.

Moreover, methanol can be obtained not only from natural gas but also from regenerative resources. The fuel cell compensates for the lower energy content of methanol by comparison with gasoline or diesel fuel with its higher efficiency. Although carbon dioxide is produced when methanol is decomposed, a smaller quantity of this greenhouse gas is generated than in vehicles with an internal-combustion engine. Furthermore, other pollutants such as nitrous oxides, sulfur dioxide or soot particles are not produced at all. A vehicle with methanol fuel cells therefore also has significant advantages for the environment and is just as quiet and powerful as its hydrogen-powered counterpart.

The fact that NECAR 3 can currently accommodate only the driver and one passenger may appear a step backwards, but in fact, accommodating the entire system for generating hydrogen from methanol in such a compact car is a mammoth achievement in itself - stationary systems of these kind are usually five to eight meters high. The current development status is by means the last chapter in the miniaturization story. The quest for intelligent solutions accommodated in the smallest of spaces goes on. Before long Daimler-Benz will be ready to present a number of new ideas in this area.

Supply and demand

The demand for environment-friendly cars is increasing steadily: The technology is available. However, mass production will remain a problem of costs as long as high development costs place a burden on low production output. The development of fuel-cell buses also depends to a large extent on how the new technology is introduced

and used in the passenger-car sector. In early 1997, Daimler-Benz established the "Fuel-Cell Project House" specifically to prepare series development. This organization is currently working on increasing the power density of the system even further, reducing costs and developing a genuine four-seat vehicle on the basis of the NECAR 3 passenger car. The aim of Daimler-Benz is to introduce a commercial fuel cell vehicle by the middle of the coming decade.



Figure 1: *The Daimler-Benz fuel-cell bus NEBUS in front of the company headquarters in Stuttgart-Möhringen. NEBUS is a genuine zero-emission vehicle: It produces no pollutants whatsoever; only pure water vapor emerges from the exhaust pipe. This bus is propelled by quiet electric motors. The necessary power (250 kW) is provided by fuel cells in the rear.*

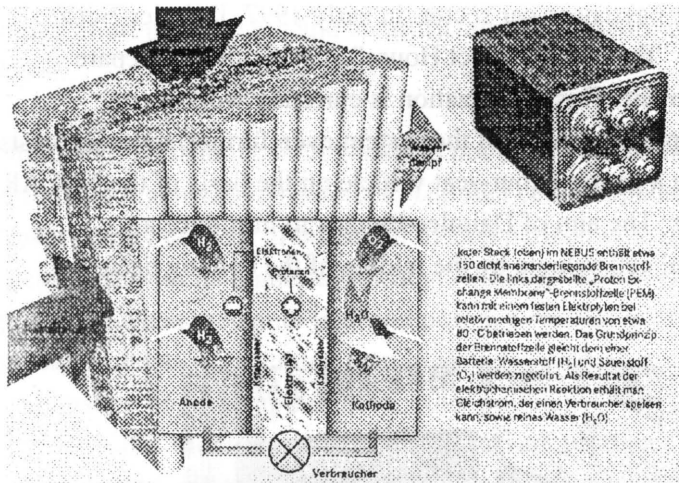


Figure 2: The "Proton Exchange Membrane" (PEM) fuel cell operates with a solid electrolyte (blue, in the middle) at temperatures around 80°C. Hydrogen (H₂) and oxygen (O₂) are added. The resulting electrochemical reaction produces direct current and pure water. Each stack in the NEBUS contains 150 tightly packed fuel cells.

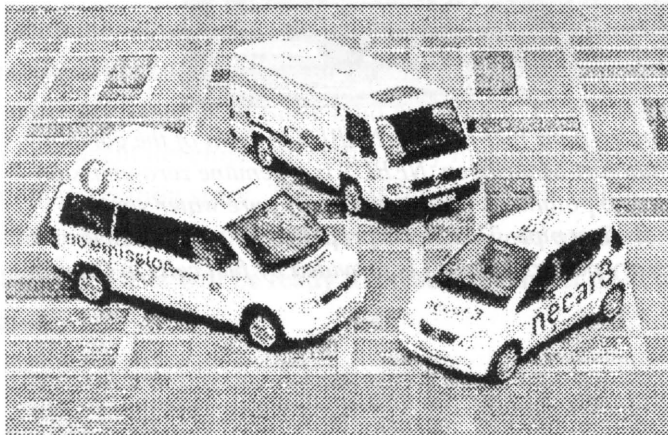


Figure 3: The prototypes of the fuel-cell car: NECAR I (rear) with 12 stacks, 230 V, 50 kW output and a power density of 21 kg/kW. NECAR II (left) with 2 stacks, 280 V, 50 kW output and a power density of 6 kg/kW. NECAR 3 (right) with methanol reformer also has an output of 50 kW, but its internal components require much less space.

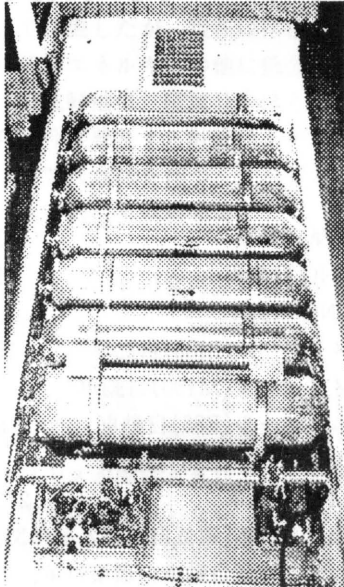


Figure 4: The hydrogen tanks of are located on the roof of the NEBUS. This saves space in the passenger compartment. The roof installation consists of seven 150-liter cylinders pressurized to 300 bar. They can provide up to 45,000 liters of hydrogen to the fuel cell. With full hydrogen cylinders, this vehicle has the range of a normal regional-service bus.



Figure 5: NECAR 3 — prototype of the world's first fuel-cell vehicle with on-board hydrogen production. A full tank of methanol, which can be pumped like gasoline, gives the vehicle a range of around 400 km.