Hydrogen Filling
Station Consortium

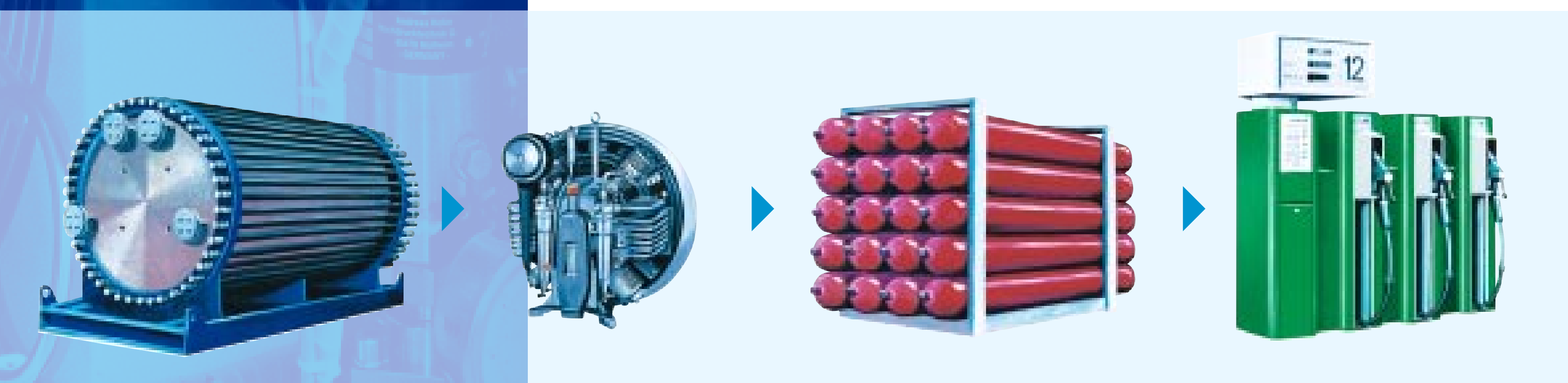
EUHYFIS

Arbeitsgemeinschaft
Wasserstoff-Tankstelle

EUHYFIS

A Hydrogen Filling Station

Based on Renewable Energy Sources



www.euhyfis.com

Green Hydrogen Traffic

The transport sector accounts for roughly one third of the overall energy consumption in the European Union. Road traffic contributes by far the largest share. Due to increasing mileage the total energy consumption in transportation rises steadily even though specific fuel demand per kilometre has slowly decreased in recent years.

The use of diesel or gasoline in internal combustion engines leads to carbondioxyde (CO_2) emissions and the release of pollutants (NO_X, SO_2, etc.). Studies on the external costs of fossil energy use estimate the health expenses caused by emissions from traffic to be in the range of 0.6 EURO per litre of fuel.

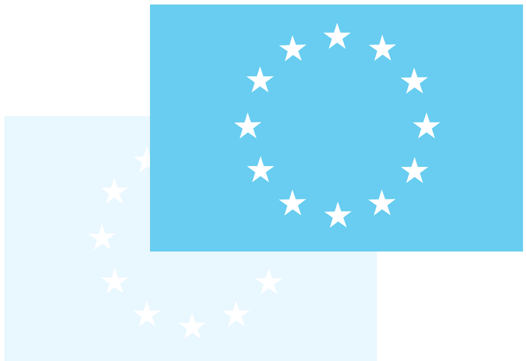
Hydrogen, on the other hand, constitutes an environmentally benign energy carrier since its consumption in fuel cells results in the mere emission of water vapour. In addition to this local point of view however, focused on the vehicle exhaust, the fuel's origin also has to be considered.

There are no natural sources of hydrogen. It has to be generated by water electrolysis or by reforming natural gas, methanol, petrol etc. Feeding renewable energy to electrolysers provides fuel which is free of emissions both in a local and global frame of reference. When this hydrogen is supplied to fuel cell vehicles, zero-emission transportation becomes a reality.

All major car manufacturers are developing hydrogen vehicles, with fuel cells as a prime propulsion option. Prototype development is ongoing with field tests in preparation. Market introduction is expected between 2004 and 2006. The Californian legislation on zero-emission traffic has been an important driving force behind these activities.

Within the next months a major demonstration project ("CUTE") for fuel cell buses in public transport will be launched. The implementation of refuelling infrastructure in everyday operation is part of the project to which the EUHYFIS consortium will contribute.

The EUHYFIS Concept

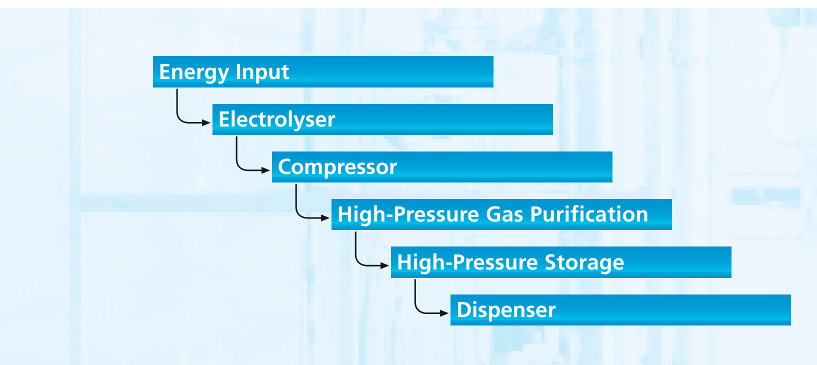


EUHYFIS is the abbreviation for EUropean HYdrogen FIlling Station. This project aims at providing a hydrogen infrastructure for road vehicles. The fuel is generated decentrally on site of the station, preferably relying on electricity from renewable energies. In case renewable sources are employed, the hydrogen can be regarded as a green energy carrier since it displays an emission balance by far superior to that of conventional fuels.

EUHYFIS offers a filling station for compressed gaseous hydrogen that

- follows a modular approach in order to be easily adapted to the customer's choice of production rates
- requires moderate investment
- is designed for robustness towards power input fluctuations induced for instance by renewable energy sources
- employs high-efficiency components
- has distinct environmental advantages.

The system consists of the full production chain as shown below. It can be delivered as a pre-assembled unit.



Three companies with complementary expertise drive the EUHYFIS project: Bauer Kompressoren from Munich/Germany, Casale Chemicals based in Lugano/Switzerland and PLANET – Planungsgruppe Energie und Technik, Oldenburg/Germany.

The European Union supported the research and development phase of EUHYFIS under the 4th Framework Programme in 1999/2000. From the year 2002 a prototype for demonstration purposes will be available with a small pre-series following.

Technical data, as far as available to date, are as follows:

- maximum pressure at compressor outlet 500 bar
- hydrogen production 55 - 60 m^3_N/h, sufficient for 3 large passenger buses
- 300 kW rated electric power demand

Until a close-meshed grid of hydrogen filling stations can be established, the target market for hydrogen fuel consists of fleet applications where vehicles regularly return to their garages. At the moment, EUHYFIS therefore primarily addresses public bus operators, taxi fleets, delivery and parcel services etc.

In a wider perspective, the EUHYFIS concept can also be adapted to various other sources of hydrogen like biogenic energy carriers and synthesis gas.

EUHYFIS 2002

This flyer updates the project information given in the EUHYFIS brochure.

Major automakers such as DaimlerChrysler want to extend the mileage of fuel cell buses by increasing vehicle tank pressure. Instead of 200 bar today (2860 psi) the future standard will be 350 bar (5000 psi). This requires compressors that can consolidate hydrogen gas in the filling station storage up to 550 bar (7860 psi).

The development of a cost-efficient and performance-optimised piston compressor which meets the above specification has started at Bauer Kompressoren and is estimated to be completed in early 2003. The projected characteristics of the new compressor are:

Intake Pressure	2 – 4 bar
Delivery Pressure	500 – 550 bar
Free Gas Delivery	20 - 40 m^3_N/h
Power Demand	8 - 12 kW

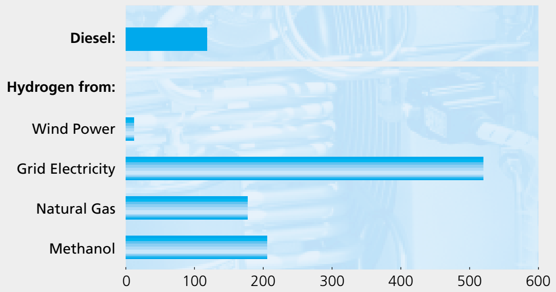
In 2001 a detailed study of hydrogen fuel supply to buses in public transport was completed at PLANET. The investigation followed the rules for life cycle assessments as laid down in the series of standards EN ISO 14040 – 14043. Seven scenarios were compared which rely on different primary energy sources (e.g. coal, natural gas, wind and water power) as well as various ways of energy conversion (electricity generation, synthesis of methanol, liquefaction of hydrogen...).

Compared to previous works in this field, the data basis could be extended substantially. It enabled the supply paths to be analysed step-by-step and in detail from primary energy to the vehicle ("from well to wheel").

The crucial question was, which of the scenarios would come off well in comparison to diesel, the standard fuel for buses today. The consumption of fossil resources and, closely linked to this, the emission of greenhouse gases belonged to the prime criteria. In this context, the "ecological rucksack" had to be considered, i.e. the effort of energy and materials to build the necessary infrastructure like chemical production facilities, wind turbines, pipelines for transportation etc.

The figure below shows that hydrogen derived from wind power has a significant ecological advantage over diesel. Other renewable energy sources yielded similar results (not displayed here). Only the renewables therefore legitimate the massive investment that will be required to convert the fuel supply infrastructure to hydrogen use.

Greenhouse Gas Emissions by the Production and Use of Road Vehicle Fuels



Emission of CO_2-Equivalents (kg/100 km), Data for 2000

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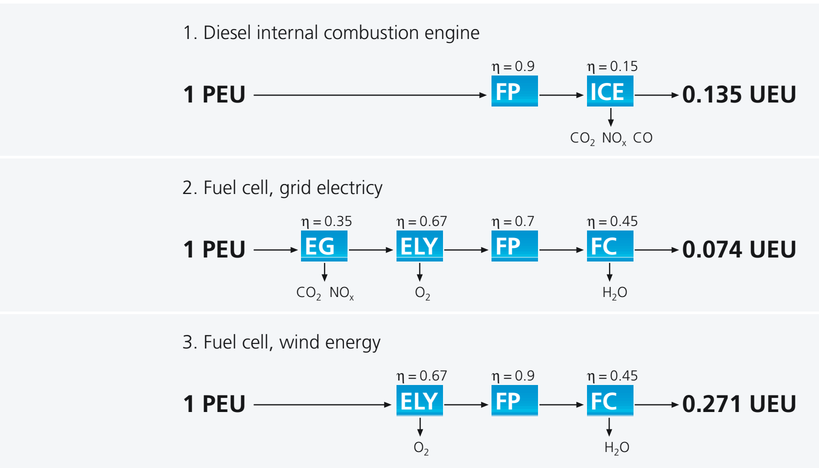
Energy Efficiency and Environmental Benefits



PEU primary energy unit
UEU useful energy unit
EG electricity generation
FP fuel processing
ELY electrolysis
ICE internal combustion engine
FC fuel cell

Energy efficiency of fuel supply chains and their environmental impact – measured in terms of emissions – are crucial ecological parameters. Damage to the environment will be lowest for supply chains with a minimal input of non-renewable resources. Considering this, all steps in processing the fuel from its primary source (an oil well, for instance) to the vehicle must be taken into account.

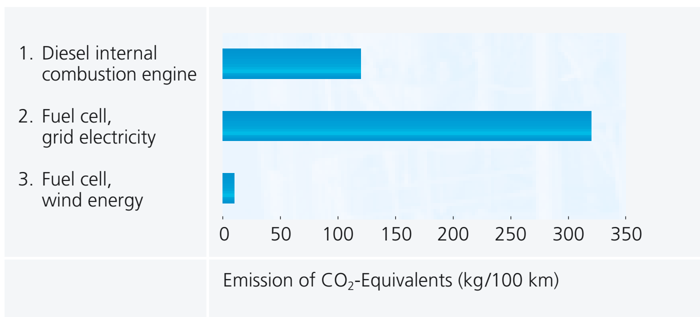
The above figure illustrates the energy efficiencies of a choice of fuel supply paths. It compares the share of useful energy left at the end of the transformation chains relative to the primary input ("well to wheel"). It is obvious that hydrogen production relying on grid electricity will be inferior to diesel propulsion, today's standard fuel in public and freight transport.

The figures cited refer to the German energy mix for electricity generation with large contributions from coal; the picture will differ for countries like Norway where water power is an important primary energy source.

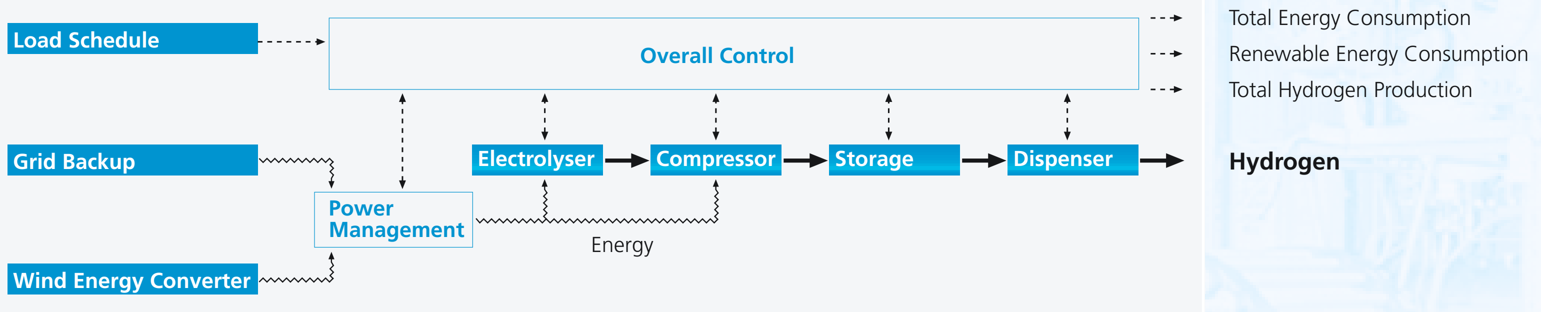
The efficiency factors stated for the single process steps are typical values that do not relate to particular systems on the market. A more detailed analysis is in preparation and will become available during summer 2001.

It should be noted that "hydrogen" here always refers to compressed gaseous hydrogen as supplied by the EUHYFIS system. Liquefaction of 1 m^3_N hydrogen requires electricity equal to 33 % of the energy content stored in this amount of gas. The primary energy demand in the case of grid electricity thus would amount to 100 % of the hydrogen energy content.

The ecological disparities become even more pronounced when emissions in terms of CO_2-equivalents are compared, as shown below. In addition to (local) vehicle emissions and contributions from the operation of the (global) supply chain, input from the materials investment into the processing equipment (the so-called gray energy) have been included. In the evaluation, the German grid mix expected for 2010 and emissions from diesel vehicles according to the EURO 4/5 regulations in force from 2005/2008 were assumed.



System Integration and Modelling



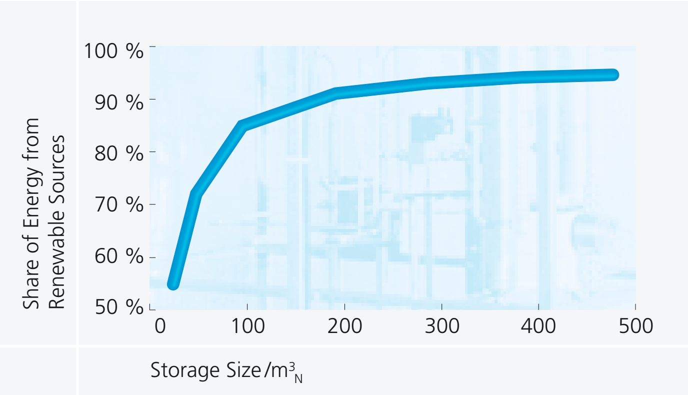
In view of the environmental benefits it is important that hydrogen fuel is derived from renewable energy sources. Most of these sources, however, display fluctuations in power production. As a loss of load cannot be tolerated for the majority of transport applications, a certain share of conventional (mainly fossil) grid backup will be required.

Obviously, the more fossil primary energy is used, the higher the level of emissions. Computer modelling is the key to evaluating the characteristics of hydrogen systems in these respects.

A minimum level of renewable energy will be necessary to achieve any environmental advantage relative to a standard (diesel) system. This level is determined by the "break even point". At this point, diesel and fuel cell vehicle produce the same level of global emissions. For the case of CO_2-equivalents and a fuel cell bus supplied by a EUHYFIS filling station, the break even point lies in the range of 65 %. In other words, a minimum of two thirds of the energy consumed for generating the hydrogen need to come from renewable sources in order to surpass a conventional diesel supply in emission quality.

Minimisation of investment costs while obtaining a maximal environmental benefit is a major issue of system integration and modelling. Studies of this kind also yield vital information on the design of control and safety management.

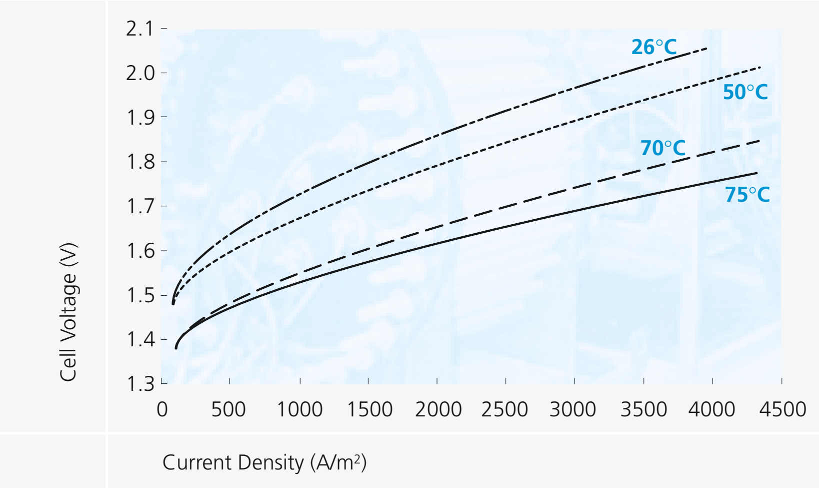
The figure below shows a typical dimensioning problem. When employing fluctuating power (wind energy in this case), storage will improve the share of "green" hydrogen available. The relationship is non-linear. Main parameters are the type of renewable energy source, meteorological site characteristics, the daily load pattern etc.



EUHYFIS services:

- **system simulation & sizing, performance prediction, performance evaluation**
- **simulation and layout of system controls**
- **integration of hydrogen storage into energy supply systems**
- **fuel cell applications**

Technology: Electrolyser



When employing renewable energy sources for water electrolysis it is vital to prevent electrode degradation induced by fluctuating energy input. Mechanical stability and process efficiency suffer when input power varies. The lifetime of standard electrodes in this operational mode only lasts a few hours. For this reason electrolysers are conventionally operated at constant rated power.

During shut-down, standard electrodes will corrode unless a protective voltage is applied. This requires an electricity backup and causes energy losses.

The objective of the EUHYFIS research was to find improved electrode materials. Such innovative electrodes were subjected to severe conditions of operation for more than 1,200 hours in a 5 kW test rig and displayed an excellent stability. After more than 3,000 total current interruptions and a large number of strong power fluctuations from a wind energy input simulator, no deactivation was observed. No protective voltage was required to stabilise the electrodes, either.

Furthermore, the newly developed electrodes display excellent current density – cell voltage characteristics. At temperatures of 75°C and 4000 A/m^2, for example, the cell voltage is 1.75 V. Under the same circumstances standard electrodes exhibit about 2.1 V. Process efficiency was thus improved by 15 %.

These advantages persist at low electrolyser temperatures which will occur when re-starting the unit from stand-by or in part-load operation. Even at 26°C (and 4000 A/m^2) the cell voltage remains below 2.1 V.

The energy required for producing 1 m^3_N of hydrogen with the new-generation electrodes is 4.2 kWh at full load (4000 A/m^2, 75°C). The corresponding process efficiency relative to the gross/net calorific value of hydrogen amounts to 84.5 % and 71.3 %, respectively. Purity is higher than 99.8 % by volume and can be increased to 99.999 % where necessary. Output pressure of the hydrogen gas ranges from 6 to 30 bar.

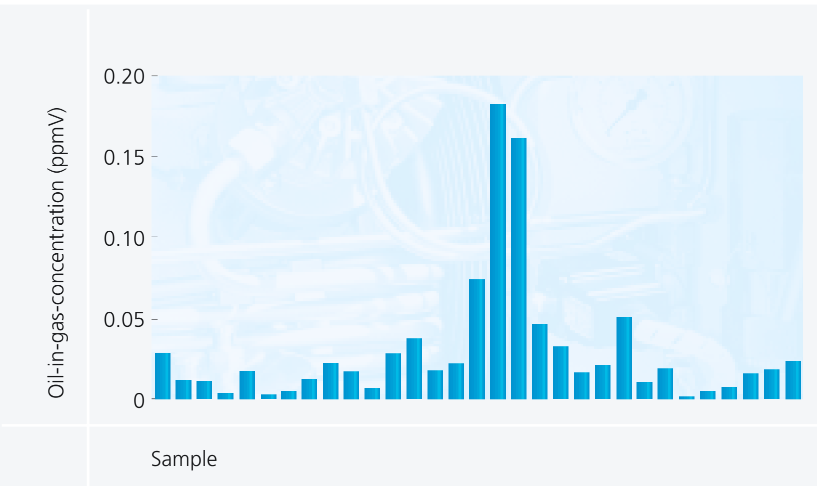
EUHYFIS services:

- **electrolysers from 1 m^3_N/h up to 100 m^3_N/h**
- **supply of ancillary and control equipment**
- **custom-tailored hydrogen generation systems**

Technology: Compressor

The compressors employed for EUHYFIS stations are based on models developed for natural gas. These types deliver a maximum pressure of up to 350 bar. The corresponding vehicle tank pressure is 200 bar (at 15°C), as established for natural gas. Major requirements consist of long-term wear resistance in a hydrogen environment and a minimum level of impurities in the compressed gas.

Standardised limits for residues in hydrogen for fuel cell use do not exist to date. The value for breathing air of 0.5 ppmV was therefore chosen as a first guideline.



The data recorded in 3,000 hours of test rig operation verify that this concentration is never surpassed. The oil-in-gas concentration typically remains well below 0.1 ppmV. Even when the outlet filters approach saturation after about 1,000 hours, a concentration of 0.2 ppmV is not exceeded.

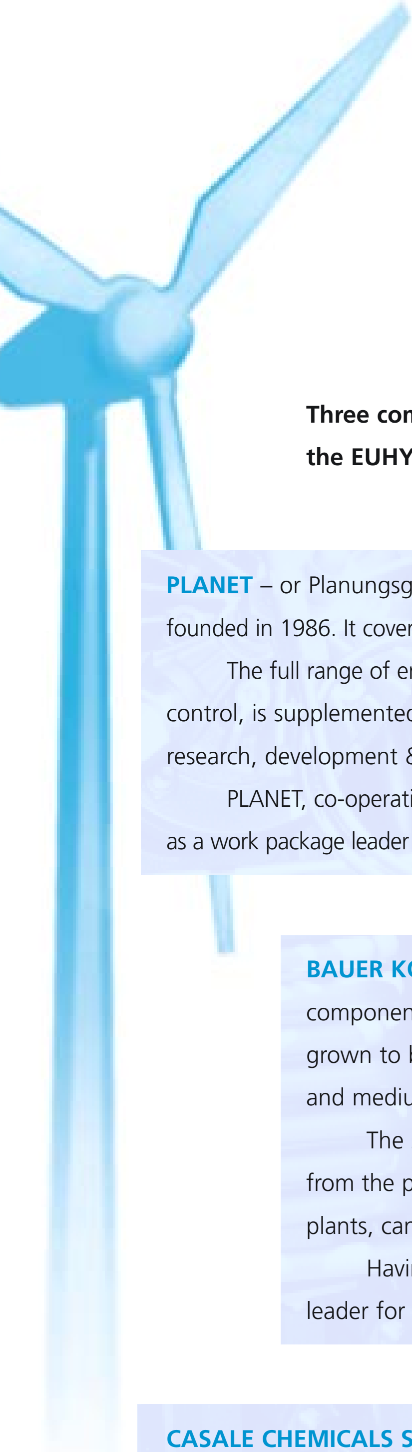
Major car manufacturers are working on raising hydrogen storage pressures onboard to 350 bar in order to increase vehicle range. This will require compressors that can deliver gas at up to 550 bar. Preparations to meet this upcoming new standard have begun in the EUHYFIS consortium.

From its activities in the market for natural gas filling stations, Bauer Kompressoren is experienced in supplying readily assembled and at the same time flexible units consisting of one or more compressors, storange bank and dispenser.
For EUHYFIS plants, the electrolyser setup is added. The storage may be incorporated in the station housing or, depending on the required capacity, placed apart. On the customer's premises only foundations and electricity & water supply will be required.

The modular concept enables future increases in gas delivery simply by adding components in existing housings or by placing further units alongside earlier installations.

EUHYFIS services:

- **dispenser and metering equipment for hydrogen and other gaseous fuels**
- **compressors and storage banks**
- **optional use of hydrogen derived as a by-product from industrial and chemical processes**



Three companies with complementary expertise drive the EUHYFIS project:

PLANET – or Planungsgruppe Energie und Technik GbR in full – is a consulting and engineering company founded in 1986. It covers the entire field of energy supply systems with a special focus on renewable sources.

The full range of engineering services, from concept development to site management and performance control, is supplemented by economic analyses and feasibility studies. The consultants acquire funding for research, development & demonstration schemes, and carry out international project management.

PLANET, co-operating with industrial and academic European partners in R&D activities, will participate as a work package leader in the CUTE demonstration project for fuel cell buses led by DaimlerChrysler.

BAUER KOMPRESSOREN GmbH is devoted to the manufacture of high pressure gas compressors and components, such as filter systems and regeneration dryers. Founded in 1946, the company has grown to become a prominent, globally active corporate group, known for reliable, top of the range high and medium pressure compressors.

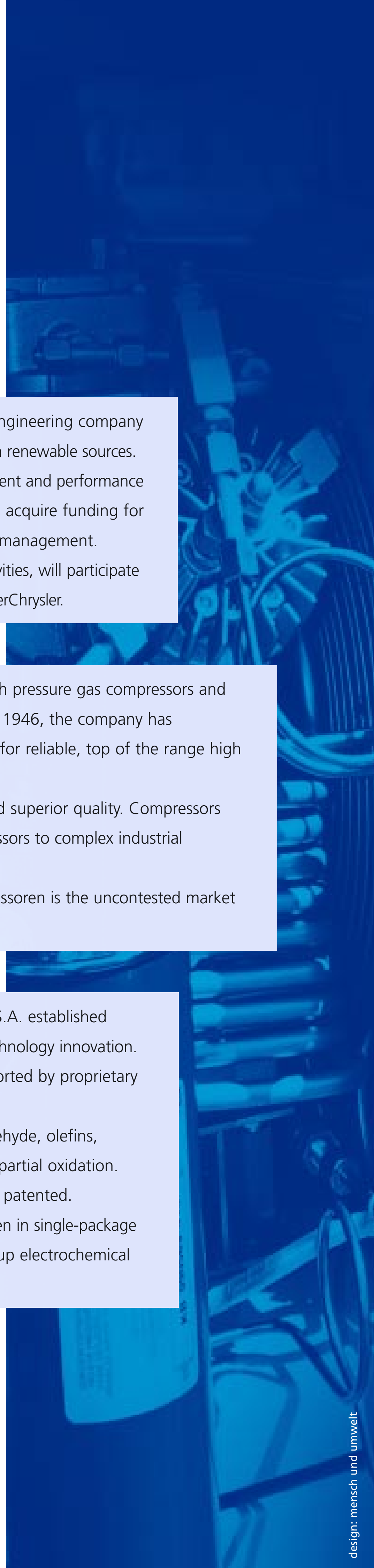
The systems are characterised by innovative technical solutions and superior quality. Compressors from the product range, reaching from standard compact diving compressors to complex industrial plants, can be tailored to meet any specific requirements.

Having supplied over 130 filling stations since 1995, Bauer Kompressoren is the uncontested market leader for CNG units in Germany.

CASALE CHEMICALS S.A. was founded in 1993 as a daughter of Ammonia Casale S.A. established in 1921. The Casale Group today comprises four companies, very active in R&D and technology innovation. Casale companies operate in the field of chemical engineering and contracting, supported by proprietary technologies and a wide range of patents.

Casale Chemicals deals with methanol derivative processes and plants (formaldehyde, olefins, resins) and hydrogen production by water electrolysis, or by natural gas reforming or partial oxidation.

Pressurised water electrolysis uses VOLTIANA® electrochemical cells, world-wide patented. Applications include electrolysers of various sizes (from 30 l_N/h up to 100 m^3_N/h hydrogen in single-package units) operating at pressures up to 30 bar. VOLTIANA® cells are also employed to set up electrochemical reactors for a wide range of processes.



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design: mensch und umwelt