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Austrian Technological Expertise in Transport

Focusing on:
Hydrogen and Fuel Cells



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PREFACE

The development of alternative drives and fuels has become a key factor in the competitive capability of transport and power engineering in recent years, since their implementation on an industrial footing secures the competitiveness of the automotive industry in particular as a global key sector and is also contributing to solving pressing environmental and transport policy problems. Austria's automotive industry has been highly successful to date and is particularly affected by this issue, since over 175,000 employees work in this sector, mainly in the production and development of drive trains. To secure its competitiveness for the long term, the BMVIT has been supporting its preparation for emerging technological transformations under the A3 technology programme ("Austrian Advanced Automotive Technology") since 2002 and under the successor programme A3plus since 2007.

To facilitate the market launch of new propulsion technologies, in addition to supporting cooperative research projects as part of the calls for proposals for the A3 programme, BMVIT is also supporting the development of "flagship projects" as major pilot projects and demonstration projects, involving developers, manufacturers and also users of these technologies. This is with the aim of further optimising these projects in real operation and preparing customers for technological transformations in transport engineering.

The four calls for proposals for the A3 programme conducted in the period 2002-2006 saw 78 cooperative development projects implemented, with a funding budget of EUR 20.4 million and an overall project volume of EUR 40 million. The two calls for proposals for flagship projects saw 8 projects being realised, with a funding contribution of EUR 3.4 million and an overall project volume of EUR 7.4 million.

In 2004, the BMVIT supplemented the A3 technology programme with the "Austrian Hydrogen and Fuel Cell Initiative", as fuel cells offer unique advantages in terms of reducing noise and exhaust gases, energy efficiency and security of fuel supply, due to the various options in the production of hydrogen. The importance of these technologies is also reflected in the project submissions, since around half of the 86 flagship and A3 projects relate to hydrogen and fuel cell developments. This brochure presents the results of these projects and provides an impression of the high level of expertise in Austrian industry and R&D institutions in the engineering and manufacture of components and products for fuel cells as well as in the production, storage and implementation of hydrogen.

CHRISTA KRANZL
State Secretary for Research/Innovation at the Austrian Federal Ministry for Transport, Innovation and Technology

AUSTRIAN TECHNOLOGICAL EXPERTISE IN TRANSPORT

With the launch of this new series of publications on "Austrian technological expertise in transport", the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) aims to provide an overview of the current state of developments in Austria on strategic research issues relating to transport. The main area of focus is on the research outcomes from the research promotion programmes and instruments of the bmvit. To provide a comprehensive overview, the publication also covers Austrian projects from European and international R&D programmes and the further R&D activities and measures known to the bmvit and aimed at supporting developments in these areas of technology.

The aim of this series of publications is to document, in a compact form, the current status of R&D on key areas of research for Austrian researchers and to present the selection of Austrian technological innovations and Austrian know-how to an international audience. In addition to this, information on peak technological achievements is to be made accessible to a wider public.

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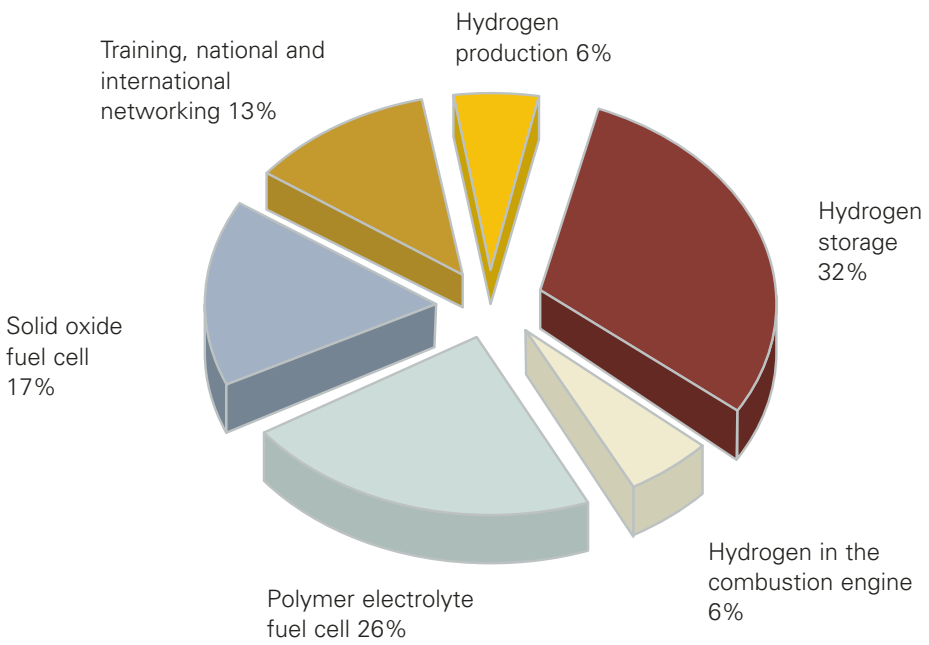
R&D OUTCOMES COVERED – BY AREA:



FOCUS:
HYDROGEN AND FUEL CELLS

The first issue of this series of publications is dedicated to the important topic of hydrogen and fuel cells. It brings together and presents for the first time the outcomes of Austrian interdisciplinary, cooperative research and development projects as well as flagship projects and demonstration projects under the A3 technology programme (Austrian Advanced Automotive Technology).

The automotive industry is facing new challenges, due to the evolving legal framework conditions such as the legislation on exhaust gases, the minimum quotas for alternative fuels and the intensified EU specifications for CO_2 emissions by motor cars, together with the Kyoto target. Peak technological achievements in the areas of drive engineering, materials research and electronics are needed to meet the increasingly rigorous environmental standards.

To comply with the latter, alternative propulsion systems and fuels will gradually replace the current combinations of petrol or diesel engines and the conventional petrol or diesel fuels. In this regard, particular interest focuses on the fuel cell, which unlike the combustion engine is not subject to the thermodynamic limits of efficiency as described by the Carnot cycle. It offers great potential for increasing energy efficiency and, in combination with the sustainable production of hydrogen, great potential for reducing greenhouse gas emissions.

Under the framework of the A3 technology programme, over the years 2002 to 2006, the bmvit supported cooperative research projects in industrial, university and extramural research, with the aim of ensuring the competitiveness of the Austrian automotive industry through innovations and increasing the social and ecological acceptance of road transport. In 4 calls for proposals for R&D projects and 2 calls for proposals for flagship projects (as major pilot projects and demonstration projects), a total of 86 projects were supported. The number of R&D or flagship projects submitted and selected for funding proves a particular interest in the field of hydrogen and fuel cell technologies. This is in accord with the strategies of major automotive groups, who all attribute great importance to hydrogen and fuel cells and who view this as a long-term target technology on the path to "zero-emission vehicles".

The A3 technology programme supported innovative approaches in the Austrian automotive supplier industry, supplementing European cooperative research activities, and is a component of the bmvit's strategic programme for "Intelligent Transport Systems and Services" ["Intelligente Verkehrssysteme und Services" – IV2S]. It sought to realise interdisciplinary research cooperations and development projects with a high degree of innovation. The aim behind this was to initiate genuine advances in technology and not just to encourage the incremental improvement of existing technologies, in order to prepare the highly successful Austrian automotive industry in good time for the emerging technological transformations. With the aim of taking a comprehensive view, the programme covered the full innovation cycle and offered funding from basic research through to demonstration projects. Funding was also given to projects seeking to adapt education and training to the new challenges and to obtain sufficient, and sufficiently-qualified, human resources. A further programme pillar supported international networking, mobility and cooperation amongst researchers. To realise synergies from the complementary expertise of the various partners, the awarding of funds in A3 went to consortia in industrial, university and extramural research.

This first issue of the periodic publication is divided into 4 chapters and contains 47 projects supported under the A3 programme, ranging from studies to demonstration projects, and covering the domain of hydrogen and fuel cells. The first chapter deals with hydrogen, and draws on descriptions of 18 R&D outcomes, of which 3 look at production and 15 at storage. Chapter two covers the subject of "hydrogen in the combustion engine", and the R&D outcomes from 3 projects are presented. Outcomes in the field of fuel cell research are presented in chapter three, and comprise 20 descriptions of R&D outcomes, of which 12 deal with polymer electrolyte membrane fuel cells (PEMFC) and 8 deal with solid oxide fuel cells (SOFC). The concluding fourth chapter covers the reports on the outcomes of 6 projects concerning horizontal and cross-technology activities such as training initiatives, measures aimed at increasing the international networking of Austrian automotive research, and support measures for SMEs.

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> THE ECO-HYDROGEN FILLING STATION OF THE FUTURE
> SUSTAINABLE PRODUCTION OF HYDROGEN IN AUSTRIA

HYDROGEN STORAGE

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> FINITE ELEMENT (FE) SIMULATION LH_2I/MLH_2I
> HYCONTROL
> HYDRO-PIM (POWDER INJECTION MOULDING)
> L-H_2 PERIPHERALS
> TANK INSULATION
> LH_2I/TLH_2I TEST PROGRAMME
> CRYOSENSE
> ALL-METAL INSULATION
> H_2 EXHAUST SYSTEM
> NANO-MG H_2 STORAGE SYSTEM
> SAFE HYDROGEN STORAGE
> LH_2 SENSOR CLUSTER

HYDROGEN

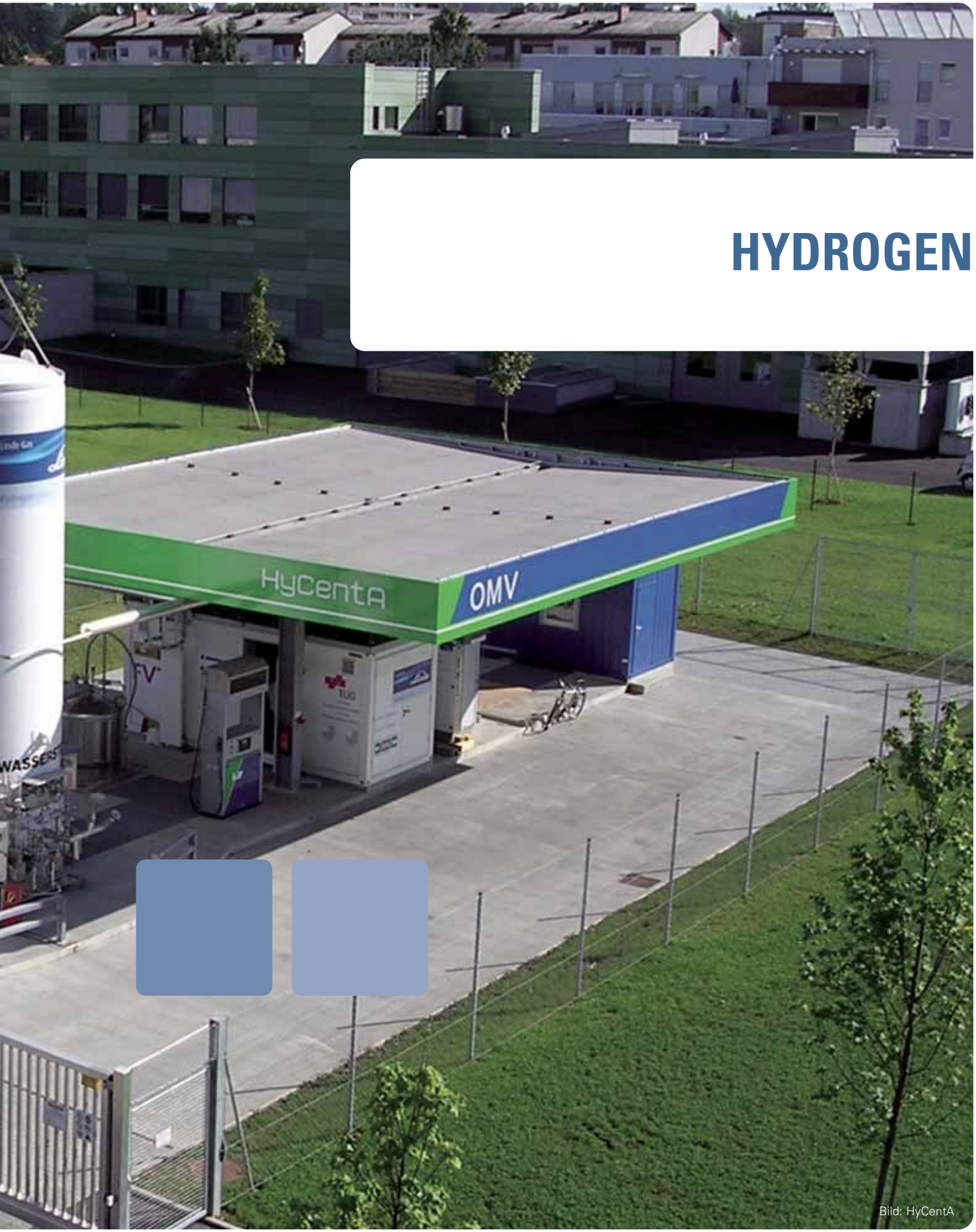


Bild: HyCentA

ECO-HYDROGEN INNOVATIVE

Innovative co-generation of eco-hydrogen as an alternative fuel using by-products oxygen and heat

In future, hydrogen can play an important role as an alternative fuel for transport applications, since it can be obtained from various primary energy sources and strongly reduces the emissions from operating vehicles (to practically zero if using fuel-cell vehicles). Hydrogen can only play this role if its production, storage and distribution can be realised on a sustainable footing (i.e. energy-efficient production from renewable energy sources – "eco-hydrogen"). To be able to supply eco-hydrogen from electrolysis using eco-electricity as an alternative fuel efficiently and thus cheaply requires innovative utilisation of the by-products of electrolysis (oxygen and water). When water (H_2O) is subjected to electrolysis, 0.5 Nm^3 of oxygen (O_2) is produced per 1 Nm^3 of hydrogen (H_2). Approximately 25-30% of the electrical energy used is converted to heat, at a temperature level of 70 – 90°C. It is only the efficient and economic utilisation of these by-products which will bring about a genuine leap forward in the technology and consequently enable the future application of eco-hydrogen as an alternative fuel. This will reduce dependence on fossil fuels in future and increase security of supply for the transport sector.

An investigation into co-generation of eco-hydrogen as an alternative fuel with efficient use of the by-products oxygen and heat in Austria, with a direction-setting case study.

In a technical analysis, various possibilities for the linked use of oxygen and heat in the production of eco-hydrogen were thoroughly researched. The most attractive options were assessed from an economic and ecological point of view, with a distinction being made between modes of operation favouring hydrogen, oxygen and heat respectively. From an ecological point of view, heat-oriented operation can be assessed particularly favourably, as fossil fuels can be replaced to generate heat. The potential of possible thermal substitution is very great, with a further possibility being to use large volumes of hydrogen as an alternative fuel with heat generation. The revenues which can be realised from selling the heat are modest, and do not make a significant contribution to reducing the costs of hydrogen (5 – 10%) by comparison with electrolytic production of H_2 without using heat. From an economic point of view, oxygen-oriented operation can be assessed favourably, since high revenues can be realised from the sale of oxygen which can significantly reduce the production costs for hydrogen by around 15 – 60%.

INFO
Project management:
Joanneum Research Forschungsgesellschaft mbH
Project partners:
HyCentA Research GmbH,
Linde Gas GmbH

The analysis of future potential indicates that substituting the entire quantity of oxygen currently being produced in Austria by air separation (to be replaced with electrolytic production of oxygen) could provide 2 – 3% of the demand for hydrogen for use in the transport sector. If 10% of the current thermal demand were to be met using heat from electrolytic hydrogen production, around 25% of current fuel demand could be covered using hydrogen.

In the case study looking at the innovative electrolytic production of eco-hydrogen at HyCentA in Graz, a feasibility analysis was carried out which shows that an air-cooled PEM electrolyser unit with a capacity of 0.5 Nm^3 H_2/h could satisfy the current demand for hydrogen in gas form at HyCentA. The heat would be used to heat offices and to produce hot water, with the oxygen being purified, filled into pressure cylinders and passed on for use as an industrial gas.

THE ECO-HYDROGEN FILLING STATION OF THE FUTURE

Demonstration of linked electrolytic production and use of hydrogen, oxygen and heat from eco-electricity at HyCentA

An innovative "eco-hydrogen filling station of the future" will be constructed at HyCentA in Graz to test the linked production (electrolysis using eco-electricity) and use of eco-hydrogen, oxygen and heat in a practical trial. During "driving events" using hydrogen vehicles, e.g. within the scope of the Second Austrian Hydrogen Conference in Graz, the operation of an eco-hydrogen filling station will be demonstrated to a specialist audience and to the general public. Future users, such as filling station operators, fleet operators (e.g. post, taxi, transport operators) will also be involved in these "driving events", in order to demonstrate the possibility for medium-term market launch of eco-hydrogen as an alternative fuel at the filling stations of the future.

The focus of the demonstration project will be on a metrological examination of the functional capability of the components, on inserting these into the overall concept at HyCentA and testing in a real-life environment. The project will expand the existing hydrogen filling station by adding the key component of innovative eco-hydrogen production, and thus the total system will demonstrate an "eco-hydrogen filling station of the future". Based on the feasibility study which is currently being developed, the detailed planning for the components for the eco-hydrogen filling station will be carried out. Tenders will be obtained and evaluated for the plant components. The plant components will be ordered; at the same time, a measuring programme to evaluate practical operation in steady-state and transient operating conditions will be devised, particularly for the four following areas:

> Use of eco-electricity
> Oxygen production and use
> Hydrogen production and use
> Heat production and use

The plant components are to be installed as a modular construction (possibly in containers). After this, the plant components will be put into operation and integrated into the existing infrastructure. In addition, aspects relevant to safety will be investigated. The measuring equipment necessary for the measuring programme will be specified and the metrology equipment integrated into the plant, in order to map typical load profiles of plants for generating eco-electricity (amongst other things) and to determine and optimise the effects on the production and use of the three co-generated products: eco-hydrogen, oxygen and heat. As part of the "driving events", hydrogen vehicles will demonstrate the "eco-hydrogen filling station of the future" as a total system for a forward-looking transport system. The hydrogen vehicles will be provided from other national and international projects, and in addition to the traditional car these may also be two-wheeled vehicles, utility vehicles or special vehicles.

Project schedule:
The project schedule is divided into the following 4 sections:
1. Preliminary works to realise the demonstration plant
2. Analysis of (future) market aspects, operational aspects and of the transport policy and environmental policy benefits
3. Prototypes of the interfaces between linked production of eco-hydrogen, oxygen and heat and the existing infrastructure, and their use
4. Operating an eco-hydrogen filling station of the future, with an accompanying metrological evaluation of different operating conditions

The publicity work, of which the "driving event" also forms a part, will be carried out in parallel to this, in order to publicise this demonstration in specialist circles and to the interested general public.

The project has been started recently, the outline therefore corresponds to the project proposal description.

Constructing an innovative "eco-hydrogen filling station of the future" to test the linked production (electrolysis using eco-electricity) and use of eco-hydrogen, oxygen and heat in a practical trial. The operation of an eco-hydrogen filling station is demonstrated to a specialist audience and to the general public by means of "driving events" using hydrogen vehicles.

INFO
Project management:
Joanneum Research Forschungsgesellschaft mbH
Project partners:
Linde Gas GmbH,
Biovest Consulting GmbH,
OMV Refining & Marketing GmbH,
HyCentA Research GmbH,
Weizer Naturenergie GmbH

SUSTAINABLE PRODUCTION OF HYDROGEN IN AUSTRIA

Evaluation of possible pathways for the sustainable production of (bio)hydrogen in Austria, with special focus on the use of renewable resources and implementation in the automotive sector.

With regard to using hydrogen as an energy carrier for the automotive sector, a lot of effort is put into researching the fuelling system, storage and propulsion technology. However, the supply of the hydrogen required is still based on conventional fuels like crude oil and natural gas even though hydrogen can be produced in regenerative ways. Austria, in particular, offers a lot of raw materials for the regenerative production of hydrogen, for example biomass like wood, straw and energy crops, but also biogenous waste from industrial production processes.

In this study, several process chains for the production and use of hydrogen are researched and evaluated using process simulation and life-cycle-analysis. These process chains comprise the whole path from the feedstock via the production process, transportation and storage to use of the hydrogen within the automotive sector. To ensure sustainable production of hydrogen, special attention has to be paid to the feedstock used. Therefore it is also part of this study to investigate the possible amounts of raw materials that can be produced in a sustainable way in Austria. Furthermore, the hydrogen production potential of these raw materials is determined.

This study analyses the possibilities for the production, storage and use of (bio)hydrogen in Austria involving dedicated utilisation in the automotive sector. The results will comprise a technical, economic and ecological evaluation of several process chains from the feedstock to implementation in the combustion engine or fuel cell of a vehicle.

Thermal (gasification), as well as fermentative (biogas fermentation, dark fermentation and photo fermentation), technologies are considered for the production of hydrogen from renewable resources and each of these technologies is researched with different raw materials. The gasification process as well as the biogas fermentation process requires a subsequent reforming step. This reformation of the raw gas can either be done in a small, decentralised reforming plant on site or in a large, centralised reforming plant that treats gas streams from several production plants. In case of the centralised reformation, the raw gas is upgraded to natural gas quality, fed into the natural gas grid and transported to the central reformer plant via natural gas pipelines.

INFO
Project management:
TU Wien – Institut für Verfahrens-technik, Umwelttechnik und Technische Biowissenschaften
Project partners:
Profactor Produktionsforschungs GmbH, OMV Aktiengesellschaft – Corporate Strategy

The study also includes two reference technologies that are state of the art. These technologies are the steam reforming of natural gas and the alkaline water electrolysis with electricity. Transportation of the hydrogen produced is considered using both trucks and pipelines, with on-board storage of the hydrogen being realised in gaseous form at 350 bar or 700 bar. Both combustion engines and fuel cells are considered as propulsion technologies for the vehicles.

The output of this study is a technical, economic and ecological evaluation of the various possible total process chains for the production of hydrogen from biomass and its application in the automotive sector in Austria.

THERMODYNAMICS IN PIPING SYSTEMS OF LIQUID HYDROGEN TANK SYSTEMS

Cryo tank

Using these cryogenic storage systems in automotive applications entails a complex design of filling, withdrawal and safety pipes, since the vessel has to be integrated in a horizontal position due to packaging constraints. Incorrect design of the piping system can lead to a phenomenon called heat pipes, which is characterised by a high heat flow from the warm to the cold end of the pipes. As a consequence, the pressure increase inside the inner tank may accelerate. Heat pipe effects in pipe systems are largely known only from practical experience and the parameters of the effects are recorded only roughly. However, it is a time-consuming and costly process to optimise a tank system to avoid such effects. Furthermore, experiments with liquid hydrogen are not without danger. As a consequence, a simulation model providing the same possibilities using computer simulation methods would be desirable.

Hence the goal of the project was to develop a mathematical model to simulate transient flow and phase transition processes of gaseous and liquid hydrogen in cryo tanks and validate the results by experimental tests. The main advantage of these calculations is the generation of a theoretical model, which allows for time- and cost-savings in building prototypes and optimising them, given sufficient iteration of this approach.

To that end, different cryogenic fluids were first compared concerning their thermodynamic properties to find safer and/or cheaper alternative fluids for validating the model. The investigations showed that no other fluid qualified to substitute hydrogen for test runs. Subsequently the behaviour of cryogenic hydrogen in pipes was analysed in model calculations under simplified conditions. In doing so, the influence of the geometry as well as the relation of heat transport via steel pipes and heat transport via hydrogen gas was investigated. In conclusion, a mathematical phase transition model was presented. This model was based on the equations for mass, impulse and energy of fluids. Special focus was also placed on modelling the boundaries between gaseous and liquid hydrogen. Until this time, all hypothetical analyses had assumed that a thermodynamic equilibrium between the liquid and gaseous phase existed in this boundary area. However, for a realistic calculation of the physical processes inside the cryo tank as well as of the boil-off rate of the hydrogen, the transient mass transfer and the extent to which the diffusion coefficients in the phase transition area depend on temperature and pressure had to be studied in detail.

The results of this simulation will be used in designing future liquid hydrogen tank systems.

Hydrogen powered engines and fuel cells represent an important development in the transition from conventional engines powered by fossil fuels to clean and environmentally sound drive systems. For the latter, liquid hydrogen stored in vacuum insulated vessels can be used as fuel.

INFO
Project management:
Magna Steyr Fahrzeugtechnik AG & Co KG
Project partners:
Messer Austria GmbH,
Montanuniversität Leoben – Christian-Doppler-Laboratorium für Rechnergestützte Angewandte Thermofluiddynamik

L-H_2 INNER TANK SUSPENSION

Combination of pipework system and inner tank suspension for L-H_2 tank systems

Given the limited resources of fossil fuels and the need to reduce pollutant emissions from private transport, sustainable alternative fuels and vehicle propulsion systems will be the key to securing our future personal mobility. International studies mostly agree that hydrogen is the most promising fuel of the future. Cryogenic tank systems, in particular for liquid hydrogen, constitute a key technology. When cryogenic liquid hydrogen is stored at 20 K (- 253 °C), the surrounding heat flows into the tank system continuously by thermal conduction over the pipework system and the inner tank suspension. Consequently the pressure inside the inner tank increases, up to a certain value determined by the limited mechanical strength of the inner tank. If the maximum allowable pressure is reached, hydrogen has to be vented off. In that case, the vented-off hydrogen is lost as fuel, decreasing the range of the vehicle and reducing the performance of the tank system.

The project works on concepts for supports for liquid hydrogen tank systems for automotive applications. To improve the performance of the tank system and to reduce system complexity, the innovative concept of combining an inner tank suspension with the pipework system is used. New fibre reinforced plastic materials play a key role in these considerations.

Up to now all functional components integrated into the vacuum space – pipes, valves and inner tank suspension – have largely been considered separately. The goal of the project was to develop a combination of these components which would reduce overall heat entry into the tank system and thus the loss of hydrogen. The core issue was to investigate what kind of functional combination of components makes sense and is feasible. In addition to the desired significant reduction of heat entry caused by heat conduction, the reduction in system complexity as well as the decreased weight of the complete tank system can prove very advantageous as well. Polymer materials, in particular composite materials, were of vital importance in finding a technical solution, due to their extremely wide range of realisable material properties (mechanical, thermal and functional properties). In addition to thermal improvements, the investigation focused on the thermo-mechanical and mechanical loads that occur in operation and in case of crashes, which have to be reliably absorbed by the pipework/inner tank suspension combination.

INFO
Project management:
MAGNA STEYR Fahrzeugtechnik AG & Co KG
Project partners:
Advanced Polymer Engineering GmbH, Polymer Competence Center Leoben GmbH

The result of the project is an innovative suspension concept, which shows several advantages compared to the current state of technology – regarding thermodynamic, dynamic and static mechanical behaviour. In experimental tests, the functionality of this innovative design using an alternative material was proven. The prototype constitutes the basis for new serial engineering projects for automotive cryogenic hydrogen storage systems.

SPD MAGNESIUM

Solid-state hydrogen storage in nanocrystalline magnesium using severe plastic deformation (SPD)

The aim of the project was to determine – using experimental and theoretical feasibility studies – whether and how a significant acceleration of hydrogen charging and discharging in magnesium hydride can be achieved by catalysts and/or by structure refinement (by two new, very promising processing methods).

Following a survey of the literature, some suitable magnesium alloys and catalysts were chosen and subsequently manufactured and processed by the two methods mentioned above. Key process parameters were deliberately varied in order to achieve desirable nanocrystalline microstructure. Afterwards the structure was evaluated using optical and electron microscope investigations. The results show that one of the main aims of the project, namely a significantly reduction of initial grain size from the 1 mm to 300 nm, could be achieved. Subsequently, samples were subjected to cyclic charging and discharging experiments with hydrogen in a computer-controlled hydrogen charging station designed and built specifically for this purpose.

The results of these experiments have proved that magnesium alloyed with catalysts in nanocrystalline form shows the desired high hydrogen storage capacity of 5 wt% as well as rapid charging and discharging kinetics, and therefore satisfies the requirements for on-board hydrogen storage for fuel cell cars.

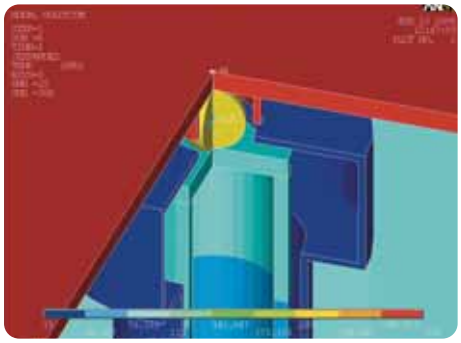
INFO
Project management:
ARC Seibersdorf research GmbH
Project partners:
Neumann Aluminium Austria GmbH,
Messer Austria GmbH,
Bitter Engineering & Systemtechnik GmbH,
Universität Wien – Institut für Materialphysik

Hydrogen – especially in combination with fuel cells – is considered to be the most promising solution for the long-term transition to alternative automotive fuels. However, a central problem to overcome on the way to implementation for automotive applications is the storage of hydrogen. An alternative approach to the two well-known methods – viz. storage in liquid state at low temperatures and as compressed gas in high-pressure tanks – is to use hydrogen storage in reversible light-metal (e.g. magnesium-based) hydrides. The considerable advantages of solid-state storage over conventional methods are mainly high volumetric storage capacity (50% more than in liquid state) and free geometry of the tank.

FE SIMULATION LH_2I/MLH_2I

Simulation of Hertzian contacts for LH_2 inner tank suspensions

As part of this project, a new insulation and suspension concept for double-walled tanks for liquid hydrogen vehicles shall be developed. The innovative approach utilises the principle of minimised heat conduction by using point contacts.



Storage of liquid hydrogen in a vehicle tank requires optimal thermal insulation of the tank to prevent boil-off of hydrogen. The current technology for the thermal insulation involves double-walled tanks that are equipped with super-insulation. The super-insulation provides excellent low heat intake. However, heat intake from the mechanical suspension of the inner tank within the outer tank must also be minimised. A fully metallic or ceramic solution is investigated for this project. A suspension concept utilising the principle of low heat conduction of point contacts is digitally simulated and optimised via finite element analysis method. The analysis parameters are validated in a related test programme (see LH_2I/TLH_2I test programme).

A local digital model of the point contact, as well as a digital model of a tank supension, is developed as part of the project. The local digital model of the point contact simulates the test set-up of the related test programme. It is used for correlation with the test results, so that the physical properties of heat conduction via point contacts can be simulated by computer. During the test programme it turned out that major influencing parameters on heat conduction not only include the temperature difference and the combination of materials, but also the local distribution of mechanical stress and the Hertzian contact pressure of the contact. These dependencies were incorporated into the computer model so that the simulation results show good correlation with the test results. The computer model now allows us to predict the heat conduction through a fully metallic or ceramic suspension utilising the principle of low heat conduction of point contacts.

INFO
Project management:
Austrian Aerospace GmbH
Project partners:
TU Wien – Institut für Angewandte und Technische Physik,
Bayerische Motoren Werke AG

The analysis model (backed both by sound theory and by experimental testing via the parallel programme) allows for optimised designs in terms of conducted heat for suspensions of cryogenic tanks utilising the principle of low heat conduction of point contacts.

HYCONTROL

Electronic control unit for liquid hydrogen tanks

Liquid hydrogen tanks in vehicles pose a technological challenge in terms of functional realisation and providing operational safety, as well as in the practicable realisation of such systems.

Hydrogen used as propulsion fuel is stored at -253°C in a double-walled tank with a high-vacuum insulated space between the walls.

The electronic control unit (ECU) to operate an automotive liquid hydrogen tank has to evaluate a large number of sensors and has to control actuators in order to provide the required functionality and operational safety. Using actuators, e.g. on tank valves and a pump for pressure build-up, the ECU is able to influence the tank system states, thereby providing certain modes of operation for the car/driver. One such mode of operation is fuelling. During this mode the fill volume in particular is monitored in order to stop the fuelling when a specified level is reached. This needs to be done to prevent the tank system from overfilling. Another key mode of operation is consumption, which is characterised by pressure regulation to maintain the pressure of the inner tank at a given value.

In the "HyControl" project, particular attention was paid to the issue of operational safety. Thus the tank ECU has been developed according to ISO 61508 SIL3 functional safety of electrical/electronic/programmable electronic safety-related systems to avoid uncontrolled emission of hydrogen in case of a critical ECU error.

Up to now, two prototype stages have been developed and produced which reflect actual progress internally in the "HyControl" project as well as on corresponding projects (e.g. further development of the hydrogen tank container). So the second prototype stage benefits from the general development process by having extended and improved functionality in many areas, such as the option to integrate the control of a boil-off management system.

The actual tank ECU hardware comprises a dual processor system with safety-relevant engineered sensor and actuator modules corresponding to SIL3. This means that comprehensive diagnostic options are implemented, through evaluation of various signals and the ability to activate test circuits. The software system developed to operate the tank ECU is characterised by a high degree of modularity, making future adjustments considerably easier. By applying partial software diversity and using two different pre-emptive operating systems, it is possible to implement the overall safety requirements successfully in the software.

To be able to run a liquid hydrogen tank in a vehicle and achieve good performance and safety calls for increased investment in the control engineering being used. Data acquisition by the sensors, data processing and tank system control must be realised in line with safety-related criteria. In the "HyControl" project, an electronic control unit is developed which accommodates these special requirements.

INFO
Project management:
MAGNA STEYR Fahrzeugtechnik AG & Co KG
Project partners:
Siemens AG Österreich,
TU Graz – Institut für Elektronik

HYDRO-PIM

Powder injection moulding of safety-optimised, function-optimised and weight-optimised components for hydrogen storage

The use of hydrogen as an ecological alternative to traditional automotive fuels has been under discussion for a long time, but up to now it has been considered too expensive and not sufficiently practicable. However, the technological advances of recent years demonstrate that hydrogen should definitely be regarded as a medium-term alternative to fossil-based energy carriers. A hydrogen-based propulsion technology would also be urgently needed if the EU target of a 20% quota of alternative fuels by 2020 is to be achieved.

In HYDRO-PIM, components for liquid hydrogen storage tanks are manufactured and tested using the innovative production technology of powder injection moulding (PIM). PIM can be used to optimise complex components in terms of weight and costs. The characterisation of powder metallurgy materials used in the manufacture of these components is likewise an integral part of the HYDRO-PIM project.

A major issue continues to be the development of suitable storage or tank units for hydrogen-powered vehicles. In order to be able to use hydrogen increasingly as an energy source, there is a need to develop effective and safe storage procedures. Pressurised-gas and liquid-gas storage have now become standard solutions. However, these tank systems are subject to great thermal and mechanical stresses. For this reason, the components of the tank systems need to be constructed as solid items and are therefore correspondingly heavy. The more complex components of such tank systems, such as valve blocks, are generally manufactured by machining (milling, lathe work, drilling). PIM (Powder Injection Moulding) makes an innovative procedure available for manufacturing weight-optimised components using high-quality materials. The procedure combines the diversity of moulds achievable using plastic injection moulding with the diversity of materials from powder technology. It allows complex components to be manufactured cost-effectively from metal (e.g. stainless steel) in significant volumes with a high degree of precision and reproducibility.

INFO
Project management:
Austrian Research Centers GmbH – ARC
Project partners:
MAGNA STEYR Fahrzeugtechnik AG & Co KG,
Ernst Wittner GmbH,
Westcam Projektmanagement GmbH

In the HYDRO-PIM project, PIM technology was used to manufacture two different components in the material DIN 1.4404 for liquid hydrogen storage tanks and the suitability of powder metallurgy materials for this intended use was examined in terms of the gas seal, suitability at low temperatures, hydrogen embrittlement and strength. By exploiting the design options afforded by PIM, it was possible to achieve a higher level of functionality and safety (e.g. fewer components – fewer seals – fewer sources of defects) with a reduced spatial requirement and a significantly-lowered weight. Appropriate design guidelines have been drawn up for PIM components which correspond to safety regulations and are intended for use with hydrogen. Currently the model parts of two components – a valve block and a further component – are being tested for suitability on a test bench at HyCentA. After this, the weight and cost reduction compared to traditional manufacturing technologies will be quantified and the potential savings for further cryogenic components estimated. With the successful use of powder metallurgy materials for hydrogen storage components, the foundations are being laid for broader implementation of the innovative PIM technology in future automotive applications.

L-H_2 PERIPHERALS

Innovative peripherals system for liquid hydrogen tanks

Hydrogen storage will play a key role in the transition to a renewable energy economy. Hydrogen stored in its liquid form at very low temperatures achieves the highest possible energy density. Thanks to its low emission fuel combustion and the long range attainable with this technology, a vehicle propulsion system with cryogenic liquid hydrogen as fuel is considered an alternative to current propulsion systems based on the combustion of fossil fuels.

The tanks currently in development for small series production have peripheral systems which are not as yet fully satisfactory. For example the dynamic response of the fuel system at low tank pressure, which occurs e.g. after finishing the refuelling process, is very poor; due to the low pressure in the tank, only a small amount of hydrogen is available to the engine and it is not possible to raise the pressure without simultaneous fuel consumption. For a vehicle being driven, this means that only limited engine power is available in such a situation. Moreover, the currently used valves still show technological deficiencies; it is not always possible to combine functional requirements (e.g. reliability) with automotive technologies. By minimising the number of pipes used, it is possible to achieve a reduction in the complexity of the tank system.

In this project, the components of a new process-engineered schematic tank circuit were studied, developed and then realised. The new pressure-generation system consists of an open heat exchanger and a hydrogen pump. Four valves operating at ambient temperature and two valves operating at cryogenic temperature are needed to control the system. The objective of the project was to develop the system components, to prove their function, to design them and to build a complete tank system using these new components, for testing purposes.

In the first phase, the partners separately developed all required components in parallel. In the second, shorter phase, the components were assembled into a complete tank system and finally tested. The test results demonstrated that the new pressure-generation system worked properly in conjunction with the complete peripherals system under all kinds of operating conditions.

The result of the project is a new kind of liquid-hydrogen tank system with considerable improvements compared to the standard solution with respect to both dynamic behaviour and reliability. Thanks to the reduced complexity of the peripherals system and the use of an alternative multilayer insulation material, it was possible to considerably reduce the inward heat transfer and the related hydrogen boil-off rate. The overall function of the tank system was validated. The prototype constitutes the basis for new serial engineering projects for automotive cryogenic hydrogen storage systems.

In the L-H_2 peripherals project "L-H_2-Peripherie", an advanced liquid hydrogen storage system for motor vehicles was developed by the project partners. The main innovation is a new pressure generation system for the withdrawal of hydrogen from the fuel tank, which is managed by a small hydrogen pump. Thus the complexity of the L-H_2 peripherals system was substantially reduced. During the project the main system components, including all valves and the hydrogen pump, were tested at component level. At the end of the project, several functional performance tests of the overall system with hydrogen were carried out to validate its functionality.

INFO
Project management:
MAGNA STEYR Fahrzeugtechnik AG & Co KG
Project partners:
Test-Fuchs – Ing. Fritz Fuchs GmbH,
VENTREX Automotive GmbH,
HyCentA Research GmbH

TANK INSULATION

Innovative insulation technologies for automotive liquid-hydrogen storage systems

Given the limited reserves of fossil fuels and the need to reduce polluting emissions from private transport vehicles, sustainable alternative fuels and vehicle propulsion systems will be the key to securing our future individual mobility. International studies mostly agree that hydrogen is the most promising fuel of the future. In liquid-hydrogen storage systems, hydrogen is stored in its liquid state at very low temperatures (approx. 20K, -253°C). In developing such cryogenic storage systems, thermal insulation of the inner tank to reduce heat input constitutes a major technical challenge. Due to this heat input, the liquid hydrogen inside the inner tank evaporates, which raises the tank inner pressure. When a certain pressure level is reached, hydrogen must be discharged in a controlled manner, which reduces the range of the vehicle.

The goal of this project is to develop an insulation for liquid hydrogen tanks which fulfils the requirements of automotive applications in terms of its thermal performance, manufacturing costs as well as environmentally sound disposal. In order to effectively stabilise the isolating high vacuum, a key focus of the project was on new getter materials.

So far, all insulation techniques have only been studied under ideal operating conditions. They have not been studied under specific automotive conditions, such as complex and permeated insulation geometries and process reliability during assembly. One focus of the project was on studying different getter materials. Getters are metal alloys which chemically absorb gases. When getters are used, a certain minimum pressure level can be maintained over a calculated operating time in the vacuum space in which the insulation is installed.

INFO
Project management:
MAGNA STEYR Fahrzeugtechnik AG & Co KG
Project partners:
ARC Seibersdorf research GmbH,
Alvatec Alkali Vacuum Technologies GmbH

In this project, a suitable vacuum chamber was prepared in such a way that the heat flow via the respective insulation design – vacuum, multi-layer insulation (MLI) or microspheres – could be measured in defined situations very similar to automotive conditions, e.g. ambient temperature between 20°C and 60°C, different vacuum conditions between 10^{-7} and $5x10^{-3}$ mbar. In each case, the effect of the getters was studied in detail by investigating the composition of the residual gas and the performance of the getter. It could be shown that using microspheres improves thermal insulation by a factor of only around 1.2, whereas MLI insulation achieved an improvement by a factor of 17 compared to vacuum insulation on its own. The residual gas pressure in the vacuum space has the greatest influence on insulation behaviour: when the residual gas pressure increases from 10^{-7} mbar to approx. $5x10^{3}$ mbar, the insulation performance of MLIs deteriorates by a factor of 2.5. This shows the importance of using effective getter materials.

Since the thermal measurements in this project were based on realistic automotive conditions for the first time, the project outcome is an aid to decision-making when choosing between different insulation concepts on the basis of validated data. The newly developed micro-structured getter design provides for flexibly adapting and optimising getter performance with regard to the composition of the residual gas and the insulation materials.

LH_2I/TLH_2I TEST PROGRAMME

Measurement of Hertzian contacts for LH_2 inner tank suspensions

Storage of liquid hydrogen in a vehicle tank requires optimal thermal insulation of the tank to prevent boil-off of hydrogen. The current technology for the thermal insulation involves double-walled tanks that are equipped with super-insulation. The super-insulation provides excellent low heat intake. However, heat intake from the mechanical suspension of the inner tank within the outer tank must also be minimised. A fully metallic or ceramic solution is investigated for this project. A suspension concept utilising the principle of low heat conduction of point contacts is representatively tested in a dedicated cryogenic test set-up. The test results form the input to a digital simulation model for such suspensions, developed in the related simulation project (see FE modelling LH_2I/MLH_2I).

In a test set-up, the heat transfer across balls between flat plates is measured at a temperature difference between room temperature and liquid hydrogen temperature by calorimetric measurement. The measurement principle is based on the measurement of the temperature gradient over a calibrated temperature reduction range on the cold side of the test set-up.

The measurements are performed under vacuum, with liquid helium as the coolant. Using this test set-up, the influence of different material pairings, coatings, Hertzian contact pressures, vacuum quality, temperature gradients, as well as the influence of preliminary mechanical wear of the balls due to vibration is measured. The test programme demonstrated an unexpectedly high dependence of the heat intake on the local distribution and the Hertzian contact pressure of the contact.

The findings from the test programme about the influence of different design parameters on heat intake via point contacts provide the input for optimised design of suspensions of cryogenic tanks in vehicles, utilising the principle of low heat conduction of point contacts. That design is experimentally proven and comprehensible in analytical terms via the parallel LH_2I/MLH_2I FE modelling programme.

In this project a new insulation and suspension concept for double-walled tanks for vehicles shall be developed. The innovative approach utilises the principle of low heat conduction of point contacts.

INFO
Project management:
Austrian Aerospace GmbH
Project partners:
TU Wien – Institut für Angewandte und Technische Physik,
Bayerische Motoren Werke AG

CRYOSENSE

CryoSense – sensors for intelligent cryogenic liquid gas tank systems

Reliable sensor systems for use with mobile and stationary tank systems containing cryogenic liquids often cannot meet the stringent demands on sensor cost posed in the automotive field. Hence the scope of the research project is the experimental evaluation of promising sensing methods for cryogenic liquids (LH_2, LNG) that are applicable in the automotive field.

Reliable and robust sensors are the basic requirement for safe operation of tank systems holding cryogenic liquids. The scope of the research carried out in the CryoSense project is therefore the development of sensor concepts to measure the amount of cryogenic liquid inside a given tank (fill level) as well as mass and volume flow of the cryogenic liquid in the tank system supply pipes. Sample measurements are used to assess the achievable measurement uncertainties of the chosen measurement principles. During the selection process, sensing principles have been favoured that minimise additional heat input into the tank and do not require major changes of the tank system design.

The basic measurement quantities to be monitored during the operation of liquid hydrogen tank systems are temperature, pressure, and tank fill level as well as flow (mass flow, volume flow) during refilling and liquid extraction phases. Pressure and temperature sensors with sufficient reliability and precision are available. The measurement of fill level is needed primarily for mobile tank systems, and is covered by various other projects of the A3 Programme. The CryoSense project accordingly focuses on the development and evaluation of robust flow sensor systems for liquid hydrogen that fulfil the following criteria:

> Small measurement uncertainties (sufficient for monitoring and billing purposes)
> Applicable at the given environmental conditions (temperature approx. -250 °C; high temperature gradients in the vicinity of the cryogenic liquid)
> Ease of system integration in existing tank systems
> Minimal additional heat flow into the tank due to the sensor system
> High stability and lifetime
> Possibility of sensor self-diagnostics and automatic calibration

After a theoretical survey of promising methods, an experimental set-up was developed that can be inserted into the cryogenic fluid pipe system (see illustration). The set-up can hold up to two different sensor front-ends that are used to determine the current flow through the pipe. The measured flow values are compared to the result of a reference sensor positioned downstream from the prototype sensors. These measurement results are used to assess the applicability of the sensor system in principle, and to estimate the performance capability of the procedures using practical measurements.

INFO
Project management:
TU Graz – Institut für elektrische Messtechnik
Project partners:
OMV Refining & Marketing GmbH, HyCentA Research GmbH

In addition to the cryogenic liquid flow rate, sensor design experiments were conducted to investigate the applicability of wireless sensors positioned inside cryogenic tank systems (with both power and information transfer provided wirelessly).

ALL-METAL INSULATION

All-metal insulation of liquid hydrogen tanks

The project concentrates on improving the insulation of double-walled fuel tanks for liquid hydrogen in respect of the criteria of industrial feasibility (costs), construction volume (range, pressure build-up time) and vacuum stability.

As part of the project, the innovative concept for all-metal insulation for automotive liquid-hydrogen tanks is to be recorded and demonstrated using analytical and experimental methods such that the fundamental suitability of this concept for the most important operating conditions (driving, pressure build-up phase, boil-off phase, servicing) can be determined. The following beneficial possibilities of this innovative insulation technique are to be exploited:

> Reducing estimated costs of manufacture and assembly
> Increasing vacuum stability, with improved oxygen compatibility
> Increasing range and pressure build-up, whilst retaining the same construction size of the tank.

In the area of simulation, the thermal load scenarios "degraded vacuum" and "sudden loss of vacuum" are to be mapped in a mathematical/physical model. The intention is to create a development tool for further tank developments.

The comprehensive previous knowledge which is being made available by the individual partners for the first time will be brought together and used to extend the existing thermal model for a concrete prototype of the thermal load scenarios: "degraded vacuum" and "sudden loss of vacuum" and to validate this with measurement outcomes.

In order to demonstrate modelling of heat intake in the event of a loss of vacuum by experiment in addition, a suitable test-bench experiment is envisaged. A test object is to be adapted for this test; this is being developed for measuring vacuum insulation.

To ensure feasibility of practical implementation, possible manufacturing and assembly techniques for membrane skins will be developed and illustrated using visual models, and design guidelines will be derived for liquid hydrogen storage using all-metal insulation.

At the end of the project, the aim is to be able to offer a clear statement regarding the suitability of all-metal insulation for use in automotive liquid hydrogen storage – taking into account the key thermal operating conditions – and to demonstrate the feasibility for practical implementation of this insulation technology on actual tank configurations.

The project has been started recently, the outline therefore corresponds to the project proposal description.

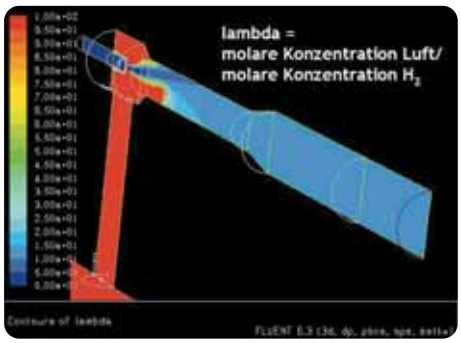
In this project, the suitability of the innovative concept of all-metal insulation for automotive liquid hydrogen tanks is examined using analytical and experimental methods. To this end, the most important operating conditions (driving, pressure build-up phase, boil-off phase, servicing) are analysed in order to provide well-founded predictions as to feasibility of implementation.

INFO
Project management:
Austrian Aerospace GmbH
Project partners:
TU Wien – Institut für Umform- und Hochleistungslasertechnik,
HyCentA Research GmbH,
Bayerische Motoren Werke AG

H_2-ADS

Feasibility study for a boil-off system for liquid hydrogen storage systems

In the event of longer resting times, hydrogen needs to be vented into the atmosphere from liquid hydrogen tanks, especially in vehicles, since there is an inevitable build-up of pressure due to the heat intake into the tank system which can never be entirely eliminated. This build-up needs to be kept within limits. For safety reasons, the release of untreated hydrogen into the atmosphere must be avoided. One option for treatment is catalytically-triggered and stabilised oxidation of the hydrogen using ambient air. The main problem with this is providing a completely reacted hydrogen-air mixture with the necessary atmospheric overpressure to allow it to flow through the catalyser component.



The focus of this project is therefore to compare and investigate various options for the addition of air. The basis for this lies in equipping an ejector pump for this particular purpose, the selection of suitable catalytic media and coatings, the equipping of the catalyser with regard to pressure drop, dimensions, prevention of backflow and thermal stressing. The investigation will also examine whether safe formation of the mixture can be achieved inside the valve, which limits the tank pressure by acting as a pressure control value. The use of suitable digital simulation procedures will assist in constructing the unit in such a way that only an ignitable mixture reaches the catalyser component. In addition, predictions are to be made for the pressure ratios and the overall mixture ratio.

During longer resting times, there is a resultant pressure build-up in liquid hydrogen tanks due to heat intake. This increase must be limited, but untreated hydrogen must not be discharged into the atmosphere. This project looks at the catalytically-triggered and stabilised oxidation of hydrogen using ambient air.

The study of specialist literature and patent documentation on the catalytic combustion of hydrogen has been completed. In parallel to this, the localised air and hydrogen concentrations during coasting down have been successfully simulated for simple configurations of jet arrangements and various counter-pressures. This model is currently being examined from a production engineering point of view.

Manufacturers of catalysers have already been contacted and components available on the market have been examined for suitability. The implementation of the jet and mixing-point evaluated during the course of the project will be realised in the coming weeks and the predictions will be tested by experiment. The aim of the project is to achieve a design proposal for a boil-off recovery system which will possibly be optimised in a further project and developed for automotive use.

INFO
Project management:
MAGNA STEYR Fahrzeugtechnik AG & Co KG
Project partners:
Test-Fuchs – Ing. Fritz Fuchs GmbH, ICE Strömungsforschung GmbH

NANO-MG H_2 STORAGE SYSTEM

Hydrogen solid-state storage system based on nano-magnesium

The results of the previous feasibility study (an A3 project) have shown a significant acceleration of the charging and discharging kinetics as well as a distinct lowering of the onset temperature in nanocrystalline magnesium, produced by means of ECAP (equal channel angular processing – a deformation process to produce a nano-structure).

The ECAP process is being further optimised with a view to economic viability. Expensive, heavy and in some instances environmentally-questionable alloying additions (heavy metals) are currently added to the storage materials in order to further improve the charging/discharging process kinetics and the onset temperature. This method needs to be optimised, or avoided altogether by using more economic and non-harmful catalysts.

In cooperation with industry partners, a blueprint will be compiled for a container made of light alloys. It should increase the storage capacity of the whole system. Furthermore, a procedure for precise measurement of hydrogen content (fill level) will be developed.

During the first stage of the project, the hydrogenation apparatus already set up for a preliminary study was extended and upgraded in order to satisfy the new requirements of the current project.

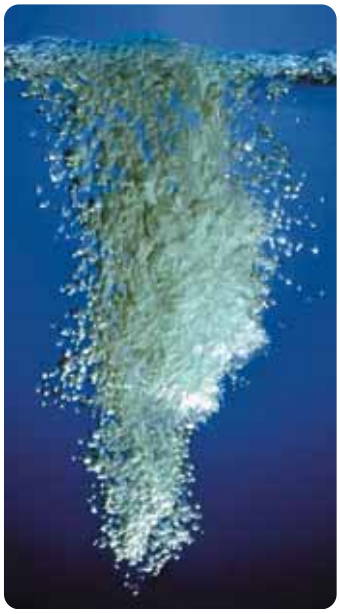
An alternative approach to hydrogen storage for automotive applications will be examined in the field of applied research. This particularly involves a closer examination of solid-state hydrogen storage in hydrides (e.g. MgH_2), which can be reversibly charged and discharged. However, rapid kinetics of the charging/discharging process and a low onset temperature are crucial objectives which precede technical and economic implementation.

INFO
Project management:
Austrian Research Centers GmbHARC
Project partners:
Neuman Aluminium Fließpresswerk GmbH,
Bitter GmbH,
Universität Wien – Institut für Materialphysik,
CARDEC Hydrogen Technologies

SAFE HYDROGEN STORAGE

Safe, unpressurised, homogeneous storage of hydrogen at room temperature

The project is investigating an innovative storage system for hydrogen based on ionic liquids. Storage is then at normal pressure and at room temperature. The aim of the project is to achieve safe storage of hydrogen at a storage medium density of five to six wt% hydrogen. In parallel, a storage process for charging and discharging using hydrogen is to be developed.



In the "Safe Hydrogen Storage" project, entirely new, homogeneous, liquid storage systems based on ionic liquids are being developed. Ionic liquids are extremely low-melting organic salts with solidification temperatures as low as minus 90°C. The full technological potential of this new class of compounds is currently not foreseeable and will lead to spectacular innovations in future – not only in the field of hydrogen storage.

Storage is handled at normal pressure and at room tempera-ture. The hydrogen is chemically bound in the ionic liquid and thus immobilised. These storage media have an extremely low vapour pressure, meaning that storage in unpressurised tank systems is possible and, moreover, igniting is ruled out. The release of hydrogen is catalytically-induced at mild temperatures and can be precisely dosed. The storage medium, even if subject to uncontrolled discharges into the atmosphere, either does not release hydrogen or only releases it very slowly. The discharged storage medium is also liquid and can again be charged with hydrogen.

To date, a functioning prototype of such a storage medium has already been developed, capable of storing hydrogen without requiring pressure, of effectively releasing hydrogen when a catalyst acts on it, and of being easily recycled. This prototype is also extremely stable against thermal decomposition and hydrolysis. However, the current storage density is only slightly above 2 wt% and is currently being increased to 4 wt% through intensive development work. An additive compound developed in parallel will further optimise the characteristics of the storage medium, in order that long-term stability and re-cycling in particular can be investigated more closely and initial predictions made regarding economic viability.

INFO
Project management:
OMV Refining & Marketing GmbH
Project partners:
proionic Production of Ionic Substances GmbH,
HyCentA Research GmbH,
Montanuniversität Leoben – Institut für Verfahrenstechnik des industriellen Umweltschutzes

LH_2 SENSOR CLUSTER

Developing an automotive sensor cluster for LH_2 tanks

The measuring system was conceived in such a way that future tank shapes for use in cars are supported irrespective of their particular geometry. Weight and cost reductions were achieved by adopting a cluster formation of sensors. The constructional design of the sensor cluster ensures that the inner tank sensor system can be replaced as needed. In the prototype (A – test bench), all the necessary sensors for calculating the volume of fuel are provided .

The functioning model is currently in the production and developmental phase. The testing/evaluation electronics associated with the sensor cluster have been fully developed, and a corresponding A model of the electronics has been built and successfully tested. The system tests required for the sensor cluster are currently in preparation, and will be carried out using a test tank at HyCentA (Hydrogen Center Austria).

The aim of the project is the development of an automotive measuring system containing all the sensors necessary to run and to monitor an automotive liquid hydrogen inner tank. As a special feature, the super-conductivity effect is to be used for fill level measuring.

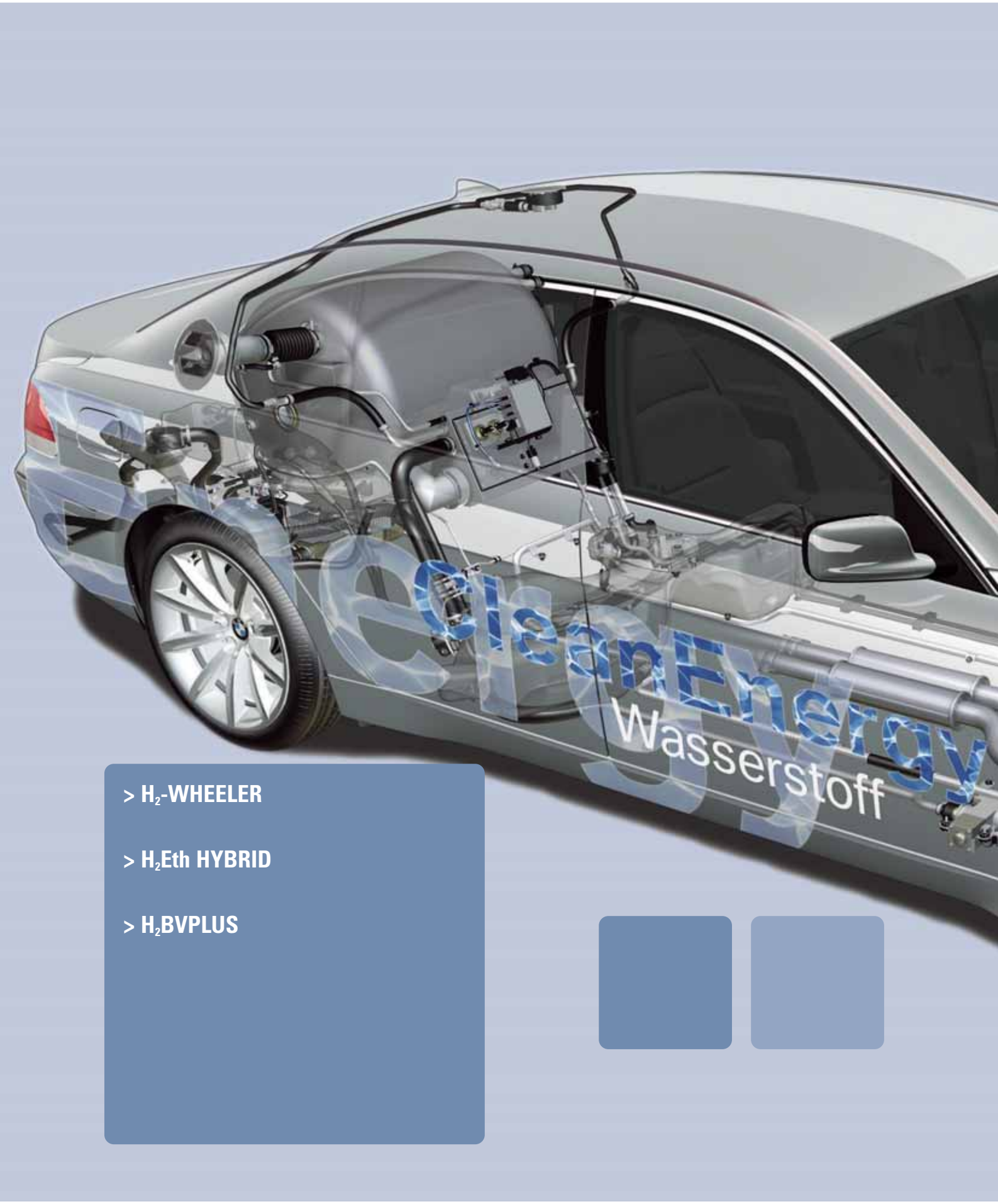
As a safety measure, the Austrian explosion protection guidelines (ExSchutz) required for hydrogen technology are being taken into account in the control and monitoring concept. Since operating a liquid hydrogen tank requires fill level measuring which is a demanding challenge in terms of safety engineering (e.g. over-filling), reliable strategies are being pursued in developing the measurement system.

The following challenges are present for fill level measuring in a cryogenic tank:

> Cryogenic temperatures: the temperature of the liquid hydrogen is approximately 20-25 Kelvin (-253°C to 258°C), depending on the pressure.
> Vacuum: In a liquid hydrogen tank, a vacuum is used for insulation between the inner and outer tank.
> Perforating the vacuum: all pipes which lead to the outside, whether fill pipes, extraction pipes or electric cables, must be passed through the vacuum chamber.
> Connecting points: durability and service life at cryogenic temperatures.
> Explosion protection: since hydrogen is a highly reactive gas, there is a risk of explosion in the event of a faulty gas leakage in the area of the connecting points.

The project is being carried out as a preparation for later series development.

INFO
Project management:
MAGNA STEYR Fahrzeugtechnik AG & Co KG
Project partners:
Spath Micro Electronic Design KEG (MEDS), HyCentA Research GmbH



> H_2-WHEELER

> H_2Eth HYBRID

> H_2BVPLUS

HYDROGEN IN THE COMBUSTION ENGINE

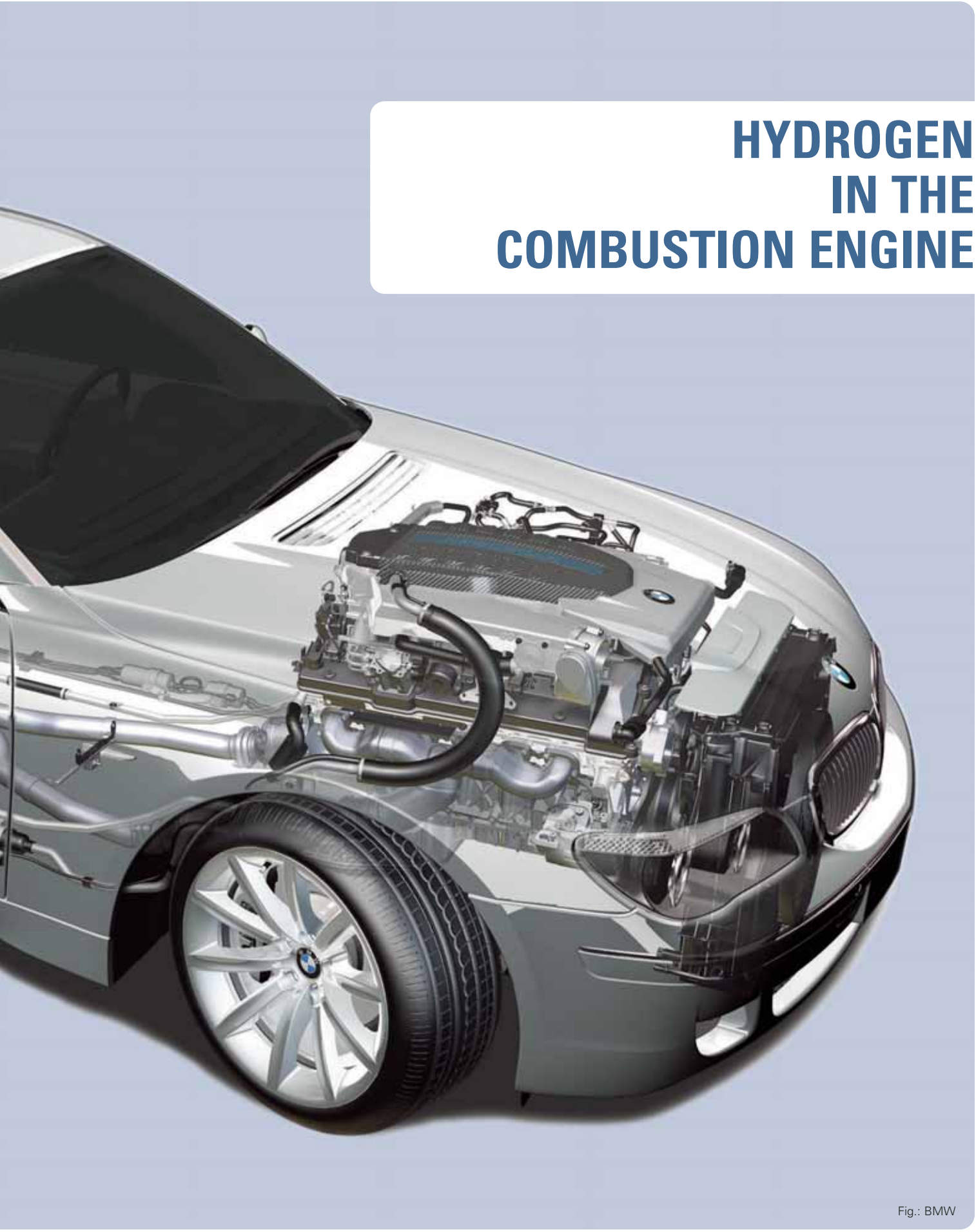


Fig.: BMW

H_2-WHEELER

H_2 in combustion engines as propulsion for two-wheeled vehicles

This study evaluates the use of hydrogen in combustion engines as a drive for two-wheeled and recreational vehicles.

INFO
Project management:
TU Graz – Institut für Verbrennungskraftmaschinen und Thermodynamik
Project partners:
HyCentA Research GmbH,
TU Graz – Institut für Fahrzeugsicherheit

The suitability of hydrogen technology for two-wheeled applications was evaluated and the necessary adjustments to the existing technology for the specific characteristics of this category of vehicles were listed. The main aspect of this was the necessary increase in vehicle weight, which was a consequence of the high weight of the fuel tank, given the specification of acceptable ranges per filling of the tank.
Profiles of requirements were drawn up, with assistance from a vehicle and engine manufacturer and a vehicle importer, in order to identify the vehicle classes for which the available space and area of use permits the adaptation of this innovative technology. From the vehicle classes identified, two vehicles were selected as examples; the latter were then used to investigate the changed driving dynamics, by means of test drives. For these tests, an urban vehicle (a 125 cc scooter) was used on the one hand – representative of two-wheeled vehicles – and an ATV (all-terrain vehicle) – representative of recreational vehicles – was used on the other hand; both were provided with corresponding additional mass to simulate the increase in mass caused by a hydrogen fuel tank. The results of these tests led to a definition of the possible area of use, having taken into account the changed technical conditions such as weight, range, driving performance etc.

Adapting the hydrogen technology in these vehicle categories represents a major intervention into the packaging of vehicles. In that respect, the height of the centre of gravity plays a key role and will be a challenge, considering the tank sizes likely to be needed. A further important aspect is the fact that the increased vehicle weight means that the engine performance and the stiffness of the frame need to be adapted to the new boundary conditions.
From today's point of view, two-wheeled vehicles with hydrogen propulsion systems can certainly be used in highly-polluted urban areas. The prerequisite for this is an adequate infrastructure which allows vehicles to be refuelled with the required amounts of hydrogen. The impact on exhaust emissions given a gradual conversion of two-wheeled vehicles to hydrogen propulsion was predicted by means of a simulation modelled on the federal territory of Austria and the municipal area of Manila. The reduction in CFC emissions in relation to overall traffic, projected for the year 2020, proves relatively modest for the Austrian federal territory (2%), while at least being moderate for the Asian metropolis (5.7%).
The current view is that the implementation of hydrogen technology in recreational vehicles is limited to vehicles operating in areas where the use of conventional propulsion technologies is prohibited. One conceivable target area is regions with potential local hydrogen supply, such as national parks or inland waterways for the vehicle categories "all terrain vehicles" and "personal water craft".

Subjectively, carrying liquid or gaseous hydrogen on board motor vehicles constitutes a potential risk for the user. To verify these risks, crash situations were simulated which demonstrated that in relation to the principle of the propulsion method, there is no advantage or disadvantage in terms of active and passive safety for the hydrogen vehicle. Furthermore, it was identified that the design and construction of a hydrogen-powered two-wheeled vehicle needs to integrate the fuel tank as a design element which cannot be concealed. This means that, under certain circumstances, standard convenienc fittings cannot be implemented on the vehicle, although on the other hand, the large and relatively stiff fuel tank (pressurised storage) can have an entirely positive influence on the design of the vehicle frame.
Supporting the calculations and tests presented, the policy position regarding the role of hydrogen as one of the alternative fuels of the future in the global energy scenario was also studied. The topic of "two-wheeled and leisure vehicles" is not being debated in the literature researched – it seems that the introduction point of this technology is still too far in the future for specific policy statements in this regard.

H_2Eth HYBRID

High-efficiency low-NO_x hydrogen / hybrid engine

GE Jenbacher´s gas engine division is one of the world's leading manufacturers of gas-fueled high-efficiency reciprocating engines, packaged generator sets and cogeneration units for power generation as well as gas engines for mechanical drive applications. GE's Jenbacher product team is constantly working on further development of its engines. In its product enhancements, focus is put on increasing efficiency, power output and power density, as well as reliability. Another area of focus is on operating engines with bio-fuels as alternative energy sources, e.g. H_2 rich gases, and on lowering emissions. To satisfy the increasingly strict exhaust emission standards and to operate the GE Jenbacher gas engines with innovative alternative gases, such as high H_2 content gases, the High Efficiency Low NO_x Hydrogen/ Hybrid Engine project was started.

GE Jenbacher's goal is designing the next generation of H_2-suitable gas engines, which can be operated on pure hydrogen as well as hydrogen-rich gases.

In the area of geothermal hydrogen, high sulphur content in the fuel gas can cause damage to the engine and can raise safety concerns. A method study about desulphurisation of the fuel gas and recycling the waste sulphur is currently underway at the company Profactor. Several desulphurisation methods will be studied and adapted for these special applications. Furthermore, the study will analyse economic feasibility. The first results will be available in the first quarter of 2008.

Burning hydrogen and hydrogen-rich gases is a challenge in terms of the safety engineering involved. The company HyCentA is working on developing a standard for the use of fuel gases with high hydrogen content. The standard will be available in the first quarter of 2008.

To develop a hydrogen gas engine with high efficiency, high power density and low emissions, a one-cylinder research engine is required to conduct the research cost-effectively. The research engine was derived by the company FVT from the Jenbacher type 4 gas engine. The design of the research engine, as well as the adaptation of the test bench peripherals, has been completed. The necessary parts are currently being sourced. The one-cylinder research engine will be put into operation at the Institute for Combustion Engines and Thermodynamics in Graz in March 2008.
The first results from the test bench using hydrogen-rich fuel gases can be expected by the end of 2008.

INFO
Project management:
GE Jenbacher GmbH & Co OHG
Project partners:
Profactor Produktionsforschungs GmbH, HyCentA Research GmbH, Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH

H_2BVPLUS

Highly efficient, clean combustion process for H_2–ICEs as an automotive propulsion system

The H_2BVplus project is aimed at investigating an H_2 self-ignition combustion process as a possible automotive propulsion system of the future. Interesting aspects of this with regard to power and efficiency levels can be derived from conventional diesel engines. The H_2 self-ignition concept is leading to expectations of improvements in efficiency levels and power density.

As experiences gained in the development of spark-ignition H_2 IC engines and of modern diesel-type IC engines point out, a combustion system employing hydrogen self-ignition opens up new opportunities concerning both efficiency and power output for alternative automotive propulsion systems. High power density should encourage acceptance of alternative fuels by future customers, who expect performance to be equal or even better than that of today's modern propulsion systems. High efficiency is targeted in H_2 vehicles on economic and energy grounds, as well as in order to minimise the space required for the fuel tank. The need for high power density is better satisfied in the H_2 engine due to the excellent ability for turbocharging, especially compared to spark-ignited engines, given that combustion anomalies such as knocking and backfiring may be ruled out. An additional and significant increase in compression ratio is possible. The absence of a particulate emission limit, which forces conventional diesel-type engines to be operated at lean mixture, allows for operation at a stoichiometric air/fuel ratio to provide both maximum mixture calorific value and, subsequently, mean effective pressure (BMEP). The injection of hydrogen within the high-pressure phase of the engine cycle additionally boosts BMEP. Diesel–DI engines are commonly limited in their rpm–range at around 4000 revs.

By contrast, the rapid reactions with hydrogen combustion are aimed at extending this range of operation into higher rpm-regions to obtain an additional increase in power density. The sophisticated layout of the combustion system should help to reduce wall-heat losses. In terms of compression ratio, efficiency and consequently vehicle operating range, the self-ignition combustion system is expected to be superior to actual H_2-Otto-type IC engines. A number of critical aspects will be investigated. These include e.g. the high self-ignition temperature of H_2/air mixtures, maximum pressure increases and ignition pressures, the impact of high EGR rates, and NO_x formation rates.

During the project, it has so far been possible to realise some self-ignited operating points with induction air heating assistance and an increased compression ratio on an Otto-type research engine inherited from earlier H_2-related projects, and also to devise promising layouts for combustion chamber and injector nozzle geometries via the extensive use of 3D CFD simulation tools. Based on these design proposals, both a completely new diesel-type research engine and the related high-pressure injection units have already been realised in hardware.

INFO
Project management:
TU Graz – Institut für Verbrennungskraftmaschinen und Thermodynamik
Project partners:
HyCentA Research GmbH,
BMW Forschung und Technik GmbH,
Hoerbiger ValveTec GmbH

Besides ongoing use of CFD simulation for layout of components and mapping high-pressure injection and diffusion combustion, the next stages of this project are to address the set-up and experimental investigation of combustion systems meeting the requirements mentioned above by altering main parameters such as compression ratio, piston and injector nozzle geometry and EGR rate.

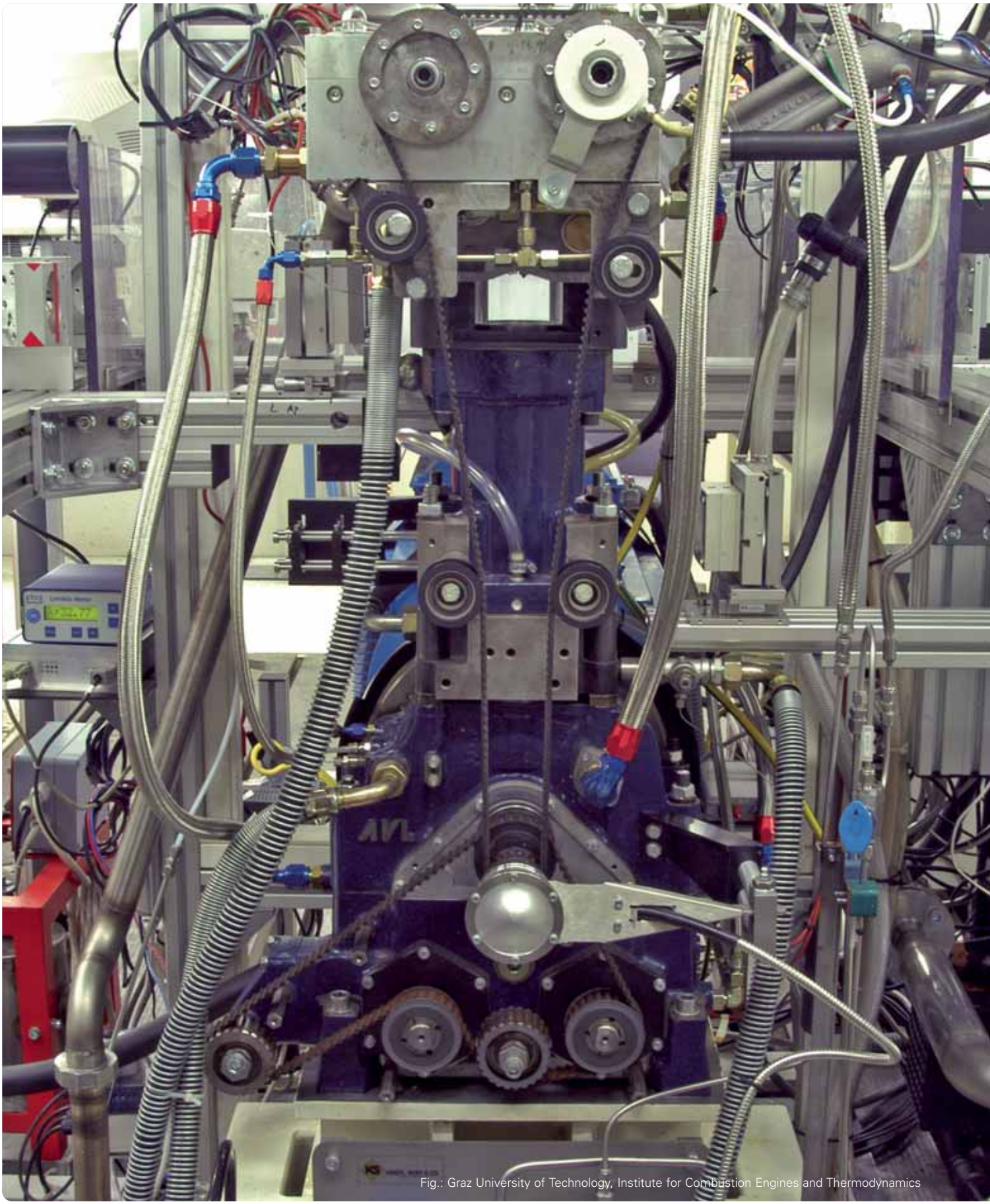


Fig.: Graz University of Technology, Institute for Combustion Engines and Thermodynamics

POLYMER ELECTROLYTE FUEL CELL

> "CDT BZ" DIRECT HYDROGEN FUEL CELL MODULE
> PEM FUEL CELL HYBRID VEHICLE
> A-CELL
> HIGH-PERFORMANCE UNIT FOR PEM FUEL CELLS
> HEAVY DUTY ZERO EMISSION (HDZ)
> PEMFC – SMALL TRACTION
> RECYCLECAT
> FUEL CELL LOGISTICS TRACTION VEHICLE/HYLOG
> ELYSE
> FluidPEM
> HT-MEA (HIGH TEMPERATURE MEMBRANE ELECTRODE ASSEMBLY)
> THDA (TOTAL HARMONIC DISTORTION ANALYSIS)

SOLID-OXIDE FUEL CELL

> ENERGY-EFFICIENT AIR-CONDITIONING FOR UTILITY VEHICLES
> HIGH-TEMPERATURE SOLID-OXIDE FUEL CELL
> ABSOCOOL-TRANSPORT
> E2MOBIGEN
> SOFC APU
> BIO-SOFC-DRIVE
> PMTECH 4 SOFC
> ABSOCOOL-TRANSPORT II

FUEL CELL

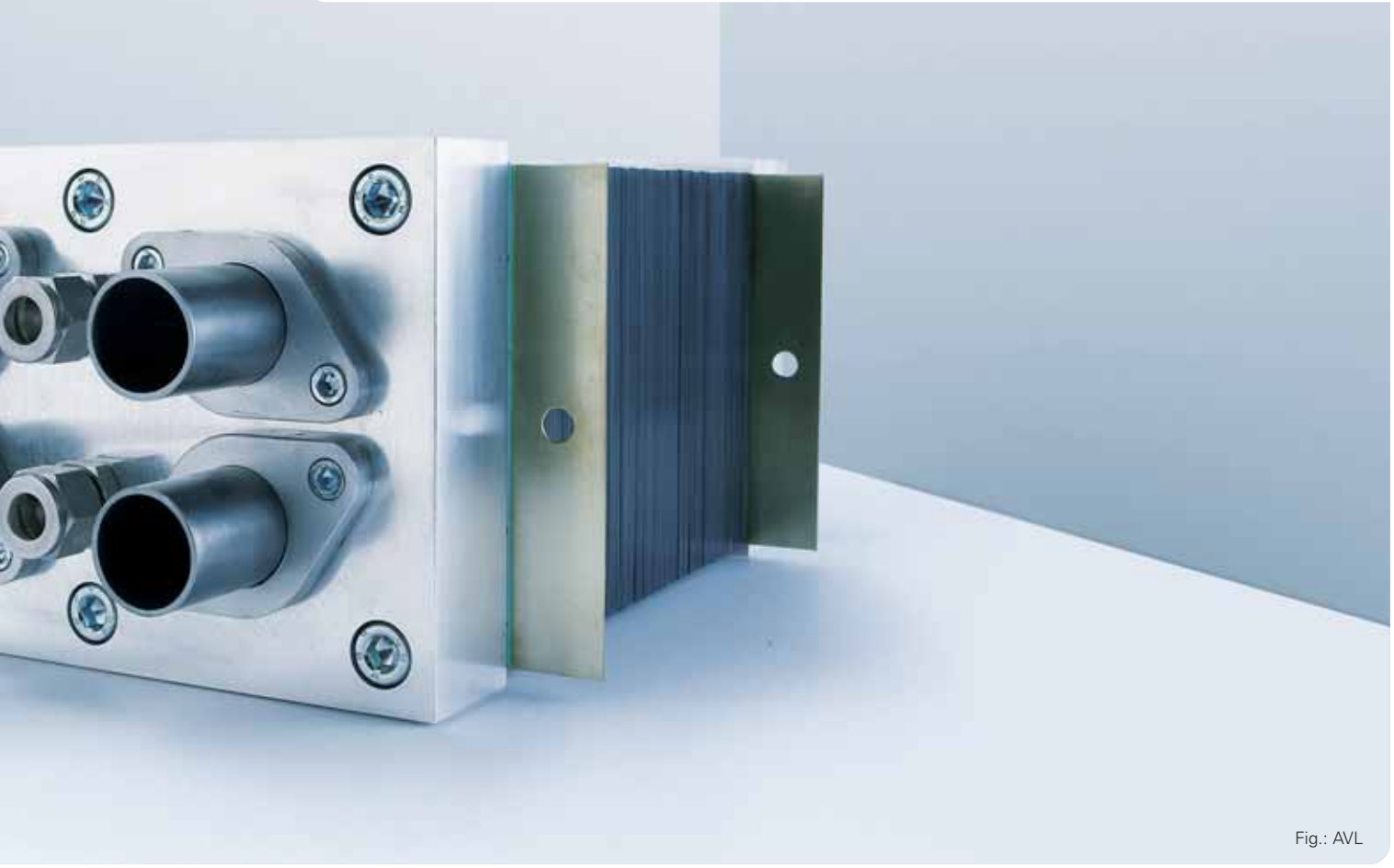


Fig.: AVL

"CDT FC" DIRECT HYDROGEN FUEL CELL MODULE

for vehicle engines and auxiliary power units (5kW)

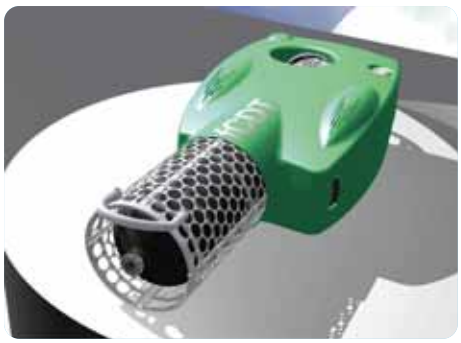
The system consists of a fuel cell unit on the basis of a PEM polymer membrane fuel cell stack with compressed hydrogen as the primary energy source. The primary development objective is a mobile fuel cell module suitable for motor vehicles. The system can be designed for electrical outputs of between 2.5 kW and 4.3 kW using the same technical infrastructure.

The 5 kW module (stack power) is equipped with a compressed hydrogen cartridge system for use in private cars and in goods transport, and is thus suitable as an APU for trucks and cars but also as a mobile energy supply for emergency and rescue uses. When refuelling, the cartridge can be either removed and replaced or refuelled in its installed state.

The aim of the project is to fulfil the requirements for serial production of mobile PEM fuel cell APUs.

Technical key data:

> Output 4.3 kW_{el}
> Hydrogen storage of compressed hydrogen (5.1)
> Cartridge tank system, pressure: 35 MPa, volumetric contents: 26l, representing 0.7 kg of H_2
> Hydrogen consumption at P_{max}: 1.1 l/s
> Operational temperature FC: 70 °C
> Stack cooling medium: glycol
> System gases overpressure: max 0.5 bar, tank system initial pressure: max. 10 bar.
> Weight: approx. 85 kg



INFO
Project management:
Bitter GmbH
Project partners:
TMG – OÖ Technologie- und Marketinggesellschaft mbH / Cluster Diesel Technologie,
Fronius International GmbH,
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH,
Johannes Kepler Universität Linz – Institut für Regelungstechnik und elektrische Antriebe,
KTM-Kühler GmbH

PEM FUEL CELL HYBRID VEHICLE

Polymer electrolyte membrane fuel cells / E-vehicle battery

An electric vehicle originally powered by lead batteries ("Hotzenblitz") formed the basis for rebuilding as a hydrogen-powered ("zero emission") fuel cell vehicle. For reasons concerning the degree of efficiency, the hybrid concept was chosen, i.e. besides the fuel cell, NiMH batteries are used for propulsion. Due to the recuperation of the braking energy for storage in the battery in the European Drive Cycle (NEDC), it proved possible to improve the total vehicle efficiency level by approximately 8%. The advantages are more marked in urban areas and less significant in inter-urban areas.

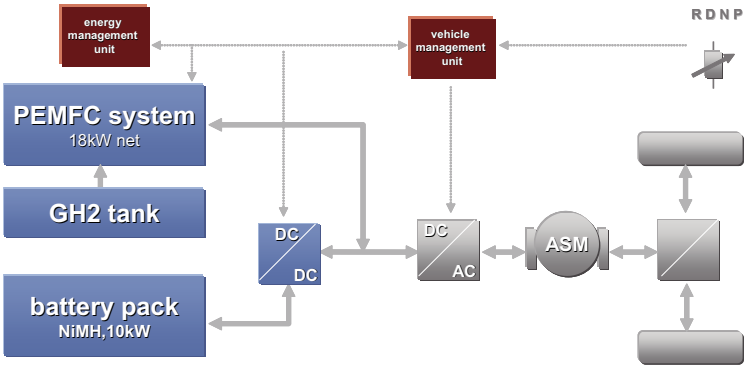
The main objective of the project was to construct a PEMFC vehicle for the participating industry and university partners, in order to develop and test development tools and components for fuel cell systems on the basis of a real platform.

Another aspect of the hybrid concept is the advantage that the fuel cell system can be designed in a smaller range. The peak powers required, e.g. for accelerating the vehicle, can be covered by the combination of battery and fuel cell. Consequently, the fuel cell unit does not have to be designed for full load. Instead, high transient peaks of the power requirement during driving are partially compensated by the battery – allowing the fuel cell system to adapt more slowly to load changes.

The system design, development and qualification of components as well as the vehicle modifications were carried out by the partner DLR (Deutsches Zentrum für Luft- und Raumfahrt – German Centre for Aviation and Space Travel). AVL made the vehicle characterisation of the basic vehicle, developed the higher level vehicle control and carried out consumption and propulsion efficiency studies. The Christian Doppler Laboratory for Fuel Cell Systems (TU-Graz) developed the PEMFC as a model. Common interfaces and standards have been specified for the efficient interaction of the individual systems in vehicles and modules, respectively, which were developed by different partners. In a parallel project in Germany, further industrial partners were integrated in the vehicle design and development.

The hydrogen-powered fuel cell hybrid vehicle was successfully put into operation. The vehicle passed the first test drive in January 2005 and was first presented to the public at the "6th International Stuttgart Vehicle Symposium" in February 2005. Results have been presented to international experts in this field, including at the EVS21 (Electrical Vehicle Symposium, Monaco, April 2005).

INFO
Project management:
AVL List GmbH
Project partners:
Deutsches Zentrum für Luft- und Raumfahrt,
TU Graz – Christian-Doppler-Labor für Brennstoffzellensystem



A-CELL

High-temperature membrane electrode units for fuel cell vehicles

In this project, innovative approaches to fuel cell research have been pursued, in collaboration with the Christian Doppler Laboratory for Fuel Cell Systems and Austrian partners from industry. The aim of developing a membrane electrode unit capable of withstanding high temperatures and unaffected by humidity for applications in temperatures of up to 180°C reflects current international efforts in the automotive sector. The research expenditure is justified by reference to the anticipated advantages of a significantly-increased catalyser tolerance to carbon monoxide, operation which is unaffected by humidity, faster reaction kinetics for oxygen reduction and improved heat management, insofar as it is possible to maintain or improve the service life and performance of the membrane electrode unit under the newly-adapted conditions by using innovative materials.

The use of fuel cells in vehicles is already set to lead the fundamental changes in the automotive supplier industry in the medium term. This will necessitate an expansion of the expertise of the Austrian automotive supplier industry to include chemical engineering. This project looks at developing the scientific basis for the medium- to long-term development of fuel cells in Austria, in order to create an advantage in terms of international competition for present and future supplier businesses.

To manufacture the electrodes, carbon nanofibres were chosen both for constructing a gas diffusion layer and also as the catalyser medium in the active layer. With their tube-shaped structure in closed graphite layers, these fibres offer improved electrical conductivity and better oxidation resistance against conventional particulate matter. Separation of the catalyser metal was carried out with very good results using a time- and cost-efficient procedure which did not include the use of organic solvents. In manufacturing the electrodes, conventional processes had to be discarded due to the characteristics of the fibre material. A new process was therefore developed, for which a patent application has been lodged due to the highly positive response from experts, and the process has already been assessed for its potential economic benefits. It enables the manufacture of precisely reproducible, high-performance electrodes using carbon nanofibres with a high degree of profitability, while entirely eliminating the need to use organic solvents.

To realise a membrane unaffected by humidity, the approach of using ionic liquids as the proton conductor was adopted. These ionic liquids can be modified practically as required, and as a rule have very high electrochemical and thermal stability. The systematic selection carried out in this project, and the subsequent electrochemical characterisation of suitable ionic liquids constitutes the basis for using them as the electrolyte in fuel cells, given the very limited published research in this area. The possibilities for realising a membrane on the basis of ionic liquids have been investigated and promising approaches already tested in fuel cell operation. The results obtained offer the basis for a successor project which will focus mainly on realising the humidity-unaffected membrane.

INFO
Project management:
TU GrazChristian-Doppler-Labor für Brennstoff-zellensysteme
Project partners:
proionic Production of Ionic Substances GmbH,
Electrovac GmbH,
Gabriel Chemie GmbH

Building on this work on basic research, the long-term aim is to develop a high-efficiency fuel cell module for on-board generation of electricity in vehicles. This aim is in line with the strategic aims of the A3 technology programme and leads to a multiple dividend, since it also accords with reducing fuel consumption and emissions (EU White Book) and reducing output of CO_2 (Kyoto Protocol). In addition, vehicles powered by electric engines reduce local emissions of pollutants and noise emissions.

HIGH-PERFORMANCE UNIT FOR PEM FUEL CELLS

Developing a bipolar high-performance unit for PEM fuel cells

Fuel cell technology is considered to be one of the key technologies of the 21st century, particularly in the automotive field, because it represents a clean and efficient alternative to the prevailing combustion engines.

In this project dealing with polymer electrolyte membranes (PEM), innovative and highly efficient bipolar units were developed which can be manufactured extremely cost-effectively using mass production methods. Using iterative linking of computer simulations and flow experiments on prototypes, an optimal structure for the bipolar units was developed. Due to their 3-dimensional design arrangement, these innovative bipolar units offer advantages when used in electrochemical reactors, since by comparison with conventional designs they ensure a much easier inward and outward transportation of raw materials and end-products.

Injection moulding was the process chosen as the mass production process to be used for the bipolar units.

The development of suitable thermoplastic compounds was the precondition for manufacturing the bipolar units using injection moulding. To specify the requisite injection moulding conditions, iterative linking of simulations and experiments was again applied, going hand-in-hand with matching the parameters with the development of the compound. The project ran over 24 months, with a key focus being on the development and characterisation of materials.

The "High-performance unit for PEM fuel cells" project focused on developing bipolar units for PEMFCs. In this project, innovative high-conductivity polypropylene compounds were developed which can be used to manufacture bipolar panels using cost-effective mass production methods.

INFO
Project management:
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH
Project partners:
Gabriel Chemie GmbH,
Electrovac GmbH,
Smotech Brennstoffzellen GmbH,
LKT Laboratorium für Kunststoff-technik GmbH,
TU Wien – Institut für Chemische Technologie und Analytik / EC 164

HEAVY-DUTY ZERO EMISSION (HDZ)

Clean long distance bus and goods traffic in Austria

The object of this project was the analysis of the potential reduction of emissions from heavy duty vehicles in inter-urban traffic. To this end, low-emission and emission-free technologies were investigated, the impact of their potential deployment were analyzed, specifically with regard to transit operations on busy routes, and potential obstacles were identified.

Work on the "HDZ – Heavy Duty Zero Emission" project included investigating concepts for realising low and zero emission propulsion systems for heavy vehicles. The current view is that technologies like CNG and LPG, as well as hydrogen with fuel cells, will be available as alternative fuels. The supply of alternative fuels such as hydrogen for heavy-duty traffic can be achieved in many different ways in the medium-term. Centralised supply of such fuel to vehicle fleets can serve as a starting-point for establishing an infrastructure for new energy sources. Yet complete supply of heavy-duty traffic using renewable energy sources will be difficult to achieve.

The legal framework in the European Union contains strict environmental protection legislation, whereas there is more room for improvement in terms of emissions regulations for vehicles. The emission regulations for heavy trucks in California, for instance, prescribe values which in some instances are many times lower than those currently prevailing and those under discussion in Europe.

The practical requirements for clean heavy-duty propulsion systems were considered using the example of the transport network of an express logistics service. The results for this specific application in an express logistics chain revealed that a minimum operational range of about 1000km, without stopping for fuel, is required. As a mid-term solution for a cleaner pro-pulsion system, a CNG concept was investigated and deve-loped. Although integrating a storage system for such a range using available technologies in current trucks turned out to be challenging, the savings in operating costs can nevertheless be a strong incentive for further development. As a long-term solu-tion, an emission free concept using a direct hydrogen fuel cell was investigated.

Detailed calculations for CO_2 and pollutant emissions were carried out for the inter-city routes chosen for study. Summarising this, it can be said that heavy trucks with trailers emit between 70 – 90% of the heavy traffic emissions on the selected routes and thus are the dominant origin. Additional calculations for other traffic participants on the A1 Westautobahn motorway showed that about 80% of total mileage is accounted for by light duty passenger vehicles, whereas these cause only 55% of the CO_2 emissions. Regarding the pollutants subject to limits, light duty passenger cars cause about 53% of particulate emissions and 30% of nitrous oxide emissions. The calculations in a scenario for the year 2020 in comparison to the year 2005 revealed a great potential for reducing emissions of particulates, nitrous oxide and carbon dioxide by using CNG, LPG and hydrogen in heavy-duty traffic.

INFO
Project management:
TU Wien – Institut für Verbrennungskraft-maschinen und Kraftfahrzeugbau
Project partners:
TU Wien – Institut für Elektrische Anlagen und Energiewirtschaft,
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH,
Öamtc Akademie,
Neoman Bus GmbH / Kompetenzzentrum Sonder-Transport-Systeme,
DHL Express (Austria) GmbH. Vossloh Kiepe

Acceptance surveys among logistic providers found a level of appreciation of and knowledge about bio fuels in particular, with less awareness of CNG and hydrogen. Surveys conducted with the general public revealed emissions of pollutants in particular as the main disturbing impact of heavy traffic for those questioned.

A symposium on "Clean Transit Traffic" in the Tyrol, with publication of parts of the findings and the project results on the web platform, marked the end of the project activities.

PEMFC – SMALL TRACTION

Implementation of a hybrid PEMFC drive train in different applications of small traction

Fuel cell technology is considered at present as one of the essential technologies of the 21st century, with regard to environmentally friendly energy supply.

Due to the cost structure of the technologies currently applied compared to that of fuel cells, the market introduction of fuel cells would, at first, be practical for applications requiring around 1 kW, for example, small traction and other small mobile applications. The costs in the case of the hybrid PEMFC (Polymer Electrolyte Membrane Fuel Cell) energy supply system are relatively low, and hydrogen consumption is low, reflecting the power of the fuel cell. This also simplifies the build-up of a hydrogen infrastructure. Furthermore, small traction is an application for fuel cells which is highly visible to the general public, increasing awareness in this area.

The aim of the "PEMFC – Small traction" project is the development and production of a hybrid PEMFC (Polymer Electrolyte Membrane Fuel Cell) energy supply system with a fuel cell unit in the range of 500 Wel to 1 kWel and its implementation in three small traction applications.

As part of the "PEMFC-Small traction" project, three small traction applications in the 1 to 3 kWel range using a hybrid PEMFC energy supply system will be constructed and their functionality tested. A further contribution to the medium-term market introduction of these applications is the concept study for construction of a pilot plant for production of hybrid PEMFC energy supply systems and components; both technical and economical aspects will be examined.

The hybrid PEM fuel cell system will be tested as the energy supply system for the drive train in a scooter and a low floor van. In the case of the 3.5 t lightweight refrigerated vehicle, the hybrid PEM fuel cell system also supplies power to the cooling unit. Vehicles of this type are considered especially suitable for refrigerated goods delivery services in central city areas.

The first vehicle ("HyCart") with a hybrid PEM-fuel cell system was finished in September 2007. It was powered by a 1 kW fuel cell unit, two 12 V lead acid batteries each with a capacity of 70 Ah, and a compressed hydrogen tank module for 350 bar (capacity of 0.94 kg H_2). The advantages of this system were demonstrated during testing; the range on one charge was increased three to four times (from 50 km to 200 km) and charging the hydrogen tank took only a few minutes compared with a charging time for lead-acid batteries of three to six hours. As an alternative to this configuration, metal hydride storage systems could be implemented instead of the hydrogen tank module.

The next step for the project is a scooter powered by a fuel cell system (nominal power of the fuel cell unit: 350 to 400 W) and two metal hydride storage units (each with a 1000 NL capacity). The energy for the cooling unit is supplied by a fuel cell with a nominal power of 1 kW and two lead-acid batteries, each with a capacity of 95 Ah. The hydrogen supply can be provided by either a 350 bar compressed hydrogen module or by a metal hydride system. The advantages of these systems for refrigerated vehicles are the reduction of emissions, the low operating noise, and an increased level of reliability for continuity of refrigeration in the event of long standing periods during delivery services.

INFO
Project management:
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH
Project partners:
Fotec Forschungs- und Technologietransfer GmbH,
TMG – Technologie- und Marketinggesellschaft mbH,
Photovoltaiktechnik GmbH,
Fronius International GmbH,
Banner GmbH, Bitter GmbH,
IO Fahrzeuge Produktions- und Handels GmbH,
S. Graf, Carello Elektrofahrzeuge Erzeugungs- und Vertriebs-gesellschaft mbH,
Schuh Karosseriebau GmbH,
ZSW Zentrum für Sonnenenergie- und Wasserstoff-Forschung,
FuMA-Tech GmbH

RECYCLECAT

Alternative sources for fuel cell catalysers

The demand for catalyser material is set to increase significantly in future, in particular as a consequence of the comprehensive introduction of fuel cell technology. To alleviate dependence on imports and to guarantee a basic supply of catalyser materials for the automotive industry, a large part of the required elements can be sourced from recycled components.

Based on the materials recycling systems and drawing on the experiences gained in recycling car exhaust catalysers, the aim is to develop a recycling process for fuel cells and to adapt this to the particular features of the components and materials used in fuel cells. The market structure and logistics routes are fundamentally similar to the existing recycling processes for car exhaust catalysers. Due to the higher load in fuel cell catalysers (compared to vehicle catalysers), efficient recycling operations are even more important.

Based on the materials recycling systems for catalyser materials from the automotive industry, a recycling process is also to be developed for PEMFC (Polymer Electrolyte Membrane Fuel Cells) and adapted to the particular features of the components and materials used in fuel cells.

The basic conditions for achieving high recycling rates are modern treatment and cleaning processes as well as an efficient collection system. If the treatment cycle can be designed efficiently, it can open up an alternative source of raw materials for fuel cell production.

The outcome of the project is new and cost-effective recycling processes for fuel cell components, under which the high-value supporting substrate and the ion conductor (polymer electrolyte membrane) can be recovered alongside the catalyser materials.

INFO
Project management:
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH
Project partners:
TU Wien – Institut für Chemische Technologie und Analytik / EC 164, Clean Air Technologies

FUEL CELL LOGISTICS TRACTION VEHICLE/HYLOG

Demonstration of a fuel cell logistics application and construction of a solar-powered hydrogen filling station at a European transit node in Upper Austria

The HyLOG project aims at developing and integrating a 2.5 kW fuel cell range extender propulsion system into a logistics traction vehicle which, in its standard configuration, is equipped with a traction battery. Operating the prototype vehicle in a real industrial applications environment is intended to demonstrate and to investigate in detail the advantages of the range extender propulsion system, compared with vehicles using a traction battery drive.

The supply of hydrogen for the range extender logistics traction motor is provided by a hydrogen filling unit constructed at the site, with the hydrogen being produced locally using renewable energy from a photovoltaic unit in an electrolyser.

The aim of the HyLOG project is to demonstrate and investigate the total system for an emission-free industrial transport logistics solution and to provide a reference project to accelerate the market launch of this innovative technology.

The HyLOG project demonstrates and scientifically investigates the implementation of a fuel cell range extender propulsion system with 2.5 kW power using the example of an intra-company logistics application. The fuel supply for this innovative transport system is provided by a self-powered hydrogen filling unit for vehicles with a 350 bar compressed hydrogen tank, built at Sattledt in Upper Austria. The hydrogen required is provided using electrolysis, employing renewable energy from a 605 kWp photovoltaic unit.

THE DETAILED PROJECT AIMS WERE AS FOLLOWS:

> Developing a 2.5 kW range extender propulsion system with a 26 litre, 350 bar compressed hydrogen tank system and its certifiable integration into a series-manufactured logistics traction vehicle on the basis of the applicable safety standards. Practical testing of the prototype in a real industrial applications environment, to gain experience and obtain data for technical-scientific comparisons with battery-powered vehicles. The implementation of the new technology in a real production environment also facilitates investigation of acceptance at corporate level and identification of logistical barriers for broad market launch.

> Erection and demonstration of operation of an autonomous filling infrastructure for vehicles with a 350 bar compressed hydrogen tank system, with local production of hydrogen through electrolysis using renewable energy from a 605 kWp photovoltaic unit. The efficiency of the solar-powered hydrogen filling infrastructure is to be improved by up to 15% through the development of a solution for DC direct linking of the electrolyser to the PV generator and by investigating and optimising the operating strategy of the overall system. Analysis of the system engineering of the overall system is intended to identify potential for standardisation and cost reduction.

> Developing and estimating the market potential for the overall system, consisting of the industrial fuel cells, logistics application and autonomous solar-powered hydrogen filling infrastructure and its subsystems. Identification and development of marketing scenarios for the range extender propulsion system in the following areas: automotive, industrial trucks and leisure applications (e.g. boats).

> Linking the installed solar-powered filling infrastructure to the European hydrogen infrastructure currently being developed.

INFO
Project management:
Fronius International GmbH
Project partners:
Bitter GmbH,
Biovest Consulting GmbH,
HyCentA Research GmbH,
Clusterland Oberösterreich GmbH / Automobil-Cluster

ELYSE

Electricity for Light duty commercial hYbrid powertrain SystEms

In the project ELYSE, the possibility of integrating a continuous fuel cell electric energy source in light duty commercial vehicles is examined. The fuel cell is operated by diesel reformat gas. The reformat gas is also used to improve exhaust gas after-treatment (Fig. 1).

The operation of light duty commercial vehicles (LD-CV) is characterised by frequent cold starting, long operation at part load and extreme changes of load. The degree of efficiency of drives suitable for this purpose was improved by the application of direct injection diesel engines and by the use of hybrid technology (e.g. Daimler Chrysler's Hybrid Sprinter). Further improvements would be possible by extending operation using just the electric drive. Moreover, demands are being drawn up on a European level for a limited, zero-emission operation of road vehicles. The crucial issue is the limited energy storage in the battery. With a fuel cell system independent of the main drive, ultimately all electrically operated auxiliary and support aggregates could be supplied optimally with electricity. At the same time, only the actually required driving power would be absorbed and, consequently, have to be provided at a time.

Thus, the aim of the "**E**lectricity for **L**ight duty commercial h**Y**brid powertrain **S**yst**E**ms – ELYSE" project is to investigate the possibilities for integrating a diesel-powered continuous fuel cell electric energy source in a LD-CV. In addition to this, the advantages and synergies arising from these new on-board components for exhaust gas after-treatment must be analysed. In particular, the current project is to investigate implementation of a high temperature PEM fuel cell to correspond to the intermittent electrical energy demand of a LD-CV.

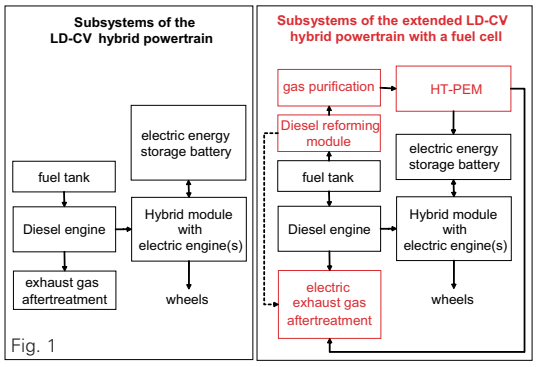


Fig. 1

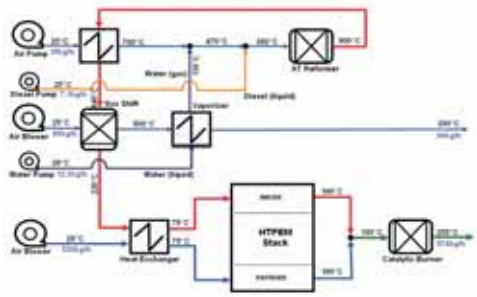


Fig. 2

The novel cell type can be operated without gas humidification at very high anode-CO concentrations. As such, it is possible to treat fluid hydrocarbons quite easily (fuel reformer without CO precision cleaning) and hence to use the conventional fuel (diesel or bio-diesel) from the tank of the hybrid drive. The reformat gas must also be used to improve exhaust gas after-treatment (engine-independent regeneration of the particle filter).

During the current first year of the project, the fuel cell system structure has been investigated and defined together with the project partners (Fig. 2). This is now the basis for ongoing component design and component research.

INFO
Project management:
AVL List GmbH
Project partners:
TU Graz – Christian-Doppler-Labor für Brennstoffzellensysteme,
CERTH / CPERI / APTL Greece,
PEMEAS GmbH,
SüdChemie, Munich

FluidPEM

Fluid-Transport in PEM Fuel Cells

PEM fuel cells, which are operated with H_2 and air, can achieve very high levels of efficiency of more than 60%, while working without emissions. Consequently there is a wide range of promising possibilities involving this type of fuel cell, such as in automotive, portable and also fixed-installation applications. However, the potential of today's PEM fuel cells strongly depends on two factors within the cell: firstly, on the flow distribution of the reactants (H_2, air) as far as the optimum supply of the active area is concerned, and secondly on heat management for the necessary cooling of the cells. In order to achieve the maximum possible performance of a stack (pile of cells) and consequently to be able to minimise the costs per kW, each individual cell must be enabled to achieve its maximum power. For this, flow and heat management must be working in an optimum way.

In the current project, the latest modelling techniques for 3D CFD simulation are combined with the most recent experimental research methods. The project consists of two sub-projects running in parallel – one in Austria and one in the UK.

In the Austrian sub-project, a new AVL simulation technique is being used for the first time for these fuel cells, enabling explicit calculation of the 2 phase current (gas and water), even in the porous gas diffusion layers (Fig. 1). At the same time, measurements are already being carried out at CDL to investigate a "spanned cell" (Fig. 2), in order to be able to validate the simulations.

In the English sub-project, the Lattice-Boltzmann Equation (LBE) method is being applied, in order to identify potential improvements using new materials with special microstructures for the gas diffusion layers in the cells produced by the leading industrial partner for the English sub-project. Lastly, the influence on cell behaviour is to be tested using AVL's validated CFD simulation program.

The technical objective of the whole project is to approximately double the power density of the cells used.

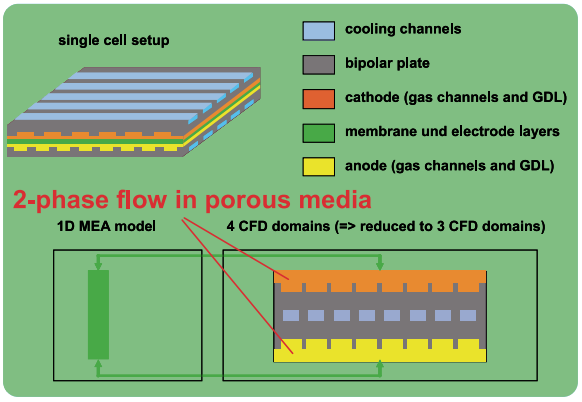


Fig. 1

Fig. 2

The performance potential of PEM fuel cells depends greatly on flow distribution of the reactants within the cell as well as on heat management. This project aims at optimising and testing the design of the fuel cells, using advanced modelling methods and experimental research.

INFO
Project management:
AVL List GmbH
Project partners:
TU Graz – Christian-Doppler-Labor für Brennstoffzellensysteme

HT-MEA

Development and small series manufacture of high-performance high-temperature membrane electrode assemblies

This project aims at developing high-temperature membrane electrode assemblies for low-temperature fuel cells. To this end, a new approach is adopted, involving a microporous, high-temperature resistant layered membrane with embedded ionic liquids as electrolyte. The electrodes using tubular carbon fibres developed in a predecessor project are being adapted and used. The expected outcomes are primarily an increase in fuel cell service life at increased temperatures, and a cost reduction.

This project, building on the outcomes of the predecessor project A-Cell, aims at developing a high-temperature resistant membrane electrode assembly, with the materials being developed or provided by the Austrian project partners.

Fundamentally, the advantages of a fuel cell operating temperature of above 120 °C can be considered as being that: performance capability is largely unaffected by humidity; heat management can be modelled far more easily in the mobile application; carbon monoxide tolerance is significantly increased; and the reaction kinetics increase with the higher operating temperature. For these reasons, attempts are being made worldwide to develop high-temperature membranes for automotive use.

The first development focus is on innovative methods for establishing proton conductivity in polymer membranes which do not conduct ions by themselves. To that end, a microporous membrane structure is being produced with ionic liquids being introduced into the open channels. Ionic liquids show a very high electrochemical and thermal stability and can be modified in practically any suitable way. A further aim is to investigate polymerisable ionic liquids.

The second focus – in production – lies in adapting electrodes using tubular carbon nanofibres, which are intended for implementation both in the gas diffusion layer and in the active layer as a catalyser medium. The criterion of homogeneous and adhesive catalytic conversion, and the electrode manufacturing process itself, have already been solved in the A-Cell project. Using carbon nanofibres as the electrode material will reduce consumption of catalyser material; on the one hand, this will reduce costs, whilst on the other it should prevent migration effects at higher temperatures during fuel cell operation.

INFO
Project management:
TU Graz – Christian-Doppler-Labor für Brennstoffzellensysteme
Project partners:
Electrovac AG, Lipp-Terler GmbH

THDA – TOTAL HARMONIC DISTORTION ANALYSIS

Developing a new stack monitoring system as a series component in stationary and mobile fuel cell applications

The THDA project is looking to develop a new electronic component for stack monitoring in mobile and stationary fuel cell systems. For fuel cells with high power density in particular, monitoring of operating limits for the stack is critical in terms of stack lifetime. A close-to-production prototype of the innovative stack monitoring system is being tested in a 5 kW range extender propulsion system under real conditions.

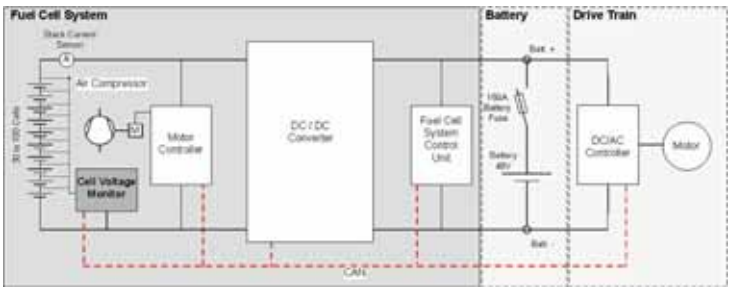
The current technology for stack monitoring includes voltage metering of each individual cell in the stack and measuring the stack current. The disadvantage of this method is that, particularly in automotive fuel cell systems with up to several hundred individual cells, signal recording and evaluation is an elaborate and costly process. These systems require expensive hardware solutions which also demonstrate high susceptibility to error.

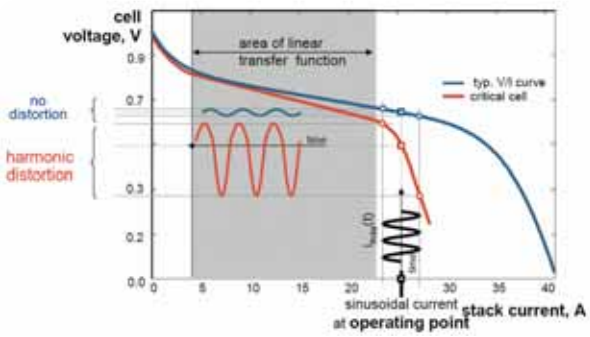
The process approach adopted in the THDA project, which has already been patented, is that of "Total Harmonic Distortion Analysis". It is based solely on metering stack current and voltage, with goal-oriented signal interpretation. Individual cells working in critical operating conditions cause characteristic frequency patterns in the measurement signal, meaning that non-permitted cell conditions can be identified. The focus in developing the method is on isolating the interference from the fuel cell system peripherals (e.g. the performance electronics), while investigating the limits of applying the method in monitoring and control of relevant boundary conditions (e.g. cold start).

Starting from the development of a largely application-independent stand-alone solution, the aim is to integrate the THDA project system into an actual 5 kW range extender application for monitoring a 100-cell stack. In this application, the use of the innovative THDA method means a drastic reduction in the number of measuring channels, from 101 to 2, and considerable simplification of signal processing. In tests closely mirroring actual conditions, the performance capability of the THDA method is to be demonstrated by comparison with individual cell voltage monitoring.

This project involves developing an electronic component for stack monitoring in fuel cell systems using measurements of stack current and voltage, and signal interpretation based thereon. Using the frequency patterns obtained, it is possible to characterise the operating conditions of the stacks. Concept testing is being carried out in a 5 kW range extender propulsion system.

INFO
Project management:
Fronius International GmbH
Project partners:
AVL List Gmbh,
TU Graz – Christian-Doppler-Labor für Brennstoffzellensysteme





ENERGY-EFFICIENT AIR-CONDITIONING FOR UTILITY VEHICLES

Feasibility study for hybrid decoupling of driving power to the air-conditioning unit from the primary drive shaft output, using high-temperature fuel cells

Air-conditioning units are significant energy consumers in utility vehicles, such as buses, where the mechanical driving power for the compressor can be up to 30 kW. In addition, it should also be possible to provide this power to the air-conditioning system even when the vehicle is stationary.

The feasibility study investigated the potential afforded by a hybrid system to power an electrically-driven compressor using a high-temperature solid oxide fuel cell (SOFC):

> Electrification using higher operating voltages (min. 42V) results in reduced compressor power requirements (according to private car simulation, around 50%)

> SOFC provides this energy with a high level of efficiency (> 50%)

> Proof of suitability of SOFC for this application (thermal cyclability)

> Development of an intelligent hybrid coupling in total thermal management to further increase efficiency levels

The core element is a micro-tubular SOFC, which is inherently more stable than the design concepts often pursued, and thus also more suitable for mobile implementation.

INFO
Project management:
ALPPS Fuel Cell Systems GmbH
Project partners:
Arsenal Research GmbH,
Fachhochschule Wels
Studiengang Öko-Energietechnik

HIGH TEMPERATURE SOLID OXIDE FUEL CELL

Fuel cell – auxiliary power unit for mobile applications

The main objective of the project was to investigate the potential to reduce fuel consumption and emissions using auxiliary power units (APUs) to generate electric power in mobile applications. Working in cooperation with the CD Laboratory for Fuel Cell Systems (Graz University of Technology), simulation models were developed as basis for the layout and design of a first prototype unit in the 1 kW power range (Fig. 1). A suitable SOFC stack was developed and supplied by the Danish project partner Topsoe Fuel Cell AS.

The industrial research partner, CTP GmbH in Graz, developed and built the cathode heat exchanger and the catalytic afterburner. Together with a pre-reformer for natural gas built by AVL, these components were integrated in an initial system set-up. This system was installed on a fully automated prototype fuel cell test bench, which was also developed as part of the research project (Fig. 2), and initial tests were conducted.

Fig. 2

One particular feature of the test bench is a Hardware-in-the-Loop system (HIL), which allows the real-time coupling of hardware on the bench as well as simulated (= virtual) components. This feature was used and tested with this first system by simulating the cathode blower and its influence on efficiency and transient performance. The whole system was operated under realistic conditions (self-sustained operation without furnace) and with transient loads.

Remarkably high fuel utilisation of 92% was achieved leading to peak system efficiencies of up to 55% and average efficiency in the load cycle studied of 37%, meaning that the target value of 35% was slightly exceeded (Fig. 3).

However, further investigations looking at system integration have shown that commercial application of this technology is only feasible if:

> conventional fuels can be used for mobile applications, i.e. standard diesel for utility vehicle applications;
> costs for particularly expensive sub-components such as the interconnectors can be reduced; and
> a higher degree of system integration can provide further benefits for the end user.

INFO
Project management:
AVL List GmbH
Project partners:
Chemisch Thermische Prozesstechnik GmbH,
TU Graz – Christian-Doppler-Labor für Brennstoffzellensysteme,
Topsoe Fuel Cell AS (DK)

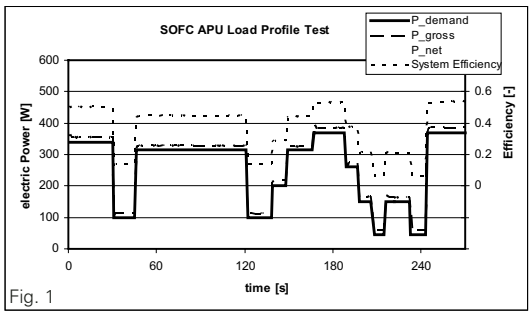


Fig. 1

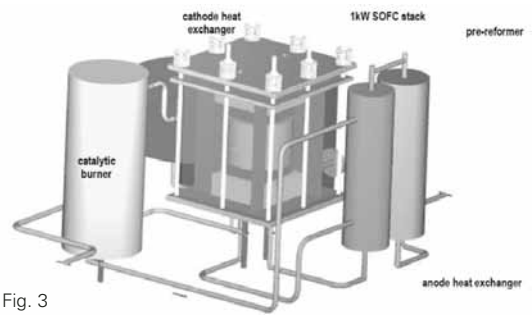


Fig. 3

ABSOCOOL-TRANSPORT

Study of the use of fuel-cell powered sorption cooling systems for refrigerated transport applications

The project uses an innovative solution with co-generated heat and electricity for refrigeration during transport, with the potential for considerable reductions in consumption and emissions. The aim of the project is to determine the extent to which the combination of high-temperature fuel cell and sorption refrigeration engineering can be used for transport refrigeration units. The anticipated result is a significant reduction in fuel consumption and in emissions (> 50%) compared with the diesel-engine driven compression refrigeration units currently in use.

The combination of fuel cell and sorption cooling engine constitutes an innovative design in the vehicle sector. This combination, in a compact form of this kind, is being investigated for the first time. This study aims to demonstrate the extent to which the heat energy of the fuel cell can be used to drive a sorption refrigeration unit.

The study demonstrated how, and at what point, integration of a system of this kind into the various modes of transport is possible and the extent to which a reduction in expenditure on fuel and thus a reduction in emissions is achieved. This project is intended not only to effect a substitution, but to go beyond this in demonstrating innovations.

The project also aims to improve the efficiency of the ancillary components, especially the refrigeration units. It was proven that a system of this kind is viable, from an energy point of view. It can also be installed in the spaces provided for present-day refrigeration units without the need for additional space.

INFO
Project management:
ALPPS Fuel Cell Systems GmbH
Project partners:
CLIMT Claassen Industrie Management Trading GmbH,
Arsenal Research GmbH

Furthermore, a combined system of this kind offers the possibility of saving a considerable amount of fuel, while simultaneously improving the efficiency level of the total system significantly, since the system is not operated in the full load range but in the part load range for a large part of the time. From the project partners' point of view, a combined system has been developed which brings together a compression section with an absorption section. The next step will be to integrate a fuel cell system. Work is being initiated on the first prototypes in a successor project.

E_2MOBIGEN

Energy-efficient mobile energy generation from diesel with fuel cells

The development of energy-efficient ancillary units for vehicles is leading to increasing electrification of those ancillary units. At the same time, customer demands in terms of comfort and safety are becoming ever greater, leading to a further increase in electricity consumption in the motor vehicle. Given this increasing demand for electrical energy, it is apparent that a separate and efficient power supply can make a significant contribution to fuel savings and to a reduction in CO_2.

This project serves as preparation for at least two technological transformations in vehicle engineering: for increasing electrification (drive by wire, etc.) on the one hand, and also for the introduction of fuel cell technology, which will have a massive influence on the structure of the automotive supplier industry.

The project is divided into two phases. In the first two years, the technology required will be developed and a prototype constructed. This work is based on a study which received funding in the First Call of the A3 Programme and which demonstrated the feasibility of the system under consideration. This will be followed by the test phase, to be carried out by the application partners.

E_2mobiGen is contributing to the following positive changes:
> "Cleaner", e.g. due to the reduction in NO_X;
> "Safer", by reducing the thermal stress on the driver; and
> "Quieter", through the practically noise-free operation of the ancillary units.

The aim of this project is to develop a high-performance power unit of great significance as an auxiliary power supply for motor vehicles in Austria. The power unit is to be equipped in an environmentally-friendly manner using a fuel cell, and operated using diesel or bio-diesel.

INFO
Project management:
ALPPS Fuel Cell Systems GmbH
Project partners:
FH OÖ Forschungs- und Entwicklungs GmbH,
Arsenal Research GmbH,
Rexxon GmbH (D),
Rosenbauer International AG

SOFC APU

Design and testing of new technologies for a competitive fuel cell-APU system

This project investigated cost-effective materials and methods for the mass production of fuel cells for powering auxiliary units in utility vehicles. Moreover, concepts for the improved integration and more extensive utilization of fuel cell systems in vehicles were analysed.

Fuel cell systems to supply electricity to auxiliary equipment in commercial vehicles have cost targets which require consistent orientation towards cost optimisation. Consequently this project examines both cost-saving materials and methods of mass production of the fuel cell, as well as concepts for increased integration and extended use of fuel cell systems in vehicles. Important requirements for the APU system, in terms of mobile use, are competitive production costs and the use of fuel available in the vehicle (e.g. diesel). With today's system approaches, components and materials used, the target costs for mobile application in vehicles cannot be achieved. For supporting the fuel cell APU to become a competitive product, a dual strategy was pursued by the consortium:

1. Increasing the degree of utilisation of the APU system through increased vehicle integration:
> Substituting component parts in the vehicle
> Common use of component parts by vehicle system and APU
> Enabling new functionalities for the whole vehicle system

2. Application of new material and design approaches for a generation of fuel cells to enable significant system simplification and cost-saving mass production.

AVL has developed two concepts for competitive systems, based on a detailed integration study. In the first concept, a stand-alone approach, the focus lies on minimising production and integration costs for rapid and successful market entry. The second concept, "PTSU – Power Train Support Unit", is aimed at maximising overall efficiency. Under this approach, key power-train functions are met using the SOFC APU system (Fig. 1).

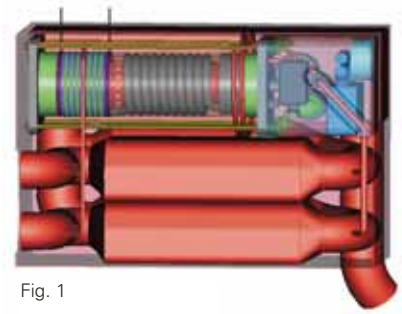


Fig. 1


Fig. 2


Fig. 3

In addition, AVL has developed a diesel-reformer and thereby enhanced the anode circuit of the APU system. Thus, it was possible to demonstrate peak efficiency of 83% and a cycle efficiency factor of 78% (Fig. 2).

As a further part of the project, two SOFC stacks with metallic interconnectors (of different generations) from the company Plansee AG were constructed and their characteristics analysed on an AVL test bed (Fig. 3). By this way, it was possible to demonstrate the performance capability of Plansee low-cost interconnector materials by comparison with the starting material.

The work on the SOFC APU project has identified various approaches for reducing the amortisation period of SOFC APU systems (for the end-user) to below two years.

INFO
Project management:
AVL LIST GmbH
Project partners:
Plansee AG,
Haldor Topsoe A/S (DK),
Montanuniversität Leoben – Department Metallkunde und Werkstoffprüfung,
TU Graz – Christian-Doppler-Labor für Brennstoffzellensysteme,
Landwirtschaftskammer Steiermark

BIO-SOFC-DRIVE

Development and demonstration of an SOFC-battery hybrid drive powered by biogenous fuels

The bio-SOFC (Solid Oxide Fuel Cell) drive project is investigating an innovative and environmentally-friendly vehicle drive – a fuel cell hybrid drive – in a small fleet test using several vehicle platforms. A micro-tubular SOFC fuel cell is used as a range extender for battery-powered vehicles, in order to achieve a significant improvement in the biggest weakness in electric vehicles, namely their range. The implementation of an SOFC system also makes it possible to use it as a charging device for the battery, since the micro-tubular solution has already demonstrated the necessary dynamics and cycle endurance.

An optimised battery and drive management system also improves the vehicle's propulsion system in a way that the greatest possible level of energy is recovered, lower fuel consumption is achieved, and the stresses on the fuel cell are constant. Existing electrically-powered vehicles are being supplemented with an "on-board charging device" which continuously tops up the battery charge.

This produces the following advantages:
> Increased vehicle range by comparison with conventional electrically-powered vehicles;
> Waste heat from the fuel cell can be used to heat the vehicle;
> The battery charge is topped up when travelling downhill, due to brake energy recuperation. This results in an additional fuel saving.

Biodiesel is used as the fuel, as a result of which the test can be carried out using the existing infrastructure, including in outlying areas such as tourism-oriented communities. In addition to this, tests are being conducted using other biogenous fuels. Small delivery vehicles, minibuses, a boat and a measurement vehicle ensure that a qualified assessment can be made regarding practicability in a representative range of applications. Internationally, range extenders are viewed as a key future solution for the fuel cell in vehicles, since the high-temperature fuel cell makes the use of renewable fuels possible. Further investigations and analyses include user satisfaction, the effects of fuel quality, comparisons with conventional propulsion systems and general information about the benefits and applicability of the SOFC-battery hybrid drive.

Particular attention is also being paid to specialist support from independent agencies who deal with safety issues, train users, assess environmental impact etc. The project is running over two years, with the first year given over to preparing the technical solution and the second year to operating the vehicles. The aim is to demonstrate the suitability of this solution for practical implementation.

The following components are being developed or built in order to realise this project:
> Battery hybrid drive concept, including intelligent battery and energy management (energy recovery);
> Biodiesel-SOFC module;
> ReDeNOx system, for comparison with the internal combustion engine.

These individual components are combined with one another in such a way that various drive concepts can be realised, measured and compared with one another.

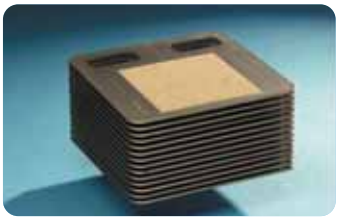
This project involves the development and fleet testing of fuel-cell battery hybrid vehicles using SOFC fuel cells and biogenous fuel. A comparison of different propulsion technologies (diesel, diesel + exhaust NO_x reduction, fuel-cell electric hybrid) is made and the bio-SOFC drive is demonstrated in ecologically sensitive areas of use in Austria.

INFO
Project management:
ALPPS Fuel Cell Systems GmbH
Project partners:
Arsenal Research GmbH,
FJ BLT Wieselburg,
ÖGUT – Österreichische Gesellschaft für Umwelt und Technik,
CLIMT Claassen Industrie Management Trading GmbH,
ÖAMTC Österreich,
MLU – Monitoring für Leben und Umwelt GmbH,
Tourismusverband Werfenweng,
Blaguss Reisen GmbH,
TU Graz – Institut für Fahrzeugsicherheit

PMTECH 4 SOFC

Manufacture of metallic high-temperature and high-performance components in the stack of a SOFC (Solid Oxide Fuel Cell) for mobile and stationary applications

The PMTECH 4 SOFC project is developing technologies for mass production of a metallic interconnector for a mobile solid oxide fuel cell



In recent years, SOFC high-temperature fuel cells have seen major steps forward in development, and are now at the point of being a commercially-viable proposition. SOFCs are based on the principle of direct conversion of fossil energy to electrical energy by means of electrochemical processes. The utilisation of an SOFC as an auxiliary power unit (APU) in a car or utility vehicle may in future result in improvements to vehicle economy and to on-board energy management. Direct electrochemical conversion from fossil fuel to electrical energy for on-board use permits a higher degree of efficiency and thus reduced consumption by comparison with the conventional combination of engine, alternator and battery.

The individual plate-shaped fuel cells, arranged in stacks in the SOFC, are separated from one another using so-called metallic interconnectors. In the composite material with the ceramic cell, the metallic interconnector is intended to perform various functions reliably over a long period of time, meaning that there are high requirements in terms of high-temperature resistance, thermal expansion coefficient, thermal and electrical conductivity and resistance to corrosion: in recent years, the Plansee company has succeeded in developing powder-metallurgy FeCr alloys with a profile which is specially-matched to the application as an interconnector in mobile fuel cells.

For this project, the following objectives were targeted:

> Innovative powder-metallurgy production routes for manufacturing films;
> Developing a comprehensive understanding of the influences on the material caused by utilisation as an SOFC interconnector;
> Innovative production technologies suitable for implementation in the mass production of SOFC interconnectors;
> Development and assessment of the characteristics of functional coatings

INFO
Project management:
PLANSEE GmbH
Project partners:
PhysTech Coating Technology GmbH,
Montanuniversität Leoben – Department Metallkunde und Werkstoffprüfung,
Joanneum Research Forschungsgesellschaft mbH,
Staxera GmbH, Hexis AG

ABSOCOOL-TRANSPORT II

Hybrid fuel cell driven absorption compression transport cooling system

The aim of this project is the implementing and testing of the possibility demonstrated in the predecessor study AbsoCool-TRANSPORT (A3 Programme – 2nd Call) for refrigeration of perishable or easily perishable goods during transport, using an innovative solution for linking electricity and heat.

For this, a prototype is to be built and tested, as the basis for further industrial manufacture and marketing. The available results indicate that the combination being sought, involving a high-temperature fuel cell and sorption refrigeration engineering, demonstrates high potential for fuel consumption savings by comparison with the current conventionally-used diesel-powered compression refrigeration units. Comparing the current state of technology in terms of the fuel cell and taking these values as the basis for a comparative calculation, the result indicates that the conventional assembly consumes around 23% more fuel. Taking into account the ongoing developments in the fuel cell segment and the resulting greater efficiency, it is possible to predict that the conventional assembly will consume up to 64% more fuel (source: Final Report, AbsoCool-TRANSPORT Project).

This also results in a significant reduction in emissions such as CO_2 or NO_X, and especially of particulates, not least due to the greater efficiency and thus lower fuel consumption, together with the demonstrably lower-polluting implementation of the biogenous fuel used in the fuel cell. A further and not insignificant point is the reduction in noise level in the area around the unit, since the currently-used internal combustion engines can be completely removed from the refrigeration units.

The project has been started recently, the outline therefore corresponds to the project proposal description.

In this project, a study is made of an innovative possibility for refrigeration of perishable or easily perishable goods during transportation. A prototype is to be built and tested which is based on a new and innovative solution for linking electricity and heat. For this, a high-temperature fuel cell is being used in combination with sorption refrigeration engineering. On the basis of the study completed as preliminary work, high fuel-saving potential is anticipated.

INFO
Project management:
CLIMT Claassen Industrie Management Trading GmbH
Project partners:
Arsenal Research GmbH,
Frigopol Kälteanlagen GmbH

> BZ-VIT
> PRO-BZ
> QUANT-B
> BZ – CORE GROUPS
> FC-HY-TECHTRAIN
> H_2 AUTOMOTIVE

TRAINING, NATIONAL AND INTERNATIONAL NETWORKING

Fig.: Universität Wien

BZ-VIT

Fuel cell – networking – internationality – transfer

The fuel cell is seen as one of the key technologies of the 21st century. In addition to a wide range of possible applications in stationary and mobile systems, this technology is finding a broad range of applications in the automotive industry, as a result of which it may be possible to achieve considerable savings on emissions in future.

The BZ-VIT project was realised to develop awareness and networking for the Austrian automotive industry on the thematic focus of fuel cells.

At a roadshow in Linz, Graz and Vienna, presentations were given to the Austrian automotive industry on how fuel cells work, on what the current state of technology is, and on forecasts for market introduction. Opel gave a presentation to the approximately 150 attendees about activities within the GM group, demonstrating the commitment with which automotive manufacturers are engaging in these issues and why people should already be focusing on the fuel cell.

In a further move, the fuel cell experts from CLIMT offered individual specialist advice to automotive suppliers on the importance of fuel cell technology, as well as on the consequences and benefits for their companies. Some interesting consequences follow from the eventuality of the combustion engine being replaced by fuel cells: one in every two companies would be seriously adversely affected. By contrast, the fuel cell presents new business opportunities for two-thirds of those who discussed the scenario in detail.

Building on this general and individual approach to awareness-raising, an international technology cooperation exchange was staged, under the title "Fuel cell for mobile applications". The aim was to achieve international networking for the Austrian companies and universities in the European research arena and also to create a platform for companies and research institutions to come together to initiate joint projects. Austrian SMEs, in particular, were given the opportunity to get access to the necessary know-how and technologies for their own development projects. On the basis of a technology catalogue with 52 offers and inquiries relating to the technology, 73 participants from five nations were able to engage in over 220 face-to-face discussions on cooperations. In nearly 100 cases, more in-depth discussions were agreed, demonstrating the success of this event. The first cooperation projects were agreed at the event itself.

Rounding off the project, a fuel cell forum was staged in Steyr, giving a final push towards establishing a domestic fuel cell grouping in the automotive sector. Around 75 participants were given a presentation on the outcomes of the BZ-VIT project, along with specialist lectures on hydrogen production and storage, international framework conditions and influencing factors for the market launch of the fuel cell as well as further presentations on initial projects on the subject of fuel cells in an automotive context.

INFO
Project management:
CATT Innovation Management GmbH
Project partners:
CLIMT Claassen Industrie Management Trading GmbH,
TMG – OÖ Technologie- und Marketing-gesellschaft mbH / Automobil-Cluster in OÖ,
DANUBE

PRO-BZ

Programme for the development of fuel cell expertise

As a first step, a record was made of the existing training programmes for fuel cell technology, and the requirements for training at the various levels of qualification were documented via interviews with key players. Proposals for training programmes were elaborated and coordinated with the interested parties. Since there are interfaces with similar proposals in other countries, the experiences gathered there were exploited.

The innovative aspect of the PRO-BZ project lies in the notion of a standardised national "multi-party discussion platform", intended to lead to objective, coordinated and qualitatively standardised Austrian training concepts.

The outcomes are available for use by training institutions.

Project scope:
> Inventory and evaluation of existing teaching methods and curricula.
> Establishing training programmes for fuel cell technology at all requisite levels of qualification, from vocational schools to postgraduate training.
> Coordination with other European systems.
> Provision of model training programmes and suggestions for training to interested schools and universities.
> Presentation of training programmes to interested parties from universities, business, departments of government, etc.
> Publicity measures, e.g. seminars, to publicise the outcomes of discussions.

A technology which is at the start of a rapid expansion, such as the fuel cell, needs a rapidly-growing reservoir of well-trained employees for its dissemination. In order to withstand international competition, cross-technology expertise is needed in the fields of electrochemistry, mechanical engineering, process engineering and electrical engineering.

INFO
Project management:
ALPPS Fuel Cell Systems GmbH
Project partners:
Fachhochschule Wels, Studiengang Öko – Energietechnik, ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH

QUANT-B

Qualification and training of teachers and skilled staff in the area of new technologies > Fuel cells and high power batteries

The QUANT-B project began with a needs assessment, with target groups for this assessment being the education sector in Austria (intermediate and higher-level vocational schools, secondary schools, specialist colleges and universities) and companies. The assessment identified an increasing demand for continuing education in the field of fuel cell technology. 83% of the teaching staff and 90% of the pupils questioned agreed with the need for continuing education; in the case of specialist colleges and universities, the percentages were 42% for the teaching staff and 67% for the students. At the companies, 79% of those questioned recognised the need for continuing education in the field.

The next step in the project was to install a demonstration fuel cell system at ECHEM. In parallel to the theoretical background, this system provides practical training for both schools and companies, using experiments and simulations.

In the first phase, the content requirement of units of training – structured as modules – for "fuel-cell relevant" types of schools, colleges and universities was evaluated in close cooperation with the PRO-BZ ("Programme for the development of fuel cell expertise") project. Using this information, model training programmes were prepared. The importance of each individual module was assessed depending on the needs of the different target groups in the education sector and in companies.

Different workshop concepts to implement these model training programmes were prepared for "high-performance and traction batteries" and "fuel cell technology".

The workshop on "high-performance and traction batteries" gives an overview of important concepts relating to batteries and accumulators, as well as examining their technical design, the chemical processes taking place, their possible applications, and the charging/discharging techniques for the most important systems. The safety measures needed when maintaining, repairing or using battery systems are also dealt with, while an overview is given of relevant literature and (school) experiments.

The presentation of the necessary physical chemistry principles, an overview of the different types of fuel cells and their applications, as well as the historical development of fuel cells were included in the "fuel cells" workshop documentation. General background information on the concepts of "energy" and "electrical energy" was also included. In the next steps, the challenges related to establishing fuel cell technology and a hydrogen infrastructure, i.e. its storage and handling, will be elaborated.

INFO
Project management:
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH
Project partners:
TU Wien – Institut für Chemische Technologien und Analytik / EC 164
CATT Innovation Management GmbH

BZ – CORE GROUPS

Formation and international networking of working groups for core technology tasks relating to fuel cells

Fuel cells and hydrogen, being areas of technology which have only been close to widespread market introduction for a relatively short time, are not so well-organised in terms of cooperations, networking and internationalisation as proven technologies such as the combustion engine. In the first project successfully completed under the A3 Programme ("BZ-VIT"), there was an expert feedback from those involved which has led to this project building on the suggestions made there.

This project has been carried out in order to encourage Austrian companies (especially SMEs) to get up to speed regarding the international standard in terms of fuel cell and hydrogen technology, and to make best use of the still very limited funds in business as well as from the public sector in this area and to supplement these as far as possible through international funding. Important aspects are:

> Bringing together the players already active in Austria, together with potentially-interested parties, for entry into using fuel cell and hydrogen technology;

> Forming working groups based on the particular interests of the participants concerned, devised under the subject headings 'low-temperature fuel cell', 'high-temperature fuel cell', 'hydrogen storage and infrastructure' and 'standardisation problems'. This latter area is already being driven forward internationally and the Austrian approach needs to link in with this.

> Developing SWOT analyses for Austrian technologies, in order to identify the need for future activities.

> EU screening, to identify the right networking possibilities, partners and project opportunities for the subject areas addressed in the working groups.

> Initial coaching of working groups, with the aim of allowing these to continue and to work independently or in conjunction with other organisations such as standardisation bodies, BIT, automotive clusters, EU thematic networks, international committees of experts etc.

The aim of this project is to establish collaboration between national players already working in the field of hydrogen and fuel cell technology, for the purposes of information exchange, jointly solving existing problems, and preparing international collaboration (EU projects).

INFO
Project management:
CLIMT Claassen Industrie Management Trading GmbH
Project partners:
TMG – OÖ Technologie- und Marketinggesellschaft mbH / Cluster Drive Technology,
CATT Innovation Management GmbH,
ARC Seibersdorf research GmbH,
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH

FC-Hy-TECHTRAIN

Integration of the topic of "fuel cells and hydrogen technology" into technical and scientific curricula

The "FC-Hy-TECHTRAIN" project looks at integrating the topic of "fuel cells and hydrogen technology" into technical and scientific curricula. The teaching staff involved in the project will be assisted in preparing and further implementing the educational programmes and will serve as contact persons for the subject area "fuel cells and hydrogen technology".

In the FC-Hy-TECHTRAIN project, a basic structure for the educational programme was elaborated. The goal was to reach all school types (secondary school, vocational school, vocational college, specialist college and university), and was made possible through the use of a modular structure for the educational material.

Eleven modules were prepared and classified into the following aspects:
The programme starts with a general introduction to the concepts energy and environment as well as an introduction to fuel cell technology. Module 3, "Fundamentals", deals with important concepts of thermodynamics and kinetics which are necessary for a better understanding of the fuel cell and the reactions taking place as well as the fuel cell behaviour under specific operating conditions.

The next 3 modules cover fuel cell technology in much more detail. They describe the reactions taking place and the behaviour of different types of fuel cells under the influence of different parameters such as temperature, pressure, and the presence of carbon monoxide. These modules also describe the electrical and thermal behaviour of the fuel cell stack and the complete system (stack and peripherals) rather than of just a single cell.

Module 7, "Fuels for fuel cells" describes the fuels available as well as the advantages and disadvantages of their application in different systems. Modules 8 and 9 focus on hydrogen as a fuel for fuel cells, including the processes for hydrogen production from fossil resources as well as renewable sources (Module 8) and the methods for its storage (Module 9). Module 10, "Safety aspects", deals especially with hydrogen and the final module, "Hydrogen economy" (Module 11), gives an overview of the often discussed long-term transition to hydrogen as an energy carrier. To facilitate integration of the subject "Fuel cells and hydrogen technology" into existing programmes, presentations on the content of the different modules were prepared.

A specialist journal was chosen to disseminate this project, as its target group matches that of this project (the journal is edited by the association of chemistry teachers in Austria and is published four times per year; subscribers include approximately 900 secondary-school and vocational-school science teachers).
Two articles were published in the course of the project (Issues 1/2005 and 1/2006); the project was also presented at the 8th European Congress of Chemistry Teachers in 2005, providing information about fuel cells and hydrogen technology and the project aims, particularly the holding of workshops for teachers.

INFO
Project management:
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH
Project partners:
FH OÖ Studienbetriebs GmbH, ALPPS Fuel Cell Systems GmbH, Verband der Österreichischen Chemielehrer

Possible integration of the topic "fuel cells and hydrogen technology" in schools was elaborated as the project was continued through workshops (in Wels, Graz and Wiener Neustadt) for teaching staff specialising in technical and natural sciences disciplines.

H_2 AUTOMOTIVE

Hydrogen – automotive energy carrier of the future

This project analyses energy supply, infrastructure, fuel cell technology and vehicle engineering in connection with the use of hydrogen as an energy carrier and fuel cells as energy converters for automotive use.

Hydrogen as an energy carrier for automotive applications is considered to be a promising scenario for sustainable mobility. The 'H_2 Automotive' study was conducted on an interdisciplinary basis to investigate opportunities for automotive application of hydrogen, starting with the production and covering applications in automobiles and the development stage of fuel cells, as well as the impact on the Austrian automotive industry.

Hydrogen is an energy carrier which can be produced from a wide range of different energy sources. It can be generated by electrolysis using renewably-generated electricity from wind, solar or hydro power, by pyrolysis from biomass, bio-reaction or – as a bridging solution – also from natural gas reformation. Though the latter still causes a certain amount of CO_2 emissions, the great potential of wind power, for instance, is that one large offshore wind farm could in the long term have enough capacity to supply the majority of vehicles in Austria with hydrogen.

The potential for a reduction in CO_2 is promising, but still demands a lot of effort before the technology can be diffused to market. Significant investment in R&D is needed to make hydrogen technology in automotive applications competitive with conventional and other alternative technologies. The buy-down costs necessary to reach this stage will demand efforts for several decades to come.

The vehicles themselves have made tremendous steps forward concerning on-board storage, electrical drive train and the overall vehicle package. Thus current concepts can be realised with a fuel economy of about 1 kg/100 km, depending on driving conditions; future concepts will bring further improvements through optimising components and intelligent application of combinations of technologies. Additional development work will be needed in reducing losses in the fuel cell ancillary units, in combining new technologies to develop total concepts, and in cost reduction.

Last but not least, fuel cell systems themselves have to overcome barriers – especially in materials development. Furthermore, there are active patents which influence the construction and costs of current systems. Key developments are therefore needed for the ancillary units, materials and catalysts, to solve the present problems.

For the Austrian automotive industry, it is vital to find international collaborations regarding these rapidly-developing technologies to establish new areas of business for the medium and long term. Thus global players such as GM, DaimlerChrysler and Magna Steyr participated in the "H_2 Automotive Workshops" in San Diego, CA (March 2006) organised by the partners of H_2A project consortium.

These developments are being provided as a web platform for the Austrian automotive industry and other decision-makers. Those involved in the Austrian automotive industry and potential future users can find out about the opportunities which exist in this field at www.h2-automotive.info.

INFO

Project management:
TU Wien – Institut für Verbrennungskraftmaschinen und Kraftfahrzeugbau

Project partners:
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH,
TU Wien – Institut für elektrische Antriebe und Energiewirtschaft,
University of California at San Diego, Center for Energy Research,
ÖAMTC AKADEMIE, Wissenschaftlicher Verein für Mobilitäts- und Umweltforschung

AUSTRIAN COMPANIES AND ORGANISATIONS IN THE SECTOR OF HYDROGEN AND FUEL CELL TECHNOLOGIES

Advanced Polymer Engineering GmbH	www.4a-engineering.at
ALPPS Fuel Cell Systems GmbH	www.alpps.at
Alvatec Alkali Vacuum Technologies GmbH	www.alvatec.com
Arsenal Research GmbH	www.arsenal.ac.at
Austrian Aerospace GmbH	www.space.at
Austrian Research Centers GmbH	www.arcs.ac.at
AVL List GmbH	www.avl.com
Banner GmbH	www.bannerbatterien.com
BMW Group	www.bmwgroup.com
Biovest Consulting GmbH	franz.leichtfried@biovest.at
Bitter GmbH	www.bitter.at
Blaguss Reisen GmbH	www.blaguss.com
CATT Innovation Management GmbH	www.catt.at
Chemisch Thermische Prozesstechnik GmbH	www.ctp.at
CLIMT Claassen Industrie Management Trading GmbH	www.climt.at
Clusterland Oberösterreich GmbH (Automobil-Cluster)	www.automobil-cluster.at
Clean Air Technologies	www.cleanair.welcometo-us.com
DANUBE	www.danube.or.at
DHL Express (Austria) GmbH	www.dhl.at
ECHEM Kompetenzzentrum für Angewandte Elektrochemie GmbH	www.echem.at
Electrovac GmbH	www.electrovac.com
Ernst Wittner GmbH	www.wittner.at
Wels HE college, Eco-Energy Engineering Dept	www.fh-ooe.at/campus-wels/studiengaenge/studiengaenge/bachelor-studien/vollzeit/oeko-energietechnik.html
FH OÖ Forschungs- und Entwicklungs GmbH	www.fh-ooe.at/fh-oberoesterreich/fe.html
FH OÖ Studienbetriebs GmbH	www.fh-ooe.at
FJ BLT Wieselburg	blt.josephinum.at
Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH	fvkma.tu-graz.ac.at
Fotec Forschungs- und Technologietransfer GmbH	www.fotec.at
Tourismusverband Werfenweng [Werfenweng Tourist Board]	www.werfenweng.org
Frigopol Kälteanlagen GmbH	www.frigopol.com
Fronius International GmbH	www.fronius.com
Gabriel Chemie GmbH	www.gabriel-chemie.com
GE Jenbacher GmbH & Co OHG	www.jenbacher.com
Hoerbiger ValveTec GmbH	www.hoerbiger.com
HyCentA Research GmbH	www.hycenta.tugraz.at
ICE Strömungsforschung GmbH	www.ice-sf.at
Johannes Kepler University Linz – Institute for Control Engineering and Electrical Drives	regpro.mechatronik.uni-linz.ac.at
IO Fahrzeuge Produktions- und Handels GmbH	www.io-scooter.com
Joanneum Research Forschungsgesellschaft mbH	www.joanneum.at
KTM-Kühler GmbH	www.ktm-kuehler.at
Styrian Agricultural Board	stmk.agrarnet.info
Linde Gas GmbH	www.linde-gas.at
Lipp-Terler GmbH	www.lipp-terler.com
LKT Laboratorium für Kunststofftechnik GmbH	www.lkt-tgm.at
Magna Steyr Fahrzeugtechnik AG & Co KG	www.magnasteyr.com
Messer Austria GmbH	www.messer.at
MLU – Monitoring für Leben und Umwelt GmbH	www.mlu.at

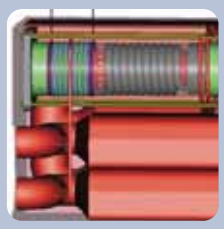
Montan University Leoben – Christian Doppler Laboratory for Computer-Aided Applied Thermofluid Dynamics	gcdw05.unileoben.ac.at
Montan University Leoben – Department for Metallurgy and Materials Testing	institute.unileoben.ac.at/metallkunde
Montan University Leoben – Institute for Process Engineering in Industrial Environmental Protection	www.vtiu.com
Neumann Aluminium Austria GmbH	www.neuman.at
ÖAMTC AKADEMIE, scientific association for mobility and environmental research	www.oeamtc.at/akademie
ÖAMTC Österreich	www.oeamtc.at
ÖGUT – Österreichische Gesellschaft für Umwelt und Technik	www.oegut.at
OMV AG	www.omv.com
Österreichisches Forschungs- und Prüfzentrum Arsenal GmbH	www.arsenal.ac.at
PEMEAS GmbH	www2.basf.de/en/pemeas
Photovoltaiktechnik GmbH	www.pvt-austria.at
PhysTech Coating Technology GmbH	www.phystech-coating.at
PLANSEE GmbH	www.plansee.com
Polymer Competence Center Leoben GmbH	www.pccl.at
Profactor Produktionsforschungs GmbH	www.profactor.at
proionic Production of Ionic Substances GmbH	www.proionic.at
Rosenbauer International AG	www.rosenbauer.com
S. Graf, Carello Elektrofahrzeuge Erzeugungs- und Vertriebsgesellschaft m.b.H.	www.graf-carello.com
Schuh Karosseriebau GmbH	www.schuh.co.at
Siemens AG Österreich	www.siemens.at
Smotech Brennstoffzellen GmbH	www.smole-ec.com
Spath Micro Electronic Design KEG (MEDS)	www.meds.at
Test-Fuchs, Ing. Fritz Fuchs GmbH	www.test-fuchs.com
TMG – OÖ Technologie- und Marketinggesellschaft mbH	www.tmg.at
Graz University of Applied Sciences – Christian Doppler Laboratory for Fuel Cell Systems	www.fuelcells.tugraz.at
Graz University of Applied Sciences – Institute of Electrical Metrology and Measurement Signal Processing]	www.emt.tu-graz.ac.at
TU Graz – Institut für Elektronik	www.ife.tugraz.at
TU Graz – Institute for Vehicle Safety	www.vsi.tugraz.at
TU Graz – Institute for Combustion Engines	fvkma.tu-graz.ac.at
Vienna University of Applied Sciences – Institute for Applied and Theoretical Physics	www.ifp.tuwien.ac.at
TU Wien – Institute for Chemical Engineering and Analysis/EC164	info.tuwien.ac.at/echem
TU Wien – Institute for Electrical Plant and Energy Management	www.ea.tuwien.ac.at
TU Wien – Institute for Combustion Engines and Vehicle Construction	www.ivk.tuwien.ac.at
TU Wien – Institute for Process Engineering, Environmental Engineering and Engineering Bio-Sciences	www.vt.tuwien.ac.at
Universität Wien – Vienna University – Institute for Material Physics	www.univie.ac.at/materialphysik
VENTREX Automotive GmbH	www.ventrex.com
Verband der Österreichischen Chemielehrer	www.vcoe.or.at
Weizer Naturenergie GmbH	www.weizernaturenergie.at
Westcam Projektmanagement GmbH	www.westcam.at









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