# Germany: Lead Market for Energy Storage & Fuel Cell Systems

A Profile of Selected Market and Research Opportunities

Industry Brochure

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## About Us

*Germany Trade & Invest* is the foreign trade and inward investment agency of the Federal Republic of Germany. The organization advises and supports foreign companies seeking to expand into the German market, and assists companies established in Germany looking to enter foreign markets.

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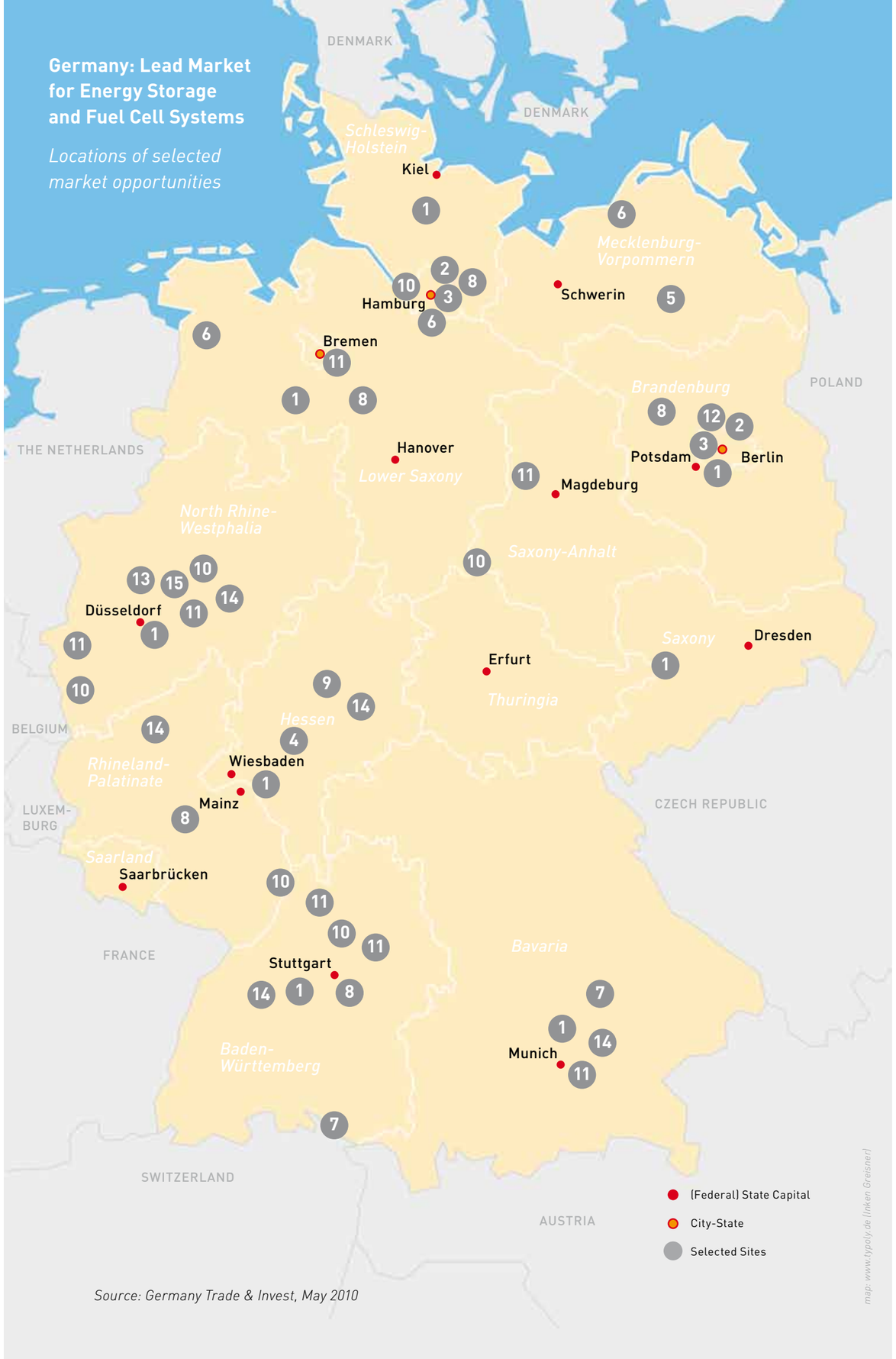


*Source: Germany Trade & Invest, May 2010*

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# Welcome Address

*Germany is a world leader in the development and commercialisation of technologies that aim to tackle global environmental challenges. The impact of climate change, rising energy demand and the depletion of fossil fuels are becoming increasingly apparent. The fundamental shift to a sustainable world can only be achieved by developing new technologies, materials and modules. Energy storage has emerged as a new industry.*

*It requires sophisticated technologies which are both environmentally friendly and forward-looking. A favorable legal framework, generous research funding and incentives for businesses are helping to create this new market. Germany has set itself the goal of covering more of its energy needs from renewable sources. Companies aiming to enter this exciting market will turn to Germany first.*

*The electricity generated from renewable sources is subject to strong fluctuations, so energy storage will play a particular role when it comes to stabilizing the power grid. At the same time, these storage modules will utilize renewable energy efficiently in order to power portable equipment and mobile applications.*

*Investors can take advantage of highly promising opportunities in Germany. They can collaborate with both leading research establishments and with numerous innovative companies throughout the value added chain.*

*The institutions and market opportunities presented in this brochure will give you an initial insight into the spectrum of opportunities available. Germany Trade and Invest, the foreign trade and investment agency of the Federal Republic of Germany, advises and supports companies looking to expand their activities to Germany. Germany Trade & Invest cooperates with numerous organizations on the federal and state level. These include the investment promotion agencies of the federal states, bilateral chambers of commerce and industry associations.*

*You are kindly invited to find out for yourself what Germany has to offer in terms of market opportunities, possibilities for cooperation and potential investment in this interesting sector.*

Rainer Brüderle MdB
**Federal Minister of Economics and Technology**

*Photo: Federal Ministry of Economics and Technology*

*Limited natural resources, climate protection and security of an affordable energy supply are compelling reasons for finding new ways of individual mobility and general energy supply. In addition to further developing sources of renewable energy and increasing their share in the overall energy mix, it is essential to strengthen efficient and clean technologies that allow us to use these. Hydrogen and fuel cell technology as well as battery technology offer great potential in regard to individual mobility and general energy supply in the future. Moreover, hydrogen is not only suitable for use as a fuel, but it is also an undisputed solution for storing large quantities of energy – for example excess energy generated in wind-parks during peak times.*

*In order to prepare markets for products and applications based on hydrogen and fuel cell technology as well as battery technology, the German Federal Government and the Federal Ministry of Transport, Building and Urban Development have adopted two path-breaking programs: The National Innovation Program Hydrogen and Fuel Cell Technology (NIP) and the program Model Regions Electric Mobility – both implemented by the NOW GmbH National Organization Hydrogen and Fuel Cell, which was set up specifically for this purpose in 2008.*

*We are well aware that these technologies will play a decisive role for the environmentally sustainable and economically competitive mobility and energy supply of tomorrow. Close cooperation between players from the worlds of politics, industry and academia as well as substantial and strategic funding are keys to the successful market entry of products. Fuel cell vehicles, hydrogen fueling stations, fuel cell heating and electricity systems for houses and ships, as well as nationwide public transport schemes for battery electric power trains are promising and internationally competitive technologies.*

*Companies operating in Germany are already global frontrunners with regard to products and applications based on hydrogen, fuel cell and battery technologies. It is our goal to keep Germany's top competitiveness and to establish Germany as a lead market for new transport and energy efficiency technologies.*

*In this publication, we have portrayed only a sampling of the latest products, applications, projects and initiatives in this field – come and see for yourself what exciting developments are taking place in Germany.*

Dr. Peter Ramsauer
**Federal Minister of Transport, Building and Urban Development**

*Photo: Federal Ministry of Transport, Building and Urban Development*

## Energy concerns drive search for renewable technologies

**This brochure aims to define the opportunities in Germany for developing and commercialising technologies for the efficient storage of electrical energy. Our objective is to inform investors about the vast potential for collaborating with companies and R&D institutions in Germany in this field.**

Limited natural resources, climate protection and the need to secure a competitive energy supply are compelling reasons for changing to renewable sources of primary energy and improving energy efficiency. This change from fossil to renewable fuels is imperative to achieve environmental objectives aimed at limiting global warming to a maximum of 2° C.

It involves nothing less than re-engineering the entire industry for generating, transporting and using energy. This transformation presents us with vast technological and economic opportunities.
While nature provides more than sufficient energy to supply our present and future needs, the technologies used to harvest natural sources still need to be developed to a level where they can compete economically with systems that have been optimised over generations.
Wind, solar energy and bio-matter will be the major sources of renewable prime energy in the future (see graph below).

The evolution of the proportions of total primary power consumption derived from renewable resources in Germany is shown on page 7. This progress is the result of a series of environmental initiatives over the period concerned and has resulted in a reduction of emissions of $CO_2$ equivalents from 988 Mt in 1990 to 774 Mt in 2007 (-22%).

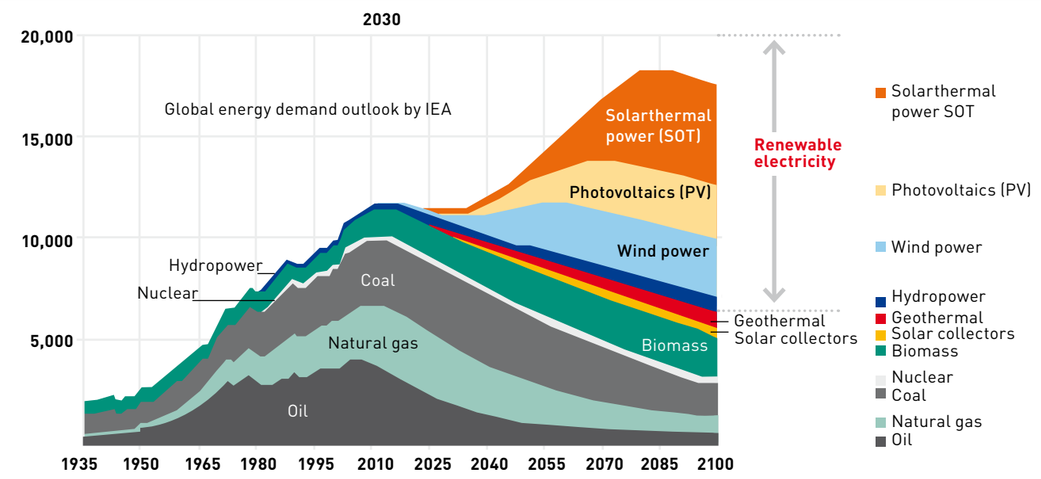
The development and commercialisation of new technologies, materials and devices is the prerequisite for mastering the fundamental change from fossil fuels to renewable fuels.

The German Federal government has set itself the following ambitious targets:

- Electrical power consumption from renewable resources 30% in 2020; approx. 50% in 2030
- Heat consumption from renewable resources 14% in 2020
- Fuel consumption (energy content) from bio-fuels 12% in 2020
- Primary energy consumption from renewable resources: approx. 50% in 2050.

*Source: BMU March 2010*

**Total global primary energy supply in Mtoe**




*Source: IEA, International Energy Agency/SOT, Solarthermal Power Generation/Ludwig-Bölkow-Systemtechnik GmbH*

A key requirement for the widespread use of solar and wind energy is technology for efficient energy storage. This is because solar and wind energy are seldom generated when or where they are consumed. Power storage allows time-shifted power output to cover demand peaks during low supply periods and, in addition, makes power available for mobile and portable applications.

**Emerging technology**
From an economic viewpoint, the market for energy storage provides a technology-driven platform for building a sustainable, profitable business. Furthermore, there are particular opportunities for small and medium sized companies.

The emerging markets for energy storage devices and fuel cells as well as efficient energy management systems (smart grids), are attractive new business opportunities for manufacturers and service providers. In Germany, these technologies represented 8% of gross domestic production (GDP) in 2007 and are expected to amount to 20% of GDP in 2020. Global sales of sustainable energy and energy storage amounted to €155 billion in 2007 and are expected to grow four-fold to €615 billion by 2020 *(Source: BMU "GreenTech made in Germany", Roland Berger energy consultants 2009).* So it is evident that ecology has become an entrepreneurial opportunity!

All of this will not happen spontaneously. The German federal government's "high-tech strategy", underpinned by generous cash grants for both research and commercialisation of innovations, as well as numerous government policies and directives have led to an attractive environment in which companies operating in Germany have taken the lead in the global market for renewable energy technologies.

Here they find an established infrastructure for research and innovation focused on environmental technologies along with a host of international companies which have played their part in making Germany the Number 1 exporter of environmental products in the world.

**Initiatives making Germany the lead market for environmental technologies**
The German federal government's high-tech strategy is a comprehensive national strategy for all ministries.

It aims to spend an additional €6 billion to develop lead markets in Germany for 17 of tomorrow's cutting-edge technologies, and places great emphasis on cooperation between industry and research institutions as well as encouraging research in small and medium-sized enterprises (SMEs). It therefore brings a new impetus, facilitating and accelerating the translation of research findings into products.

Technologies for achieving ambitious climate goals are of particular importance to the federal government, which has formulated the Integrated Energy and Climate Programme (IEKP). This comprises 29 measures, including: combined heat & power, carbon capture & storage, smart metering, use of renewable heating, biofuels, reform of vehicle tax, battery-powered electric mobility (e-mobility), as well as hydrogen and fuel cells. Both R&D and demonstration projects aimed at proving economic viability are supported.

**Development of renewable energy supply in Germany**

**Share of renewable energy sources**

| | 1998 | 2002 | 2004 | 2006 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| Renewable electrical power (%) | 4.7 | 7.8 | 9.2 | 11.6 | 15.1 | 16.1 |
| Heat from renewable resources (%) | 3.6 | 4.3 | 5.5 | 6.1 | 7.7 | 8.4 |
| Renewable fuel for mobility[1] (%) | na | na | 1.8 | 6.3 | 5.9 | 5.5 |
| Total renewable energy (%) | 3.2 | 4.5 | 5.8 | 7.9 | 9.5 | 10.1 |
| Renewables/primary energy[2] (%) | 2.6 | 3.2 | 4.5 | 6.3 | 8.2 | 8.9 |

[1] *Fuel for all combustion engines (excluding aviation fuel)*
[2] *Renewables as a percentage of total primary energy consumption*

*Source: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)*

**Batteries**
Mobile energy storage systems are the foundation stones for the future of hybrid electric vehicles (HEVs) and full electric vehicles (FEVs), as well as those powered by hydrogen and fuel cell technologies. Therefore, new energy storage mechanisms need to be developed that are efficient, light, safe and affordable and which address the range-anxiety of today's drivers by allowing them to complete 200-300 kilometre journeys without refuelling.

The public-private innovation initiative "Lithium Ionen Batterie LIB 2015" was founded towards the end of 2007 to develop suitable batteries. As this involves raising the power performance and storage capacity of batteries five- to ten-fold, an industrial consortium comprising BASF, Bosch, Evonik Industries, LiTec and Volkswagen has committed €360 M to R&D efforts, backed by a €40 M grant from the German Ministry of Research & Education (BMBF).

**E-mobility**
Furthermore, the "Model Regions for Electric Mobility" programme of the Federal Ministry of Transport (BMVBS) has allocated €115 M over three years (2010-11) to promote e-mobility in public spaces. This is part of a €500 M grant from the government's "stimulus package" which is to be spent over the same period and is being augmented by a number of regional and company-sponsored intitiatives aimed at promoting e-mobility.

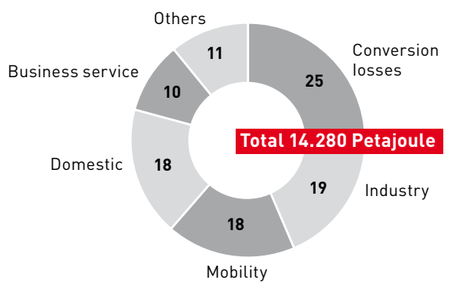
In eight selected model regions across Germany the programme sets out to generate maximum empirical value from different technological and operational concepts and under varying regional conditions. Furthermore, field and fleet tests with passenger cars and delivery vans and tests of diesel hybrid buses in public transport are being carried out. The overall goal is to have 1 million electric vehicles on Germany's roads by 2020. In addition, a pilot plant for recycling of lithium batteries is being constructed.

**Fuel cells**
To boost developments in technology and infrastructure for utilising hydrogen and fuel cells, a strategic alliance between the German government, industry and the academic community – named NIP – was formed in 2006. Its mission is to demonstrate the viability of hydrogen technology through demonstration and research projects. NIP has a total budget of €1.4 billion at its disposal, funded 50% by industry and 50% by federal grant. This budget is managed by NOW, a federally owned body.

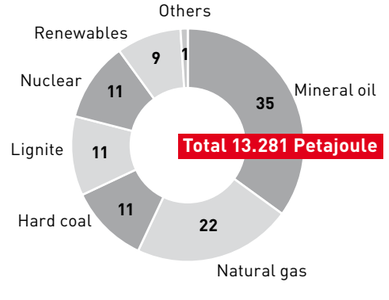
These initiatives include both mobile and stationary applications as well as a number of niche markets. All are portrayed in this brochure.
In addition to these national demonstration projects, there are also a large number of company-driven projects in this sector. A selected few are also to be found in this brochure, enough to give you a flavour of the rich business opportunities currently awaiting investors in Germany.

**Primary energy sources and uses in Germany**

**Analysis of primary energy consumption 2008 (%)**




**Analysis of primary energy sources 2009 (%)**




*Source: AGEB*





## Options expand to meet storage requirements

**The choice of technology for storing power depends on a number of factors. Fortunately, new developments are widening the field all the time, allowing optimum solutions for most requirements.**

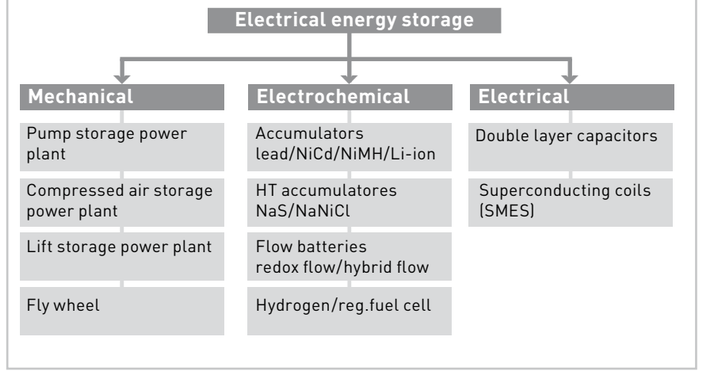
Many different technologies and systems can be used to store power. The choice will depend on the following factors:

- Stationary or mobile application
- Centralised or decentralised facilities
- Energy volume to be stored
- Geological environment
- Storage duration
- Power rating for charging and discharging
- Time required to initiate charge/discharge
- Black start capability
- Technical maturity
- Public concern

The costs for storing energy are significant (see page 18). Therefore, alternatives to storage such as expanding the transmission grid capabilities and collaboration with partners, also need to be explored.

The most commonly used storage systems, as determined in a study commissioned by BMWi and executed by Fraunhofer-Gesellschaft, are illustrated in the following diagram:

**Classification of electrical energy storage**




*Source: Fraunhofer ISE*

*Pumped storage hydro power station in Geestacht, near Hamburg was built in 1958 and is the largest of its kind in Northern Germany. It is part of an environmental energy park with wind and PV-solar power generators. Power rating: 120 MW power and energy storage capacity of 600 MWh. Full discharge capacity reached within 70 seconds, It is activated 4.800 times p.a.*

Photo: Pumpspeicherwerk Geesthacht

## Mechanical systems for storing electricity

**Pumped storage hydro power station**
There are 33 pumped storage hydro power plants in operation in Germany today, with a total capacity of 6.6 GW. This represents about 95% of the total capacity used to store electrical energy in the country. Only one new plant, with a capacity of 1 GW, is scheduled for start-up before 2024.

The technology is reliable, has a high efficiency (75-85% of energy stored can be retrieved) and has an excellent capability for storing energy over long periods of time. Furthermore, such a plant has good "black-start" capabilities, which means that it can be switched on and off at very short notice (approximately 15 seconds) and does not require any external energy sources.

Most conventional power stations are not capable of black-starting.

Pumped storage hydro power stations can only be effectively operated if the local geography offers appropriate storage possibilities at different heights. Therefore, the potential for this technology as an attractive investment in Germany is limited because the north German plains offer no such elevated areas for storage of energy from off-shore wind parks in the North and Baltic seas.

*Huntorf Air Storage – Gas Turbine Power Plant*

*290 MW Diabatic CAES plant commissioned in 1978 in Huntorf in Niedersachsen was the first of its kind in the world. The plant uses compressed air stored in salt caverns for the combustion process of a two stage gas turbine.*

Photo: E.ON Kraftwerke GmbH

**Compressed air energy storage (CAES)**
At present there are only two commercial compressed air energy storage facilities in the world, one in the US and one in Germany.

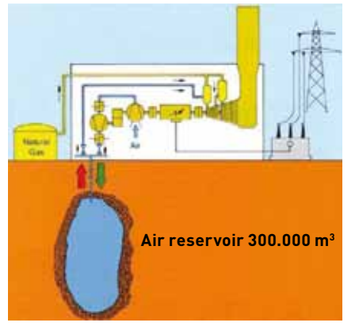
While the diabatic system has an operating efficiency of only 45% – much of the heat generated during compression is lost – the efficiency level for an adiabatic system, where the heat from compression is retrieved, has been shown to reach 55%. This technology can be classed as "technically proven" to capacities of up to 100 MW.

A consortium – made up of RWE, General Electric, Züblin, Ooms-Ittner-Hof GmbH, Erdgasspeicher Kalle GmbH and DLR – has recently been awarded federal government funding to build an adiabatic CAES system in Northern Germany. This demonstration project aims to develop performance parameters for such a system and prove its commercial viability.

CAES systems could be linked to the salt domes found in Northern Germany. Once hollowed out, these domes could conveniently be used as large "pressure vessels" for energy storage.

**Fly wheels**
Storing energy in fly wheels offers immediate availability of limited amounts of energy. Such devices are normally used to secure uninterrupted power supply or to store brake-energy in rail traction vehicles. High-velocity fly wheels capable of discharging energy for up to 10 minutes are being developed to upgrade the quality of distributed power.

**Lift storage power plant**
By raising and lowering weights in cavities, this system can be used to store energy. It has so far not been commercially realised but could be developed in areas where unused mine shafts are available.




**Turbine operation mode:**
Daily output power for 2 hours at peak load periods,
Power supply into grid 290 MW

**Compressor operation mode:**
Operated daily for 8 hours during low load periods,
Power drawn from the grid 60 MW

*Fitted with a hybrid energy storage system (Siemens) street cars can cover up to 2,5 km without overhead power connections. This is made possible by employing a combination of electric double-layer capacitors (EDLC) and a nickel-metal-hydride battery. These enable the breaking energy to be stored effectively and utilized for supporting the traction. This has a number of benefits such as: power consumption is reduced by a third, thereby cutting emissions by 80 t $CO_2$ p.a.; power cables can be removed from areas where they are a visual blight (e.g. in historical malls) or where it is inconvenient to keep and maintain them (e.g. at traffic intersections or in tunnels).*

Photo: Siemens

## Electrochemical systems for storing electricity

**Accumulators**
Electrochemical accumulators for storing energy, such as acid/lead, NaS, nickel/metal hydride (NiMH) and lithium ion (Li-ion) batteries, are graded by volume and energy density/weight ratio, rate of discharge and energy efficiency, as well as by the memory effect (how often the battery can be recharged).

There are a large number of battery technologies that each have the potential for success in the future. While acid/lead batteries have been the workhorse for the industry for over 100 years, providing low-cost and robust performance for conventional vehicles, their performance does not cover demands presently being met by traction batteries.

The market for traction batteries for hybrid electric vehicles (HEVs), presently dominated by the NiMH type, is estimated to be about $1 billion – a growth of $800 million in just five years.

The global market for consumer lithium ion batteries is scheduled to double from around $10 billion currently to $20 billion in the next decade. While the market is presently driven by a growing demand for consumer products such as mobile phones, notebooks/laptops, digital cameras and games, growth in future will be driven by automobile applications. This development will impact the availability of raw materials (e.g. rare earth metals and lithium), an issue which will spur the development of technologies for the recycling of such advanced batteries.

**Traction batteries for transport applications**
Batteries are able to store and discharge energy efficiently. However, they suffer from low energy/weight density. To power an electric car over 500 km, for example, requires a battery weighing 850 kg and holding 540 kg of electrolyte. Therefore, batteries are the preferred power source only for small vehicles driven in urban environments in a stop & start mode.

In order for electric mobility (e-mobility) to be universally employed, it will be necessary to develop batteries capable of higher power output, shorter charging times, lower weight, longer life-times and substantially lower costs. Until this happens, there will be a demand for new business models involving leasing and exchange of batteries.

It has been estimated that 50% of all car journeys are less than 5 km in distance and that today 80% of the petrol used is for journeys covering under 100 km.

Traction batteries, such as those used to power automobiles, might also be employed by smart power load management systems to store renewable power generated locally. In practice this means that an electric car which is plugged into the mains could be both charged and discharged several times during the night to help stabilise the local power grid, and yet still be fully charged in the morning, ready for the drive to work.

"Redox flow batteries" work on the principle of storing electrical energy in an electrolyte outside the battery. Flow batteries can therefore be rapidly "recharged" by replacing the electrolyte liquid while simultaneously recovering the spent material for re-energising. They thus allow energy and performance to be scaled independently of each other because the energy is related to the electrolyte volume (tank size) and the power to the reactor size.

Through their modular construction and relative simplicity, they can achieve a high service life combined with high availability. In addition, external storage of reactants avoids self-discharge problems experienced by primary and secondary battery systems. They are, however, still in the early stage of development and are mainly used for stationary applications.

**Hydrogen**
Despite being one of the most common elements on earth, hydrogen is only found in chemically bound forms such as water and hydrocarbons like crude oil and natural gas.

Hydrogen gas is today predominantly generated from natural gas (largely methane) and petroleum products and is mainly used in the petroleum and chemical industries. Volumes of "co-product hydrogen" from the chemical industry, presently burned in conventional power plants, are limited. Therefore, they will play only a restricted role as a supply source for fuel cell-driven automobiles.

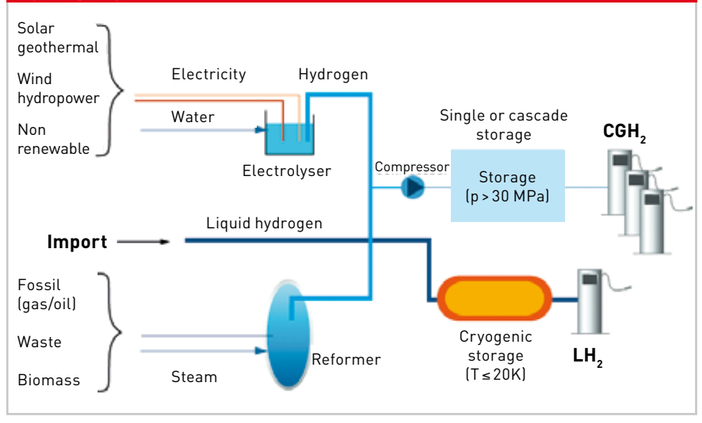
The cheapest source of "bio-hydrogen" is the gasification of bio-matter, but this has limited availability. In the long term, imports of "$CO_2$-free hydrogen", for example, from Iceland (using geothermal heat) or from renewable power sources, such as from the Nordic countries (hydro power) and North Africa (solar thermal power) will become attractive, once economic viability has been established.

Hydrogen is generated from water (at 70-80% yield) in electrolysers using power from wind or photovoltaic units and can readily be transported by pipeline, thereby replacing high voltage transmission lines. This will be the most abundant source of "renewable-hydrogen" and will play a key role in integrating renewable sources of energy into the energy mix. Hydrogen can be used to store sustainable energy safely over long periods and can subsequently be used for transport and industrial applications.

A major bottleneck limiting the implementation of hydrogen-based energy technologies is the lack of efficient storage solutions. Solving this problem will mean building a capital-intensive hydrogen infrastructure and will, therefore, initially be limited to heavy-use centres.

Technologies for hydrogen storage such as compressed cylinders, cryogenic tanks, chemical hydrides and carbon nano-tubes are being developed with a view to reducing cost.

**Hydrogen production from both renewable and fossil fuels**




*Source: HyWays*

Underground salt domes, of which about 50 are presently used in northern Germany for strategic natural gas storage, are ideally suited for the storage of large volumes of hydrogen. These domes are located close to the offshore wind parks and offer one business opportunity in northern Germany to store large volumes of hydrogen safely over significant periods (see page 23).

Currently, only hydrogen allows the long-term economical storage of large amounts of energy. This is illustrated impressively by the key economic indicators collated by ENERTRAG in Brandenburg (demonstration project page 58/59). The company is forced to store wind energy over periods of several months due to seasonal fluctuations in wind intensity, in order to operate a stable and sustainable energy supply grid.

As ~70 times more energy can be stored if hydrogen is used instead of compressed air at the same pressure, this is clearly the technology of choice in that particular location. A further advantage is that hydrogen can also be sold as a fuel for vehicles powered by fuel cells.

Hydrogen and $CO_2$ can be reacted to produce methane, which of course can be "stored" in the established infrastructure for natural gas (see page 76/77).

Converting hydrogen back to electrical power can be achieved by employing conventional thermal systems using gas turbines or engines with an efficiency of approximately 35-40%. Fuel cells are more efficient. They convert around 50% of the energy to electrical power and can be operated with 90% overall efficiency if the associated heat is utilied.

**Fuel cells**
Fuel cells are considered to be the energy converters of the future because in principle they achieve particularly high levels of electrical efficiency, a high overall utilisation ratio with simultaneous use of heat. They can operate with both hydrogen and hydrocarbon fuels after reformation and are suitable for decentralised electricity and heat supplies as well as for powering electrical vehicles.

One highly promising new avenue is onboard electricity generation in vehicles and on aeroplanes. This will enable considerable fuel savings without pollution. However, when the carbon emissions are considered, fuel cell operation based on fossil energy sources will not bring any great relief to the climate system. For a sustainable improvement in $CO_2$ emissions, it is therefore essential to replace fossil energy with renewables to provide the hydrogen.

Fuel cell systems are set to establish their place on the market as substitution products by replacing conventional technologies. They will be assessed on the basis of application-specific criteria such as efficiency, power/weight ratio, power/volume ratio, lifetime, and last but not least, procurement and operating costs.

Should they fare worse than conventional systems in the economic and technical evaluation, additional customer benefits will become a must. The first experiments with car and bus fleets are now taking place worldwide, as well as field trials for supplying energy to buildings, in order to demonstrate technical feasibility.

Germany and other countries are also stepping up product development. Field tests provide a number of insights into daily operation that can then be incorporated into the development of the next generation of products. Furthermore, inexpensive solutions are being developed both for core components – membranes, catalytic converters and bipolar plates – and peripheral components – pumps, valves and sensors. Considerable R&D efforts are still required to deal with the many open questions that remain, before fuel cells are ready for use, cost-competitive and ready for market launch. The systems must be made more reliable, efficiency must be maintained over their service life and this needs to be sufficiently long.

The challenges for successful R&D work oriented towards user requirements, therefore, consist of identifying innovative applications with additional customer benefits, and also of fulfilling and even exceeding application-oriented criteria. This level of development requires ever more complex investigational methods to achieve further progress. As a result, it is essential that we develop tools that provide us with new insights into the field of structural impact relations and material properties, and those used to characterise, model and simulate cells, stacks and systems.

The performance of existing tools must also be improved. Moreover, the verification of R&D activities requires the construction and continuous adaptation of suitable fabrication techniques up to and including pilot-plant scale. Fabrication capacities should reach a level that will permit a statistically reliable assessment of function and quality. A suitable management system for quality assurance will need to be developed and implemented.

*DMFC fuel cell stack*

*DMFC fuel cell module*

Photo: Forschungszentrum Jülich

*Forklift truck powered by fuel cells*

**Hydrogen and fuel cells for transport applications**
Thanks to its high energy/weight ratio, hydrogen will be the preferred renewable fuel for buses and light trucks with medium-load driving in stop & start mode as well as for automobiles driving long distances at high speed on motorways.

Equipped with a fuel cell using 6 kg of hydrogen (in a 120 kg pressure tank) a car can travel a distance of about 500 km.

Long-distance hauliers driving heavy vehicles with high loads will, however, have to continue to drive with conventional combustion engines powered by diesel/biodiesel.

**Energy density of fuels (lower heating value)**

| | Energy per unit mass | Energy per unit volume | |
|---|---|---|---|
| | | Liquids at NBP | Gases at STP |
| | *(kWh/kg)* | *(kWh/l)* | *kWh/Nm³* |
| Diesel | 11,9 | 10 | – |
| Gasoline | 12,0 | 8,8 | – |
| Methanol | 5,5 | 4,4 | – |
| Hydrogen | 33,3 | 2,4 | 3,0 |
| Methane | 13,9 | 5,9 | 10,0 |
| Propane | 12,9 | 7,5 | 25,9 |
| Butane | 12,7 | 7,6 | 34,4 |

Source: DWV

## Electrical systems for storing electricity

**Electric double-layer capacitors (EDLC)**
These are also known as supercapacitors, "SuperCaps" or "BoostCaps". They are electrochemical capacitors that have an unusually high energy density when compared to common capacitors, often thousands of times greater than a high-capacity electrolytic capacitor.

Some of the earliest uses were in motor start-up capacitors for large engines in tanks and submarines. As the cost has fallen they have started to appear on diesel trucks and railroad locomotives. Their ability to store energy quickly, efficiently and exhibit temperature stability for an almost unrestricted number of cycles, makes them particularly suitable for regenerative braking applications.

Use of batteries in such applications is limited because of their inability to absorb large amounts of energy in short periods. Capacitors are also used in PC cards, flash photography devices, portable media players and in automated meter reading devices.

**Superconducting magnetic energy storage (SMES)**
These systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature.

*Development of new materials for batteries and prototypes of specialised batteries by the Fraunhofer Battery Competence Network*

Photo: Fraunhofer ICT

A typical SMES system includes three parts: superconducting coil, power conditioning system and cryogenically cooled refrigerator. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. The stored energy can be released back to the network by discharging the coil.

Due to the energy requirements of refrigeration and the high cost of superconducting wire, SMES is currently used for short duration energy storage. Commercial uses are rather limited.

## Summary

- When the level of renewable power as part of the total energy mix increases, this energy needs to be stored in order to secure power supply integrity. This field presents substantial investment opportunities.
- These are many different demands on stored energy, and no one technology fits all requirements. While some technologies for storage of large volumes of energy are technically proven and commercially available, others require further R&D to develop them to full market maturity.
- Long-term centrally operated large storage systems (pumped water, compressed air and hydrogen) are capital intensive with long depreciation periods. The entrepreneurial risk is substantial. Hydrogen, especially in connection with fuel cells, has the advantage that it can be used for a large number of applications.
- The costs for storing large volumes of electrical energy vary between €0.03/kWh for short storage periods of a few hours, to €0.12/kWh for long-term storage and up to €0.35/kWh for special applications (see page 18).
- Investments for batteries are depreciated over short periods so they can readily be introduced with great flexibility. In conjunction with "smart grids", they have great potential for stabilising the grid and improving the efficient and cost-effective use of energy, once the appropriate systems and devices have reached their full potential. They will then be an interesting alternative to costly grid expansions.
- For stored energy used to power mobile applications, the volume and weight of the fuel required for a journey are deciding factors when choosing the most convenient and cost-effective system for travel.

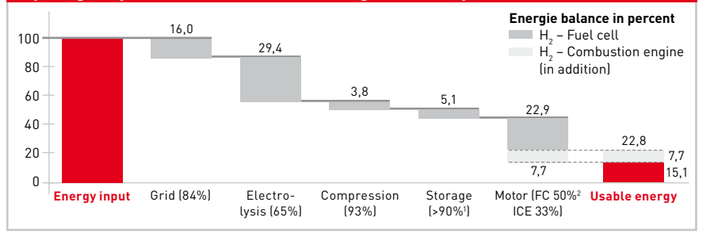
Electrical power is the preferred universal secondary energy carrier of choice and fuel cells, batteries and capacitors are essential to secure economical and sustainable energy solutions.

While there is no universal energy storage system for all mobile applications the following preferences have become evident:

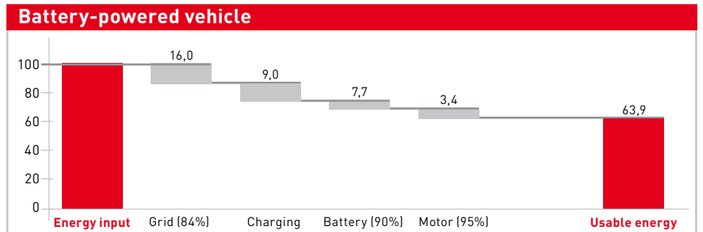
- Traction batteries: small or medium vehicles, driven with a light load in a stop & start mode in urban/city areas
- Hydrogen/fuel cells: buses and light trucks with medium load driven in stop & start mode; automobiles driven long distances at high speed on motorways.
- Conventional combustion engine/biodiesel: long-distance hauliers driving heavy vehicles with high loads.
- One or more systems may be combined in "hybrid systems" using battery with fuel cells or conventional motors as "range extenders". Such hybrid models are now offered by a number of car makers.

**Battery vehicles vs. fuel-cell-vehicle**

**Hydrogen-powered vehicle ($H_2$ through electrolysis)**




**Battery-powered vehicle**




[1] Compressed gaseous $H_2$ at 70 Mpa and 15°C
[2] Improvement potential of 10% assumed

*Source: BMU*

## Efficiencies and ecological impact

The economic viability and ecological impact of energy storage systems are determined by the efficiency with which energy is stored and retrieved. The following values have recently been published by the IFEU, which has developed a closed "storing and release" cycle.

The only mature technology for storing large volumes of electrical power is pump storage combined with hydro-electric power stations. Although diabatic compressed air energy storage systems and storage of large volumes of hydrogen have been realised commercially in a few cases, the technologies still need further development. Electrolysers are commercially available but the limited market demand to date has not allowed this technology to develop low cost structures required for widespread use. Likewise, the cost and efficiency of large fuel cells for converting hydrogen to power still needs to be developed. This also applies to the use of pure hydrogen in gas turbines.

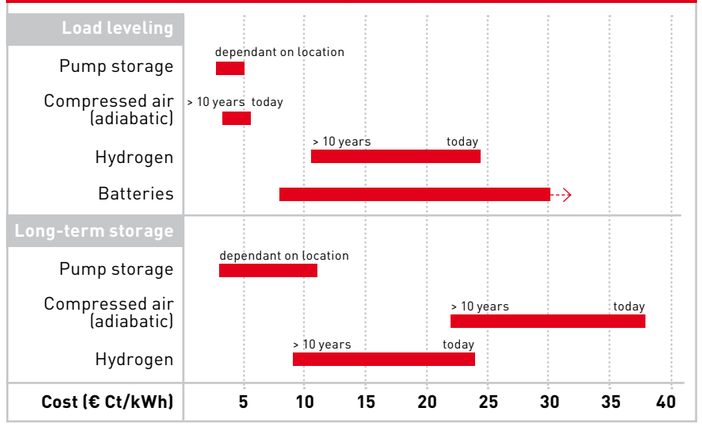
**Economic evaluation**
Clearly conversion efficiencies impact the economical evaluation of different storage systems. In a study published by VDE, the costs for constructing, operating and financing storage systems were estimated and are summarised in a graphic on this page. The VDE looked at "full cost" (building, financing and operational costs) for both short-term storage for load-levelling and for long-term storage applications.

**Efficiency of energy conversion processes (% electrical conversion)**

| | Storage | Discharge | Overall |
|---|---|---|---|
| Pump storage hydro power station | 84-88 | 86-91 | 72-80 |
| Compressed air energy storage (adiabatic) | 77-81 | 81-86 | 62-70 |
| Lead batteries | 80-88 | 81-90 | 65-79 |
| Li ion batteries | | | 90-95 |
| Redox flow battery | 84-90 | 83-89 | 70-80 |
| Hydrogen, electrolysis, fuel cell | 59-66 | 35-65 | 21-43 |

*Source: IFEU – Institut für Energie- und Umweltforschung Heidelberg GmbH sponsored by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)*

**Full cost comparison of mass storages**




*Source: IFEU – Institut für Energie- und Umweltforschung Heidelberg GmbH sponsored by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)*





## Mobility powered by renewable energy

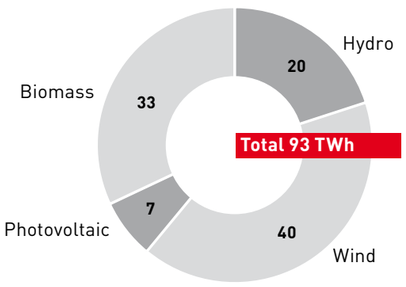
**Powering cars, buses and trucks with renewable energy is a major challenge. But the long-term rewards of building the required infrastructure are high, in terms of energy security, environmental protection and business opportunities.**

The key challenge for developing future transport mobility powered by renewable energy is the provision of affordable energy security and environmental protection.

Federal German objectives are to:

- Secure the technological and competitive position of an industry which provides approximately 2 million direct and indirect jobs and generates an added value of about €250 billion/year
- Reduce strategic dependence on imported oil
- Achieve the various climate and environmental targets
- Improve energy efficiency by 3%/year
- Increase the use of renewable energy for mobility (excluding aviation fuels) from 6% in 2008 to 17% by 2020.

**Renewable power generation in Germany 2009 (%)**




*Source: AGEB*

**Battery e-mobility**
The German government has set a target of 1 million BEV/PHEVs (out of a total of 50 million vehicles) on the road by 2020. This will require approx 0.12 TWh of energy, assuming an energy efficiency of 12 kWh/100 km and an annual average mileage of 10,000 km/vehicle. This is less than 1% of total national energy consumption and thus the amount can readily be provided by Germany's present power infrastructure.

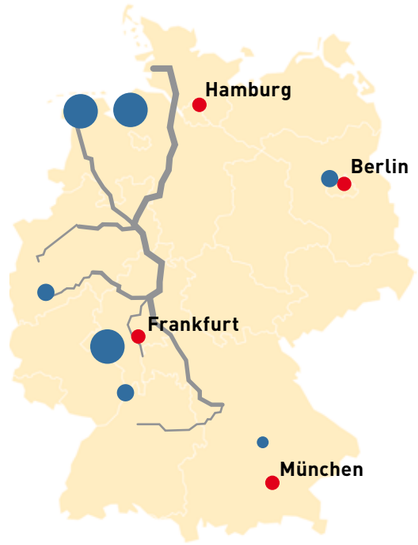
Once the number of electric vehicles has increased to that level, the energy stored in such batteries could be used to stabilize the grid by discharging during times of low renewable energy generation. Systems to manage such "smart grids" are described in the project "ICT for Electromobility" on page 56/57. This will however be of limited relevance as long as the total energy volumes remain relatively small (e.g. if 1 million cars discharge 1 kWh this would amount to 1 GWh and compares to 8,5 GWh stored in one pumped hydro station.). However, the contribution to achieving the economic and emission targets will be more substantial.

In an investigation into the cost of building charging points and switching stations the Fraunhofer ISI has come to the conclusion that charging vehicles at home will be the most economical route (€100 – 200 per charging point). Public charging points will be more expensive as they will have to be protected against vandalism. They are, however, essential for public acceptance of this technology.

Infrastructure for a battery switching station is estimated at around €750,000 and will require an additional outlay of €1.5 million for batteries (assuming 180 batteries to serve 700 cars/day at a cost of €8,000/battery). Business models for such battery switching stations or e-car sharing programmes need to be developed.

Currently, facilities for charging electric vehicles are being built in the eight "Model Regions for Electric Mobility" programme areas (see page 36/37) in order to standardise systems, develop business models and optimise cost structures.

## Infrastructure in Germany




**Liquid hydrogen production**

- 800 – 2100 GWh
- 248 – 800 GWh
- 24 – 248 GWh

**$CH_2$ transport by pipeline**

- 6641 – 6911 GWh
- 5947 – 6640 GWh
- 5 – 2310 GWh

*Source: GermanHy*

**Steps in the development of a hydrogen-infrastructure (2030 "moderate scenario")**

- *Infrastructure will be built up gradually, starting from densely populated urban areas*
- *During the introductory phase (until 2030) the transport by trailer of centrally produced liquid hydrogen to filling stations dominates*
- *With growing demand most hydrogen will be distributed by pipelines*
- *On-site production of hydrogen from natural gas, biomass and electrolysis will play a role in some regions*

**Hydrogen/fuel cells**

The federal strategy for sustainable fuels has identified hydrogen as an important medium long-term energy carrier for mobility and has set a target of 1 million hydrogen powered vehicles on the road by 2020.

A detailed study ("GermanHy") has been federally funded to identify perspectives for the introduction of hydrogen as a transportation fuel in Germany until 2050. Three scenarios based on different assumptions were developed. Some conclusions of this investigation were:

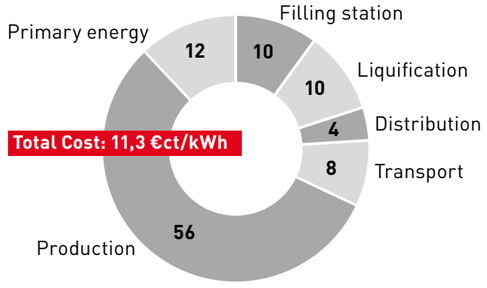
- Hydrogen has the potential to become an important energy carrier in the transport sector by 2050 and cover some 20% of the total (incl. rail) transport energy demand.

- Hydrogen will first be used in highly populated centres, where demonstration projects are already in operation (e.g. Berlin, Hamburg, the Rhine/Main area, the Rhine/Ruhr area, Stuttgart and Munich). Furthermore, where such user centres are close to each other, they will be connected by pipeline and allow commuter traffic.

- Costs for building a comprehensive network of hydrogen filling stations have been estimated by GermanHy as € 1 billion p.a. (until 2030). Earlier estimates slate the costs for building 1.000 stations in 5 years by 2017 at € 1,7 billion.

- Hydrogen is generated from a range of primary energies. Initial sources will be "by-product" hydrogen from industrial processes as well as from on-site reformation of natural and biogas. Supply from the gasification of biomass will play a limited role. In the longer term, wind energy and coal, coupled with $CO_2$ sequestration, will be important primary sources of hydrogen. The share of renewable energies in hydrogen production can be raised to above 60% by 2050.

**Analysis of the cost structure for hydrogen supply (%) in 2040 "moderate scenario"**




*Source: GermanHy*



An analysis of the expected cost structure for the supply of hydrogen as a transportation fuel was published by GermanHy and is illustrated in the graph on page 20.

The analysis shows that the cost of the primary energy is relatively low but that hydrogen production and logistics (filling stations, compression or liquefaction, distribution and transport) will be the main cost drivers.

Battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs) and fuel cell/hydrogen propulsion are complementary technologies aimed at achieving the federal objectives outlined above.

*Membrane electrolysis producing chlorine: Dow Chemicals in Stade. Power consumption: 600 MW, hydrogen is generated as a co-product.*

Photo: DOW Chemicals Stade


**Chemical infrastructure in Germany for supply of hydrogen**

Germany is the world's largest exporter of chemicals. It is the preferred location in the EU for production of chemicals and associated process industries, such as glass and ceramics, paper, board and biofuels.

Global players such as Dow Chemical, INEOS and SABIC have a significant production base in Germany and continue to expand here. Years of investment and production optimisation have resulted in a network of highly integrated production sites, linked by good logistical infrastructure and enjoying first class energy supply and service provision.

The benefits that investors enjoy are profiled in GTAI's publication "Germany's Chemical and Related Process Industry - A Profile of Selected Investment Sites". In it, we analyse the benefits of investing alongside Germany's global chemical producers on their well honed and well connected production complexes – not just for fellow chemical concerns, but for a wide range of associated process industries. The information can be downloaded from our website or ordered directly (see back cover for details).

Today most hydrogen is generated from fossil fuels such as natural gas, via steam-methane reforming (SMR), or from various residues using either partial oxidation (POX) or autothermal reforming (ATR) processes. The balance is generated as a co-product during the electrolytic production of chlorine from brine.


- *Geographical distribution of selected (out of, 4.700) biomethane plants in Germany*
- *Injection points into national natural gas pipeline network*

*Source: Deutsche Energie-Agentur GmbH (dena)*

Much of this co-product hydrogen from the chemical industry is currently burned in conventional power plants. Although it will play a role in the early stages of market development, supply is limited and it will only have a subordinate part in supplying the large volumes of hydrogen required for future fuel cell-driven vehicles.

Whether hydrogen is produced from fossil fuels, biogas, or from other renewable resources, Germany offers the potential investor an ideal infrastructure to realise his objectives in record time.

**Natural gas infrastructure for biogas logistics**

In Germany's rural areas, over 4.700 biogas plants convert biomatter (agricultural residues, plant and animal waste, whole cereal plants and grain) to methane, which is then used to generate approximately 1,600 GWh/year of renewable energy. This is fed into the power grid at generous feed-in tariffs.

These biogas plants are mostly located in isolated rural areas where there is no infrastructure of the sort required for operating large and efficient combined heat and power (CHP) units. Therefore, legislation has been passed that allows biogas to be injected into Germany's 400,000 km natural gas pipeline grid. Clearly biogas needs to be upgraded to meet the quality specification of natural gas.

In this way, the natural gas grid will be used to efficiently pipe biogas to large, centralised reformers, which will then produce "bio-hydrogen" close to the point of consumption. Today in Germany there are 24 biomethane plants which feed in 155 million m³/year of bio-methane into the natural gas grid. A further 40 are approved or already under construction.

Further sources of biofuels include: sewage gas from waste water treatment plants; carbonisation gas from pyrolysis plants (see page 60: Blue Tower project); coal mine gas; glycerine (from biodiesel production); solvents from exhaust gas cleaning systems, e.g. in paint shops; and traditional fermentation alcohols such as ethanol or methanol. The technology, infrastructure and economic framework are thus in place for building a bio-based hydrogen infrastructure.

**Hydrogen in natural gas**

The NATURALHY project, financed by the European Commission through FP6, aims to promote the development of the hydrogen infrastructure by adding hydrogen to the existing extensive European natural gas networks. The consortium involves 39 partners, including network operators, hydrogen producers, specialist practitioners and academic researchers in all relevant fields.

*Photo: KBB Underground technologies GmbH*

*Salt caverns are solution mined via wells in salt formations (bedded salts or salt domes) of sufficient thicknesses at depths of up to 2,000 m. Cavern dimensions can be more than 300 m height and 60 – 100 m diameter; volumes are generally in a range of between 500,000 – 800,000 m³. The specific properties of salt make it an ideal host rock for the location of stable tight caverns, suitable for storing gaseous and liquid hydrocarbons, as well as compressed air and hydrogen.*

## Energy storage systems for grid stabilisation

In a recently published white paper[1], BCG estimates that about 28 GW of compensating power capacity will be required in Germany by 2025 to store up to 40 TW h of electrical energy. This compares to present storage capacity of approx. 7 GW in Germany. These estimates are based on demands anticipated for predictable fluctuations (day/night, seasonal) and unpredictable ones (weather conditions).

[1] „Electricity Storage: making large-scale adoption of wind and solar energy a reality" by Cornelius Pieper and Holger Rubel of The Boston Consulting Group (BCG).

Insufficient ability to compensate for fluctuations is already a reality today. During 2009 when renewable power feed-in was high and electricity demand low, the spot prices for electricity in Germany actually sank to approx. minus €500/kWh despite a robust grid structure linked to European consumers.

dena (see page 29) has commissioned a consortium to develop a long-term perspective for integrating renewable energies, especially wind energy, into the German energy system.

Members of the consortium are Deutsches Windenergie-Institut, EnBW Transportnetze, E.ON Netz, Institut für solare Energieversorgungstechnik, RWE Transportnetz Strom, Vattenfall Europe Transmission and Energiewirtschaftliches Institut Köln (the consortium leader). The final report will be published by dena by the end of 2010 and will outline solutions on how to integrate wind energy (20 GW from offshore and 28 GW land-based generators by about 2020). The question of how to balance power generation with demand is pivotal for integration of fluctuating renewable power sources into the grid.

As this problem is shared by other European countries, the recently published Seatec project ("North Seas Countries' Offshore Grid Initiative") aims to connect the growing number of wind farms in the North Sea, thereby stabilizing the collective power input into the grid. Furthermore, pumped water power stations in Scandinavia will be employed to absorb excess power generated during high wind periods and feed it back into the grid during periods of high power demand.

A memorandum of understanding outlining the way forward will be signed by the end of 2010 by Ireland, the UK, the Netherlands, Belgium, Luxembourg, Germany, Denmark and Sweden.

Although grid extension can solve some problems, it does have its limitations such as its inability to compensate for day/night fluctuations. Furthermore, large parts of Europe experience similar weather conditions and there are transmission losses incurred by high voltage AC transmission lines (15% per 1,000 km).

Employing conventional fossil fuel fired back-up power plants to stabilize fluctuations caused by off-shore wind farms and other decentralized power generators will be limited by the strain they would place on the grid. A further approach for balancing the grid is to manage the consumption of power. This is described in the "Smart Grid" projects (see pages 54-57).

Photo: Alpha Ventus

*The consortium of EWE, E.ON and Vattenfall, the German Offshore Test Field and Infrastructure GmbH, or DOTI, has built its twelfth and last wind turbine in the 30 m deep North Sea, 45 km north of the island Borkum. The time required to complete all twelve turbines was just under seven months, making Alpha Ventus the world's first offshore wind park to employ a dozen 5-MW class wind turbines. The wind turbine construction measures around 148 m to 155 m from the sea surface to blade tip, the rotor has a diameter of 126 m and weight of one turbine is approx. 1,000 tons, construction from 01/08 to 11/09. The sums invested by EWE, E.ON and Vattenfall for this pioneering project amount to €250 M.*

Photo: ENERTRAG

*Electrolyser producing hydrogen from windpower*

## Summary

There are many technologies for storing electrical energy:

Pumped hydro is a mature technology with high efficiency of approx 80%. However the geography in the north German plains limits its implementation. Furthermore its environmental impact inhibits public acceptance.

CAES technology is being developed by a consortium comprising RWE, General Electric, Züblin, Ooms-Ittner-Hof GmbH, Erdgasspeicher Kalle GmbH and DLR.

This R&D project has been awarded a federal grant to build a demonstration plant to test technology for an adiabatic compressed air storage power plant in Germany by 2013. However, power and capacity for energy storage are limited.

Storage of hydrogen in underground salt caverns has still to be demonstrated on a large scale. It is the only technology which is able to store large amounts of energy decentrally with high flexibility. Cost and efficiencies need to be improved.

A further benefit of hydrogen is that it may be used to power mobile applications.

The much discussed idea of using "vehicle to grid" technologies, using BEV/PHEV batteries to stabilise the grid, will have little impact for the next decade (if 1 million traction batteries discharge 1 kWh, this amounts to only 1 GWh). Furthermore the Li-ion batteries are optimised for power and not for energy storage and will, therefore, have relatively high costs.

## Recycling

**Batteries**
A pilot plant for recycling lithium ion batteries will be constructed on Chemetall's production site for lithium and special metals and derivatives in Langelsheim.
This venture has received a federal grant of €8.4 M, with Chemetall contributing a similar amount.
Total investment is €18 M.

Chemetall is part of a consortium of 12 partners from industry and academia participating in a project named "LithoRec", a comprehensive research and development project aiming at developing technologies for the recycling of metals such as lithium and cobalt from traction batteries.

The collaborative effort is led by the TU Braunschweig and the Niedersächsischen Forschungszentrum Fahrzeugtechnik, and has a total budget of €18 M over three years, running until September 2011.

**Fuel Cells**
For almost a decade, the Hydrogen Institute of Applied Technologies (HIAT), located in Schwerin, has been conducting research aimed at reducing the amount of precious metals, such as platinum, used in fuel cells.

A collaborative research project – dubbed reACT, in which companies Remetall Drochow GmbH, FuMa-Tech GmbH, EKPRO GmbH and inhouse engineering GmbH have joined with the universities of Potsdam, Jena and the HIAT GmbH – has now qualified for a federal grant. Its goal is to further develop technologies to recycle precious metals from fuel cells and spent catalysts used in transport vehicles.

# Producers in Germany

Investors will find a well-developed fuel cell and battery industry network in Germany, capable of supplying materials, components, modules, and complete systems for specific applications. Selected companies – all potential partners for collaboration – are listed in the tables below. These tables are not exhaustive.

| | |
|---|---|
| **OEM / Fuel cell system integrators** | |
| Automobile and buses | Daimler, Opel/GM, Volkswagen, Ford, MAN, Honda |
| Materials handling/light duty vehicels | Kion (Linde, Still), Jungheinrich, Webasto, MULAG |
| Ships | Howaldtswerke-Deutsche Werft, Meyer Werft |
| Light traction | Clean Mobile, Masterflex, Hawk Bikes, Velo-Form, Herkules Accell, Meyra-Orthopedia |
| Back-up power and UPS | PASM, Rittal, P21, Zebotec, B+W Electronic Systems, ECG, RAU |
| APU | Hymer Mobile, Bürstner-Reisemobil, Burow-Mobil, Euro-Mobil |
| Stationary applications | MTU Onsite Energy, BAXI INNOTECH, Vaillant, Bosch Thermotechnik, Infraserv Knapsack, Infraserv Höchst, Udomi |
| **Fuel cells systems** | |
| Automotive/ materials handling/light traction | NuCellSys, Proton Motor, Smart Fuel Cell, Masterflex, Heliocentris, H-Tec |
| Ships | Siemens, MTU, Proton Motor Fuel Cell, Fronius |
| Portable | SFC Smart Fuel Cell, Elcomax, FWB Kunststofftechnik, N2telligence, Enymotion |
| Stationary | MTU Onsite Energy, BAXI INNOTECH, Vaillant, Hexis, EBZ, Ceramic Fuel Cells |
| Back-up power and UPS | P21, Future-e, Zebotec, SFC Smart Fuel Cell, Enerday, H-tec, B+W Electronic Systems |
| APU | SFC Smart Fuel Cell, Truma, Enymotion, eZelleron, Swarco FuelCell, MFC |
| **Fuel cell stack** | |
| MCFC | MTU Onsite Energy |
| SOFC | Staxera, EBZ, Ceramic Fuel Cells, Enerday, eZelleron |
| PEMFC | Schunk, Proton Motor, Elcomax, Masterflex, Baltic Fuel Cells, Truma |
| DMFC | SFC Smart Fuel Cell , FWB Kunststofftechnik, Baltic Fuel Cells |
| **Stack components** | |
| MEA | SolviCore, 3M, Baltic Fuel Cells , FuMA-Tech, BASF |
| Bipolar plates, end plate | Schunk, SGL Carbon, Eisenhuth, Reinz, Plansee, Gräbener, Borit Leichtbau |
| Separator/gasket | Freudenberg, Eisenhuth, Kerafol, SKF Sealing Solutions, SGL Technologies |
| Electrode/gas diffusion layer | Freudenberg FCCT, SGL Carbon, Baltic Fuel Cells, GKN Sinter Metals, Gaskatel |
| Catalyst | Süd Chemie, Umicore, BASF, W.C. Heraeus |
| Filter | Freudenberg FCCT, SGL Carbon, Mann & Hummel |
| **Balance of plant (BoP)** | |
| Electrolyzers | H-tec, zebotec, ELT Elektrolyse Technik, Hydrogenics Deutschland |
| Reformer | WS Reformer, Mahler AGS, Messer Griesheim, Praxair Industriegase, Air Liquide |
| Pumps/compressors | WILO, Grundfos, Gebr. Becker, Gardener Denver, HNP, Schwarzer Precisions, IWAKI |
| Valves | Bosch, Bürkert, Otto Egelhof GmbH, GHR Hochdruck-Reduziertechnik , NassMagnet |
| Power inverters | SMA, KACO, Hella KGaA Hueck & Co, Voigt & Haeffner, Agilent Technologies, Flexiva, ABB |
| **Infrastructure/technology providers** | |
| Biomethan gas conditioners | MT-Biomethan, Landwärme, ÖkoBit, Planet Biogastechnik |
| Biogas plant | Schmack, BioConstruct, EnviTec, WELtec, Viessmann Werke, BIOGAS NORD, MT-Energie |
| **Distribution** | |
| Dispenser and filling stations | Linde, TOTAL, WEH, Aral forschung, Deutsche Shell, Dynetek Europe |
| Others | Hs turbo, ANDREAS HOFER Hochdrucktechnik |
| **Storage of $H_2$: natural gas** | |
| Underground storage | KBB, E.ON, Verbundnetz Gas, RWE Gasspeicher, ExxonMobil, Kavernspeicher, Staßfort StatoilHydro, Total, ConocoPhillips |
| Pressure tanks | MCS, Hella KG Hueck, Honda, Germanischer Lloyd, Dynetek Europe |
| Metal hydrides/nanostructures | Cardec, Udomi, BAYER Tech. Services, Baltic Fuel Cells, GFE |
| **Manufacturing** | |
| Project developer for FC and $H_2$ | Overspeed, Planet Energie |
| Labs and certifiers | TÜV Süd, TÜV Rheinland, TÜV Nord, UL International, TesTneT, ZSW, ET Energie Tech., moehwald |
| Fuel cell production plant technology | Trumpf, FIX Maschinenbau, Manz Automation, SITEC, Freudenberg, Schiller Automation, Gräbener Maschinenbau, IKA, Mechatronics |

Source: VDMA, Germany Trade & Invest

## Major producers of batteries in Germany

| Producers | Web-sites | Comsumer/portable use | Industrial/stationary use | Mobile traction | Special applications |
|---|---|---|---|---|---|
| BAE Batterien | www.bae-berlin.de | | ■ | ■ | ■ |
| BMZ | www.bmz-gmbh.de | ■ | ■ | ■ | ■ |
| DBM | www.dbm-energy.com | | ■ | ■ | ■ |
| Deutsche Accumotive (JV of Daimler and Evonik) | n/a | | | ■ | |
| Diehl & Eagle Picher | www.battery.de | ■ | | | ■ |
| Exide Technologies | www.exide.de | | ■ | ■ | |
| FRIEMANN & WOLF | www.friwo-batterien.de | ■ | | | ■ |
| GAIA | www.gaia-akku.com | | ■ | ■ | ■ |
| Enersys – Hawer | www.enersys-hawker.com | | | ■ | ■ |
| HOPPECKE | www.hoppecke.de | | ■ | ■ | |
| Johnson Controls Power Solutions | www.johnsoncontrols.com | | | ■ | |
| Li-tec Battery (JV of Daimler and Evonik) | www.li-tec.de | | ■ | ■ | |
| Mittermaier und Söhne | www.bayernbatterien.de | | ■ | ■ | |
| Moll | www.moll-batterien.de | | | ■ | ■ |
| Tadiran (saft group) | www.tadiranbatteries.de | ■ | ■ | | ■ |
| Varta Microbatteries | www.microbatteryshop.com | ■ | | | |
| Werbat | www.werbat.de | | ■ | ■ | |

## Example of possible partners for battery manufacturers

| | Chemiepark Wolfgang | Daimler | Digatron | Drewag | Eaton Corporation | Effekta Regel | EnBw | Enertrag | E.ON | Evonik Saar Power | EWE | GE Digital Energy | Juwi | M+W Zander | MAN | Meyer Werft | MVV | N-Energy | Opel | Rittal | RWE | Siemens | Sixt | Solarparc | ST AWAG | Südchemie | Voith | Volkswagen | Younicos |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Utilities | | | | ■ | | | ■ | | ■ | ■ | ■ | | | | | | ■ | ■ | | | ■ | | | | ■ | | | | |
| Integrators | | | ■ | | ■ | ■ | | | | | | ■ | | | | | | | | ■ | | | | | | | | | |
| PVJ wind park developers | | | | | | | | | | | | | ■ | | | | | | | | | | | ■ | | | | | |
| Hybrid power plant manufacturers | | | | | | | | ■ | | | | | | | ■ | | | | | | | | | | | ■ | | | ■ |
| Turn key plant manufacturers | | | | | | | | | | | | | | ■ | | | | | | | | | | | | | | | |
| Automobile | | ■ | | | | | | | | | | | | | | | | | ■ | | | | | | | | | ■ | |
| Ships/rail | | | | | | | | | | | | | | | | ■ | | | | | | ■ | | | | | | | |
| E-car sharing | | | | | | | | | | | | | | | | | | | | | | | ■ | | | | | | |
| Material suppliers | ■ | | | | | | | | | | | | | | | | | | | | | | | | | ■ | | | |

## Expertise is all around

**Germany is well endowed with industry organisations to help potential investors in all sorts of ways. Some of the leading bodies are shown here.**

### NOW GmbH
### Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

The National Organisation for Hydrogen and Fuel Cell Technology (NOW GmbH) was founded in 2008 by the German Federal Government, through an initiative of the Federal Ministry of Transport, Building and Urban Development (BMVBS). NOW's task is to coordinate and implement two federal programmes: the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP) and the Model Regions Electric Mobility Programme of BMVBS.

NOW's prime function is to initiate, evaluate and bundle projects in a meaningful way. But it also has cross-sectional functions which include topics such as production technologies, education and training, communication at the interface between government and industry, and public relations activity to raise awareness for these technologies and their products.

In its committees, NOW brings together representatives from the areas of politics, industry and the academic community. The advisory council provides a neutral platform which is used to develop NIP flexibly and in line with market requirements. Formulating political objectives, promoting technologies and preparing markets are tasks undertaken in an integrated process in which the partners constantly provide each other with new stimuli and valuable feedback. Thus full use can be made of the specific strengths of each individual partner.

International cooperation is another major concern for NOW. After all, using clean and economically sustainable technologies is a global challenge. The International Partnership for the Hydrogen Economy (IPHE) involves governments in these discussions. Germany will chair the IPHE in 2010–2011, with NOW running the secretariat.

**www.now-gmbh.de**

### Deutsche Energie-Agentur GmbH (dena) / German Energy Agency

The Deutsche Energie-Agentur GmbH (dena) – the German Energy Agency – is the centre of expertise for energy efficiency and renewable energy sources. It focuses on the development of sustainable energy systems which make optimum use of energy and integrate renewable energy sources. dena's mission is to generate economic growth and maintain prosperity with ever lower energy inputs. If this is to be achieved, energy must be generated and used in both a national and international context as efficiently, safely and economically as possible with the least possible impact on climate.

dena is developing energy efficiency and renewable energy markets in cooperation with stakeholders from the worlds of politics and business and from society at large. dena is working not only on consumption-side issues such as buildings, power and mobility, but also on issues of generation, networking and storage.

dena encourages copybook projects, identifies and rewards pioneering work, advises politicians, manufacturers and service providers, cultivates opinion leaders, informs consumers, builds networks, evaluates technologies, analyses foreign markets and models future scenarios. dena primarily relies on market mechanisms and innovative energy services, backed up by appropriate regulatory policies and promotion programmes.
Due to the huge potential energy efficiencies involved, Russia is one of dena's key cooperation partners. This is why dena holds a 40 percent stake in the Russian-German Energy Agency (rudea) which was established in July 2009.

dena was established in the autumn of 2000 with its head office in Berlin. Shareholders in dena are the Federal Republic of Germany, KfW Bankengruppe, Allianz SE, Deutsche Bank AG and DZ BANK AG.

**www.dena.de**

### DWV
### Deutscher Wasserstoff-Verband (German Hydrogen and Fuel Cell Association)

The German Hydrogen and Fuel Cell Association (DWV) is a non-profit organisation which promotes the introduction of hydrogen as an energy carrier, primarily in the energy and transportation sectors. Furthermore, it supports R&D to this end. DWV represents about 300 members and is financed by membership fees and contributions. All interested companies and private persons worldwide are welcome to join.
DWV brings experts, companies and research institutes together to form a "lobby" for the promotion of one energy carrier of the future. To this end it cooperates with many national and international associations and institutions.

**www.h2de.org**

**BAM**
**Bundesanstalt für Material-forschung und -prüfung**
**(Federal Institute for Materials Research and Testing)**

The Federal Institute for Materials Research and Testing (BAM) has the task of overseeing safety in technology and chemistry. With an annual budget of €130 M (split between basic funding from the Federal Ministry of Economics and Technology and third-party funding) its staff of approximately 1,800 people is engaged in three main areas:

- Research and development (R&D)
- Testing, analysis, approval and certification
- Consultation, information and advice.

Most of its work centres on safe handling of dangerous goods as well as on safe operation of technical systems and processes. This is based on assessment of procedures for safe and environmentally compatible behaviour of materials, including advanced methods for chemical analyses, investigation of damage mechanisms and failure analysis.

One example of its activities is assessing and advising on the safety-related properties of gases, e.g. hydrogen for industrial or automotive applications.

BAM produces over 6,000 test reports and certificates on a wide range of subjects, publishes about 580 scientific and technical publications and holds around 860 lectures and courses annually. It is involved in more than 1,200 national and international commitments including 88 statutory and regulation committees, 570 standardisation committees (ISO, CEN, and DIN) and 90 teaching positions.

Industry, public administration, as well as standardisation and regulatory bodies account for three quarters of its customers, the balance being made up of technical organisations, R&D institutes and professional organisations.

BAM is a partner and service provider to industry and commerce, policy makers and consumers alike.

**www.bam.de**

**TÜV SÜD**

With consolidated annual sales of €1.4 billion, TÜV SÜD is a globally operating technical services and certification body. It pursues the philosophy of "choose certainty" when dealing with customers.

Headquartered in Munich, Germany, it operates with approximately 14,000 staff in over 600 locations in Europe, the US and Asia. TÜV SÜD's certified experts and technical consultants offer their core competencies – consulting, testing, certification and training – to customers from very varied industries, thereby covering the entire value-added chain. Strategic business areas for TÜV SÜD are industry, mobility and personnel.

TÜV SÜD customers benefit from a comprehensive range of services in the field of process engineering in the area of hydrogen and fuel cell technology. The company supports manufacturers, system integrators and operators in all aspects of their activities. For instance, the certification of hybrid vehicles that use hydrogen, or the safety concept for a stationary fuel cell, might start with a look at the relevant aspects of explosion protection for the hydrogen filling station.

TÜV SÜD's reference list includes Daimler, BMW, Porsche, Linde, Air Liquide, Volkswagen, General Motors, MAN, Fronius, Smart Fuel Cell, Proton-Motor and H2Logic. TÜV SÜD also supports nationally and internationally funded hydrogen projects.

**www.tuev-sued.de**



## Fuel Cells

**VDMA**
**Verband Deutscher Maschinen- und Anlagenbau e.V.**
**(German Engineering Federation)**

Mechanical engineering is a key technology in Germany. Almost 1 million employees in the sector generate annual sales of over €200 billion, of which 75% is exported.

The German Engineering Federation (VDMA) represents more than 3,000 member companies in the mechanical engineering industry, making it one of the largest and most important industrial associations in Europe. Its members cover the entire value chain from components and plant manufacturers, system suppliers and system integrators through to service providers.

More than 200 manufacturers of drive technology, batteries and components are organised in the Research Association for Power Transmission Engineering (FVA). VDMA and FVA are principal sponsors of the MobiliTec trade fair for hybrid and electric power train technologies, mobile energy storage and alternative mobility solutions at the Hanover Fair.

"VDMA Fuel Cells" represents 60 fuel cell and component producers. Many more drive technology and fuel cell component suppliers are organised in VDMA associations such as "VDMA Pumps + Systems or VDMA Compressors, Compressed Air and Vacuum Technology".

"VDMA Fuel Cells" is an industry network for manufacturers of fuel cell systems and components and leading research institutes, focusing on networking, systems and components optimisation, industry initiatives and public relations.

Two task forces have been formed within VDMA Fuel Cells to support members in the full cell business.

- The lobbying "Task Force Industry Policy" generates fuel cell statistics and develops political positions and strategies.
- The "Task Force Industry Network" addresses issues related to the optimisation and the serial production of fuel cell systems and components.

**www.vdma.org/brennstoffzellen**
**www.fva-net.de**

**HyCologne**
**Wasserstoff Region Rheinland**
**(Hydrogen Region Rhineland)**

The chemical and petrochemical industry around Cologne produces significant quantities of hydrogen as a byproduct of its reactions. An industrial-scale infrastructure for collection and transport of the gas has been in operation for some 70 years.

A regional technology cluster, called HyCologne, has been founded to support the development of hydrogen as a fuel. It is a public-private partnership with about 20 participating companies. It maintains close contact with the R&D facilities of car makers Ford, Daimler and Toyota, as well as three Max Planck institutes and the Cologne University of Applied Sciences.

HyCologne is one of Germany's most advanced hydrogen initiatives and is a partner in the international Hydrogen Bus Alliance. In mid-2010 the first hydrogen fueling station for buses will be ready for operation to serve the first fleet of 18 metre long hybrid fuel cell buses going into service in the Cologne area.

HyCologne's major aims are:

- Development of a hydrogen-powered bus fleet, including a local supply infrastructure
- Development of a fuel cell power plant to generate heat and electricity (CHP)
- To offer consulting services for public and private organisations

**www.hycologne.de**

**H2 Herten Wasserstoff-Kompetenz-Zentrum (Hydrogen Competence Centre H2Herten)**

The Hydrogen Competence Centre H2Herten brings together a local cluster of hydrogen and fuel cell activities in the "Hydrogen City" of Herten, located in the middle of the Metropole Ruhr area, the energy region of North Rhine-Westphalia.

The three main projects of the Hydrogen Competence Centre are:

Renewable hydrogen production
- A demonstration plant known as Blue Tower is capable of producing 37,500 MWh of energy a year and 150 $m^3$ of hydrogen an hour from biomass.
- A wind-powered electrolysis plant supplies the H2Herten application centre with renewable hydrogen and electricity.

Production and development
The $H_2$Herten application centre offers offices, laboratories and workshop areas. National and international hydrogen/fuel cell companies can be found on the site. The whole spectrum from production of hydrogen and fuel cells to stationary and mobile applications can be found in Herten.

**Hydrogen supply/logistics hub**
A hydrogen filling station supplies hydrogen-powered vehicles in the area.

It is located close to the logistics hub/autobahn network offering its customers prime access to the largest chemical cluster in Europe.

**www.wasserstoffstadt.de**

**The Boston Consulting Group**

The Boston Consulting Group (BCG) is a global management consulting firm and the world's leading advisor on business strategy. The company partners with clients in all sectors and regions to identify their highest-value opportunities, address their most critical challenges, and transform their businesses. BCG's customized approach combines deep insight into the dynamics of companies and markets with close collaboration at all levels of the client organization. This ensures that its clients achieve sustainable competitive advantage, build more capable organizations, and secure lasting results. Founded in 1963, BCG is a private company with 69 offices in 40 countries.

BCG's Energy Practice Area helps companies to orientate their businesses in an increasingly complex environment. In doing so, it partners with all relevant market players: international energy companies, major integrated oil companies and utilities, global power developers, grid operators, and emergent energy trading companies. Recent studies on energy storage and solar energy, in addition to further information about BCG, can be found at

**www.bcg.de.**

**LBST LUDWIG-BÖLKOW-SYSTEMTECHNIK GMBH**

Ludwig-Bölkow-Systemtechnik GmbH (LBST) is an expert consultancy for energy and environment issues, supporting international clients from industry, finance, politics and non-governmental organisations in strategy, technology and sustainability.

Its cutting edge competence is based on over two decades of continuous experience and on its interdisciplinary team of leading experts, bridging policy, economy and technology.

LBST support its clients with:
- System and technology studies: technology assessment and due diligence; energy and infrastructure concepts; feasibility studies;
- Strategy consulting: product portfolio analysis, identifying new products and services; market analysis, decision support, and policy support;
- Sustainability consulting: life cycle and carbon footprint analysis; natural resources assessment (energy, minerals, water); sustainability due diligence;
- Coordination: project management, monitoring and assessment; and
- Capacity building: studies, briefings, expert workshops, training.

Particular expertise exists in energy (renewables, energy storage, hydrogen and fuel cells) and mobility (fuels and drives, infrastructure, mobility concepts). LBST's work in sustainability cuts across all sectors.

A key common denominator of all activities is the rigorous systems approach, making sure all relevant elements of a tightly networked system are taken into account, thus providing customers with a comprehensive and complete basis for their decisions.

With its deep understanding of developments and technologies and its truly independent advice, LBST helps its clients to secure their future.

**www.lbst.de**

**Roland Berger Strategy Consultants**

Roland Berger Strategy Consultants, founded in 1967, is one of the world's leading strategy consultancies. With 36 offices in 25 countries, the company has successful operations in all major international markets.
In 2008, it generated more than €670 M in revenues with 2,100 employees. The strategy consultancy is an independent partnership exclusively owned by about 180 partners.

Roland Berger Strategy Consultants covers every key strategic topic that is decisive for its clients' success: growth, portfolio optimisation, internationalisation, cross-border mergers and acquisitions, post-merger integration, marketing and branding strategies, strategic alliances, reorganisation and corporate restructuring as well as value-based management.
Since 76% of its projects are of an international nature, it combines a global outlook with local expertise. Each project involves local experts who are thoroughly conversant with the countries concerned.
"In the field of environmental technology Roland Berger Strategy Consultants has outstanding expertise in environmentally friendly power generation and storage, energy and material efficiency, waste management and recycling, sustainable water management and sustainable mobility. Clients are global groups, environmental technology companies, the financial sector and public authorities."

**www.rolandberger.com**

## Support at every level

**Germany's ambition to stay at the cutting-edge of innovation and green technologies means there is plenty of financial support available for investors from regional, national and international sources**

To maintain Germany's competitive edge in "green technologies", the federal German institutions and the German states (Länder) have designed an extensive range of support programmes, often within the European Union's overarching framework for industrial development. Some of these programmes specifically address the issue of electrical energy storage; others address activities in general in innovation and the high technology and green technology sectors.

Efforts to store electrical energy form part of the prestigious green technology industry and qualify as innovative high-technology research. They thus hold high potential to be supported and subsidised by various support mechanisms on the German market.

To provide a systematic overview, the following introduction to the subsidy and support landscape in Germany has been split into administrative levels and can, to a certain extent, be seen as cumulative funding opportunities.

**Funding at EU level**
The Lisbon goals of the European Union express its ambition to become the most competitive and knowledge-driven economic area in the world. The resulting multi-billion Euro initiatives, such as the European Commission's Seventh Framework Programme for Research, Technical Development and Demonstration (FP7), place special attention on cooperative energy research, both applied and pioneering.

Germany represents a key player in green technology efforts due to its high market share and innovation leadership in the green technology sector. Already German participants are taking a lead role in several multi-million Euro programmes in the field of electrical energy storage and there are ongoing calls for proposals for new projects for 2010 with funding of up to €600 M in the field of storage R&D.

Several parallel programmes have a broader focus, such as the Eurostars programme, which is aimed at directly supporting cross-border R&D activities with grants of up to €1 M. Electrical energy storage research would qualify for these grants.

**German federal funding**
In recent years green technology has become one of the defining features of the German economic landscape. In order to boost the green economic sector federal German institutions have initiated subsidy programmes for basic research, applied R&D, pilot projects, project finance and international cooperation.

Large-scale "lighthouse" projects include electrical energy storage, such as the smart grid projects of the federal E-Energy initiative or the €500 M initiative aimed solely at boosting electric mobility, which forms part of Germany's public spending initiative to fight the global recession.

One of the most significant initiatives in this field is the Basic Energy Research 2020+ programme of the Ministry for Education and Research (BMBF), with some €2.2 billion of funding. This includes the "Lithium Ionen Batterie LIB 2015" programme. Similarly, the Federal Ministry of Transportation (BMVBS) is running a €115 M programme on "Model Regions for Electric Mobility" and the Federal Ministry of Economics and Technology (BMWi) has a €115 M programme to support, amongst other energy issues, energy storage R&D.

In addition to the programmes aimed specifically at green energy issues there are several federal programmes supporting R&D in general and high-technology in particular. The EXIST programme, for example, supports the commercialisation of sophisticated high-technology developments, while the ZIM programme funds innovative R&D cooperations and projects. Eligible are project costs up to €350,000 with grants up to 50% for small and medium-sized enterprises (SMEs).

Furthermore, there are several federal financial vehicles in place to support innovative high-technology enterprises in their various entrepreneurial stages with seed money and venture capital, such as the ERP-Startfonds and the High-Tech Gründerfonds.

The implementation of green technology and renewable energy projects by end customers is supported by the KfW-Bank, which offers subsidised loans under its renewable energy programme or energy and environmental efficiency programmes with values up to €10 M.

From an export perspective, Germany seeks to unlock the growth potential of its electrical energy storage enterprises by leveraging its "Auslandshandelskammer" (AHK) contacts, providing a systematic information and organisation platform together with "Germany Trade & Invest" and, last but not least, by initiating special export support programmes with the "Energy Efficiency Made in Germany" and "Exportinitiative Renewable Energies" programmes by the BMWi.

**State and regional funding**
On a state level, all 16 German Länder have come up with programmes to enhance their already established capabilities in the various segments of the green technology industry. In order to stimulate these developments most of the state ministries for economic development and environment have established subsidy programmes to promote excellence in high-technology R&D and entrepreneurship. They have also established cluster initiatives, for example in Bavaria, Saxony, Schleswig Holstein, Thuringia and North Rhine-Westphalia (NRW), and are actively pushing green business development.

Some states have put electrical energy storage on their agendas as a particular support issue. For example, Brandenburg has its REN programme, with individual grants of up to €1 M, and NRW has its Ziel2 programme with €46.5 M of funding for electric mobility.

All states have initiated support programmes for the wider field of renewable energy (often covering electrical storage activities), either directly with grants or indirectly through consulting, networking and promotion. Grants and competition prizes are given by the relevant ministries or clusters for high-technology initiatives, green technology R&D, green technology implementation, start-ups and pilot projects.

In addition to grants and indirect support, state banks provide support in the form of equity, subsidised loans, guarantees and other favourable financial means specifically designed for high technology or clean technology projects, including energy storage investments.

Again, looking beyond their borders, the relevant ministries of economics seek to boost the growth of their regional clusters through their own export initiatives, such as NRW. International or Bayern International. They jointly organise subsidised trade fair and marketing trips into relevant markets as well as events – with green technology and renewable energy again featuring heavily on the agenda.

Lastly, depending on the geographical and structural situation of the area, some regions are also eligible for special EU support for cross-border activities, some of which explicitly name green technology or energy-related activities on their agenda, for example the INTERREG IV A programme "Deutschland–Nederland" 2007–2013.

To sum up, electrical energy storage efforts are eligible for a whole range of support mechanisms. The importance of the green technology and energy sector has been recognised at all administrative levels.

Germany, within a dynamic European context, is positioning itself as a key player in this segment by creating a market with lighthouse projects as well as green energy and pricing policies. To this end it is creating a generous support and subsidy landscape for technological ventures that promise attractive growth rates in the next decade.


Modellregionen Elektromobilität


Photo: Daimler

## Project

Model Regions Electric Mobility
www.now-gmbh.de

## Key data

**Locations**
8 Model regions:
Hamburg, Berlin-Potsdam, Saxony, Munich, Region Stuttgart, Rhine-Main, Rhine-Ruhr, Bremen-Oldenburg

**Project supported by**
NOW GmbH

**Project leader**
NOW GmbH

**Further partners**
8 model regions

**Time line**
2009 – 2011

**Investment for demo project (M€)**
115

## Thumbnail sketch

The programme "MODEL REGIONS FOR ELECTRIC MOBILITY" of the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) allocates €115 M in funding to the promotion of electric mobility and the general development of electric mobility starting from regional clusters, aiming at establishing Germany as European lead market in this field.

## Project details

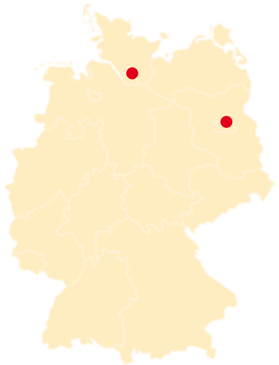
The second recovery programme is part of the 2009 German Stimulus Package and has a runtime of two years until 2011. In eight selected model regions across Germany the programme sets out to generate as much empirical value from different concepts to contents, with regard different technological and operational concepts and varying regional conditions as possible. The focus in the model regions lies on the integration of manufactures, customers and public transportation services, utilization patterns of electric mobility solutions, demonstration of different technologies, integration of different transport modes and the development of new business models. Cross-sectional tasks include communication and expectation management, regulatory framework and scientific infrastructure development.

## Business and investment opportunities

Suppliers are invited to support the build-up of vehicle fleets (passenger cars, buses) based on battery-electric power trains or hybrid as well as the charging infrastructure for e-mobility and development of new business models.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| e-vehicles integrated into public transport system | ● | ● | ● | ● | ● | | ● | |
| Car sharing services | ● | ● | | | | ● | ● | |
| Linked with other e-mobility services (e-bikes) | ● | ● | | | ● | ● | ● | |
| Free accessible charging stations on public roads | ● | | | | | | | |
| e-delivery services | ● | | ● | ● | ● | | | ● |
| Production line for e-vehicles or traction storage | | | | ● | | | ● | |
| Personal e-mobility centre | | ● | | | | | | ● |
| e-mobility for commuters | | ● | | | | | | |
| Hybrid bus services | | | ● | ● | ● | ● | ● | ● |
| Communication of renewable energy projects in buses | | | | | ● | | | |
| Development of special vehicles (e-garbage collection, e-bikes) | | | | | | ● | | |

# Clean Energy Partnership (CEP): Hydrogen for road transport



Clean Energy Partnership CEP

Ein Projekt im Nationalen Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie (nip)


*Refuelling a hydrogen-driven car does not differ much from filling a conventional vehicle. The differences result from the high volatility of hydrogen, its low temperatures, or the high filling pressures. Most hydrogen in the world is produced from natural gas or LPG by steam reforming.*

Photo: CEP

## Project

Clean Energy Partnership (CEP)
www.cleanenergypartnership.de

## Key data

**Locations**
Berlin, Hamburg

**Project supported by**
NOW GmbH

**Project leader**
NOW GmbH

**Further partners**
BMW Group, BVG, Daimler, Ford, Opel/GM, Hochbahn, Linde, Shell, Statoil, Total, Toyota, Vattenfall, Volkswagen

**Time line**
2004 – 2016

## Thumbnail sketch

With its roots in the"Transport Economic Energy Strategy", the Clean Energy Partnership (CEP) aims to provide comprehensive evidence that it is possible for normal customers to safely use hydrogen for road transportation. With the goal of energy diversification and a broader usage of renewable energy sources, hydrogen offers a unique opportunity.
The project is divided into three phases. The final one starts in 2011 and targets preparation of the market for commercial hydrogen-powered vehicles by 2016.

## Project details

CEP is one of the largest and – as regards to the technologies to be tested – one of the most multifaceted projects in the world. It covers several hydrogen filling stations as well as a fleet of round 40 hydrogen cars and a number of buses, as well as a multitude of $H_2$-applications; decentralised production of hydrogen – either by electrolysis or by LPG-reforming, central hydrogen production by natural gas reforming and liquefaction as well as hydrogen distribution, storage and supply at the filling stations and the mobile use in fuel cell propulsion systems or in internal combustion engines. Leading technology suppliers, oil-, gas- and energy companies as well as the majority of German vehicle manufacturers are participating in this innovative project.

## Business and investment opportunities

CEP is an open partnership and welcomes further members willing to develop their position in Germany e.g. suppliers/manufacturers of:

- $H_2$/FC-Vehicles, fuel cell systems and components as well as suppliers of filling and storage devices
- A supplier of test and diagnostic tools and a service provider (maintenance, engineering, etc.)

Participants in the Clean Energy Partnership are continuously developing their products and applications and therefore provide a wide range of business opportunities for suppliers along the entire value chain e.g. companies building the $H_2$-infrastructure such as system and component suppliers for $H_2$ production, transport, distribution; as well as service providers, filling station operators, engineering, maintenance/service companies.

# HyFLEET:CUTE: Hydrogen-powered bus fleet




*Operation of hydrogen buses in regular public service*

Photo: HyFLEET: CUTE

## Project

HyFLEET:CUTE
www.global-hydrogen-bus-platform.com

## Key data

**Locations**
Berlin, Hamburg

**Project supported by**
EU-Project

**Project leader**
Daimler AG

**Further partners**
31 partners from industry, government, academic and consulting organisations

**Time line**
2006 – 2009

**Investment for demo project (M€)**
18.5

**Environmental benefit**
$CO_2$ emission reduction

## Thumbnail sketch

Design, construction, testing of the next generation of fuel cell and internal combustion engine buses. Development and testing of a new hydrogen refueling infrastructure involving hydrogen produced from LPG and bio DME while stationary fuel cells power the site. Operation of existing fueling stations in 9 cities. Globally 33 hydrogen fuel cell powered buses in 9 cities – Amsterdam, Barcelona, Beijing, Hamburg, London, Luxembourg, Madrid, Perth, Reykjavik provide real life experience.

## Project details

In Hamburg, the bus fleet has been increased from 3 to 9 buses with fuel cell technology. In Berlin, a new fleet of 14 hydrogen internal combustion engine buses is deployed. In addition to the functional aspects of optimising the fuel consumption and energy efficiency of the entire system, the project will also analyse and study public opinion on the risks and advantages of hydrogen and hydrogen-powered transport systems as well as inform the community and key decision-makers about the potential advantages of a hydrogen-based transport system and how they can help to develop it. Partner organisations active in Germany are: Hochbahn, Vattenfall, hySOLUTIONS, BP, Daimler AG, EvoBus GmbH, MAN Nutzfahrzeuge, NEOPLAN Bus, TOTAL Deutschland, BVG.

## Business and investment opportunities

This is an open partnership and companies are invited to participate as partners. Furthermore, this demonstration project and its national commercialisation are a great business opportunity. All suppliers of products and services along the value chain are welcome. It is estimated that there are well over 30 000 buses in operation, providing public transport in Germany. In addition, there are numerous bus fleets operated commercially.

# Zero Regio: Hydrogen-powered mobility




*Multi-fuel service station at the Industrial Park Höchst, Frankfurt/Main*

Photo: Infraserv GmbH & Co. Höchst KG

## Project

Zero Regio
www.zeroregio.com

## Key data

**Location**
Frankfurt/Main

**Project supported by**
European Commission
(6th Framework Programme)
and Industry

**Project leader**
Infraserv GmbH & Co. Höchst KG,
Frankfurt/Main

**Further partners**
Daimler AG, Fraport AG,
TÜV Hessen GmbH, Linde AG,
Eni Deutschland GmbH,
Sapio S.r.l., Eni S.p.A.,
Regione Lombardia,
Mantova Townhall, CRF,
JRC-Ispra , Uni Bocconi,
Uni Lund, Uni Roskilde,
Saviko consultants.
(in all 16 partners from
4 countries)

**Time line**
November 2004 – May 2010

**Investment for demo project (M€)**
19.75 (EC Contribution: 7.46)

## Project details

Zero Regio is a demonstration project aiming at developing and testing hydrogen refueling systems and fuel-cell passenger cars in European cities under real conditions. The project is carried out in Frankfurt/Main, Germany and Mantova, Italy. One multi-fuel public service station has been built at both locations where hydrogen dispensers are fully integrated in the station. In Frankfurt/Main, by-product hydrogen available at the Industrial Park Höchst is employed to power FC-driven vehicles. In Italy, hydrogen from industrial sources and from on-site production is used.

5 A-Class F-CELL cars from Daimler are operated in Germany.
3 Panda fuel-cell vehicles from Fiat are operated in Italy. All vehicles have performed excellently with high availability and no road calls.
All infrastructure systems have performed in line with expectations.

Transport of hydrogen in a high pressure pipeline, refueling hydrogen at 700 bar and hydrogen compression in an ionic liquid compressor are the new technologies tested in this project. These innovations will be employed in the future along with larger demonstrations of fuel-cell vehicles and hydrogen infrastructure. They will form the basis for hydrogen commercialisation in individual transport.

## Business and investment opportunities

Organisations and companies active in developing fuel-cell technology for individual transport will benefit from the experience and results of the project. Refueling infrastructure based on by-product hydrogen in the current initial phase of hydrogen economy can and should be developed in many regions in Germany. 700 bar refueling technology installed in Frankfurt/Main is in accordance with SAE requirements and can be readily used for the next generation of vehicles such as B-class F-Cell vehicles from Daimler on a large scale.

*Modern sailing yachts are ideal "customers" for the HyPort initiative as they have a rising demand for reliable power for GPS, kitchen and laptop etc. By employing a hydrogen fuel cell system, controlled by a novel energy management system, the entire on-board supply for a variety of yachts is powerd by a single energy source.*

Photo: HyPort

## Project

HyPort initiative
www.hyport.de

## Key data

**Locations**
Coastal areas and lakes in Mecklenburg-Vorpommern, Lead site is Waren/Müritz

**Project leader**
HIAT (network coordinator) gGmbH

**Further partners**
This is an open network with presently 20 members from industry, academia and municipal suppliers

**Time line**
Initiative was started in 2008 – open end

## Project details

The HyPort initiative is focused on promoting the use of fuel cells and corresponding fuels – including the relevant logistics and storage infrastructure – in the maritime sector.

HyPort is an open network comprised of companies from different spheres: the maritime industry, industrial production and logistics of hydrogen, fuel cells production and tourism.

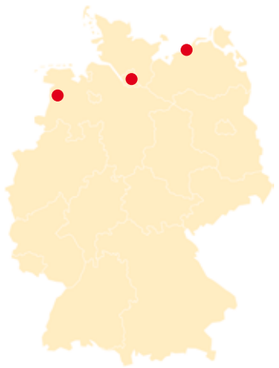
The network offers a platform for cooperation. Partners are invited to jointly participate in selected projects where they collaborate for mutual benefit. HIAT gGmbH – located in Schwerin – initiates and coordinates such projects and is, furthermore, able to support projects by providing professional consultants.

## Business and investment opportunities

In times of high wind intensity, wind power generation in Mecklenburg-Vorpommern cannot be fully utilized due to limited capacity of the power grid. One possibility to overcome this problem is to store the excess wind energy in the form of hydrogen.

Therefore, the main beneficiaries of the initiative are:

- Suppliers of energy and energy storage systems
- Suppliers of modules and systems for water-based leisure/ outdoor activities and municipal use
- Companies active in the renewable energy space



e4ships
Brennstoffzellen im maritimen Einsatz
nip

*The container with the HotModule for the Viking Lady is transported to be performance tested. The fuel cell stack is integrated into a rectangular metal container.*

Photo: MTU Onsite Energy

## Project

e4ships
www.e4ships.de

## Key data

**Locations**
Hamburg, Papenburg, Rostock

**Project supported by**
NOW GmbH

**Project leader**
NOW GmbH

**Further partners**
21 partners including shipping lines, ship yards, ship builders, universities and research organisations, systems and component suppliers, public and industry representatives

**Time line**
July 2009 – 2016

**Investment for demo project (M€)**
51.3

**Environmental benefit**
Elimination of particle and $CO_2$ emissions, silent operation (especially relevant for hotels)

## Thumbnail sketch

Goal is to reduce $CO_2$ and particle emission in coastal areas, caused by large ships. Systems in different vessels should all conform to common technical standards and be capable of integration. Targeted applications: ferries, yachts, passenger cruisers, commercial ships and navy. It is envisaged that fuels such as diesel, ethanol, synthetic biofuel (XtL) and hydrogen will be used.

## Project details

"e4ships" consists of four separate project modules involving on-board energy supply with fuel cell APU (100-500 kwel):

- The "Pa-X-ell" project will develop fuel cell modules to provide decentralised generation of heat and power for cruise ships.
- The "SchIBZ" (German: 'ship integration fuel cell') project will develop a seagoing fuel cell system with onboard diesel reformer, which will be tested in everyday operation on the high seas.
- The "HyFerry" module will equip several ferries operating in coastal waters with hydrogen-powered PEM fuel cells in hybrid systems.
- The "Toplaterne" (German: 'masthead light') partners jointly address all issues relating to environmental, technical and economic evaluation of fuel cells used on ships

## Business and investment opportunities

This project provides attractive opportunities for producers of devices for use on ferries, cruise ships, yachts, research and commercial vessels. Module and component suppliers who are capable of marine installations are invited to join present partners in this interesting market.

NOW estimates that the global market potential for providing fuel cell based auxiliary power supply units (500 kW fuel cell systems) for commercial maritime applications is approx 1.200 x p.a.. This is based on the assumption that 10% of new ships would benefit from using fuel cell technology. On average, about 3.000 commercial liners are built every year.

This includes:

- Suppliers of fuel cell systems and components
- System and component suppliers for fuel treatment
- Companies active in the supply chain for fuels including hydrogen and its precursors as well as the associated equipment suppliers (e.g. reformers, storage and logistics infrastructure)
- Battery and battery systems suppliers and integrators
- Service providers

# Bodensee Projekt: Fuel cells for outdoor leisure

BodenseeProjekt
Brennstoffzellen im Freizeitbereich


*Fuel cells used for auxiliary power supply of mobile and portable applications (up to 250 W) are under development. The use of fuel cells to provide stand-alone power in mobile homes, sailing boats, holiday cottages and hunting and hiking lodges is well established.*

Photo: SFC

## Project

BodenseeProjekt
www.now-gmbh.de

## Key data

**Locations**
Lake Constance/
Baden-Württemberg,
Bavaria

**Project supported by**
NOW GmbH

**Project leader**
NOW GmbH

**Further partners**
Elcomax, SFC smart fuel cell,
Truma Gerätetechnik,
Clean Mobile, EnyMotion, ZBT

**Time line**
2009 – 2011

**Investment for demo project (M€)**
26 (48% by NIP)

## Thumbnail sketch

Fuel cells for the leisure market in recreational areas on Lake Constance and surrounding areas: e.g. tourist boats, light vehicles, power supply for camping applications

## Project details

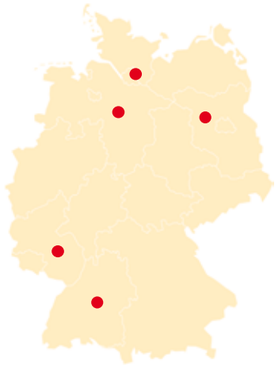
To date, this project consists of four modules:

- Development of new technology for production of low cost DMFC (using methanol as a fuel) and HTPEM by elcomax, SFC Smart Fuel Cell and Truma Gerätetechnik.
- Development of a power train for Light Electric Vehicles (LEV) with improved efficiency of the power supply system for different LEV-applications by Clean Mobile and SFC Smart Fuel Cell.
- Development of a power system with fuel cell and reformer for powering leisure vehicles for on-board systems. The system will be field-tested in off-grid Auxilary-Power-Unit for leisure vehicles employed by selected users and vehicle manufacturers.
- Existing 250 W fuel cell systems, powered by LPG camping gas will be integrated to power mobile homes and boats. EnyMotion, Dometic and ZBT (Zentrum für BrennstoffzellenTechnik) will jointly optimise such systems with respect to reliability and all-weather capability.

## Business and investment opportunities

This is an open partnership and companies that are willing to play a definite role in this innovative leisure oriented market segment are welcome to join in.
Furthermore, this project and especially its nation-wide commercial roll-out is an interesting business opportunity for companies developing modules and services along the entire value-chain from fuel cells, fuel infrastructure to new business models.

# Callux: Fuel cells for domestic power and heating



callux
Praxistest Brennstoffzelle fürs Eigenheim

nip

Ein Projekt im Nationalen Innovationsprogramm
Wasserstoff- und Brennstoffzellentechnologie


*The fuel efficiency of fuel cells employed in combined heat & power mode, exceeds 80%. The electrical power generated by Galileo 1000N unit (a SOFC fuel cell) is 1kW/el, while 2kW/th thermal heat is generated.*

Photo: Callux/EWE AG

## Project

callux
www.callux.net

## Key data

**Locations**
Baden-Württemberg, Rheinland-Pfalz, Hamburg, Brandenburg, Niedersachsen

**Project supported by**
NOW GmbH

**Project leader**
Center for Solar Energy and Hydrogen Research (ZSW)

**Further partners**
BAXI Innotech, EnBW, E.on Ruhrgas, EWE, Hexis, MVV Energie, Vaillant, Verbundnetz Gas

**Time line**
September 2008 – 2015

**Investment for demo project (M€)**
86

**Environmental benefit**
Energy saving, low $CO_2$ emissions

## Thumbnail sketch

Germany's biggest practical test for fuel cell heating systems for domestic use. Fuel cell heaters provide environmentally friendly heat and power from natural gas, cutting $CO_2$ emissions by a third and saving an additional approx. 5% in power transmission losses. Further benefits of the system lie in the ability to feed decentralised power into the grid. In addition, fuel cell heaters also produce thermal energy to heat private homes. The project is sponsored with env. €40 M by BMBVS with an equivalent sum being committed by industrial partners.

## Project details

The goals of callux are:
- To demonstrate the technical maturity of natural gas driven fuel cells
- Further support reliable supply of cost-effective products to this market
- Develop a cost-effective supply chain by securing the necessary market volume
- Enhance product profile in the market
- Validate requirements and set standards for customers

Approx. 800 fuel cell heating appliances are to be installed during the callux field test by 2012 and will be operational by latest. BAXI Innotech, Vaillant, and Hexis provide provide 2 types of fuel cells that run on natural gas and bio-methane (appropriately treated to meet established gas pipeline specifications).

## Business and investment opportunities

This demonstration project should be of interest for all producers of fuel cell- and balance-of-plant components who are looking for strategic investments.

Furthermore, component suppliers and companies interested in building and operating the appropriate infrastructure are invited to participate in this growing market.

# NEEDS: Fuel cells for decentralised commercial users



Nationales Innovationsprogramm
Wasserstoff- und
Brennstoffzellentechnologie

*The picture shows a fuel cell installed at the Erdinger Brewery (Munich Area, Bavaria), a "HotModule HM 300" with an electrical capacity of 237 kW and a thermal capacity of over 200 kW. The electrical efficiency of the systems is approx. 50% (overall efficiency 90%). Biogas containing approx 85% methane is supplied by a waste water treatment plant. After appropriate scrubbing, the biogas is fed into the multi-carbonate fuel cell where electricity and heat is generated for the for the production processes and for all other activities in the buildings. The $CO_2$ emissions are reduced by 1200 t p.a. by this initiative.*

Photo: © Tognum AG, MTU Onsite Energy

## Project

NewEcologicEnergyDecentrally Supplied – NEEDS
www.now-gmbh.de

## Key data

**Location**
Hessen

**Project supported by**
NOW GmbH

**Project leader**
NOW GmbH

**Further partners**
Diverse,
MTU ONSITE ENERGY

**Time line**
2008 – 2011

**Investment for demo project (M€)**
3.8

**Environmental benefit**
$CO_2$ reduction

## Thumbnail sketch

Goal of NEEDS is to develop standardised fuel cell systems to operate on bio-fuels such as biogas, sewage gas, pyrolysis-and synthesis-gas to supply heat for decentralised industrial users. As 2/3 rds of Germany's prime energy consumption is used for generating power, heating and warm water, this project will make a significant contribution to climate protection.

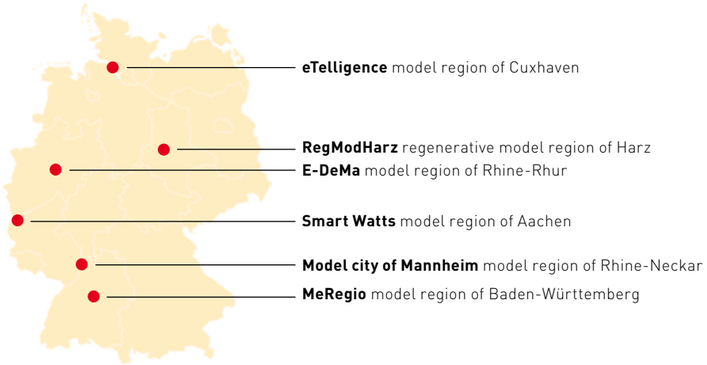
## Project details

It is envisaged that 60 power units cells utilizing bio-energy to generate power and heat for decentralised commercial consumers will be built by 2014. Two units consisting of a bio-gas fermentation, a gas scrubber and a molten carbonate fuel cell (MCFC) will be installed in early 2010 in the towns of Barth and Giessen and further ones are being planned for Potsdam (Speicherstadt) and Hamburg (HafenCity). In this system, the fuel cell provides the base-load power supply, while the gas engine utilizes peak production volumes of biogas and thereby avoids flaring off bio-gas during peak production. Heat energy is utilized to feed municipal heating systems or can be supplemented by absorber refrigeration systems that can use waste heat to generate refrigeration for air conditioning and production.

## Business and investment opportunities

Installation of further units are envisaged for clinics, residential/office buildings (e.g. for renovation of federal buildings in Bonn and Berlin), industrial facilities (e.g. breweries, effluent treatment plants, laboratories), substitute systems for mains power in computer centres, and to generate premium power for medical and IT applications and communications technology. Suppliers of the relevant devices or components are welcome to participate in this market.

Furthermore, there is an opportunity for companies with activities in the biogas production as well as in its supply value chain including production, purification, feed systems, service & maintenance of energy infrastructure.




*The E-Energy model region of Cuxhaven has a broad-based mix of renewable energies – such as wind and biomass – and is thus especially suitable for the eTelligence project.*

Photo: EWE AG

## Project

E-Energy
www.e-energy.de

## Key data

**Locations**
6 selected model regions: Cuxhaven, Rhine-Ruhr, Baden-Württemberg, Rhine-Neckar, Harz and Aachen

**Project supported by**
Federal Ministry of Economics and Technology,
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

**Project leader**
Ancillary research commissioned by the BMWi

**Further partners**
Partners are the six E-Energy model regions, companies from the ICT and energy industries, institutes and universities.

**Time line**
2008 – 2012

**Investment for demo project (M€)**
140

**Environmental benefit**
Reduced emissions through the development of decentralised, renewable energy generation and improved efficiencies in the electricity industry.

## Thumbnail sketch

The goal of E-Energy is to optimize all areas of the electricity industry from generation, distribution and storage through to consumption by using innovative information and communication technologies.
The superior objectives are security of supply, economic efficiency and environmental compatibility.

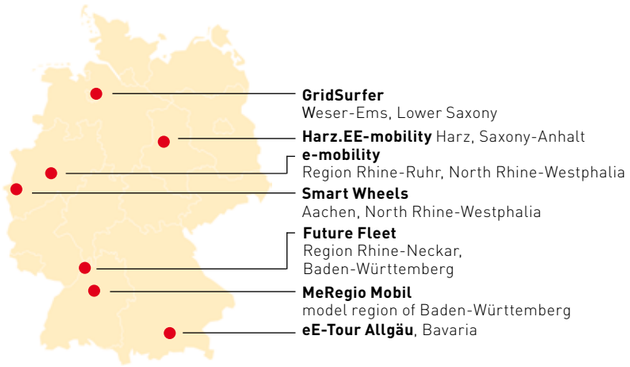
## Project details

There are six model regions in Germany: eTelligence (model region of Cuxhaven); E-DeMa (model region of Rhine-Ruhr); MeRegio (model region of Baden-Württemberg); ModelCity of Mannheim (model region of Rhine-Neckar); RegModHarz (regenerative model region of the Harz); Smart Watts (model region of Aachen)

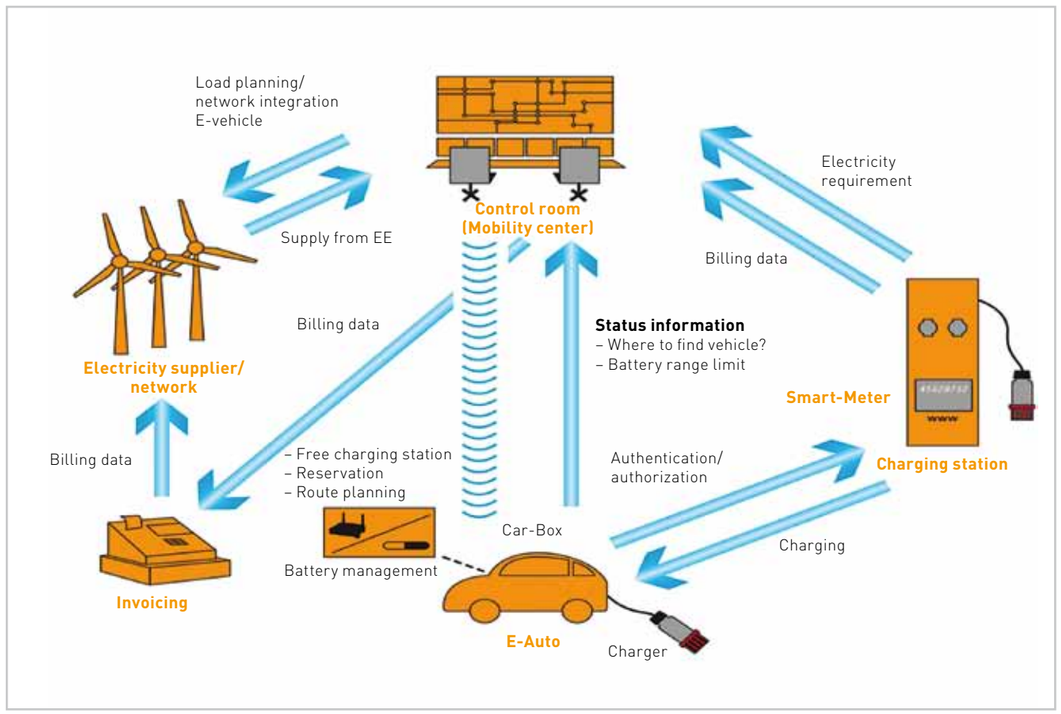
Everyone in the energy market benefits from E-Energy: the power generators, the power utilities and grid operators, private and industrial consumers, as well as, the environment. For example, E-Energy enables the development of decentralized and renewable energy sources by providing highly efficient solutions for their system integration. These will provide a complex control system that balances out the volatility of renewable energies and smoothes out peak loads. In this way, energy consumption can be shifted to times when cheaper electricity is available. The "Internet of Energy" will also allow optimum integration of electric vehicles in the power grid, so that electric mobility can make an important contribution towards increasing energy efficiency as an energy storage solution and balancing power potential.

## Business and investment opportunities

According to a study conducted for the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, until 2030 between €6 and €8 billion will be invested each year in the development of renewable energies to implement the German government's goals. To connect all electricity consumers to the "Internet of Energy" will require approximately 60 million gateways based on intelligent electricity meters. With the amendment of the German Renewable Energy Law, from 2010, power companies must offer these smart meters and new buildings and extensively renovated buildings must be fitted with them where this is technically feasible and not unreasonable from a financial point of view. Based on smart meters and gateways, established companies as well as start-ups will develop attractive business models for new services. They will invest in products for remote meter reading and load balancing in industry and in the smart homes of the future. Extensive new hardware and software will be needed for the intelligent integration of decentralized electricity generators and consumers (e.g. electric vehicles) and optimum management of the grid infrastructure, from generation through to consumption.




**ICT FOR ELECTROMOBILITY**




*Schematic description of the operational dynamics of ICT Electromobility*

Source: ICT for Electromobility

## Project

ICT for Electromobility
www.ict-em.de

## Key data

**Locations**
7 pilot projects:
- GridSurfer, Lower Saxony
- Harz.EE-mobility, Saxony-Anhalt
- e-mobility, Rhine-Ruhr region
- Smart Wheels, Aachen
- Future Fleet, Rhine-Neckar region
- MeRegioMobil, Stuttgart, Karlsruhe
- eE-Tour Allgäu, Bavaria

**Project supported by**
Approx. €45.5 M BMWi and approx. €9.5 M BMU

**Project leader**
German Aerospace Centre (DLR), Cologne

**Further partners**
Power companies, industrial and software enterprises are involved, as well as universities and research institutes

**Time line**
2009 – 2011

**Investment for demo project (M€)**
More than €100 M, including own funds of the consortia

## Thumbnail sketch

Seven projects with a total of 47 participants are examining the contribution that modern information and communication technology (ICT) can make in the field of electromobility. The topics include decentralized communication, information and billing systems for the charging and discharging of electric vehicles and new mobility services. Furthermore, the integration of electric vehicles in intelligent power networks ("smart grids") is to be examined and tested.

## Project details

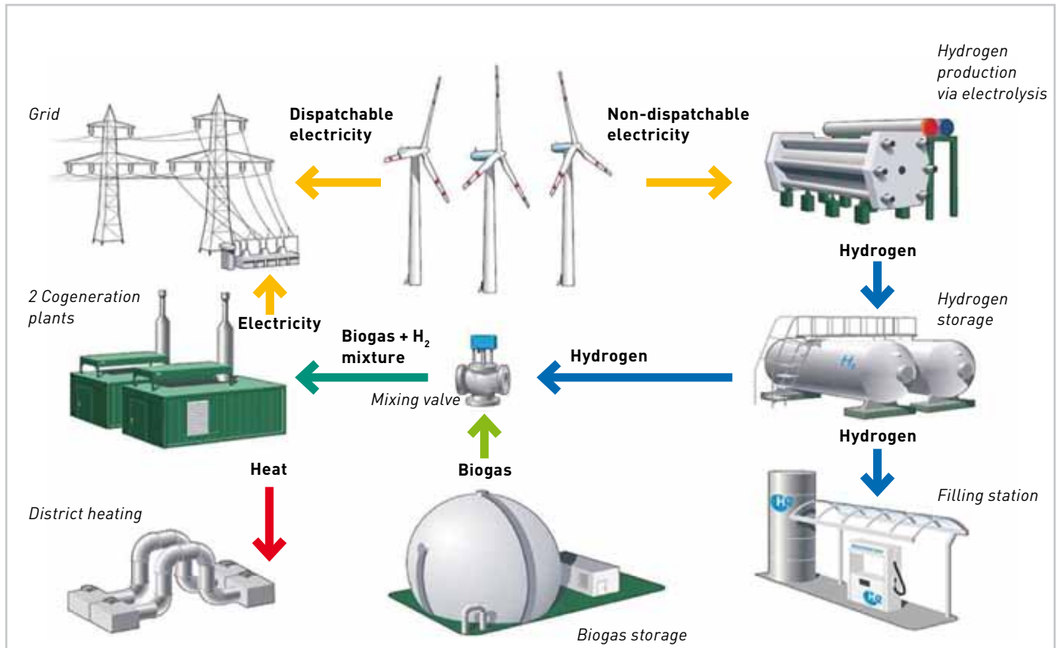
Sustainable individual mobility can only emerge if power grids, technology and electromobility develop into an energy-efficient mobility infrastructure. New, modern information and communication technologies are necessary. With their help, it will be possible to integrate the new electric vehicles into the electricity grids efficently.

Each region will focus on different topics aimed at creating an efficient infrastructure:
- GridSurfer: Battery-changing concept to extend driving reach in rural areas. Among other things, storage of fluctuating renewable energy, energy management in a smart energy system, controlled (bi-directional) charging
- Harz.EE-mobility: ICT-based key technologies for efficient introduction of electromobility for 25 EV into the smart grid with high level of renewable power
- e-mobility: Development and large-scale demonstration of an innovative charging, control and billing infrastructure for e-mobility for grid integration.
- Smart Wheels: Development of new "smart billing" business models. Integration into the infrastructure of municipal utilities for e-bus, train, BEV and scooters
- Future Fleet: Equipping company vehicle fleets with BEV and charging stations. Control of the vehicle fleet via a software-based fleet management solutions
- MeRegioMobil: Field trial with large number of BEV and smart charging stations. Use of the batteries as dynamic storage units for energy in the grid
- eE-Tour Allgäu: Integration of e-mobility into a rural region and use for tourism in Germany's largest tourism region. Operation of different e-vehicles owned by different operators and for different uses in a single ICT system (fleet diversity).

## Business and investment opportunities

A change towards electromobility has an enormous impact on the entire automotive value-added chain and other sectors of the economy, such as power companies, ICT service providers or research institutions. The global market for electromobility is expected to the worth of €470 billion by 2020. Overall, there is a strong need for investment, particularly in key tech-nologies in the field of battery systems, vehicle and ICT technology. Investments can be made at every point on the value-added chain which encompasses raw materials, components, vehicles, electricity (fuels), infrastructure and mobility providers.

ENERTRAG




*This innovative system allows the operation of a stabilized electricity grid entirely powered by renewable energies. It also supplies hydrogen for mobility applications, as well as heat for local district heating. The prototype installation comprises 3 wind turbines (2 MW / unit) connected to the grid, but also to an electrolyser (gas production: 120 Nm³/h of hydrogen, 60 Nm³/h of oxygen; op. pressure: 15 – 20 mbar (atm.) ), a compressor (nominal flow: 2 x 60 Nm³/h of hydrogen, output pressure: 43 bar (abs.) ), a stationary hydrogen storage (3 pressure vessels, storage capacity: 1.350 kg H2 at 43 bar ( abs.) ), a biogas production unit with a nominal production rate of about 300 m³/h, and a storage capacity of ca. 2.600 m³; and two CHP (combined-heat-and-power) units (max. yearly production capacity: 2.776 MWh of electricity each, and ca. 2.250 MWh heat). This thermal output is enough to heat about 80 single-family houses.*

Source: ENERTRAG AG

## Project

ENERTRAG Hybrid Power Plant
www.enertrag.com

## Key data

**Location**
Gut Dauerthal (100 km north of Berlin)

**Project leader**
ENERTRAG AG

**Further partners**
ELT, TOTAL, BTU Cottbus

**Investment for demo project (M€)**
21

**Environmental benefit**
Increase of the wind energy utilization,
$CO_2$-free fuel production for mobility applications.

## Thumbnail sketch

ENERTRAG, a profitable publically-owned company that already operates more than 440 wind generators producing over 1,5 TWh of energy p. a., is currently building its hybrid power plant which utilizes a mix of wind power and biomass energy to supply an independent, integrated and self-stabilized sustainable power network.
Hydrogen, produced during high-wind periods is used together with biogas, to generate electricity during low-wind or still periods and thereby smooth out any possible misbalance between supply and demand.
In the near future, a part of this sustainably-produced hydrogen will also be supplied to a number of hydrogen-fuelled mobile applications.

## Project details

Components of the ENERTRAG Hybrid Power Plant:
- Three wind turbines with an installed power of 2 MW each and a total annual average power generation of around 15.000 MWh/a.
- One electrolyser producing 120 Nm³/h hydrogen and 60 Nm³/h oxygen at 15-20 mbar. Hydrogen is later compressed and stored in 3 pressure tanks with a total capacity of 1.350 kg at 31 bar (a).
- One biogas plant with a nominal production capacity of about 300 m³/h biogas and a storage capacity of about 2.600 m³.
- Two cogeneration power stations (CHPs) fuelled by a mixture of biogas (min. 30%) and hydrogen (max. 70%), for generating electrical power (between 350 kW and 700 kW, depending on the biogas/hydrogen mixture rate), and heat (340 kW to 680 kW).

Advantages: The system maximizes the potential of wind and bioenergy for producing a self-stabilized, sustainable electricity supply without overloading the capacity of the transmission net or affecting the main grid parameters ( voltage and frequency ).

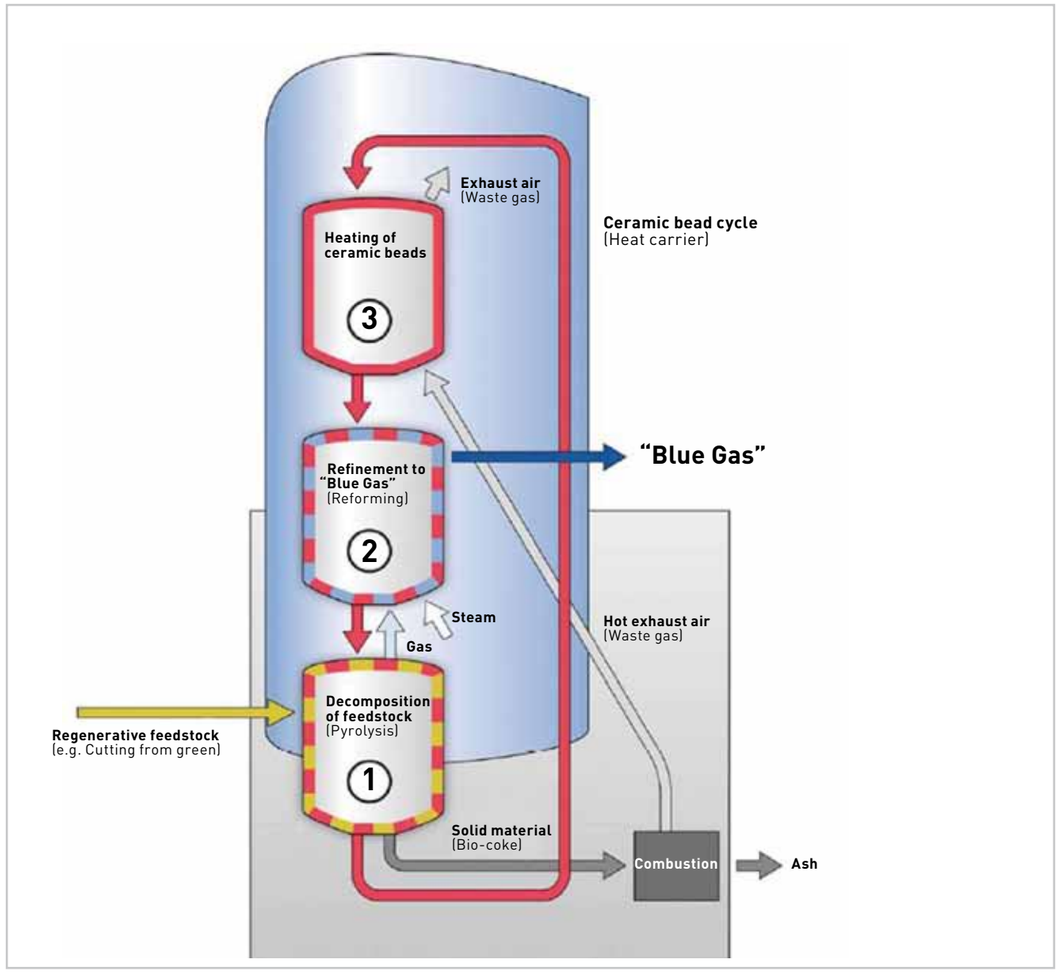
## Business and investment opportunities

ENERTRAG AG aims to commercialise this complex and innovative system on a global scale. For this purpose we are interested in contacting possible strategic partners. On the case of our current facility, we are looking to broaden our customer portfolio for $CO_2$-free hydrogen and electricity. Furthermore, we would like to be in touch with companies that could support further grid integration.

# Blue Tower: Hyrogen from biomass



BLUE TOWER




*Climate-friendly gas production*

Source: Blue Tower

## Project

Blue Tower:
Gasification of biomass for hydrogen or for power generation
www.blue-tower.de

## Key data

**Location**
Herten/NRW

**Project leader**
Shareholders of H2 Herten:
Blue Tower GmbH (10%) and
Blue Tower Capital GmbH (90%)

**Investment for demo project (M€)**
24.6

**Environmental benefit**
Savings: 15.300 t/a $CO_2$
17,8 Mill Nm³ natural gas

## Thumbnail sketch

High temperature gasificaton of up to 48 kt/a biomass/organic residues from forestry and agriculture to produce clean, hydrogen-rich gas used to generate 37,500 MWh/a electrical power. The "waste" heat is used to dry input materials. Alternatively "renewable" hydrogen may be produced. Even without federal subsidies, investment is profitable.

## Project details

Blue Tower uses multi-feedstock technology which implies that garden waste, roadside green cuttings, olive stones and even chicken manure can be used as a fuel source. Benefits are:

- Wide choice of most cost-effective feedstock for any given time
- No conflict with the food industry and
- Flexibility for choosing optimal investment location.

The clean product gas created by pyrolysis and reformation in the "Blue Tower", is especially rich in hydrogen, low in tar and practically nitrogen-free. It can be used to generate hydrogen or SNG which may be fed into the natural gas supply network. The process takes place under atmospheric pressure and has proven to run safely under stable conditions. Minimal safety measures are necessary and no waste water is generated.

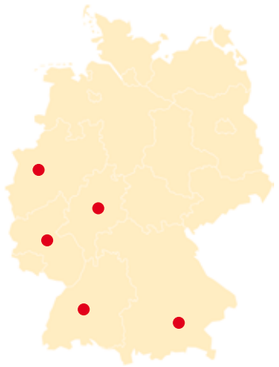
## Business and investment opportunities

This technology offers specific benefits for generating energy or hydrogen from waste and the ability to produce a clean, high calorific value fuel gas from a wide variety of waste and biomass streams e.g. materials such as agricultural waste manure from chicken farms. We plan to commercialise this technology globally and are looking for strategic partners for doing so.

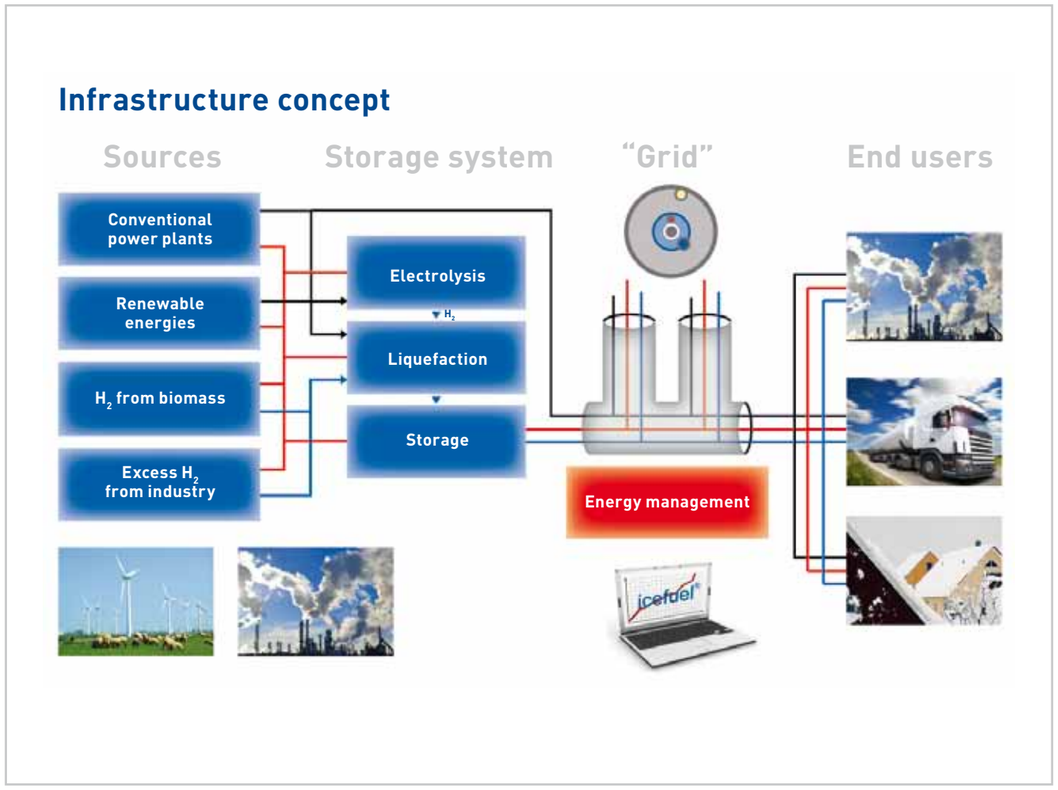
The following opportunities have been identified in Germany:

- Friesoyther (NW Germany): A two line plant will generate 11 $MW_{el}$ from 90.000 t/a chicken manure.
- Offenbach a.d. Q. (SW Germany): Green cuttings, sewage sludge (10%) and grape residues will be used to generate 2 $MW_{el}$.

Blue Tower offers a solution to chicken farmers who need to dispose of manure in a cost-effective way. Apart from generating electrical power, this technology allows the minerals in the droppings to remain biologically accessible. Low temperature processing allows the ash to be used as a mineral fertiliser. A decentralized solution to dispose such waste materials is of particular interest in Northern Germany where > 1,2 M tons p.a. of chicken manure is generated. Presently, a large part of that is transported to Eastern Germany, where it is used as a fertiliser. This solution suffers from high logistics costs as well as a number of other problems related to the nature of such solid matter. Blue Tower technology enables chicken farmers to solve this problem economically, thereby allowing them to further expand their activities.



# icefuel®

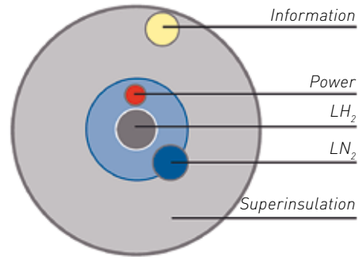



*Schematic illustration of the icefuel®-system*

*Source: icefuel®*

*Pipe concept*

- *Superinsulation: Heat conductivity < 1·10-3 Wm-1K-1 (conv. insulation materials: 30 - 40·10-3 Wm-1K-1)*
- *Flexible manufacturing and laying of pipes similar to underground cables*
- *Technical concept superinsulated umbilicals for hybrid transport of cryogenicfuels, power and information*




*Source: Oceaneering*

## Project

icefuel® (integrated cable energy system for fuel and power)
www.icefuel.de/www.icefuel.eu

## Key data

**Location**
Bayern, Hessen, Rheinland-Pfalz, NRW, Baden-Württemberg

**Project supported by**
Federal funding

**Project leader**
Supervision:
VDI/VDE
Coordination:
EVONIK Degussa GmbH

**Further partners**
LEONI, DLR, EWE,
TÜV Süd Industrieservice,
Karlsruhe Institute of Technology,
ZAE Bayern,
Institute for Micro Technology Mainz,
Mensch – Marketing – Technik (engineering office)

**Investment for demo project (M€)**
R&D Project costs: 4

## Description of initiative

icefuel® is an energy infrastructure system for the parallel transport of cryogenic fuels (liquid natural gas or hydrogen), electric power and data in a novel thermally insulated "umbilical" cable. Due to its high specific energy density and low viscosity pipes with relatively small pipe dimensions are adequate.

Using a number of cutting edge technologies, icefuel® was conceived as an energy storage, transfer, and conversion system which enables new ways of buffering fluctuating peak loads and creating an equilibrium between power generation and consumption.

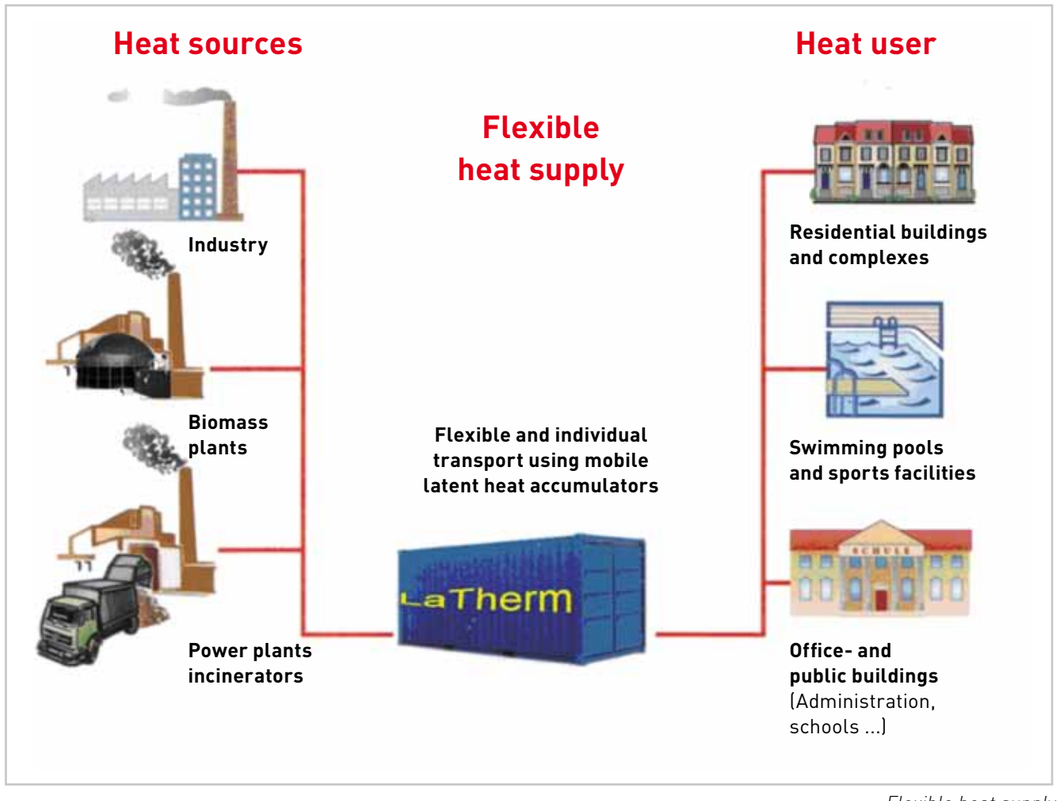
This project has matured to the stage where field trials are being planned to demonstrate the technical and commercial viability of the icefuel® system (cable lengths of several hundred meters).

## Business and investment opportunities

The icefuel® system opens new markets for producers of devices using micro-system technologies and components, cables, fuel-cells, new materials, thermoelectric generators, electrolysers, liquifier technology, superconductors, energy providers, system integration and -operation and fuel/fuel systems.

New project partners contributing know-how and/or capital are very welcome.

LaTherm




*Flexible heat supply*
*By storing heat in a container, it is possible to heat areas that are removed in both time and space from the heat source.*
*This enables heat from many sources to be used, even if only intermittently available. By drawing on a number of different heat sources, energy can be supplied with a high level of reliability.*

Source: LaTherm

**Project**

LaTherm Utilization of waste heat
www.latherm.de

**Key data**

**Location**
Dortmund

**Project supported by**
Seed capital, hi-tech fund

**Project details**

LaTherm supplies its customers with heat for warm water and heating at stable prices. To this end, they store waste heat from industrial operations – steel works, chemical/power plants, industrial processes (CHP) – in mobile containers capable of efficiently storing large amounts of heat energy. For this reason this business qualifies for the "CHP incentive" in Germany. The heat storage medium is a PCM substance which is environmentally benign and non toxic (sodium acetate, a commonly used food additive).

Containers are constantly supervised via mobile communications to calculate the optimum exchange time to secure the supply of heat.
This system has been shown to have commercial advantages over piped municipal district heating up to a distance of 20 km. As it utilizes "waste heat", it is able to guarantee long term stable pricing. It also does not require the high initial investment and maintenance of district heating.
Typical customers are swimming pools, hospitals and schools.
Heat stored in one container is sufficient to heat a family home for 3-4 months, however LaTherm prefers customers who have a heat demand of > 1 MWh/day.

**Business and investment opportunities**

LaTherm is interested in rolling out this business model globally and is therefore keen to explore possible strategic alliances.

**Let's work together**
The cluster concept is a simple one: companies have teamed up to create and finance regionally organised groups of professionals who take care of the industry in their region. Most receive both public, and government support. Close contact with academia is a high priority. German industry has benefitted greatly from this innovative scheme which led to rapid progress in all spheres.

Different clusters have now evolved regional initiatives aimed at developing the emerging economy of fuel cell and energy storage. Their main focus is on the marketing of applications in this area and attracting possible investors. In addition, they manage networks of partners and partners-to-be and foster innovation by promoting contact between local companies and universities and colleges. Another important job is to communicate the industry's opinion to both the public and the authorities.

So far, nine regional initiatives have been established:

- Landesinitiative Brennstoffzellen- und Wasserstofftechnologie Hamburg,
- Landesinitiative Brennstoffzelle & Batterietechnologie Niedersachsen,
- Brennstoffzellen + Batterie-Allianz Baden-Württemberg,
- Wiba – Koordinationsstelle der Wasserstoff-Initiative Bayern
- ELEMENT 1 Berlin
- $H_2$BZ-Initiative Hessen,
- Fuel Cell and Hydrogen Network NRW
- Brennstoffzellen-Initiative Sachsen
- Wasserstofftechnologie-Initiative Mecklenburg-Vorpommern e.V.

All of these help to maintain the country's unique position as the world's premier location for energy storage and fuel cell industry.




## Collaboration paves the way for rapid innovation

**Close cooperation and extensive networking between academia and industry are key factors behind Germany's success in research and development. Its array of world-class research institutes also plays a central role**

There are many reasons why science and technology are so successful in Germany. One of the most important is close cooperation between universities, research institutes and industry. Such networks have been established in 32 regions across the country.

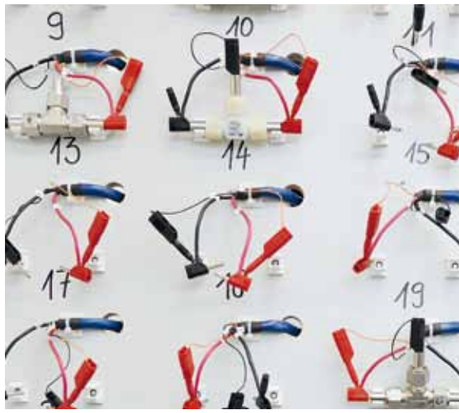
Cutting-edge research also takes place at hundreds of non-university institutions in such well known establishments as the Max Planck Society, the Helmholtz Association, the Leibniz Association or the Fraunhofer-Gesellschaft.

Here scientists can find optimum conditions of a standard found at very few other institutions around the world.

Intensive cooperative research and development is required for new technologies to become economically competitive and for various energy sources to be integrated. One good example of such a cooperative approach is the work done by the German Renewable Energy Research Association (FVEE). It has created an informal, decentralised platform for communication among scientists working in the field of sustainable energy supply and has been expanded into an efficient knowledge network.
Today, the approximately 1,800 scientists from member institutes constitute one of the largest networks of experts in the field of renewable energy in Europe. The FVEE also embarks on collaborative research projects with industry. Furthermore, it is a partner of policy-makers for the implementation of a sustainable energy supply.

Finally, the FVEE organises conferences and workshops for the public on research topics involving renewables, where future opportunities and perspectives are presented and discussed.

To give investors an overview of the many opportunities for tapping into Germany's vast R&D network, 16 R&D institutes working on energy storage and fuel cells will be profiled in this brochure.



*A fully automated computerized battery test system*

Photo: Institut für Physikalische Chemie Westfälische Wilhelmsuniversität

*The table below shows which topics the members of the FVEE are working on (institutes are listed in alphabetical order). Percent figures indicate the relative number of scientists working on each topic. In total there are 1,800 scientists representing 80% of R&D capacities active in the area of renewable energies in Germany.*

| | | |
|---|---|---|
| Photovoltaic | 28% | *Jülich, Fraunhofer ISE, HZB, ISET, ISFH, ZAE Bayern, ZSW* |
| Solar thermal power plants | 4% | *DLR, Fraunhofer ISE* |
| Solar heat and cold | 4% | *DLR, Fraunhofer IBP, Fraunhofer ISE, ISFH* |
| System tech & network mgmt | 10% | *DLR, Fraunhofer ISE, Jülich, ISET, ZAE Bayern* |
| Solar construction | 12% | *Fraunhofer IBP, Fraunhofer ISE, ISET, ISFH, ZAE Bayern, ZSW* |
| Biomass | 3% | *DLR, Fraunhofer IBP, Fraunhofer ISE, ISET, ZAE Bayern, ZSW* |
| Fuels | 3% | *DLR, ISET, Fraunhofer ISE, ZAE Bayern, ZSW* |
| Geothermal | 3% | *Fraunhofer IBP, GFZ, ZAE Bayern* |
| Wind energy and ocean current | 3% | *ISET* |
| Fuel cells & hydrogen | 29% | *DLR, Fraunhofer ISE, Jülich, HZB, ISET, ZAE Bayern, ZSW* |
| Energy storage | 8% | *DLR, Fraunhofer IBP, Fraunhofer ISE, ZAE Bayern, ZSW* |
| Technology assessment | 2% | *DLR, Jülich, ZSW* |

*Source: FVEE*

## Fraunhofer-Gesellschaft

Fraunhofer-Gesellschaft is the largest organisation for applied research in Europe with more than 80 research units, including 60 Fraunhofer Institutes at different locations in Germany. The majority of the 17,000 staff is comprised of qualified scientists and engineers, with an annual research budget totalling €1.5 billion. Of this, €1.3 billion is generated through contract research.

Two-thirds of the research revenue is derived from contracts with industry and from publicly financed research projects. Only one-third is contributed by the German government in the form of institutional funding. Research centers and representative offices are maintained in Europe, USA, Asia and in the Middle East

## Fraunhofer Energy Alliance

The Fraunhofer Energy Alliance is the gateway to Fraunhofer's R&D services in energy technology and energy economics. In collaboration with industrial partners, the Fraunhofer Energy Alliance aims to strengthen technology leadership in the field of energy efficiency and renewable energies.
It offers a simple access to the expertise of the Fraunhofer Institutes, particularly to small and medium-sized companies, but also to politics and the energy business sector.
The main objectives of the Fraunhofer Energy Alliance are sustainability, security, safety and profitability of the energy economy as well as providing scientific advisory to the German government and the European Commission.

With 2,000 employees the Fraunhofer Energy Alliance focuses on the following business areas:


Photo: Fraunhofer IKTS

- **Renewable energies**
  biomass, biogenous gases and alternative combustibles, photovoltaics, solar thermal heating and cooling, solar thermal power plants and wind power

- **Smart grids**
  technical and economic concepts; system analyses: simulation, forecast and optimisation; management and operation management: energy data management, monitoring, control systems; implementation and technology: measurement and controls technology, communications technology, inverters

- **Energy storage and micro-energy technologies**
  battery technologies, material development for batteries, battery management and monitoring, super caps, fuel cells, micro energy harvesting, power electronics, piezo- and thermo-electric energy converters, phase change materials (PCM), thermal energy storages

- **Buildings and components**
  low-energy-houses, air conditioning and solar cooling, building technology control and operation optimisation, optimised façade and shading systems, innovative building materials and glazing, thermal insulation and solar control, utilisation of PCM/PCS materials in building components

- **Energy efficiency**
  combined heat and power (CHP) systems; using heat for cooling; LowEx: heating and cooling with waste heat and environmental energy; Organic Rankine Cycle (ORC) - electricity from waste heat; power electronics

Photo: BMU Langrock

## Fraunhofer Institute for Solar Energy Systems

The Fraunhofer Institute for Solar Energy Systems ISE is committed to promoting energy supply systems which are sustainable, economic, safe and socially just. It creates technological foundations for supplying energy efficiently and on an environmentally sound basis in industrialised, threshold and developing countries.

To this purpose, the institute develops materials, components, systems and processes for seven different business areas:
- Energy-efficient buildings and technical building components
- Applied optics and functional surfaces
- Solar thermal technology
- Silicon photovoltaics
- Alternative photovoltaic technology
- Renewable power generation
- Hydrogen technology.

With a staff of 930 (2009, including students), Fraunhofer ISE is the largest European research institute. As a complement to its research and development work, the institute offers related testing and certification services to clients. At present, Fraunhofer ISE has the following accredited testing units: TestLab Solar Thermal Systems, TestLab Solar Façades, TestLab PV Modules as well as the photovoltaic (PV) calibration labs CalLab PV Cells and CalLab PVModules.

Further service units include a test facility for compact heating and ventilation units, a laboratory for quality control of phase change materials (PCM), a test stand for thermally driven heat pumps and a battery testing laboratory.

The external laboratories and outposts of Fraunhofer ISE, whose focus is on the development of materials for solar cells or semiconductors, are the Laboratory and Service Center (LSC) in Gelsenkirchen, the Center for Silicon Photovoltaics (CSP) in Halle on the Saale and the Technology Center for Semiconductor Materials (THM) in Freiberg.
CSP is operated in cooperation with Fraunhofer IWM Freiburg and Halle, and THM in cooperation with Fraunhofer IISB respectively.

The Fraunhofer Center for Sustainable Energy Systems (CSE) in Boston was founded in 2008. At CSE, the close co-operation between researchers from Fraunhofer ISE, Fraunhofer CSE and the Massachusetts Institute of Technology MIT foster that the established European know-how and technology in the field of renewable energy is adapted for and introduced into the American market. The activities concentrate on solar technology and energy-efficient building.

With activities extending well beyond fundamental scientific research, the institute is engaged in the development of production technology and prototypes, the construction of demonstration systems and the operation of testing centres. The institute plans, advises, tests and provides know-how and technical facilities as services. Fraunhofer ISE has been certified according to DIN EN ISO 9001: 2000 since March, 2001.

## Fraunhofer Battery Network

At more than 16 Fraunhofer Institutes researchers are working on battery-related topics. The Fraunhofer Battery Network provides a gateway for customers and collaborators to these research groups. The research area covers nearly all themes in this field:

- Material development (electrodes, binders and separators, liquid and solid electrolytes) and testing
- Material modelling and simulation
- Battery production process optimisation
- Test cells, prototypes
- Battery characterisation (electrical behaviour, aging, safety tests)
- Battery modules and packages (module design on basis of customer specifications)
- Safety requirements (thermal management, innovative cooling concepts)
- Innovative battery management systems
- Safety tests
- Simulation and modelling of battery behaviour (e.g. SOC and SOH)
- Technical system integration
- Training and seminars
- Studies, roadmaps, strategies.

## The Helmholtz Association

The Helmholtz Association with 28,000 employees in 16 research centres is Germany's largest scientific organisation and has an annual budget of approximately €2.8 billion. The Helmholtz Association contributes to the solving of major challenges facing society, science and industry with top scientific achievements in six research areas: energy, earth and environment, health, key technologies, structure of matter, transport and space.

## GKSS Research Center in the Helmholtz Association

The GKSS Research Centre Geesthacht is a non-profit research institute. As a member of the Helmholtz Association of German Research Centres, GKSS is engaged in use-inspired research at its headquarters in Geesthacht near Hamburg and its outstation in Teltow near Berlin. More than 800 employees work in three institutes: for Material Research, Polymer Research and Coastal Research.

The materials scientists develop innovative lightweight materials as well as materials for a wide range of applications. Their alloys are used, for example, in the automobile industry and in aircraft construction. Scientists study some of the materials in the form of ultrafine metal powders for their potential to store hydrogen.

In addition to investigating new metallic materials, GKSS researchers also study polymers for use as membranes in a range of applications, including gas-phase separation, fuel cell technology and osmotic power plants. Activities in Teltow focus on the development of biomaterials for the field of regenerative medicine.

In Geesthacht, the materials researchers benefit from the special structure of the centre: the internationally renowned experts work together on a project, from the initial concept to the processing and testing of complex components under realistic conditions. The special strength of the Geesthacht material researchers lies in this unique form of collaboration.

GKSS Research Centre relies on a unified strategy involving the establishment of tight-knit networks and alliances with partners from science and industry. GKSS establish research platforms which provide nucleation points for national and international research alliances, promote the development of advanced technology and increase Germany's attractiveness as an international location for science and innovation.

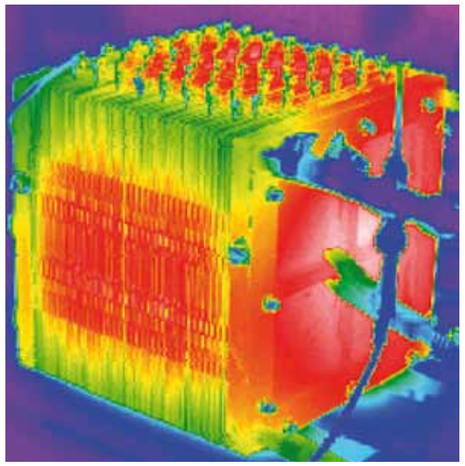


Photo: Forschungszentrum Jülich

## Jülich Institute of Energy Research in the Helmholtz Association

With a staff of about 4,400, Jülich Forschungszentrum – a member of the Helmholtz Association – is located near Aachen (close to the border with the Netherlands and Belgium) and is one of the largest research centres in Europe. It pursues cutting-edge interdisciplinary research on solving the grand challenges facing society in the fields of health, energy and the environment, and information technologies. Building on its two key competencies – physics and supercomputing – this research centre focuses on long-term, fundamental and multidisciplinary contributions to science and technology as well as on specific technological applications. Scientific and technical work at the Research Centre is conducted in 10 Institutes and joint scientific and technical facilities.
The Institute of Energy Research (IEF) investigates modern energy conversion technologies. The topics it covers range from photovoltaics and fuel cells, through nuclear fusion and nuclear safety research, right up to innovative coal and gas power plants. This gives rise to an unrivalled breadth of research topics, all bound together by scientific methods and systems analysis.

Furthermore, a number of projects are administered by this institute for third parties such as federal ministries, the EU and regional bodies.


## German Aerospace Center (DLR)

DLR is Germany's national research centre for aeronautics and space and with more than 6,000 employees the largest engineering research facility in Germany. Its extensive research and development work in aeronautics, space, transportation and energy is integrated into national and international cooperative ventures.

Energy research has been part of DLR's agenda for over 30 years. About 400 researchers and technical as well as administrative staff address energy challenges at DLR. The budget exceeds €42 M, of which more than 60% are earned from competitive public and industrial contracts.
DLR's research strategy in the energy sector is focused on specific subjects, making use of synergies with its other research priority topics. The main fields of energy research at DLR are:

**Fuel cells**
- Development and optimisation of solid oxide fuel cells (SOFC) and polymer electrolyte fuel cells (PEFC) by improved design and production processes
- Sophisticated analysis, diagnostics and characterisation
- Integration into applications, especially transportation systems and highly efficient hybrid systems with gas turbines

**Solar thermal power plants**
- Optimisation of quality and reliability of technical components and reduction of production costs
- Investigation and preparation of new plant designs to achieve higher energy gain and lower costs
- Development and application of international standards for performance measurements of components
- Development of hydrogen production processes from thermochemical cycles

**Technology assessment and scenarios**
- Assessment of the development of energy technologies and their potential
- Elaboration of energy scenarios towards a sustainable energy system

**Gas turbines**
- Increased efficiency by optimising combustion, gas flow, and heat management using sophisticated measurement and simulation tools
- Increased flexibility by preparing the use of different fuels, including alternative fuels from biomass and hydrogen
- Reduction of noise and chemical emissions like NOx and CO.

## Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)

ZSW is one of the leading European research institutes in the fields of solar energy and new energy storage technology and was established in 1988 as a non-profit foundation. Research and development work covers the entire value-added chain of the topics – from materials development to system testing with a turnover of €80 M in 2008.
Topics being pursued by its 200 staff in its three locations in Baden-Württemberg are listed below together with their current goals:

**Photovoltaics: materials research**
- From the optimisation of semiconductors for the absorption of solar radiation to the development of new types of solar modules, from the development of production processes for thin-film PV modules (both conventional and on flexible carrier foils) and the development of organic absorber solar cells

**Photovoltaics: systems technology**
- From the optimisation of solar power plant yield to laboratory and outdoor tests; from PV system measurements to site and technology evaluation

**Fuel cells**
- From modelling, design and realisation of PEM fuel cell stacks to design and realisation of fuel cell systems ranging from 5 W to 50 kW and application-oriented tests of components, stacks and subsystems up to 120 kW

**Energy storage in batteries and supercapacitors**
- From the development of new active materials, to design and realisation of lithium-ion batteries and to system optimisation of lead-acid batteries; the analysis of aging mechanisms and battery system and safety tests

**Renewable fuels/hydrogen technology**
- From the development of processes for the production of hydrogen or synthetic fuels from renewable raw materials to fuel reforming for fuel cell operation and $CO_2$ separation in power plant processes

**Energyeconomy systems analysis**
- From strategic studies on energy systems and the evaluation of their development prospects to the actual implementation of innovative energy technologies and policy consultancy.

Photo: ZBT Duisburg

## Center for Fuel Cell Technology (ZBT)

ZBT was founded in the year 2001 by the faculties of energy technology (mechanical engineering) and electrical power systems and networks at the University of Duisburg. It is supported by the Ministry for Energy and the Ministry for Science in North Rhine Westfalia.

ZBT is a non-profit limited company and acts as a service provider for industrial and public clients. The scientific-technological divisions of ZBT perform typical tasks for industrial-near research. The project portfolio contains development of reactors and systems, benchmark of components, screening of materials and influencing factors on their performance, studies and education for professionals.

Work focuses on membrane fuel cell technology (PEFC/PEM) and engineering projects for home energy supply, traction, mobile power supply and other special applications. Topics are:

- Fuel processing
- Fuel cells and systems
- Electrochemistry and coating
- Micro-systems
- Hydrogen technology
- Production technology
- Test & qualifications.

## Münster Electrochemical Energy Technology (MEET)

MEET is a newly established battery research centre at the University of Münster. Here an international team of 100 scientists with an excellent reputation, work on innovative electrochemical energy storage devices with enhanced performance, longer lifetimes and much higher energy while still providing maximum safety. Researchers look for answers to pressing issues of electro-mobility and energy efficiency and aim to increase the competitiveness of North Rhine-Westphalia and Germany in these technologies of the future, especially in lithium-ion technology.

MEET offers its services to interested parties in the public or industrial sectors. The battery laboratory includes modules for synthesis of active materials, the production of electrodes and cells, cell testing, safety laboratory and electrical measurement technology.

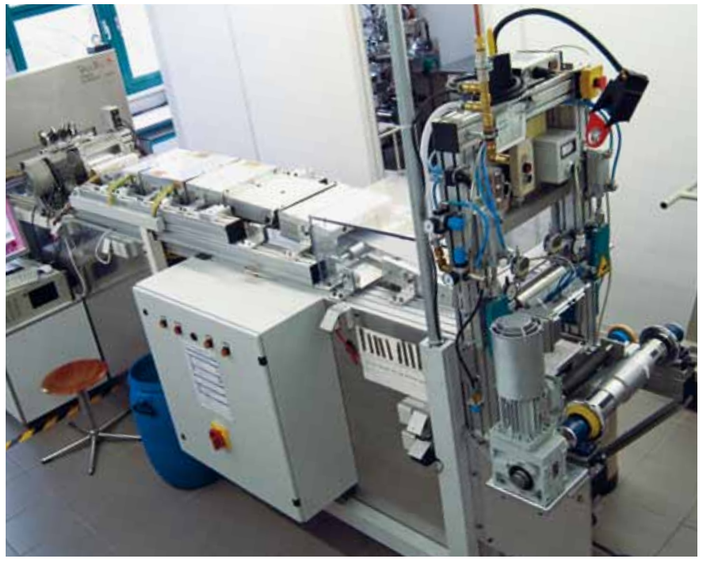
Third parties who are interested in research collaborations on energy storage materials and systems – including active and non-active materials – will benefit specificaly from infrastructure for:

- Aging tests and post-mortem analyses on lithium-ion cells
- Safety tests: to determining the electrical, mechanical and thermal safety of cells
- Analyses (chemical, physical, electrochemical) of battery materials
- Advisory service for introducing the technology into targeted markets.

## Lithium Ion Battery (LIB 2015)

The "LIB 2015" consortium – made up of BASF, BOSCH, EVONIK, LiTec, and VW – was initiated to develop and commercialise lithium-ion batteries that will enable electrically powered vehicles (PHEV and BEV) to reach driving ranges of at least 200 km. This means that the energy densities of 150 to 200 Wh/kg are achieved and would mean that such batteries will have the capability to store two to five times more energy than present modules can. Furthermore such batteries should have a life of 8 –10 years.

The consortium has received a €60 M federal grant and will jointly spend €360 M to bring to market such high performance batteries that are safe and above all affordable by 2015. Their competencies cover a broad range, extending from material research to system integration. BASF, Freudenberg Vliesstoffe and SGL Carbon are responsible for materials science, while development of prototypes and cell technology is in the hands of the Fraunhofer Institute Itzehoe and the companies Gaia, Leclanché and Bosch. Volkswagen will integrate the battery into vehicles and EnBW will develop models for integrating batteries into smart grids for balancing the national power grid. The universities of Münster, Berlin, Bonn, Clausthal, Darmstadt, Giessen, Hannover, the Paul-Scherrer Institute in Switzerland and the Leibniz Institute of Dresden are committed to fundamental research projects. The consortium partners see their competitive advantage in the unique constellation of this venture.



*Electrode coating for Li-ion cell manufacture*

Photo: ZSW Ulm

## Description of institute

ZSW (Centre for Solar Energy and Hydrogen Research Baden-Württemberg) has a strong expertise in the area of new energy technologies and is located in Southern Germany. We are performing applied R&D in close cooperation with industrial partners. Currently about 200 employees including PhD students and trainees are working at ZSW's three locations. Our target group is the public sector, industry, small and medium-sized enterprises, research institutes, energy suppliers, associations, politics. Turnover currently reaches € 20 M, with a third-party financing share of 80%.

**www.zsw-bw.de**

**Research focus**
ZSW location in Ulm "New Energy Technologies" has a strong expertise in the area of energy conversion and energy storage. We are performing applied R&D in close cooperation with industrial partners. Our knowledge base includes among others material development, application systems as well as modelling and testing of advanced batteries, super capacitors and fuel cells. Key issues of developments are increased lifetime, safety and cost reduction.

**Goals of research**
**Short-term**
Development of advanced active materials for batteries (cathode, anode, electrolyte) to improve safety, lifetime, performance and cost

**Medium-term**
Development of new manufacturing technologies and prototype manufacturing of li-cells with new chemistry

**Long-term**
New batteries for new energy storage systems for hybrid and full electric vehicles with increased lifetime, high safety and reduced cost

**Competence specialization**
New materials are the key to high performance of new energy storage systems for hybrid and full electric vehicles. The subjects range from basic materials science investigations to post-mortem analysis. An interdisciplinary team of scientists, engineers and technicians qualified in chemistry, materials research, physics or chemical engineering is currently focusing on the research and development of new materials for lithium-ion batteries and super capacitors for automotive applications.

Key issues of development are increased lifetime, safety and cost reduction.

- Process development for batteries and super capacitors
- Design of new cell configurations
- Study of aging and safety mechanisms
- Electrical and safety tests of components and complete modules
- Post-mortem analysis and failure study of commercial batteries
- Simulations and modelling.

**Resources**
Laboratories and test facilities battery and fuel cell test benches, modular fuel cell system platform, gas processing laboratories, synthesis laboratory, software for simulation and modelling.

Energy storage – competent and well equipped:
- ICP-OES (elemental analysis)
- Scanning electron microscopy (LEO1530VP) with EDX analysis
- 3D optical microscopy
- X-ray powder diffractometry (phase analysis, Rietveld refinement, micro and high temperature diffractometry)
- Gas adsorption methods (BET)
- Mercury porosimetry
- Determination of particle size and shape distribution (Sysmex FPIA-2100). Thermal analysis combined with mass spectrometry
- Several test benches for cells, modules and batteries in the range up to 1500A and 600V
- Test bunker to evaluate the hazard potential of batteries in extreme and abuse conditions

**Global network**
- German and European car manufacturers and suppliers in the field of batteries
- Use of batteries in utilities and different stationary applications
- Manufacture of portable equipments using batteries.

## Opportunities for cooperation

We are looking for partners to work on economic scale-up processes, aging mechanisms and safety related studies from concept to pilot production.

Examples of projects carried out by ZSW:

- Development of a battery monitoring and management system for advanced batteries
- Several projects for performance determination of different kind of batteries
- Projects for life time determination of batteries and their prediction
- Different projects for determination and evaluation of the hazard potential of batteries in extreme and abuse conditions
- Optimisation of a charging algorithm for a HEV battery optimisation of the thermal management system for a supercap module
- Optimisation of a fuel cell-battery hybrid system

*Dual fluidised bed reactor for material testing*

Photo: ZSW Stuttgart

## Description of institute

ZSW (Center for Solar Energy and Hydrogen Research) has a strong expertise in the area of new energy technologies and is located in Southern Germany. We are performing application oriented R&D in close cooperation with industrial partners. Currently about 200 employees including PhD students and trainees are working at ZSW's three locations. Turnover currently reaches € 20 M, with a third-party financing share of 80 %.

**www.zsw-bw.de**

**Research focus**
ZSW location in Stuttgart has besides PV-technology a strong expertise in gas processing technology. Focus is on two main areas: thermochemical conversion of biomass and fuel reforming synthesis.

**Goals of research**
**Short-term**
Market implementation of home-fuel cell systems: callux (www.callux.net)

**Medium-term**
Commissioning of AER-demonstration plant in Geislingen,
Establishment of R&D platform "BtG" (Biomass-to-Gas),
Development of new routes for the production of substitute natural gas (SNG)/hydrogen from renewable energy sources

**Long-term**
Development and implementation of polygeneration concepts (electricity/fuels) to increase the share of renewables in the energy system in order to meet the $CO_2$ reduction targets.

**Competence specialization**
ZSW develops and tests new technologies, especially for the production of hydrogen and synthesis gas. Our activities are focused around: fuel reforming, the production of synthesis gases from biomass using gasification/pyrolysis, gas cleaning and conditioning and fuel synthesis.

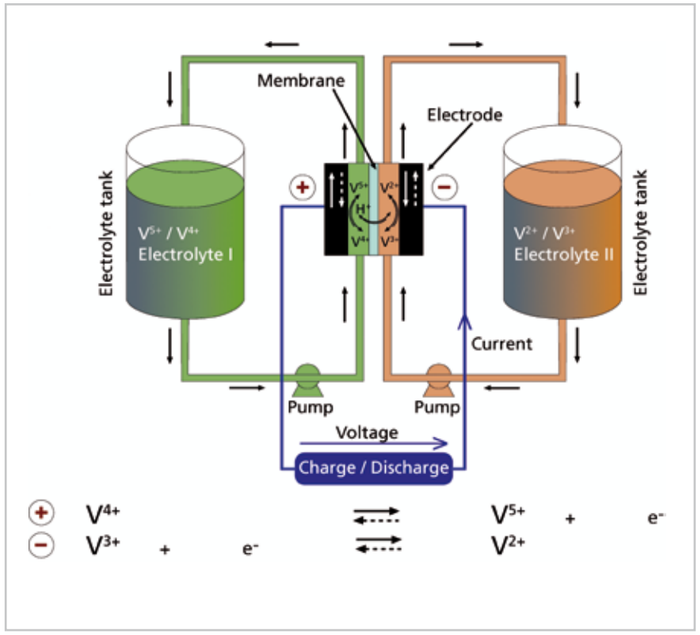
**Resources**
The facilities include labs for biomass conversion, hydrogen generation, carbon-based fuel powered PEM fuel cell systems and material analysis, as well as a chemistry lab. Fixed and fluidized bed reactors, and a coupled dual fluidized bed reactor (DFB) are employed for process development and material testing. Characterisation of materials is done by a thermal-gravimetric analysis (TGA) system. Test facilities for substitute natural gas synthesis, tar cleaning etc. are available. Furthermore ZSW provides test benches for characterising system components and for complete fuel cell systems.

**Global network**
The ZSW is involved in various networks in the field of renewable fuels and hydrogen and also coordinates projects in interdisciplinary R&D. Network partners are universities and research institutes as well as small-and-medium-sized businesses and industrial firms.

## Opportunities for cooperation

Project: Substitute natural gas (SNG) from Biomass
A pilot plant based on innovative AER (Absorption Enhanced Reforming) gasification technology for decentralised generation of power, heat and fuels ($H_2$, SNG) from biomass will go on stream end of the year 2011. The AER process delivers a hydrogen-rich producer gas which is adapted for downstream methanation to generate substitute natural gas (SNG). The feasibility of methanation was proven using a demonstration reactor (100 $kW_{SNG}$).

Project: SNG from Electricity
Together with the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) and the Solar Fuel Technology GmbH & Co KG, the Centre for Solar Energy and Hydrogen Research (ZSW) has developed a new method for electricity storage to guarantee stability in electricity grids with a high percentage of fluctuating renewable power generation. In this concept, excess renewable electricity (e.g. from wind turbines) is used for hydrogen generation via water electrolysis. In a downstream process, hydrogen and $CO_2$ (e.g. from biogas) are converted to methane which is fed and stored into the gas grid as SNG.




*Schematic view of a Vanadium Redox-Flow Battery:*
*The Vanadium Redox-Flow Battery consists of a stack, in which chemical reactions take place in two electrolytes separated by a membrane. In this type of battery, electrical energy is converted into chemical energy of the electrolyte liquids, which are stored in tanks separated from the battery.*
*Therefore such systems allow large amounts of energy to be stored and makes them particularly interesting for stationary applications which require large volumes of energy to be saved.*

Source: Fraunhofer UMSICHT

Fraunhofer UMSICHT

## Description of institute

The Fraunhofer-Gesellschaft is one of the world's major international research organizations (non-profit). It receives funding both from the public sector (approximately 40%) and through contract research earnings (roughly 60%). As a consequence, the Fraunhofer-Gesellschaft operates in a dynamic equilibrium between application-oriented fundamental research and innovative development projects. As a member of the Fraunhofer-Gesellschaft with 59 institutes, Fraunhofer UMSICHT with eight specialized business units follows the line of applied, cutting-edge research and development.

**www.umsicht.fraunhofer.de**

**Research focus**
Fraunhofer UMSICHT develops applied and custom-made process engineering technologies. Starting from the project idea over proposal procedures to the development and market introduction, Fraunhofer UMSICHT offers its clients R&D expertise and thus opens up international markets for them. Research focus of business unit Energy Efficiency Technologies: energy storage and energy efficiency.

**Goals of research**
**Short-term**
Research on redox-flow batteries, Compressed Air Energy Storage (CAES) and systemic analysis of energy storage in the grid

**Medium-term**
Extension and integration of renewable energies inter alia with electrical energy storage

**Long-term**
$CO_2$-neutral energy production, higher efficiencies of plants and a secure grid

**Competence specialization**
Our objective is the intelligent integration of energy systems into existing and new supply structures as well as their efficient utilization. We combine fossil and regenerative energy sources with central and local conversion processes in order to create custom-made, economically and ecologically balanced systems which pave the way for local synergies.

The institute has special competences in the field of energy storage. Our research focuses on redox-flow batteries, Compressed Air Energy Storage (CAES) and systemic analysis of energy storage for the integration of renewable energies in the grid.

**Resources**
With the non-material support of the city Oberhausen and the local industry, Fraunhofer UMSICHT was founded as a non-profit technical-scientific institution in June 1990. The newly constructed institute buildings were ready to be moved into in January 1993. They comprise office space (2000 m²) with EDP center, library and lecture room as well as three halls (4500 m²) for the physical, analytical and biotechnological laboratory, workshops and pilot plant stations.

Its more than 331 staff members produced a turnover of more than €21 M in 2009.

A huge test laboratory for redox-flow stacks and batteries (up to 80 kW) as well as a test facility for lithium batteries (up to 120 kW) are available.

**Global network**
Fraunhofer UMSICHT contributes to different IEA (International Energy Agency) annexes. There are also cooperations with the University of Michigan and with the four main transmission system operators in Germany.

## Opportunities for cooperation

The purpose of the project "Advanced Energy Storage – development of scalable, stationary energy storage in order to relieve the electricity grid while integrating renewable energy" is to technologically assess and develop improved electricity storage systems. Under the direction and supervision of Fraunhofer UMSICHT five institutes work together.

A research focus is the development of redox-flow batteries, their testing in a laboratory and also their optimisation.

Systemic topics:
- Analysis of the energy storage demand in different countries
- Business models/storage services in the grid
- Integration of hybrid vehicles
- Virtual energy storage based on demand side management.

Technological topics:
- Redox-flow batteries
- Compressed air energy storage (adiabatic and isothermal concepts)
- Cold storage for demand side management.

Fraunhofer ICT

*Simulation of environmental conditions (rain water test) which forms part of our development of concepts to ensure safety. It includes testing of batteries subjected to malpractice.*

Photo: Fraunhofer ICT

## Description of institute

The Fraunhofer-Institute for Chemical Technology (ICT) in Pfinztal is a non-profit organization and carries out research and development work within the key competences areas applied electrochemistry, energetic materials, energetic systems, environmental engineering and polymer engineering. We engage in contract research for industry, and collaborate with companies on research projects co-financed by the German government or the EU. The 440 staff earned around €28.5 M in revenue during 2009.

**www.ict.fraunhofer.de**

**Research focus**
Batteries, fuel cells, electrochemical sensors and electro-catalysis are the main research focus of the Applied Electrochemistry Department. Here research and development activities in both civil and military sectors range from material characterisation and optimisation, through the development of rapid characterisation methods for materials, components and systems, to process development and the manufacture of prototypes. In addition to a fully-equipped electrochemical laboratory, we offer our customers wide-ranging electrochemical know-how.

**Goals of research**
**Short-term**
For batteries: to develop materials for lithium-ion batteries with enhanced capacity and performance; new, constructional and electronic protection concepts to ensure safe operation under defined conditions.
For fuel cells: to develop alkaline systems and HT-PEM fuel cells which operate above 130°C enabling a greater choice of catalysts and fuels.

**Medium-term**
For batteries: to develop scaleable electricity storage devices with an output range between 100 kW and 5 MW for decentralized, network-integrated storage systems. Development and demonstration of redox-flow-batteries for different applications e.g. in conjunction with wind turbines.

**Long-term**
New storage systems with greatly increased energy density e.g. lithium oxygen, lithium sulphur and redox-flow batteries.

**Competence specialization**
Fraunhofer-Network of Batteries is coordinated by Fraunhofer ICT.

- Fraunhofer-Network of Electrochemistry: 13 Fraunhofer-Institutes collaborate to form this network which pools its electrochemical know-how to construct pilot units and optimise processes.
- Battery technology: focus is on designing and developing components, modules and batteries. E.g. ionic liquids and polymers are researched as electrolytes as well as lithium battery systems such as lithium-oxygen or lithium-sulphur. Battery systems are also selected for specific applications Hybrid systems involving two or more technologies are assembled e.g. combinations of fuel cells and batteries.
- Redox-flow batteries: aim is to develop suitable electrolytes, electrodes and membranes, as well as optimize process parameters.
- Fuel cells: currently, hydrogen and methanol are most often used for electricity generation in fuel cells. Current research is focused on developing fuel cells for both mobile and stationary applications for using alternative fuels such as bio-ethanol and ethylene glycol. This requires new catalysts, membranes, electrolytes and electrode structures especially when the cell is operated at elevated temperatures of up to 250 °C.
- Safety: safety tests can be carried out. These include, comprehensive mechanical and electrical tests, misuse tests and performance tests on cells and modules.

**Resources**
Electrochemical equipment incl. potentiostats, galvanostats and electrochemical impedance measurement sites. Additional facilities such as extensive testing and development methods for batteries/fuel cells and components have been developed.

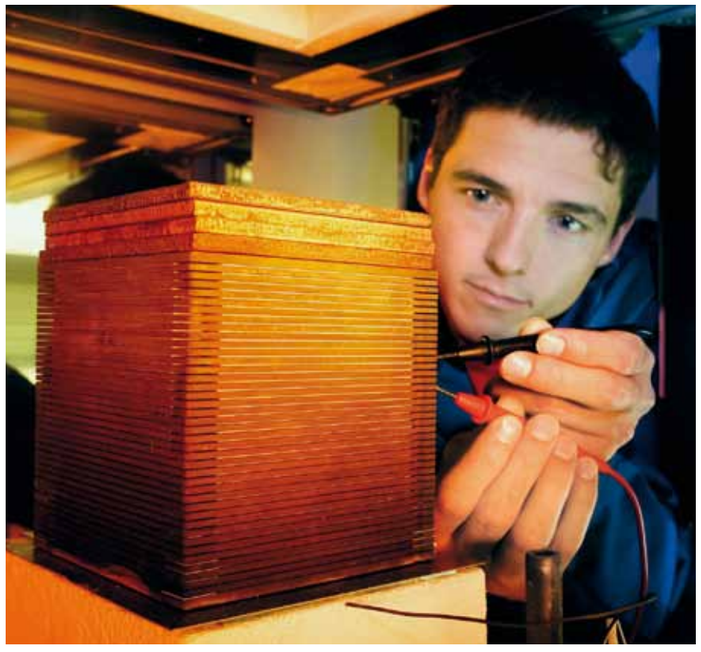
Safety tests can be performed to specific standards and regulations. These include comprehensive mechanical and electrical tests, misuse tests and performance tests on cells and modules from µW to 160 kW (1000V to 600A).
In addition to development of materials and systems, the ICT also carries out environmental performance evaluations for various components and products.

**Global network**
Fraunhofer ICT cooperates worldwide with research institutions and industrial partners.

One example:
With the University of Michigan we launched two joint research teams addressing the increasing global demand for more efficient and sustainable technologies for transportation.

## Opportunities for cooperations

Nondisclosure agreements,
IP rights and the exclusive utilization of the results form part of our standard contracts.



*The performance of fuel cells is tested under extreme conditions in the fuel cell test center of the Fraunhofer IKTS Dresden. State of the art stack metering modules – capable of monitoring SOFC-stacks as well as complete fuel cell systems – form the heart of the new testing centre. The full spectrum of fuels (natural gas, bio gas, liquid fuels) can be employed. This enables an assessment of devices under field-conditions, thereby contributing to the industrial development of next generation fuel cells.*

Photo: Fraunhofer IKTS

Fraunhofer IKTS

## Description of institute

The Fraunhofer nstitute for Ceramic Technologies and Systems is one of the best ceramic institutes in the world with the unique combination of structural and functional ceramics in one place. Our projects are mainly focused on applied research and financed by industrial partners (41 %), local (10 %) and federal government (15 %). The overall annual budget of the institute for 2008 was €20.8 M and this has been continuously growing since 2005. The main markets and research areas for us are: renewable energy, Li batteries, stationary power plants and health care.

**www.ikts.fraunhofer.de**

**Research focus**
Grounded in its extensive knowledge of ceramic technologies and systems which cover the complete field of advanced ceramics, IKTS has specialised in the development and testing of fuel cell systems (SOFC and PEFC), thermoelectric generators and energy storage devices like Li batteries. The materials and components as well as their integration in system prototypes are in the focus of our research.

**Goals of research**
Development of SOFC systems for Micro CHP, materials and components for Li-ion cells and supercaps, inks for back off-line processing for solar cells.

**Medium-term**
Development of portable SOFC systems based on planar stacks for power range 100-300 W, technology for Li-cell manufacturing.

**Long-term**
Development of SOFC stacks and systems for power range >20 kWel for stationary power generation.

**Competence specialization**
IKTS covers the complete field of advanced ceramics, from basic research to applications. It has three core competencies: materials expertise, manufacturing technologies, and systems and product integration. It develops materials, technologies and components in the field of advanced ceramics and hard metals/cermets.
Customer projects span the entire value chain, from first concept to laboratory scale and finally to prototype production. Prototypes are produced in relevant quantities on pilot plants to facilitate the market entry.

The development of new ceramic materials, effective processing and components as well as their system integration is the unique combination offered by IKTS. Knowledge about the material properties, technology costs and desired system functions allows us to develop products in fields where ceramic materials and ceramic technologies (screen printing, tape casting etc.) are used (e.g. fuel cells, solar cells, Li batteries and supercaps).

**Resources**
The institute has a permanent staff of 218 scientists and technicians who operate in more than 100 excellently equipped labs and pilot plants with a floor space of 9400 m² of which 40% are dedicated to energy systems. The technological lines for powder processing, ceramic multilayer technology and coating are available to develop and upscale the manufacturing processes up to prototype scale.

The development of SOFC fuel cells is enabled by equipment (incl. software) for:

- Thick film technology
- Multilayer ceramics
- Simulation
- SOFC and system technology
- Low and high-temperature electrochemistry
- Development and preparation of test stands for system components (cells, burners, reformers etc.)
- Test benches for stack and system testing under laboratory conditions.

**Global network**
Currently, the Fraunhofer IKTS cooperates with more than 250 national and international partners in numerous projects. Fraunhofer IKTS is a member of the Fraunhofer Energy Alliance and is well integrated in German and European research activities. Vaillant, Plansee, Bosch and Continental are among our important customers. IKTS collaborates with partners in USA, Russia, China and Brazil.

## Opportunities for cooperation

Fraunhofer IKTS has been working on SOFC components and stacks since 1993. In numerous projects with industrial partners the basics for modular planar SOFC stack manufacturing has been developed and transfered into industry. Currently, the Micro CHP system for natural gas as a fuel is under development in cooperation with Vaillant within the framework of the Callux programme set up by the German government to accelerate the market entry of fuel cell technology. Recently, it was shown by our scientists that biogas as one of the most promising renewable fuels can be effectively (electrical efficiency up to 60%) converted to electricity using SOFC technology. The efficient biogas production, purification and conversion in SOFC are the core technologies under development at Fraunhofer IKTS. In this field the know-how can be offered along the whole value chain: from biological substrate to electricity production in power plant. The demonstration and research and development projects in this area are now the focus of our interest. The goal of future activities is to provide SOFC units in the power range >20 kW for operation on biogas, natural gas and (bio)ethanol for power generation.

Fraunhofer ISE

*Test bench for characterisation of reversible fuel cell stacks*

Photo: © Fraunhofer ISE

## Description of institute

With a staff of 930 Fraunhofer ISE is the largest European solar energy research institute (see page 69). Within the business area Hydrogen Technology more than 80 scientists, engineers, PhD and other students work on the research and development of fuel cells and hydrogen generators.
We offer and perform research and development services based on contract research for industrial partners or in public funded projects. The annual budget is in the order of €4 M, with about 40 % provided directly by industry.

**www.ise.fraunhofer.de**

**Research focus**
For over 20 years, Fraunhofer ISE has been carrying out applied research in the business area Hydrogen Technology. The work covers applied research and development on hydrogen production by means of reforming and electrolysis, hydrogen storage as well as hydrogen conversion into electrical power and heat by means of PEM fuel cells.

**Goals of research**
**Short-term**
Development of hydrogen technology including approaches and components up to prototypes and market-ready products.

**Medium-term**
Technological support for the commercialisation of fuel cells and hydrogen generators.

**Long-term**
Establishment of hydrogen as one of the future energy carriers for a sustainable energy economy based on renewable energy sources.

**Competence specialization**
- Components and automated LT and HT fuel cell systems ranging from 1 $W_{el}$ up to a few $kW_{el}$
- Stacks and systems for PEM electrolysis ranging from a few $W_{el}$ up to a few $kW_{el}$
- Automated reformer systems in the 1 $W_{el}$ to 20 $kW_{el}$ range with product gas purification for (bio-) ethanol, (bio-)diesel, gasoline, kerosene, LPG (camping gas) and natural gas
- Catalyst development and characterisation for reformer systems and gas purification
- Hydrogen generation using chemical hydrides
- Component and system development for redox flow batteries
- Characterisation and modelling of hydrogen components and systems
- Development of control and safety technology
- Monitoring of hydrogen systems in field tests
- Accredited tests for components and systems as well as VDE certification.

**Resources**
The scientific investigation of the physical, chemical and electrochemical reactions and mechanism constitutes the basis for an optimized design of our components and systems. In order to constantly improve our technology, we employ simulation tools, dynamic simulation models, wide-ranging characterisation options for in-situ and ex-situ diagnostics and automated long-term measurement equipment. The scientific and technical equipment comprises state-of-the-art analysis tools e.g. standard MS, GCs, FTIR, Environmental Scanning Electron Microscope (ESEM) with EDX and an Inductively Coupled Plasma (ICP-MS) unit. Core equipment are purpose-built test benches e.g. a multi-channel impedance system for spatially resolved measurement on PEM fuel cell stacks.

**Global network**
ISE cooperates with almost 100 national and international organizations. Of particular interest in the business area Hydrogen Technology are:

- Close co-operation with the Industry/University Cooperative Research Center for Fuels of the University of South Carolina
- German-Canadian projects on micro water management in PEM fuel cells with five German and five Canadian research organizations.
- Cooperation with the German VDE for certification of portable and micro fuel cell systems.

## Opportunities for cooperation

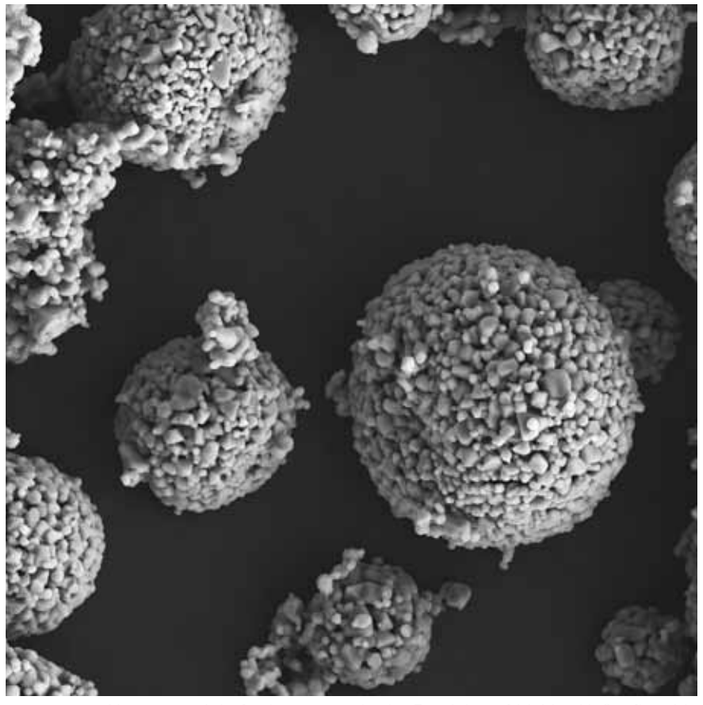
We offer our clients research and development services in the following areas:

- Reforming of liquid and gaseous fuels
- Membrane electrolysis
- Membrane fuel cells

Currently we are extending our portfolio to include the conversion and usage of biomass (gasification of wood).
Another new focus is the generation of solar hydrogen by direct coupled multi-junction III-V solar cells with PEM water electrolysis cells.

# KIT: Material for energy and hydrogen storage devices





*Nanomaterials for battery cathode: Particles of Li-Mn-Al-Oxyfluoride synthesised by milling, spray-drying, and calcination.*

Photo: KIT

## Description of institute

The Karlsruhe Institute of Technology (KIT) was founded in October 2009 by a merger of Forschungszentrum Karlsruhe GmbH and Universität Karlsruhe (TH). With approximately 8000 employees and an annual budget of €700 M it is among the largest research and education institutions worldwide. The largest and most visible research units are the "KIT centres" and "KIT focuses". One of the four "KIT Centres" is the Nano-Micro centre. Here the Helmholtz Programme NANOMICRO is the largest individual unit.

**www.kit.edu**

**Research focus**
Research teams of the Helmholtz Program NANOMICRO: Science Technology Systems, focus on novel materials for storage of electricity or hydrogen. This includes the synthesis and the characterisation of materials, and the development of components and systems for energy storage devices.

**Goals of research**
**Medium-term**
Identification of new nanoscale reaction systems with very high reversible hydrogen content, suitable thermodynamic properties and fast kinetics. Synthesis of new reversible, thermally stable electrode materials with high energy density and high cycle life.

**Long-term**
System integration of new hydride materials in high temperature PEM fuel cell environment. Large lithium ion battery cells of novel materials with higher specific energy and improved cycle stability.

**Competence specialization**
NANOMICRO researchers have a broad and globally recognised expertise in nanotechnology, in particular for sophisticated synthesis, structuring processes and characterisation techniques of nanoscale composites. Research topics for energy storage cover all aspects from fundamental materials research to fabrication of components and systems. Examples include hydrogen tanks and large-format battery cells.

State-of-the-art-equipment required for R&D of micro systems and nanomaterials is available for scientists to develop novel materials for hydrogen storage and battery cells. The outstanding properties of nanomaterials are being exploited as conversion materials for storage of hydrogen with nanoscale hydrides. In addition to improving the storage capacity times required to charge and discharge hydrogen were reduced significantly by employing novel nano-dopants. Furthermore, conversion materials as well as intercalation materials were developed for battery electrodes.
In the future, research will be extended to include the development of super capacitors.

**Global network**
- Hydrogen storage: co-ordination of collaborative research projects EU-RTD Project NANOHy (Novel Nanocomposites for Hydrogen Storage Applications), EU-ERA NET Hy-CO, GCSFP (German Chinese Sustainable Fuel Partnership), Partner in EU projects: EU-IP StorHy (Hydrogen Storage for Automotive Applications) EU-IP NESSHY (Novel Efficient Storage Systems for Hydrogen) EU-IP COSY (Complex Solid State Reactions for Energy Efficient Hydrogen Storage)
- Batteries: coordination of the BMBF Consortium South Electro Chemistry for Electro Mobility, BMBF research project with industry (Li-Tec, Evonik Litarion, and IoLiTec), KIT e-drive-Project House with Daimler AG.

## Opportunities for cooperation

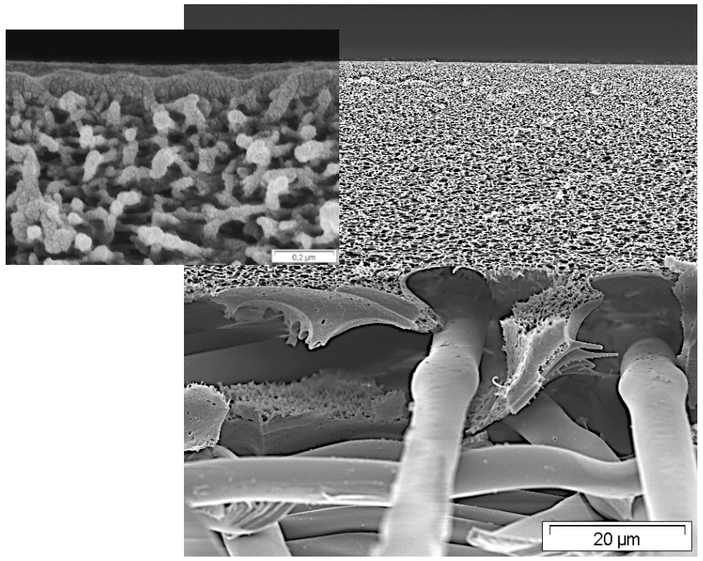
Functional nanocomposites for storage of hydrogen are synthesised by high-energy ball milling and characterised. Structures and storage capacity are then verified and tailored to achieve fast and stable cycling behaviour. The synthesis process is scaled up to pilot plant scale, so that the storage material can be integrated in tanks and tested in the process environment. Tests follow with nanocomposites in the kg range to investigate safety relevant properties and to develop techniques for safety handling.

For the development of novel batteries nanoscale conversion materials e.g. fluoride or magnesium based systems, and intercalation materials e.g. Li-Mn-spinells, Li-oxyfluorides and Li-olivines are synthesised and if needed coated, doped and structured. Their electro chemical potential is investigated with knob and Swagelok cell tests. Cells can be constructed with novel electrolytes e.g. based on ionic liquids.

All cell components are tested together and tuned. Electrodes are produced with the most promising materials by tape casting. At least large format cells are constructed and electro chemically characterised. Furthermore, thin film cells can be produced by PVD processes and laser sintered as well as structured including a solid state electrolyte.

# GKSS: Novel nanostructured polymer membranes






*Microstructure of Gas separation Membrane*

GKSS
FORSCHUNGSZENTRUM
in der HELMHOLTZ-GEMEINSCHAFT

## Description of institute

GKSS is one of 16 members of the German Helmholtz Association with a total staff of approximately 800 employees, including about 420 scientists, engineers and technicians. It is active in the research fields of materials, neutron and synchrotron radiation and coastal research.

Its Institute of Materials Research, Materials Technology, Depts. of Nanotechnology and Sustainable Energy Technology focus on several aspects of hydrogen technology, from hydrogen generation over separation from exhaust gases and processing to storage and use in polymer membrane based fuel cells.

**hydrogen.gkss.de**

**Research focus**
Development of novel polymer based membranes. Major applications include sustainable hydrogen generation by wind, solar energy or natural and bio gas, processing and cleaning as well as fuel cells e.g. for future zero-emission automobiles, trucks, trains and ships.

**Goals of research**
**Short-term**
Development of polymer based membranes with high proton conductivity for fuel cells; Development of polymer based membranes with high flux and high selectivity for $CO_2/N_2$ and $CO_2/H_2$ separation.

**Medium-term**
Development of polymer based materials for hydrogen generation by solar energy (artificial photosynthesis).

**Long-term**
Integration in stationary and transport applications.

**Competence specialization**
Primary focuses of development are:
- Membranes for hydrogen separation (e.g. in direct production of hydrogen by photocatalytic processes or separation from exhaust gases in power plants)
- Membranes for hydrogen processing (e.g. drying, separation of impurities)
- Membranes for PEM and Direct Alcohol Fuel Cells
- Low-cost production of membrane materials, development of corresponding engineering processes for industrial use
- Testing of the membrane materials in near application conditions

**Resources**
Equipment for membrane production, characterisation, processing up to the square meter pilot scale; Equipment for characterisation of electron- and proton conductivity; Membrane module test facilities.

**Global network**
GKSS has more than 20 years research experience in membrane technology. Collaborations exist with partners from Europe and South America. Industry is involved in several projects.

## Opportunities for cooperation

Cooperations are sought in the framework of direct contract research (target companies: membrane and module manufacturer, process technology for the application of membrane technology), also public funded projects are possible, as well as licensing of patented materials, specific materials processing routes and prototype constructions.

Mem-Brain
Gas separation membranes for zero-emission fossil power plant (Helmholtz Alliance, 2007 – 2011)

Solhydromics
Nanodesigned electrochemical converter of solar energy into hydrogen hosting natural enzymes or their mimics (EU-CP, 2009 – 2011)

Carbomembran
Mixed matrix membranes with carbon nanotubes for the gas separation and desalination (BMBF, 2008 – 2010)

Helmholtz – National Research Council of Canada cooperation "Development of membrane-electrode-assemblies for fuel cell operation at high temperature and low humidity conditions" (Helmholtz – NRC, 2008 – 2011)

*Photo: GKSS*

# GKSS: Novel nanostructured materials for efficient storage of hydrogen



*Europe's largest hydrogen storage tank based on complex hydrides and containing 8 kg of sodium alanate storage material, constructed and built at GKSS*

Photo: GKSS

## Description of institute

GKSS is one of 16 members of the German Helmholtz Association with a total staff of approximately 800 employees, including about 420 scientists, engineers and technicians. It is active in the research fields of materials, neutron and synchrotron radiation and coastal research.

Its Institute of Materials Research, Materials Technology, Depts. of Nanotechnology and Sustainable Energy Technology focus on several aspects of hydrogen technology, from hydrogen generation over separation from exhaust gases and processing to storage and use in polymer membrane based fuel cells.

**hydrogen.gkss.de**

**Research focus**
Development of novel light-metal hydrides and hydride based prototype hydrogen storage systems. Major applications are stationary, including storage of hydrogen generated by wind, solar heat or natural gas as well as mobile e.g. storage in future zero-emission automobiles, trucks, trains and ships.

**Goals of research**
**Short-term**
Optimisation of materials for hydrogen storage (targets: capacity >5wt%, >40vol%, Temp. of Operation < 200°C, reaction enthalpy ca. 30 kJ/(mol $H_2$), materials cost < 50 €/kg).

**Medium-term**
Development of hydrogen storage tanks, cost effective materials production (target value: cost of complete storage system 500 € per kg of stored hydrogen in series production).

**Long-term**
Integration in industrial applications, focus on storage of regenerative energy, use in stationary and transport applications. Target: more compact (better factor 2), cost effective storage.

**Competence specialization:**
Primary research & development competetences are:

- High capacity light-metal hydrides and composites and suitable catalysts for fast hydrogen sorption, optimised for application requirements
- Low-cost, large scale production of nanocrystalline hydrogen storage materials, development of corresponding engineering processes for industrial use
- Testing of the materials in larger powder beds and test tanks under application oriented conditions
- Application specific optimisation of tank design (e.g. for hydrogen generators, mobile applications)

**Resources**
Equipment for hydrogen storage materials production up to the kg pilot scale, comprehensive materials characterisation.
Hydrogen storage tank test facilities.

**Global network**
GKSS has more than 14 years research experience in nanocrystalline light metal hydrides (more than 80 publications, 7 patents, 5 patent applications pending) and was/is involved in international projects and cooperations in this field (EU IP's STORHY and NESSHY, Helmholtz Initiative FUNCHY, Marie Curie RTN COSY, EU CP FLYHY. GKSS constructed Europe's largest tank for solid state hydrogen storage based on complex hydrides (8 kg NaAlH4). Collaborations exist with partners from Europe, North- and South America as well as China. Industry is involved in several projects.

## Opportunities for cooperation

Cooperations are sought in the framework of direct contract research (target companies: powder materials producers, manufacturers of equipment for and end users of hydrogen technology), also public funded projects are possible, as well as licensing of patented materials, specific materials processing routes and prototype constructions.

Coordinator of the following public funded projects:
- FUNCHY
  (Helmholtz Initiative,
  http://funchy.gkss.de, 2005 – 2010)
- COSY
  (Marie Curie Research
  Training Network,
  http://www.cosy-net.eu,
  2006 – 2010)
- FLYHY
  (European CP FP7,
  http://www.flyhy.eu, 2009 – 2011)

Partner of the following projects:
- NESSHY
  Novel Efficient Solid
  Storage for Hydrogen
  (http://www.nesshy.net,
  2006 – 2010)
- GCSFP
  Development, Upscaling and
  Testing of Nanocomposite
  Materials for Hydrogen Storage
  (Project in the National Innovation
  Program Hydrogen and Fuel
  Cells, 2009 – 2012)

# FZ-Jülich: Fuel cell research from basic principles to complete systems



*Flexible line coater*

JÜLICH FORSCHUNGSZENTRUM

## Description of institute

The Institute of Energy Research (IEF) investigates fuel cells with an institutional and third party funded staff capacity of approximately 160.

The Institute of Materials Synthesis and Processing (IEF-1) deals with material and component development for fuel cells (SOFC).

The Institute of Microstructure and Properties of Materials (IEF-2) focuses on high-temperature materials for fuel cells (SOFC).

The Institute of Fuel Cells (IEF-3) specializes in the fundamental topic of electrochemistry and process engineering for fuel cells (SOFC, HT-PEFC, DMFC) and fuel processing from middle distillates.

**www.fz-juelich.de**



**Research focus**
With its wide-ranging expertise in physics, chemistry and engineering science and its core competences in solid state and material research, engineering and simulation science and imaging, Forschungszentrum Jülich (FZJ) is well equipped to make major contributions to tomorrow's energy supply using fuel cells. The fuel cell activities are supported by systems analysis and scientific supercomputing.

**Goals of research**
**Short-term**
Solving structure-activity relationships by using analytical methods to gain a deeper understanding of the processes in fuel cells, to increase performance and life.

**Medium-term**
Implementation of automated manufacturing and assembly techniques for cell and stack components with regard to quality, reproducibility and the reduction of material and production costs.

**Long-term**
Verification of systems with optimized performance, durability and reliability: integrated stack module with SOFC, DMFC for light traction and HT-PEFC with fuel processing for on-board power supply.

**Competence specialization**
An integrated and interdisciplinary approach ensures excellent communication between the different disciplines.
Powder synthesis and production of ceramic and metallic materials and mixed materials for bulk and layered elements are carried through by IEF-1. Further topics are those based on powder technologies and coating processes for metals with improved functional porosity.

IEF-2 competences are focused on the investigation of physical-mechanical properties of high temperature structural metallic materials, structural ceramics and metallic and ceramic coating systems. This requires new approaches for materials testing and investigation and new methods for material characterization and analysis.

IEF-3 is focused on the basic topic of electrochemistry and process engineering for fuel cells, which are accompanied by physico-chemical analysis, system analytical studies, fundamental modeling and simulation as well as experimental and theoretical system evaluation.

**Resources**
Infrastructure facilities for fuel cell R&D are geared towards the requirements of different fuel cell types:

- Supercomputers for time-saving model calculations
- Physicochemical fuel cell laboratory with facilities for imaging, electrochemical, chemical, and physical analyses
- Universal automated and certified test rigs for fuel cells, stacks and processing units with in-situ diagnostic devices, data acquisition and evaluation
- Fabrication technology with a universal coating and treatment facility for the automated, near-industry fabrication of functional coating systems and an assembly robot for MEA and stack assembly
- Supply systems for short- and long-term operation of fuel cell stacks, reformers and systems with fuel cells
- Verifiers and test facilities for studies on system behaviour.

**Global network**
FZJ has a long history of strategic cooperations, global networking and the licensing of technology. The partnerships with industry provide FZJ with knowledge on industry requirements and desired operational conditions. This leads to a smooth technology transfer of FZJ results. Intense dialogue and relationships have been established with research institutes and universities.

## Opportunities for cooperation

The cooperation with industry has led to light-weight SOFC stacks for automobile applications. These results will be further exploited with the intention of achieving cost reductions for stationary stacks and of adopting interconnect manufacturing methods.
Within the European Real-SOFC project, lifetimes of approximately 10.000 hours have already been proven with Jülich stacks. In order to further extend this performance, the degradation effects on materials must be fully understood. On the other hand, methods for accelerated testing must be developed.
A joint collaboration has been initiated with the National Research Council Canada in the field of performance and durability enhancement for DMFC systems. Furthermore, FZJ is cooperating with Oak Ridge National Laboratory on the analysis and characterisation of materials and processes for cost-effective efficient fuel cell systems.
Jülich DMFC research is working with partners from industry in a project consortium on developing a marketable DMFC energy system for a forklift truck. Together with Airbus Deutschland, FZJ is engaged in R&D activities focusing on fuel cell applications for generating electricity from kerosene on board aircraft.

# DLR: Solar thermal generation of hydrogen



Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

*Focal concave mirrors-Heliostat field in Almeria*
*The concave mirrors (Heliostats) can be rotated to focus the moving sun onto a central solar receiver at the top of the tower*

Photo: DLR

## Description of institute

Deutsches Zentrum für Luft- und Raumfahrt (DLR) is the German aerospace centre, its space agency and with more than 6000 employees the largest engineering research facility in Germany. The scientific focus of the DLR Institute of Technical Thermodynamics (DLR-TT) is on solar thermal power plants, fuel cell technology, thermal process engineering and system analysis.

The division "Solar Research" with a staff of 75 persons focuses on concentrating solar technologies for power and fuel production. DLR is a world leader in solar thermal hydrogen production.

**www.dlr.de**

**Research focus**
Development of solar thermal reactor technology for large scale hydrogen production. The focus lies on reaction improvement, reactor materials and components development, integration, automation and economic evaluation.

**Goals of research**
**Short-term**
Development of components for industrial solar-driven hydrogen production based on established processes like steam methan reforming and demonstration of the technology in a MW plant.

**Medium-term**
Development and demonstration of the economically most promising carbon-free hydrogen production processes with efficiencies above the competing renewable processes like wind-powered electrolysis.

**Long-term**
Market introduction of solar thermal hydrogen production as the most efficient technology for large scale plants.

**Competence specialization**
DLR is a world leader in the development of solar thermal power plant technology as well as in solar process heat generation, solar fuel production, storage, and photo catalytic water treatment with the focus on industrial process integration.

It has more than 30 years experience in both national and international cooperative RTD projects for the application of solar radiation. The RTD work followed in all segments using concentrated solar energy for power production, for solar chemistry, solar materials research, techno-economic system analyses including feasibility and market studies, engineering, plant operation simulation and for performance prediction as well as solar field design, development of economic/financial analyses of the implementation of solar power plants in the European energy supply from Mediterranean countries. Since 1992 the DLR Solar Research has acted as "operating agent" for the International Energy Agency (IEA) e.g. for the SolarPACES Implementing Agreement.

**Resources**
DLR operates world class solar test facilities to establish new applications of concentrated solar radiation in the chemical industry and for material research in Cologne and is present with a permanent delegation at the Plataforma Solar de Almería, Spain. Well equipped labs, workshops and simulation tools in Stuttgart and Cologne allow for thermal, chemical, optical and system technological R&D activities. Research installations, such as a 25 kW solar furnace and a 20 kW solar simulator, are available for external users from industry and research.

Because of the high quality of the work done, Solar Research is able to gain 60% of its resources via third-party funding.

**Global network**
DLR's work is globally embedded in networks like the SolarPACES and Hydrogen Implementing Agreements, the International Partnership for the Hydrogen Economy and the European Hydrogen and Fuel Cell Joint Technology Initiative via the N.ERGHY assocoation where DLR is responsible for hydrogen production. DLR cooperates worldwide with research institutions and industrial partners.

## Opportunities for cooperation

DLR's research for hydrogen generation is focused on two thermo-chemical cycles.
With the HYTHEC/HYCYCLES projects, prototypes for solar sulfuric acid splitting necessary to drive sulfur based thermochemical hydrogen production cycles were developed and operated. The hybrid-sulphur thermo-chemical cycle involves the transformation of $H_2SO_4$ into $SO_2$ and oxygen at elevated temperatures generated by solar heating. After oxygen removal, the aqueous $SO_2$ solution can be electrolyzed with significantly lower energy input than pure water, producing hydrogen while recycling $H_2SO_4$. The other cycle – an EC-project named "HYDROSOL" – uses metal oxides. At temperatures of around 800°C these split water molecules into its components by integrating the oxygen into their lattice. Hydrogen can be easily extracted. After saturation of the lattice the metal oxide is regenerated by heating it above 1000°C. DLR and its partners have successfully demonstrated this cycle in the solar furnace in Cologne and on a solar tower in Almería. This process was awarded the Descartes Price 2006, the IPHE Technical Achievement Award 2006 and the Expo Eco Tech Award 2005.

Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

*In 2009 the first airplane (Antares DLR-H2) powered by fuel cells lifted off from Hamburg airport.*
*The use of fuel cells has the following benefits:*
*The exhaust is totally free of particles and consists only of water.*
*If hydrogen is produced by renewable energies, the plane is powered without generating any $CO_2$.*

Photo: DLR

## Description of institute

Deutsches Zentrum für Luft- und Raumfahrt (DLR) is the German aerospace centre, its space agency and with more than 6000 employees the largest engineering research facility in Germany. The scientific focus of the DLR Institute of Technical Thermodynamics (DLR-TT) is on solar thermal power plants, fuel cell technology, thermal process engineering and system analysis.

The division "Electrochemical Energy Technology" with a staff of about 50 persons focuses on fuel cell research & development and system integration for mobile, stationary and portable applications.

**www.dlr.de**

**Research focus**
Fuel cell system development with focus on stationary power plants & aerospace applications. Hybrid power plants in the combination of solid electrolyte fuel cells and gas turbines with high electrical efficiency (>60%) at moderate power size are studied. Multifunctional use of fuel cells in aircraft comprise electricity and water generation as well as use of exhaust gas for inerting of jet fuel tank.

**Goals of research**
**Short-term**
Fuel cell and battery systems with improved power density and extended durability. Demonstration of functionality in aircraft and hybrid power plant applications. Development of detailed models.

**Medium-term**
Demonstration of research system in aircraft with improved performance and beneficial system integration in aircraft. Demonstration of a research hybrid power plant.

**Long-term**
Transfer of aircraft fuel cell system technology to system integrators. Commercial use of the concepts and of the obtained knowledge. demonstration of full scale hybrid power plants by industry.

**Competence specialization**
Overall objective is to make low- and high-temperature fuel cells economically viable by cost reduction, perfomance improvements, extended durability and superior reliability in novel system architectures.

- Research on low-temperature fuel cells concentrates on extending the temperature operation range using novel membranes, economically viable production processes, the integration of novel sensor technology into the fuel cell stack to achieve fully automated operation and overall system engineering.
- Research on high-temperature fuel cells focuses on thin layer SOFC cells in planar design for temperatures around and below 800 °C using plasma injection technologies. Technological benefits and cost effective manufacturing are investigated.
- Aircraft fuel cell system provides significant benefits for inefficient operation regimes of civil aircraft. System modelling, airworthy system design and qualification as well as demonstrator integration in research aircraft have been realised.

**Resources**
The division "Electrochemical Energy Technology" comprises a staff of about 50 persons with test equipment for cell development, cell and stack tests as well as system test. Over 30 test stations for single cell, stacks, batteries and systems are available (up to the 100 kW). Specific expertise and equipment for aircraft qualification and high/low pressure operation is established. Diagnostic methods comprise XRD, SEM/EDX, XPS, TGA, porosimetry, AFM/STM, calorimetry, Raman and IR spectroscopy and in-house developed current density distribution measurement tools and locally resolved impedance measurements. Large scale research facilities include large plasma spraying facilities as well as the DLR manned aircraft Antares as well as access to the A320 research aircraft D-ATRA.

**Global network**
DLR's R&D projects are performed in cooperation with numerous industrial partners and institutes (e.g. EU projects). Networks include EU, national and local associations (N.ERGHY, NOW, BzABW). Strategic partnerships exist with Airbus, EADS and BASF. Research networks with Canada (NRC and Universities), France (CEA) and national Institutes are established, e.g. ZSW, ZBT, FhG-ISE and Universities.

## Opportunities for cooperation

- DLR aims to become a technology leader in the area of hybrid power plants which involves the coupling of microgas turbines and fuel cells. These promise to be low in pollution and highly efficient power plants. In Stuttgart, a laboratory for the project hybrid power plant using a micro-turbine and fuel cell test was set up. An important aspect for the operation of a hybrid power plant is the pressurised operation of the high-temperature fuel cell. DLR has developed and installed a dedicated test rig for testing fuel cells up to 8 bar which is a necessary qualification test for the hybrid power plant.
- DLR – in cooperation with Airbus – is developing multi functional fuel cell systems in aircraft to increase aircraft efficiency & safety and reduce emissions. This involves:
  - Electrical main engine start
  - Emergency power supply
  - Water generation (potable water and water for toilets)
  - Heat generation (icing prevention, hot water generation)
  - Explosion and fire prevention and suppression (inerting of fuel tanks, cargo and e-bay compartment)
  - Cockpit/cabin air humidification.

Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

*Test facility for the investigation of air-heated regenerator storage designed to cover a large operation range in terms of temperature and pressure, suited to various storage applications, including solar thermal power plants based on air-cooled central receivers, adiabatic compressed air, energy storage (AACAES) or storage-supported combined-cycle power plants in CHP operation.*

Photo: DLR

## Description of institute

Deutsches Zentrum für Luft- und Raumfahrt (DLR) is the German aerospace centre, its space agency and with more than 6000 employees the largest engineering research facility in Germany. The scientific focus of the DLR Institute of Technical Thermodynamics (DLR-TT) is on solar thermal power plants, fuel cell technology, thermal process engineering and system analysis.
The Institute of Technical Thermodynamics is one of 32 research institutes of the DLR. Research efforts of its 160 staff members in Stuttgart, Cologne and Almeria (Spain) are focused on efficient energy conversion with low environmental impact and on the improvement and acceleration of the use of renewable energy sources.
About 50 % of the annual budget of €17 M is earned through competitive external grants and contracts.

Present fields of activity are:
- Solar Research, solar thermal power plants
- Electrochemical energy technology, incl. fuel cell technology
- Thermal process technology and
- Systems analysis and technology assessment.

**www.dlr.de**

**Research focus**
The division "Thermal Process Technology" with a staff of more than 30 persons focuses on high temperature thermal energy storage, high performance heat exchangers and fuel processing.

The aim is the development of cost effective, efficient and reliable thermal storage systems. Research focuses on characterisation of storage materials, enhancement of internal heat transfer, design of innovative storage concepts and modelling of storage components and systems. Demonstration of the storage technology takes place from laboratory scale to field testing (5 kW – 1 MW).

**Goals of research**
**Short-term**
Sensible heat storage based on concrete, for liquid heat transfer fluids (oil, compresssed water etc.) and packed bed for gaseous fluids (air, flue gas etc.).

**Medium-term**
Latent heat storage based on salts and salt-systems as phase change material for two phase heat transfer fluids like water/steam.

**Long-term**
Thermo-chemical storage deploying reversible chemical reactions for long-term storage with minimised losses.

**Competence specialization**
DLR has profound experience in the development of sensible and latent heat storage systems. The development of sensible storage is based on a special concrete for the temperature range 100 to 400 °C. These activities included the development of a modular 10 MWh design and its qualification in successful tests with a 500 kWh storage test module.

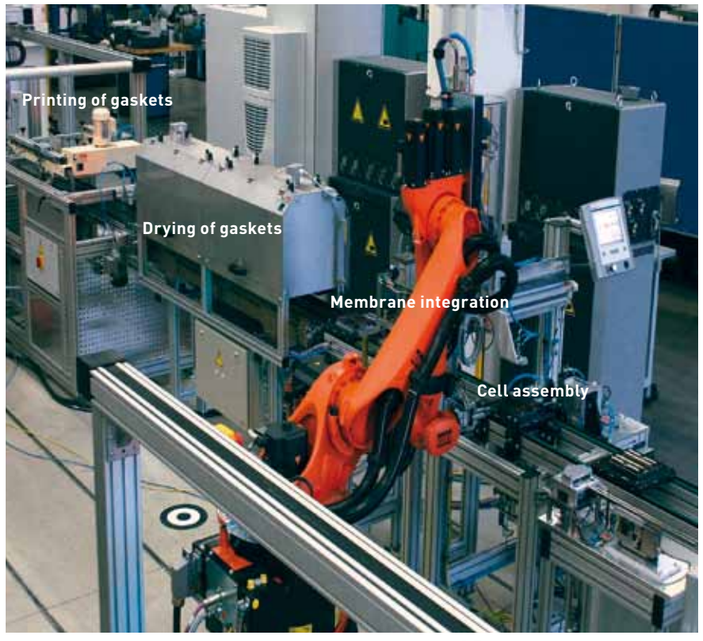
The development of latent heat storage design concepts focuses on applications steam as primary working fluid or process medium. Main results were the qualification of nitrate salts as latent heat storage materials and the development of a graphite or metal fin-tube design. For the first time, sufficient values for the effective thermal conductivity above 10 W/mK could be realised. The new design concept was successfully demonstrated with different nitrate salts at phase change temperatures of 140°C, 220°C and 306° in the power range of 20 kW to 500 kW.

**Resources**
In the division "Thermal Process Technology" more than 20 scientists and engineers focus on high temperature thermal energy storage and thermo-chemical storage development. A thermoanalysis laboratory equipped with STA, DSC, Laser-Flash and TCT (hot wire method), apart from standard equipment, allows for material characterisation of solid, liquid and phase-change storage media. Test facilites for storage component tests are available in the range of 5 to 100 kW with different working fluids like thermal oil, air and water/steam.

**Global network**
Concerning the heat storage topic, DLR is integrated in the IEA "energy storage for energy conservation" ECES programme, and is cooperating with various national and international research institutions like the Bavarian Center for Applied Energy Research (ZAE Bayern) in Germany, CIEMAT in Spain, CNRS in France, PSI in Switzerland, WIS in Israel and NREL in the USA. Industrial partners are, amongst others Ed. Züblin AG, RWE Power and SGL Carbon GmbH.

## Opportunities for cooperation

In the field of thermal energy storage the scientific challenges are covered in three areas of research: The identification of materials with superior thermo-physical and thermo-mechanical properties, the designing of cost effective and reliable components, and the development efficient system integration. In accordance with its mission, DLR is looking for industrial partners for technology transfer.




*Automated PEM-fuel cell assembly line*

Photo: ZBT

## Description of institute

The fuel cell research institute Zentrum für BrennstoffzellenTechnik GmbH ZBT, founded in 2001, is affiliated to the University of Duisburg-Essen and is sponsored by funds from the Region of North Rhine-Westphalia and the European Union. This non-profit fuel cell research institute provides research and development for industrial and public clients and performs services in the field of fuel cell technology. It views itself as a bridge between basic research at the associated university and the needs of the industry. ZBT R&D is financed by direct industrial contracts and public-funded joint projects.

**www.zbt-duisburg.de**

**Research focus**
ZBT's technology portfolio covers the entire value chain for fuel cells and peripheral components e.g. those required for fuel preparation. ZBT pursues an interdisciplinary systems approach to problem solving. Therefore it has expertise in bipolar plates, fuel cell stacks, APU systems, catalyst testing, decentralized hydrogen production, modelling and system structure simulation. Know-how on components is sourced from a large network of specialist partners.

**Goals of research**
**Short-term**
Become known as a leading institution for the development of fuel cells, their components and complete fuel cell systems; generate different technology bases for the early market success of fuel cell.

**Medium-term**
Develop mass production technologies for fuel cells and their components; transfer knowledge to partners for industrial production of components and systems.

**Long-term**
To be a prime partner of the European fuel cell industry for the development of products, production lines and their testing and certification in the area of fuel cell and hydrogen technology.

**Competence specialisation**
ZBT provides contract development services for the total value chain from design to certified commercial production of fuel cell systems. Expertise for components is accessed from specialist partners for micro-fuel cells up to 1 kW aimed at APU and UPS markets.

- Technologies for reformers utilising low boiling fuels such as natural gas, LPG, methanol, ethanol are available for prototyping and licensing
- Technologies for fuel cells and their components for micro fuel cells and stacks up to 1 kW are also available for prototyping and licensing
- Pilot line developing for automated mass production processes including use of high pressure injection molding machines and automated stack assembly is avaiable
- Sophisticated measuring techniques and analytics for fuel cells with focus on bipolar plates, GDL and flow fields are offered for measuring service
- Officially certified testing and approval laboratory for fuel cells and fuel cell modules has been established

**Resources**
ZBT is staffed with about 90 professionals (mainly mechanical and electrical engineers, chemists and technicians). The facilities are available for R&D work performed by ZBT and partners. Laboratory and workshops are known to be of the latest standard available for fuel cell development.

**Global network**
ZBT is an active part of the VDMA Working Group Fuel Cells, DWV, Fuel Cell and Hydrogen Network NRW, Fuel Cell Europe, New European Research Grouping on Fuel Cells and Hydrogen - N.ERGHY and others. International cooperations with German, European and Canadian stakeholders are an essential part of the daily R&D work performed.

## Opportunities for cooperation

ZBT provides a one stop service for developing components from the material to the complete manufacturing system. This includes aspects such as quality control of all components from materials to the final device or system. National and international cooperations with industrial and R&D partners have successfully been established.

- Sub-kW PEM fuel cell stacks for APU solutions
- High-temperature PEM fuel cell stack technologies and system approaches and novel fuel cell approaches for micro technologies
- Sub-kW fuel cell system prototypes for APU and UPS solutions based on hydrogen and LPG
- Reformer technologies for LPG and natural gas
- Production technologies for fuel cell components especially injection moulded bipolar plates based on graphitic materials and gaskets for fuel cell stacks
- Automated assembly line for PEM fuel cell stacks
- The first approved testing laboratory for fuel cells established – offering certified testing procedures for CE certification processes

ZAE BAYERN
BAYERISCHES ZENTRUM
FÜR ANGEWANDTE ENERGIEFORSCHUNG E.V.

*Electrodes for supercapacitors based on thin layered fiber reinforced carbon aerogels*

Photo: ZAE Bayern

## Description of institute

The Bavarian Center for Applied Energy Research (ZAE Bayern) is a non-profit institution comprising three divisions which are all committed to R&D for efficient energy consumption as well as to the generation of renewable energies. ZAE Bayern is partly funded by the Bavarian Ministry of Economics, Transport and Technology (BayStMWIVT).
Furthermore, some projects are financed by industry.

**www.zae-bayern.de**

**Research focus**
We focus on research on components for both electrical and thermal energy storage. Specifically, we work on double layer and hybrid capacitors, as well as on redox-flow-batteries for charge storage and on phase-change materials (PCM) for heat storage. Furthermore, the adsorption of gases and vapors are investigated.

Performance parameters of modules and systems are simulated and monitored.

**Goals of research**
**Short-term**
Research on functional materials both for electrochemical and thermal energy storage. Thermal energy storage system analysis and demonstration projects with special emphasis on power density, energy density, degradation and costs.

**Medium-term**
Development of thermal storage devices for buildings and mobile applications in cooperation with industrial partners. Energy efficiency of industrial processes by the implementation of thermal energy storage technologies.

**Long-term**
Development of electrochemical storage devices (advanced Lithium ion batteries and super capacitors) for e.g. automotive applications. Integration of advanced storage systems in smart grid systems.

**Competence specialization**
Working on both electrical and thermal energy storage technologies gives us the benefit of developing synergies between these two fields. For the storage of electrical energy we improved electrolytes and electrodes for stationary flow batteries and are developing innovative anode structures for lithium ion batteries. Furthermore, innovative carbon based electrode materials and hybrid composites are developed together with new cell designs for super capacitors.
The work on thermal energy storage technologies embraces both sensible and latent heat storage and includes thermo chemical processes based on sorption storages. The activities range from analysis of the thermal properties of suitable materials to the monitoring of demonstration plants in real size applications.

**Resources**
- Facilities for testing electrochemical, chemical and physical performance of batteries and super capacitors
- Facilities for measuring wide-range thermal properties of phase change materials (PCM) and liquid and solid sorbents
- Various test rigs for thermal energy processes experiments (latent and sorption)
- Experimental set-up for hydro-thermal stability of adsorbent materials
- Simulation tools are developed for monitoring melt/crystallisation and sorption processes
- Equipment for synthesis and structural characterisation of nonporous materials

**Global network**
ZAE Bayern has a long history of strategic cooperations, global networking and the licensing of technology. ZAE Bayern is involved in a number of activities within the framework of the International Energy Agency. Partnerships with industry provide ZAE Bayern with knowledge of industry requirements, desired operational conditions and economic boundary conditions.

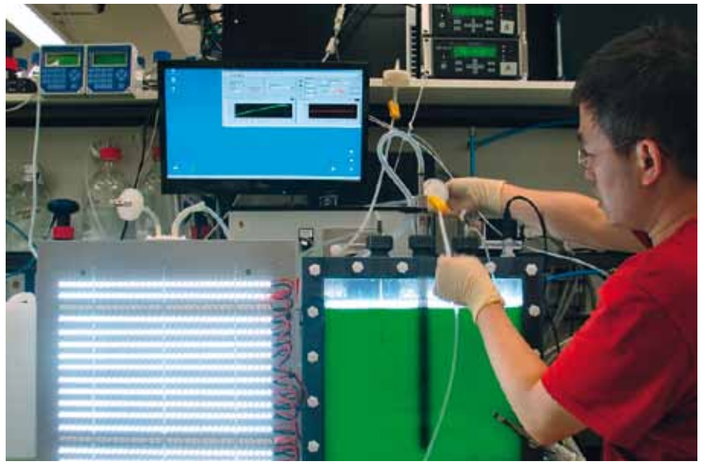
## Opportunities for cooperation

Some examples among the many projects in the thermal energy storage field:

- Mobile thermal energy storage systems for utilisation of waste heat from industrial processes are under investigation. PCM and sorption storage systems were developed and monitored. The economical feasibility will be evaluated.
- Open sorption storage systems are able to convert thermal energy from heat to cold. Such a cooling application for industrial waste heat is being investigated and will be tested in a pilot plant.
- New inexpensive PCMs for high temperature applications will be developed and characterised.
- New cooling systems for buildings are developed and tested within the project development and practical performance testing of building components with PCM in demonstration buildings (www.pcm-demo.info).

# Ruhr-Universität Bochum: Production of hydrogen by micro-algae

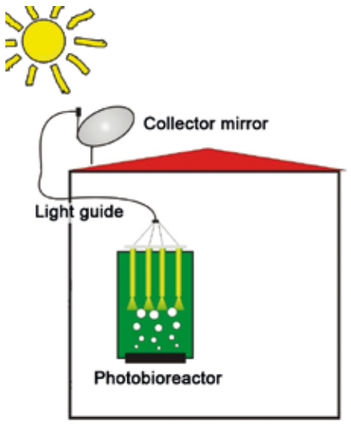





## Description of institute

Ruhr-Universität Bochum
in cooperation with
HU Berlin, FU Berlin,
MPI Mülheim, Universität Köln,
Universität Duisburg-Essen

**www.bpf.ruhr-uni-bochum.de**




Photos: Ruhr-Universität Bochum

**Description of research**
This is a research initiative aimed at harnessing cyanobacteria for energy production. The R&D programme will design and generate a cyanobacterial cell producing hydrogen from sunlight and water. In addition, operational Photo-bioreactors for large scale hydrogen production will be constructed.

This major R&D initiative is based on the leading European expertise in biohydrogen production by utilising cyanobacteria. It is a collaborative initiative of selected research institutes in Germany with industrial partners and has qualified for a federal grant (BMBF).

The first milestone is the development of a labscale (5 l) continuous photobioreactor and a cyanobacterial design cell in which electrons originating from the water-splitting process are mainly used for hydrogen production. This technology will be up-scaled to a large demonstration reactor (100 l). Once this system has been optimised and the design-cell has been generated, it opens up the possibility for large industrial scale reactors.

We envision that this technology will be used to power innovative concepts based on LEDs, light guides, light collectors etc. Furthermore we are developing semi-artificial systems ("Biobatteries") as "proof of principle" for water-based hydrogen production: they involve isolated proteins which are immobilized on gold electrodes for hydrogen production from photosynthetic water oxidation.

## Opportunities for collaboration

This initiative is a special opportunity for companies engaged in the development of bioreactors as basis for a future scale-up for mass-production (modular cheap flat-plate bioreactors). Furthermore companies interested in developing a position in a future mass production are encouraged to develop cheap LEDs with focus on red light (i.e. about 720 nm). We are also developing technologies for collecting sunlight and channeling it through glass fibres to the vessels containing the cyanobacterial cultures. In this way, reactors do not need to be located in an outdoor environment.

## About us

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see map
**Germany:**
**Lead Market for Energy Storage & Fuel Cell Systems**
***Locations of selected opportunities for R&D collaborations***
inside the cover

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***Locations of selected market opportunities***
inside the front cover

## Germany: Lead Market for Energy Storage and Fuel Cell Systems

*Locations of selected opportunities for R&D collaborations*


*Source: Germany Trade & Invest, May 2010*

map: www.typoly.de (Inken Greisner)