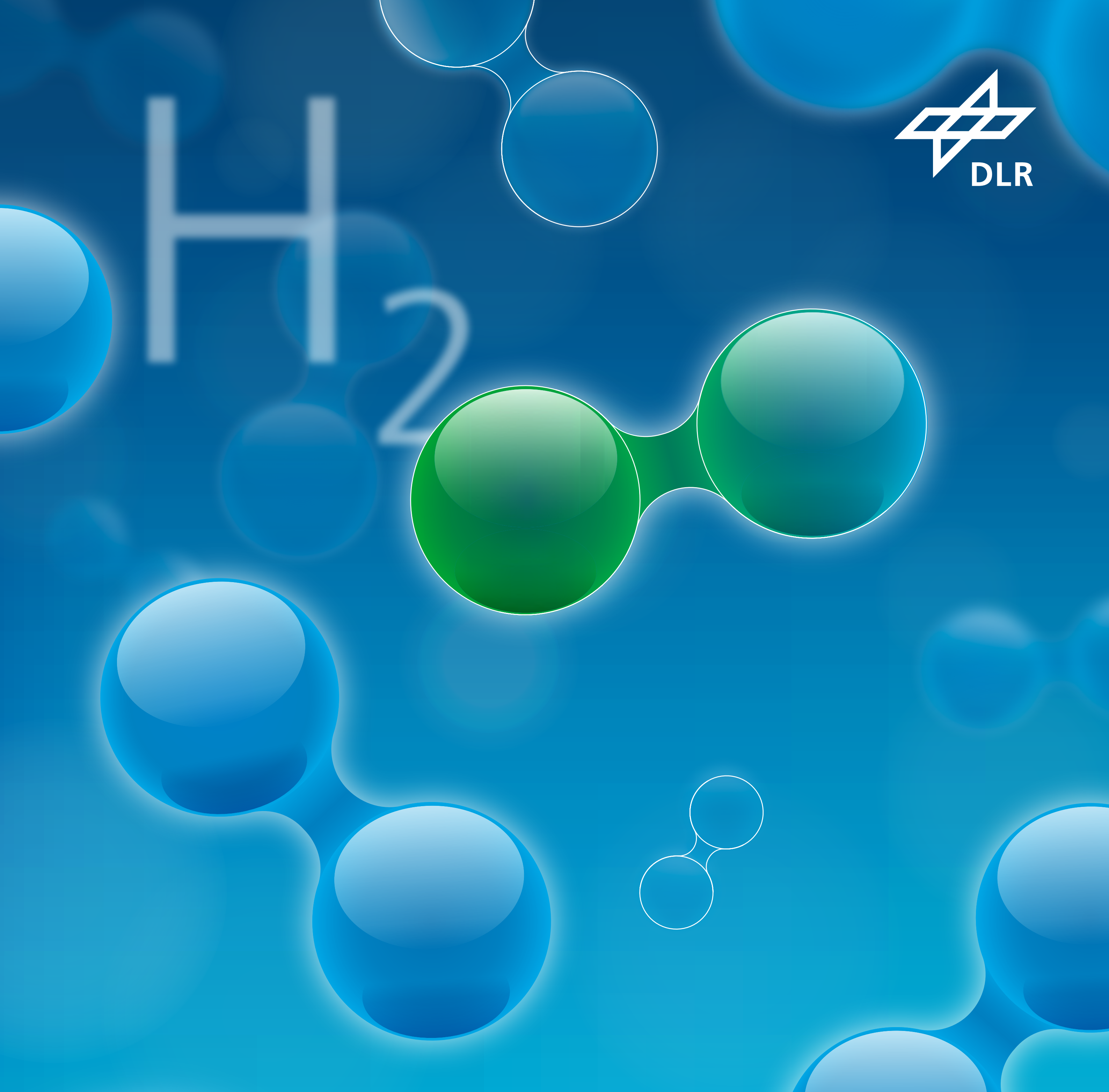


HYDROGEN RESEARCH AT DLR

Setting the course for a climate-neutral energy and transport system

HYDROGEN RESEARCH AT DLR

Paving the way for a climate-neutral future

As a versatile element, hydrogen can make a significant contribution to climate protection. Produced in a sustainable way, hydrogen and its derivatives can replace fossil fuels in industry, transport and the energy system to reduce carbon dioxide emissions. Our researchers are working on all aspects of hydrogen research – from climate-friendly production to storage, distribution and use.

DLR is researching various processes for separating hydrogen from water using renewable energy. These include water electrolysis, biogas reforming, and both photoelectrochemical and thermochemical water splitting. DLR is also working on solutions for long-distance transport, distribution and storage. Another area of research is energy converters such as fuel cells. These convert hydrogen into electricity – for mobile applications such as the propulsion of trains, road vehicles, ships or aircraft, and for stationary applications such as industrial processes or electricity supply. In addition, DLR is researching how gas turbines can be powered by hydrogen for use in industry and energy supply. The use of hydrogen for rocket propulsion is another important field.

At the same time, DLR is investigating the system as a whole. How can industry and society best meet the challenges of transitioning from a fossil fuel-based economy to a hydrogen-based system? The ecological, social and economic implications are being examined as part of these technology assessments.

DLR has unique large-scale facilities for developing technical solutions from laboratory to industrial scales. Together with partners from industry, we are working on application-oriented solutions to specific problems.

To ensure that DLR innovations reach the market quickly, DLR also encourages and supports its own staff and external start-ups to set up companies using DLR technologies.

With its many years of experience, application-oriented research and unique large-scale facilities, DLR is making a significant contribution to the development of the future hydrogen economy in Germany.

Generation

1	Electrolysis	Splitting of water into hydrogen and oxygen using electricity
2	Solar hydrogen production	Use of solar energy to split water via a thermochemical process

Transport, Storage, Distribution

3	Pipeline	Hydrogen transportation using new or modified gas distribution systems
4	Storage caverns	Balancing seasonal demand variations using large underground hydrogen storage systems
5	Tank vessel	Import of hydrogen produced in a climate-friendly way by tanker vessels
6	Tank truck	Hydrogen distribution via the road network
7	Service station	Provision of hydrogen for mobile use (cars, lorries, trains, aircraft, ships)

Use

8	Buildings	Use of hydrogen for electricity and heating in buildings
9	Industry	Hydrogen for electricity and heat, as a reducing agent and a raw material for production
10	Power plants	Electricity generation with hydrogen as a fuel and using the waste heat
11	Refineries	Production of synthetic hydrogen-based fuels
12	Public transport	Hydrogen-powered public transport vehicles
13	Cargo bicycles	Hydrogen as a power source for cargo bicycles
14	Cars	Fuel cells as a propulsion technology in cars
15	Lorries	Hydrogen-powered heavy goods vehicles
16	Ships	Hydrogen as a fuel for maritime use
17	Aircraft	Use of hydrogen or synthetic fuels in air transport
18	Trains	Use of fuel-cell-powered trains on non-electrified routes
19	Rockets	Hydrogen as a rocket fuel

PRODUCTION

Electrolysis and solar processes

Hydrogen produced in a climate-friendly way has the potential to significantly reduce or even eliminate carbon dioxide emissions from the energy supply system. However, hydrogen production is relatively energy-intensive, and production capacity is far from sufficient to meet demand in the short to medium term. In addition, production costs need to be reduced further. Climate-friendly production processes are therefore one of DLR's research priorities. The focus is on reducing the costs and increasing the efficiency of water electrolysis, as well as developing solar-thermal processes and photoelectrochemical systems.

Electrolysis is an established and commercially available technology. DLR is conducting research into the further development of low-temperature electrolysis processes, such as alkaline or proton exchange membrane electrolysis, and high-temperature electrolysis processes. In Germany, the electrolysis capacity fed by electricity generated using renewable resources is still low. In addition to expanding production capacity in Germany, the growing demand for hydrogen should also be met by imports from countries with the highest proportion of renewable energy resources.

Solar-thermal processes for hydrogen production promise particularly attractive efficiencies. Solar-thermal power plants concentrate solar radiation and convert it into thermal energy. This thermal energy can be used to split hydrogen from water without the use of electricity. Suitable locations for such power plants are in regions of the world which are rich in sun. DLR is one of the world's leading research institutions working to develop components and processes for solar thermochemical hydrogen production. The vision is to bring the processes to industrial applications as a building block of the energy transition. The first pilot plants for research and development are already in operation.

Photoelectrochemical processes promise comparable efficiencies to solar-thermal processes. DLR is investigating both types of process in detail and evaluating systems that use them to produce hydrogen.

TRANSPORT, STORAGE AND DISTRIBUTION

The key attributes for transport – from production to use and storage – in a hydrogen economy are reliability, safety and cost-effectiveness. This involves transport routes that connect globally dispersed production sites to hubs in consumer countries and on to the point of use. Depending on the distance, hydrogen could be transported directly by ship, truck and pipeline, or converted into ammonia, methane or liquid organic hydrogen carriers, a class of organic compounds that can absorb and release hydrogen through chemical reactions. It is not yet clear which of these approaches will be the safest and most economical. DLR researchers are therefore investigating and evaluating different transport options.

In addition to technology assessment, there is also significant progress in transport technology development. For example, DLR is working on concepts for importing hydrogen by tanker vessels and the necessary port infrastructure. It is also investigating how the existing natural gas distribution network needs to be adapted for hydrogen transport.

An essential component of the overall hydrogen infrastructure will be large storage facilities. In Germany, underground storage in salt caverns is the most suitable option. DLR is investigating the quality of the hydrogen, the durability of the materials used and the safety of such storage facilities, as well as their best possible integration into the overall energy system.

In addition to stationary hydrogen storage, storage for mobility applications is a key technology.

THE HYDROGEN SYSTEM

The advantages of a hydrogen economy include the possibility of flexible operating electrolysis plants and the conversion of stored hydrogen into electricity at times of insufficient electricity generation from renewable energy sources; the use of long-distance transmission systems for energy transport is another potential benefit. Only once the transport, power generation, heat and industry sectors are fully coupled can climate-friendly hydrogen develop its full potential and become the second pillar of a sustain- able energy system, alongside electricity from renewable sources. The prerequisite for this is that infrastructures are coordinated across sectors. This includes all technologies for storage, transport, conversion and use. DLR is investigating the entire process chain, including the technical integration of hydrogen plants into energy systems.

Fundamental approaches to coupling the sectors are being researched at DLR. One example is fuel-cell vehicles – these use hydrogen to generate electricity for the electric motor. DLR is working to make renewably produced energy sources such as hydrogen usable for powering different vehicles. In addition to setting up a refuelling infrastructure, an important goal is to enable the vehicles to feed electricity into the grid when needed. Another example is electrolysis plants, whose waste heat is used in local heating networks.

DLR is developing scenarios for the use of hydrogen in energy and transport systems and working on market introduction strategies. Also being researched are business models for the production and storage of hydrogen, for example in salt caverns, and analysing the suitability of various locations. These are located mainly in northern Germany, where the local geology is particularly suitable for such infrastructure.

Proactive, forward-looking action can help to identify opportunities for new hydrogen technologies in good time, helping policymakers reach optimal decisions for the long-term benefit of the environment and society.

HYDROGEN IN TRANSPORT

On land, on water, in the air and beyond

Where petrol, diesel, kerosene or heavy oil are used today, climate-friendly hydrogen is a sustainable alternative for the mobility of tomorrow. Compared to battery concepts, hydrogen-based propulsion solutions can demonstrate their benefits when it comes to transporting heavy loads over long distances. In addition to long ranges, they offer the familiar convenience of quick refuelling. In addition, the fuel cells used do not produce any emissions during operation except for water vapour.

DLR is developing sustainable fuel cells and new types of hydrogen tanks for mobile use and integrating them into the overall systems: – cars, buses, trucks, (cargo) bicycles and trains, as well as aircraft and ships.

Scenarios for the market introduction of hydrogen-powered vehicles and the evaluation of the associated emissions and traffic development, including social and economic impacts, are also part of the DLR portfolio.

Road, rail and water

Fuel cell vehicles are attractive for private mobility as well as for passenger and freight transport. DLR is analysing their market and application potential for more sustainable mobility. For rail, fuel cells are an environmentally friendly alternative to diesel on routes without overhead lines. Together with a rail vehicle manufacturer, DLR has developed the world's first fuel cell-powered train. For use in mobility applications, DLR is researching fuel cells with correspondingly high performance.

For shipping, DLR is investigating maritime energy systems that use hydrogen for propulsion as well as heating and cooling. Important aspects such as durability, suitability for everyday use and integration of the systems on board are being studied. For example, electricity can power the ship and also refrigerate the cargo.

Flying – in the air and in space

Fuel cells and electric propulsion for the air transport system of tomorrow are a particularly complex technical challenge. The aim is to make them quiet, efficient and low in emissions. DLR is a pioneer in the use of hydrogen fuel cells in aircraft. By expanding its test infrastructure, DLR will soon be examining systems in the megawatt power range. Additionally, hydrogen can be used as a fuel for modified gas turbines. This is of particular interest for regional to medium-haul aircraft and requires aviation-grade hydrogen storage systems and new combustors. Suitable materials are an important factor in their development.

Synthetic liquid fuels based on hydrogen also offer an advantage, because they can be used wherever climate-friendly alternatives such as batteries or fuel cells cannot easily replace a conventional propulsion system. Existing propulsion components and infrastructure usually need only slight modifications to run on synthetic fuels. The chemical and physical properties of climate-neutral fuels, as well as their performance, composition and production methods, are being investigated in cooperation of several DLR institutes. In doing so, DLR provides a whole-system view of new technologies, from development to sustainability analysis.

The use of hydrogen as a fuel requires new design and production concepts to integrate the tanks into the vehicle structure, with the aim of meeting the certification requirements to ensure safe operation.

Hydrogen has both a future and a heritage in energy intensive applications. It has been an integral part of spaceflight for many decades. DLR is working on modelling the entire process from regeneratively produced hydrogen to novel fuels and testing them in rocket propulsion systems – an important contribution to sustainable spaceflight, exploiting synergies with the energy and transport sectors.

HYDROGEN FOR POWER, HEAT AND INDUSTRY

Fuel cells and gas turbines can be used to produce controllable electricity and heat. Both are key requirements in an energy system based on intermittent renewable energy sources. This means that overcapacity is not wasted; these outputs can be stored and delivered as needed to meet fluctuating consumer demand.

Gas-fired power plants must be modified to run on pure hydrogen. DLR is currently collaborating with turbine and power plant manufacturers to research fuel flexibility on a megawatt scale and is developing concepts for making mixtures of natural gas and hydrogen as stable – and low-emission – as possible.

DLR is also working to address the feasibility of hydrogen technologies for delivering electricity and heat used in energy-intensive industrial processes. For example, renewable hydrogen can replace the coke – made from coal – that serves as a fuel and reducing agent in blast furnaces used for iron and steel production. Renewable hydrogen can also replace natural gas in ammonia production. Hydrogen is needed in refineries and for carbon capture and utilisation technologies, which can recycle waste carbon dioxide into chemical feedstocks.

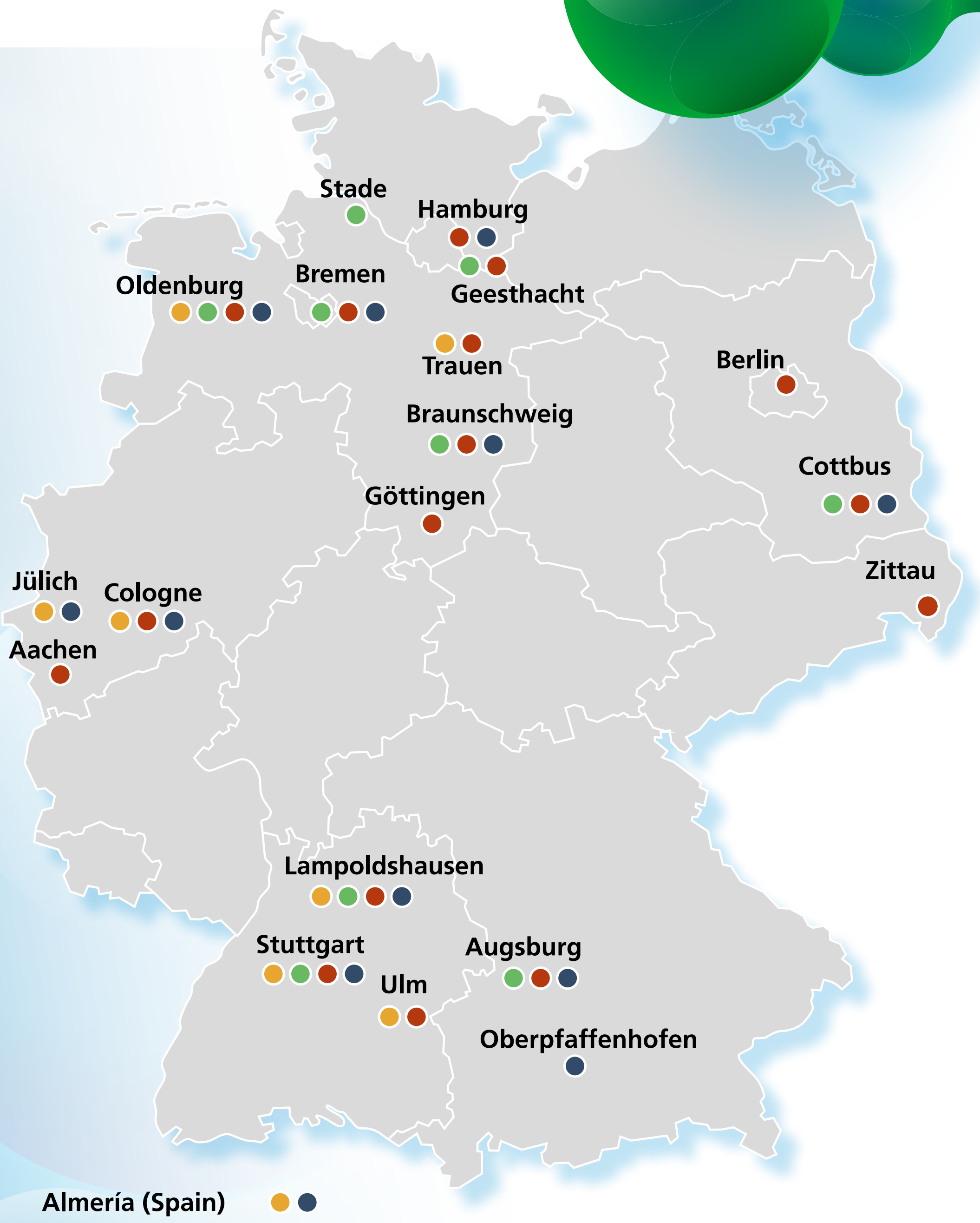
Hydrogen and sustainability

DLR is actively researching the sustainability of a hydrogen-based economy.

For example, DLR is investigating the environmental impact of hydrogen emissions, including indirect effects on greenhouse gases and aerosol particles. Detailed examinations are also being conducted on the consequences of increased ice cloud formation and emissions associated with hydrogen-based liquid aviation fuels.

Moreover, the use of critical materials like platinum in fuel cells also impacts the sustainability of a hydrogen economy; DLR is exploring alternative materials.

DLR SITES
with hydrogen activities



GENERATION: ELECTROLYSIS AND SOLAR-THERMAL PROCESSES

STORAGE AND DISTRIBUTION

USE

SYSTEMS/MARKET ANALYSIS, TECHNOLOGY EVALUATION, SUSTAINABILITY

PRODUCTION

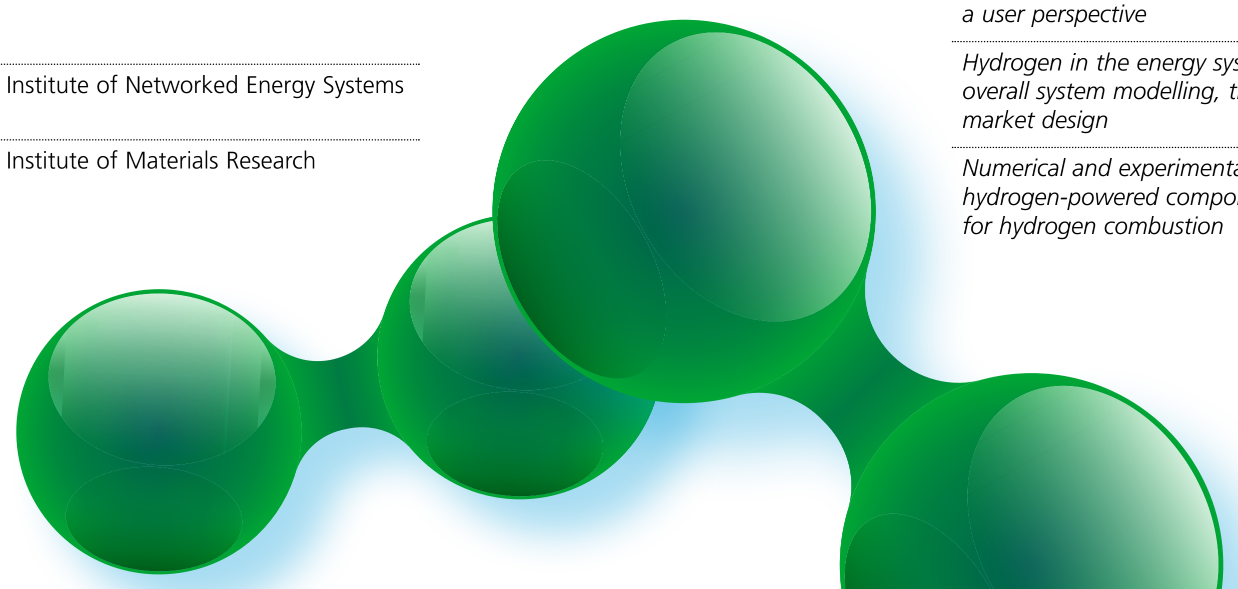
Main area of focus	Institute
Development and scaling of solar thermochemical, electrochemical and photoelectrochemical processes and their components	Institute of Future Fuels
Operation and development of solar thermal or combined heat and power infrastructure	Institute of Solar Research
Hydrogen electrolysis and co-electrolysis from materials to system	Institute of Engineering Thermodynamics
Development and testing of materials for hydrogen environments	Institute of Materials Research
Operation of a research and development electrolysis plant (PEM) in collaboration with an energy company, integration of an H_2 liquefier into existing H_2 plants	Institute of Space Propulsion

TRANSPORT, STORAGE AND DISTRIBUTION

Main area of focus	Institute
Hydrogen-specific lightweight tank structures and their integration into space, air and ground vehicles, Production technologies, components, crash and impact testing and approval procedures	Institute of Structures and Design
Development and investigation of hydrogen storage and conditioning technologies for air transport	Institute of Electrified Aero Engines
Development of vehicle technologies – storage, cryogenic component cooling, energy recovery systems, metal hydride storage for heat and cold generation	Institute of Vehicle Concepts
Development of seaworthy tanks for liquid hydrogen and alternative fuels and tankers, including port infrastructure	Institute of Maritime Energy Systems
Development and testing of components and supply systems for space propulsion and hydrogen technologies (LH_2, GH_2 up to 800 bar)	Institute of Space Propulsion
Fuel handling in cryogenic tank and distribution systems, testing and modelling	Institute of Space Systems
Hydrogen storage for stationary and mobile applications	Institute of Engineering Thermodynamics
Design, manufacture, integration of hydrogen tanks, approval and quality control	Institute of Lightweight Systems
Numerical determination of the hydrogen diffusivity of complex materials for storage and transport	Institute of Test and Simulation for Gas Turbines
Storage caverns, gas grid infrastructure, gas purity	Institute of Networked Energy Systems
Development of materials for hydrogen tanks and their insulation	Institute of Materials Research

USE

Main area of focus	Institute
Development and (experimental) investigation of hydrogen technologies up to high product maturity for gas turbines and aircraft engines	Institute of Propulsion Technology
Design of methods and materials for hydrogen-fuelled gas turbines, hybrid electric propulsion systems and space propulsion systems, including manufacturing technologies, component and impact testing and certification procedures	Institute of Structures and Design
Hydrogen for reducing CO_2 in industry	Institute of Low-Carbon Industrial Processes
Integration and use of fuel cell and hydrogen technologies for the electrification of propulsion systems for aviation	Institute of Electrified Aero Engines
Systems integration in ground vehicles, fuel pump/building to vehicle interface, vehicle components	Institute of Vehicle Concepts
Investigation of maintenance concepts for hydrogen-powe-red aircraft and their system architectures	Institute of Maintenance, Repair and Overhaul
Development and integration of marine energy systems, de-carbonisation of shipping through the use of hydrogen and alternative fuels	Institute of Maritime Energy Systems
Testing of space propulsion systems, CO_2-neutral heat and power, modular test environment for hydrogen technologies	Institute of Space Propulsion
Developing and testing of fuel handling technologies for space systems	Institute of Space Systems
Fuel cell component development and diagnostics, hybridised fuel-cell systems, systems integration and simulation-based layout and design for stationary and mobile applications	Institute of Engineering Thermodynamics
High-temperature damage of materials and components by direct hydrogen combustion	Institute of Test and Simulation for Gas Turbines
Integration and testing of hybrid propulsion systems for general aviation	Innovation Center for Small Aircraft Technologies MM (P)1
Development of innovative combustor concepts and decentralised power plant systems, design of hydrogen-based liquid fuels	Institute of Combustion Technology
Operational strategies for the use of hydrogen in mobility	Institute of Transportation Systems
Hydrogen in the transport system – potential applications, market introduction scenarios, distribution of hydrogen refuelling stations in the transport network	Institute of Transport Research
System-friendly integration of hydrogen technologies into the overall energy system	Institute of Networked Energy Systems
Materials, additive processes, coating systems, sensor technologies and thermoelectric generators for direct hydrogen combustion and for space propulsion systems	Institute of Materials Research



SYSTEM ANALYSIS

Main area of focus	Institute
Whole-system analysis and evaluation of hydrogen-powered gas turbines and aircraft engines	Institute of Propulsion Technology
Numerical methods, integrated data management and machine learning to assess the efficiency of hydrogen specific lightweight structures	Institute of Structures and Design
Analysis and assessment of hydrogen technologies for aeronautics	Institute of Electrified Aero Engines
Design requirements for H_2-based components and systems to mitigate natural and anthropogenic threats	Institute for the Protection of Maritime Infrastructures
Demand and profitability scenarios, refuelling analysis, operating processes	Institute of Vehicle Concepts
Integration into airport processes, review of the economic viability of hydrogen in the air transport sector, forecasting and evaluation	Institute of Air Transport
Process evaluation, market analysis and assessment of global potential for solar hydrogen production	Institute of Future Fuels
Economic and environmental lifecycle analysis and assessment of hydrogen powered aircraft	Institute of Maintenance, Repair and Overhaul
Emissions measurement, climate modelling, strategic support to the aviation industry addressing environmental impacts and sustainability	Institute of Atmospheric Physics
Systems analysis of rocket propulsion systems and hydrogen-carrying propulsion systems	Institute of Space Propulsion
Systems analysis and numerical simulation of tank and distribution systems	Institute of Space Propulsion
Tools for techno-economic analysis of solar-thermal technologies	Institute of Solar Research
Design, integration and evaluation of hydrogen powered aircraft	Institute of System Architectures in Aeronautics
Numerical and experimental lifespan assessment for hydrogen-carrying components and hot gas components for hydrogen combustion	Institute of Test and Simulation for Gas Turbines
Multidisciplinary technology assessment and road mapping for hydrogen and derived synthetic fuels in combustors and powerplant systems	Institute of Combustion Technology
Economic and societal systems evaluation, transformation pathways for alternative propulsion systems and fuels, from a user perspective	Institute of Transport Research
Hydrogen in the energy system: technology assessment, overall system modelling, transformation scenarios and market design	Institute of Networked Energy Systems
Numerical and experimental lifespan assessment for hydrogen-powered components and hot gas components for hydrogen combustion	Institute of Materials Research

More information on DLR´s energy research can be found here!

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