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Facts for the energy decisions of tomorrow

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PAUL SCHERRER INSTITUT

PSI

ETH Eidgenössische Technische Hochschule Zürich

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ENERGIE-SPIEGEL

FACTS FOR THE ENERGY DECISIONS OF TOMORROW

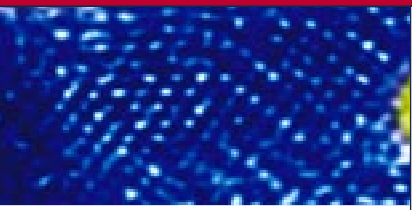
High Tech Materials for Sustainability

Working materials are key elements of the path to a more sustainable energy system. Materials with new properties make possible new processes and higher efficiencies. New energy technologies based on these materials are more economical and save resources. They also save the environment, because fewer pollutants and greenhouse gases are produced. With its large facilities and unique analytic capabilities, PSI can provide essential contributions to materials research for new energy technologies.

Catalysts based on modern, tailored materials are essential in current energy technology. For example, catalytic processes can transform renewable biomass into fuels. In transportation there are also examples of uses beyond the classic exhaust catalyst, such as removing nitrous oxides from diesel exhaust or reforming gasoline to produce hydrogen for fuel cells. The success of fuel cell vehicles essentially depends upon two key components; highly permeable, low cost membranes that can raise the power density of fuel cells and electro-catalysts that make high efficiencies possible.

Modern power plant technology is also inconceivable without high temperature materials. The corrosion resistance of key materials, for example fuel rod tubes in current nuclear power plants, is an important topic. Future high-temperature reactors, as well as solar-chemistry plants are not possible without materials that can withstand high temperatures. In this Energie-Spiegel, we show where energy research at PSI is placing its emphases on high-tech materials.

Innovation with Catalysts und Membranes



Energy research is not just aimed at saving resources and using renewable energy. It also aims to raise efficiency – from the transformation and storage of energy to customers' final end-uses. Where energy transformation processes push against physical or economic boundaries, high performance materials can open a way. Modern energy technology is now inconceivable without catalysts and membranes.

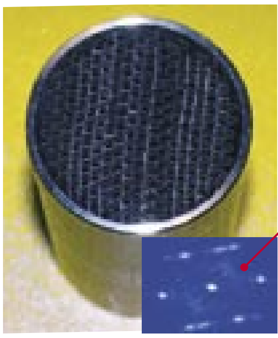
Catalytic processes often reach higher energy efficiencies than conventional processes. Catalysts therefore make chemical plants more economical, ecological, and also more sustainable – smaller, simpler, more efficient and economical in energy and material use.

Catalysts are used in the form of small pellets or coatings with many fine pores and very large active surface areas. Total surface areas, including all porosities, can total up to 1000 square meters per gram of material! The development of catalytically active systems that consist of metals, alloys and oxides has achieved large advances in the last decades. Targeted catalyst design, which is based on a fundamental understanding of catalytic processes, is replacing traditional screening processes.

PSI is tackling this task from different sides. In its large facilities, catalysts are analyzed and characterized. Evidence of catalytic mechanisms and efficiency based on model systems are compared to theoretical predictions. These results are then tested in the energy-relevant processes.

Treating Diesel Exhaust Diesel vehicles produce hazardous emissions like nitrous oxides (NOx) and soot particles. Only when modern diesel motors are combined with an effective exhaust catalyst do they become an attractive alternative to Otto cycle gasoline engines. The high capacity coated catalysts created at PSI are being tested for use with construction machinery, among other applications.

Burning Methane Combustion turbines burning a lean mix of natural gas (methane) require a stable combustion process in order to avoid damage to the turbine



X-ray picture of catalytically active platinum particles.

Low Pollution: For the catalytic combustion of methane a special catalytic coating is depositied on a monlithic metal surface.

and achieve high efficiency and low emissions. This can be achieved through the use of platinum in a catalytic pre-burner. PSI has contributed substantially to understanding this process. As an alternative to the pre-burner, the catalytic reforming of methane is being investigated to produce hydrogen (through a reaction with water or carbon dioxide).

Reforming Gasoline to Hydrogen Gas Fuel cell automobiles cannot use gasoline directly as fuel. It must first be reformed to hydrogen and CO_2, preferably directly in the vehicle. Without catalysts this process takes place at around 1000° C, producing large amounts of poisonous carbon monoxide, which requires elaborate and costly measures to remove. Catalysts developed at PSI which operate at temperatures of 600° C are therefore very attractive for reformer development.

Fuel Cells for Cars Hydrogen and oxygen produce electricity directly with high efficiency at about 80° C (see Energiespiegel 6). Electro-catalysts like platinum make the flow of electricity possible. Because no combustion process is involved, no harmful emissions are created – the product is pure steam. PSI is investigating the possibility of using less of the expensive platinum or replacing it through new types of catalysts.

Polymer-electrolyte Membranes In the area of fuel cell development, PSI is not only engaged in catalyst research. A central part of the advance in fuel cells is based on the synthetic membrane (see Energiespiegel 6) that separates the reacting elements, while still conducting ions at the same time. The essential functions of this membrane (contact with the electrodes, conductivity, gas separation, and mechanical stability) are being further optimized at PSI. The goal is to manufacture an efficient, long-lived, and economical membrane. A lifespan of 4000 hours at a service temperature of 80° C has already been demonstrated in the laboratory. Now this knowledge must be demonstrated on a pilot scale.

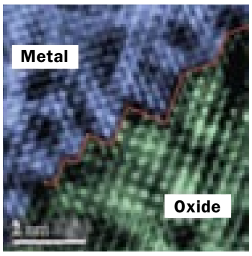
Long-lasting: Fuel cell membranes have achieved a service life corresponding to 200,000 km at an average speed of 50 km/h.

Stronger Fuel Rods

The futher development of fuel rods for light water reactors (LWRs) is important, because the higher their performance and energy content, the more economical the fuel cycle becomes.

In 1980, a fuel rod lasted about three years in operation, providing heat energy equivalent to about 15,000 to 25,000 tonnes of diesel oil. Today, fuel rods can be used almost twice as long – while meeting high safety requirements and greatly reducing the volume of high-level nuclear waste.

International Development PSI is at the forefront of fuel rod manufacturing, together with the Swiss power plants. One example is the improvement of the protective fuel rod tubes that surround each of the 100 to 250 fuel rods in a fuel bundle.



Laboratory test: The atomic structure on the surface between metal and oxide of the fuel rod tube gives clues to the corrosion process.

The zirconium alloy tubes are exposed to extreme operating conditions: For more than 1200 days they are surrounded by chemically aggressive water with a flow rate of between 2 to 8 m/s at a temperature of around 300° C. In addition, the intense neutron flux means that each zirconium atom may be displaced multiple times from its position in the crystal lattice of the metal. In spite of this, the tube must remain physically stable and resistant to corrosion – an extreme challenge in materials science! This requires comprehensive laboratory and radiation testing.

Afterwards, test fuel rods are examined at PSI for their micro-structural properties and their changes interpreted according to model calculations. This know-how leads to further improvements. For example a failure rate has been reached today of less than one rod in 20,000 that reaches final burn-up.

Heat Testing Materials

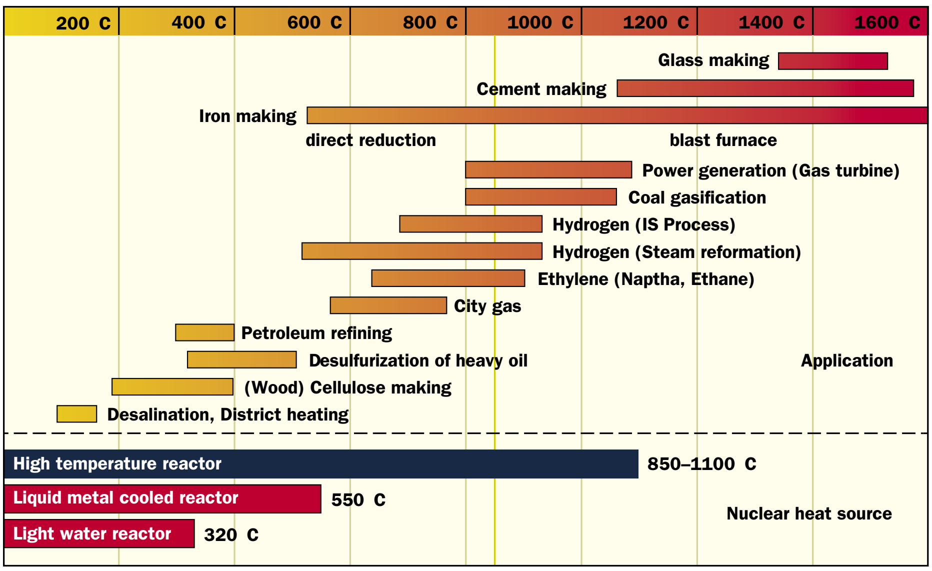
The nuclear power plant of the future must have a solid safety design, in addition to high efficiency. It must optimize fuel burn-up and generate competitive, CO_2 free power. The step to a very high temperature reactor (VHTR) is not so far, but it requires new materials.

The higher the operating temperature in a nuclear reactor, the higher the efficiency. Gas and liquid metal cooled reactors are being developed today that work at a temperatures of between 500 to 1000 °C. They not only produce electricity efficiently, but also produce process heat that can be used for many purposes, for example creating hydrogen for fuel cells. Such R & D takes place within the international community efforts like the EU Framing Program and the US Initiative for Generation IV Reactors.

Temperature, pressure and high mechanical loads in the reactor demand tough materials with great strength and outstanding durability. The thermal and mechanical aging conditions are aggravated by radiation conditions that lead primarily to embrittlement.

PSI carries out related experiments that are unique in the world. At the spallation neutron source, metal corrosion is studied related to lead-bismuth (Pb/Bi) eutectic alloy coolants, which attack iron materials more strongly under high temperature and radiation conditions. This work with PSI's own liquid metal target creates the basis for selecting the best-suited materials for building a fast reactor with a Pb/Bi coolant.

In another project, molybdenum and tungsten alloys, as well as ceramically bound materials (like fiber-reinforced carbon and silicon-carbide ceramics). will be radiated at temperatures up to 800 to 900 °C! This allows development of suitable materials for use in gas-cooled high temperature reactors (HTGRs).



The high temperature reactor could be coupled directly with energy-intensive industries requiring process heat (from 600°C) and replace traditional fossil energy sources without airborne emissions.

Jefferson Tester is professor of chemical engineering at the Massachusetts Institute of Technology (MIT). He led the MIT Energy Laboratory for the last twelve years and now leads the Program for Sustainable Energy and Non-polluting Chemical Transformation. He is a member of advisory committees for numerous national laboratories, in particular the plenary research commission of PSI.

"World Class Research"

What does materials science research mean for the development of energy systems? A high performance material is often decisive in the performance of a critical component in a novel energy system. If it is missing, the whole concept will fail. This can be a material for the surface of a heat exchanger, a highly selective catalyst or a selectively permeable membrane for an essential separation process.

Where has new materials technology been important for increasing efficiency? High performance, corrosion resistant alloys were essential for the development of gas turbines. In the exploration and development of oil and geothermal energy, coating drill bits with synthetic diamonds has raised their service life and drilling speeds. Fiber reinforced polymer blades are used today in wind turbines. Thin-film coating techniques have essentially improved the insulating properties of window glass.

What significant advances in materials science research do you expect to contribute to the energy sector by 2020? Our ability to design new materials at the molecular level opens many chances to develop materials tailored for energy production. New catalysts increase the selectivity and speed of electrochemical reactions in fuel cells and batteries. Selective membranes make possible the separation of carbon dioxide from power plant exhaust gases. High temperature superconductors will be introduced for the transmission and storage of electrical energy. And we need corrosion and abrasion-resistant coatings for surfaces exposed to extreme temperatures or aggressive media.

Which topics are of particular interest at MIT? Reducing emissions and increasing efficiency in the use of fossil fuels and biomass, and the transformation of biomass waste and sludge into gas or liquid fuels under hydrothermal conditions. We are also interested in the separation and sequestration of CO_2, as well as drilling processes for geothermal energy, where the costs increase not just linearly, but exponentially with depth. In every development of technologies for more sustainable energy systems, a fundamental understanding of the phenomenon is in the forefront.

Where are the USA's priorities in energy-driven materials research? A large part of US research deals with the fundamentals of nano-structured materials and their related raw materials. In my view this program is not balanced with regards to its orientation towards future applications. In a new study, in which I participated, the President's Council of Advisors on Science and Technology has recommended a reinforcement of work on materials in "Pasteur's Quadrant," including both fundamentals and direct applications that are important for renewable energy. This goal has not yet been fully reached in the USA.

Where can PSI provide essential contributions to the progress in this area with its large research facilities? As a national research and user laboratory PSI is a unique resource, for Switzerland and worldwide. With the SLS and the neutron source, world class research facilities are united at a single location. They will be very valuable to the researchers at PSI for exploring structures on the atomic and molecular levels.

IMPRESSUM

ENERGIE-SPIEGEL, or Mirror On Energy, is the newsletter of the GaBE project at PSI. GaBE is the abbreviation for Ganzheitliche Betrachtung von Energiesysteme, which translates as Comprehensive Analysis of Energy Systems. The Energie-Spiegel appears every four months. Contributors to this edition include Prof. A. Wokaun, K. Foskolos, Dr. G. Bart, Dr. G. Scherrer, Dr. F. Vogel, and Dr. J. Wambach.

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Responsible for Content
Paul Scherrer Institut
GaBE
Dr. Stefan Hirschberg
5232 Villigen PSI
Tel. 056 310 29 56
Fax 056 310 44 11
stefan.hirschberg@psi.ch
www.psi.ch/GaBE

Editor
Ruth Schmid

Subscriptions and Circulation
renate.zimmermann@psi.ch

Layout
Monika Schlapbach

Energy Systems Analysis at PSI
The goal of energy systems analysis at the Paul Scherrer Institute in Villigen is to analyze present and future energy systems in a comprehensive and detailed way, considering in particular health, environmental and economic criteria. On the basis of Life Cycle Assessment (LCA), energy-economic modeling, risk analysis, pollution transport models and finally multi-criteria decision analysis, it is possible to compare different energy scenarios to create a basis for political decision-making.

GaBE works closely with other institutions, including:
- ETH Zürich
- EPF Lausanne
- Massachusetts Institute of Technology, MIT
- University of Tokyo
- Europäische Union, EU
- International Energy Agency, IEA
- Organisation für wirtschaftliche Zusammenarbeit und Entwicklung, OECD
- Organisation der Vereinten Nationen, UNO