EXCELLENCE IN MATERIALS SCIENCE AND ENGINEERING

More than one hundred materials scientists, chemists, physicists, mechanical engineers and technical staff focus at IEK-1 on the development of inorganic materials (in particular functional ceramics) and multi-layered components for highly efficient future energy conversion and storage systems.

EXPERTISE

Our transversal expertise ranging from solid state chemistry and synthesis, powder-based and wet-chemical processing, sintering, to thin film and thermal spraying technologies has allowed for rapid adaption to the emerging challenges in science, from battery research to ceramic matrix composites.

To fulfill our mission, 1,250 m² of excellently equipped lab surface, including two clean rooms, and a new membrane center (15 Mio €, finished in 2016) are available. A unique research infrastructure offers more than 30 different materials synthesis routes, processing and coating technologies of inorganic materials such as ceramics and metals. Experimental activities are complemented by modeling at the meso- and macroscopic levels (Monte Carlo simulations, Computational Fluid Dynamics, Finite Element Analysis) which allow a better understanding and prediction of materials and processes.

Our aim is to be at the forefront of the development of functional materials and production-relevant and scalable processing techniques, which enable a facile technology transfer. A large part of our equipment meets industrial standards, supporting a pronounced collaboration with industry. Our long experience in project planning and management is attested by several national and international coordinated consortia and research programs.

PARTNERSHIP

We foster intense collaboration within our growing network of academic and industrial national and international partners. Furthermore, we established close strategic cooperation with neighboring universities (RWTH Aachen University, Ruhr Universität Bochum, Universität Duisburg-Essen as well as University of Twente, NL) in the frame of professorships, as well as with WWU Münster (through Helmholtz Institute Münster).

RESEARCH AREAS

Bridging the gap between basic science and applications, our research encompass:

- **MATERIALS FOR POWER PLANTS**  
  Prof. Dr. R. Vaßen  
  Tel: +49 2461 61-6108  
  r.vassen@fz-juelich.de

- **GAS SEPARATION MEMBRANES**  
  Prof. Dr. W. A. Meulenberg  
  Tel: +49 2461 61-6323  
  w.a.meulenberg@fz-juelich.de

- **SOLID OXIDE CELLS**  
  Dr. N. H. Menzler  
  Tel: +49 2461 61-3059  
  n.h.menzler@fz-juelich.de

- **ELECTROCHEMICAL STORAGE**  
  Prof. Dr. Fattakhova-Rohlfing  
  Tel: +49 2461 61-85051  
  d.fattakhova@fz-juelich.de

High-temperature materials, especially thermal and environmental barrier coatings for gas turbines deposited by thermal spraying (for power generation and aircraft engines)  

Gas separation membranes for oxygen and hydrogen production, including proof-of-concepts for gas supply and catalytic membrane reactors  

Solid Oxide Cells (fuel cells and high-temperature electrolysis), from materials development to cell manufacturing and improvement of performance  

Solid-state lithium and sodium batteries, from the development of electrolyte and active materials to the integration in full cells
MATERIALS DEVELOPMENT
Functional materials and electroceramics – these are the keywords of our scientific research, either at high temperatures or at ambient conditions, either ionic conductors or electrocatalysts: more than 20 years of experience are the basis for further innovations.

**GENERAL SCOPE**
The team „materials development“ is focused on the preparation of powders for ceramic and composite materials. From classic and novel synthesis methods to large-scale production, the powders are specially produced for use in electrochemical applications. The applicability of the materials is evaluated on the basis of chemical and physical properties initially investigated on generic ceramic specimens. Materials of interest are then processed to realistic components using conventional ceramic technologies and the materials’ quality is optimized for the intended application.

**CURRENT DEVELOPMENTS**
Triggered by the need for better energy storage systems for future energy supply, the team is working on new battery materials. Major effort is devoted to solid electrolytes with the aim to develop safe and large-scale solid state batteries for stationary applications and other electrochemical applications. The research includes low-cost and tailored synthesis methods and experienced processing aiming to produce dense ceramics as ion-selective membranes. Depending on the target size and application, the thickness of the membranes may be varied from 10 µm to 1 mm using different fabrication technologies. Presently, the materials under investigation are garnet-type lithium-ion-conductors and NaSICON-type lithium- and sodium-ion-conductors.

Using our experience in electroceramics, the team also works on electrode materials, especially on cathodes for solid state batteries and on the interaction between solid electrolytes and cathode materials.

**CONTACT**
Dr. Frank Tietz
Tel: +49 2461 61-5007
f.tietz@fz-juelich.de

IEK-1: Materials Synthesis and Processing
Forschungszentrum Jülich GmbH
52425 Jülich, Germany
The team “Particle-based processing and sintering” provides specific net-shaping and sintering technologies, which can be applied for metallic and ceramic powders. The equipment is comprised of technologies for net-shaping powders, as well as specific sintering technologies, which enable superpositioning of pressure and/or electric field, aiming at full densification of the ceramic.

NET-SHAPING OF CERAMIC AND METALLIC POWDERS
The team deals with the net-shaping of metallic or ceramic powders by powder compaction, dip coating, tape casting or powder injection molding. A specific expertise exists in the processing of parts with well-defined porosities up to 80 Vol. %, which can be used e.g. as heat exchangers, current collectors, electrodes or metallic supports of electrochemical devices like fuel cells or gas separation membranes. Furthermore, we are able to manufacture metal-ceramic composites with layered structures and tailored interfaces.

SINTERING UNDER PRESSURE AND/OR ELECTRICAL FIELD
Different sintering techniques are available to densify a wide range of ceramic and metallic powders (yttria, ceria, tungsten, titanium, etc.) up to the theoretical density. A hot press (HP) with a MoSi$_2$ heating element enables sintering at temperatures up to 1600°C under vacuum, air and argon up to a maximum load of 100 kN. A hot isostatic press (HIP) can be operated under argon or nitrogen at temperatures of up to 1900°C and pressures of up to 300 MPa. Two field-assisted sintering/spark plasma sintering (FAST/SPS) devices enable rapid densification of ceramic, metal or composite powders. Here, temperatures up to 2,200°C and pressures up to 100 MPa can be achieved with graphite tools. Higher pressures up to 400 MPa are possible with alternative tool materials. Another mode of operation is flash sintering with voltages up to 1000 V accompanied by external heating via induction coil or MoSi$_2$ heating element.

CONTACT
PD Dr. Martin Bram
Tel: +49 2461 61-6858
m.bram@fz-juelich.de
IEK-1: Materials Synthesis and Processing
Forschungszentrum Jülich GmbH
52425 Jülich, Germany
THIN FILM TECHNOLOGIES
Thin-film technology enables the mass production of highly complex systems. The development of efficient and thus economically viable production methods is an important aspect for all kinds of energy converters and storage devices. This is why IEK-1 relies on physical vapor deposition (PVD), chemical vapor deposition (CVD), atomic layer deposition (ALD) and coating technologies based on liquid precursors and inks.

**PHYSICAL VAPOR DEPOSITION**
This technology is particularly suitable for dense layers on outer (“visible”) surfaces. IEK-1’s expertise is thermal evaporation, electron beam evaporation and magnetron sputtering (direct current, middle frequency, radio frequency or High Power Impulse Magnetron Sputtering). It is possible to deposit metals, as well as glasses or ceramics (for example oxides or nitrides).

**CHEMICAL VAPOR DEPOSITION**
IEK-1 uses metal-organic chemical vapor deposition (MO-CVD). Relatively low coating temperatures (100-300 °C) can be achieved by using metal-organic precursors. Moreover, a processing in which the layers are built up by single atomic layers in succession (called atomic layer deposition: ALD) is possible. The ALD technique provides conformal coating of a few nanometers on inner surfaces of porous materials.

**LIQUID PRECURSOR-BASED FILMS**
Wet-chemical coating methods are based on emulsions, sols or solutions which are coated on substrates. Subsequent heat treatment leads to dense layers. Spin coating, dip coating and inkjet printing in a cleanroom environment are used to apply the liquids.

**APPLICATIONS**
Thin-film technologies at IEK-1 lead to outstanding performance improvements of energy converters and storage devices, as protective layers in batteries, and as electrochemically active layers in solid-state batteries, fuel cells and gas separation membranes.

**CONTACT**
Dr. Sven Uhlenbruck  
Tel: +49 2461 61-5984  
s.uhlenbruck@fz-juelich.de  

IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany
THERMAL COATING TECHNOLOGIES
The team develops thermal coating technologies focusing on thermal spraying processes. Thermal spray techniques comprise coating processes in which surfacing materials are heated to the more or less plastic or molten state and then propelled onto a prepared surface. Powders, suspensions, or solutions are used as feedstock. The substrate remains unmelted. The energy carrier is a high-energy gas jet originating from compressed gas, from combustion of a gaseous or liquid fuel, or from plasma generated by an electric arc discharge.

THERMAL SPRAY PROCESSES
At IEK-1, various state-of-the-art industrial coating equipment is available, covering a wide range of materials and applications:

- Cold gas spraying (CGS), aerosol deposition (AD),
- High velocity oxy-fuel spraying (HVOF),
- Atmospheric plasma spraying (APS),
- Low pressure plasma spraying (LPPS), LPPS-Thin Film (LPPS-TF), and plasma spray–physical vapor deposition (PS–PVD).

THERMAL COATING TECHNOLOGIES

Thermal spraying can provide relatively thick coatings over a large area at high deposition rates. Coating materials include:

- Alloys, e.g. MCrAlY, NiCr, stainless and ferritic steels, Inconel;
- Metals, e.g. tungsten, copper, titanium;
- Oxide ceramics, e.g. ZrO$_2$, Al$_2$O$_3$, TiO$_2$, spinels, pyrochlores (e.g. Gd$_2$Zr$_2$O$_7$), perovskites, aluminates;
- Non-oxide ceramics and composites, e.g. B$_4$C, WC/Co, MAX phases.

PROCESS DIAGNOSTIC METHODS
Plasma and particle in-flight characteristics are analyzed to gain understanding of the process and to manage quality:

- Plasma: enthalpy probe, optical emission spectroscopy;
- Particles: particle temperatures, velocities, and diameters, shadowgraphy of the particle flux;
- Stresses: in-situ measurement by curvature analysis.

CONTACT
Dr.-Ing. Georg Mauer
Tel: +49 2461 61-5671
g.mauer@fz-juelich.de

IEK-1: Materials Synthesis and Processing
Forschungszentrum Jülich GmbH
52425 Jülich, Germany
The modelling team develops mathematical and numerical descriptions of the physical processes governing materials processing and the subsequent operation of the produced components.

**PROCESS MODELLING**
Modern processing routes require a good theoretical understanding of the underlying physical processes. With the help of theoretical descriptions and simulations, we can obtain insights into the processes that are crucial for the development towards manufacturing routes for well-designed materials. This includes the simulation of flow fields of plasma jets with Computational Fluid Dynamics (CFD), the coupling of electrical, thermal and mechanical fields during field assisted sintering with Finite Element Analysis (FEA), and the simulation of microstructural evolution with Monte Carlo methods.

**FUNCTIONAL PROPERTIES**
The final functionality is related to the properties and microstructure of a given material or layer. Calculations of e.g. gas flows through porous supports of membranes or the stress development in solid-state composite battery cathodes are important for facilitating their development. First, we analyze the real microstructure of the as-manufactured components (acquired by μCT or FIB-SEM) with FEA or CFD calculations. Afterwards, design parameters and microstructural or material properties are systematically varied and their impact on the performance is studied. This helps us to optimize the components, which can then be produced experimentally. In addition, we developed a statistical life-time model for thermal barrier coatings based on the mechanical stresses and fatigue occurring during operation.

**INFRASTRUCTURE**
We run our own computing cluster (320 cores and 3.2 TB RAM) and different workstations. The most important thermo-mechanical material properties and sintering parameters can be measured with our own equipment.

**CONTACT**
Dr. Robert Mücke
Tel: +49 2461 61-4066
r.muecke@fz-juelich.de

IEK-1: Materials Synthesis and Processing
Forschungszentrum Jülich GmbH
52425 Jülich, Germany
The team focuses on developing materials solutions for protective coatings such as thermal barrier coatings (TBC) and environmental barrier coatings (EBC) for highly thermomechanically loaded components, primarily in stationary and aircraft gas turbines. In order to ensure fast development cycles, special emphasis is given to the assessment of their functionality and lifetime at high temperatures under realistic test conditions.

**ADVANCED MULTILAYERED EBCS AND TBCS**

Starting from the specification and synthesis of new, mainly ceramic materials, components with TBCs and EBCs based on advanced multilayered and/or graded architectures are manufactured. The application of new processing technologies allows for the development of EBC/TBC systems with well-controlled properties in terms of microstructure and local composition. Pyrochlores such as $\text{Gd}_2\text{Zr}_2\text{O}_7$, complex perovskites or (hexa)aluminates are of particular interest for TBC applications. Due to their relatively low fracture toughness, double-layer systems developed at IEK-1 are usually required. Research on EBCs currently focuses on rare-earth silicates and other oxides. For the improvement of adhesion of thick coatings on inhomogeneous substrates such as ceramic matrix composites or abradables, advanced laser surface texturing is employed.

**TBCS RESISTANT TO MOLTEN DEPOSITS**

An increasingly important aspect at even higher temperatures is the resistance of porous layers against infiltration by calcium-magnesium-aluminium silicates (often called “CMAS”). These silicates are present in air as solids and are also produced by abrasion in the rephrase. They are deposited on the turbine components and can penetrate the barrier coatings in their molten form. Once they solidify, they cause considerable damage by decreasing the strain tolerance. In addition to the Gd-containing pyrochlores, aluminates also show a better stability than YSZ.

**CONTACT**

Dr. Daniel E. Mack  
Tel: +49 2461 61-2971  
d.e.mack@fz-juelich.de  

IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany
SMART COATINGS
The team develops layer systems with additional functional properties such as sensing properties, self-healing capabilities or enhanced strain tolerance. In addition, the team combines the achievements of the high temperature protective coating and the thermal coating technology teams. A further activity is the development of functional layers for gas separation applications or for solid oxide fuel cells. Furthermore, innovative coating processes especially suitable for functional coatings, such as the aerosol deposition process, are developed.

**ADDITIONAL FUNCTIONALITIES IN HIGH TEMPERATURE COATINGS**

Sensing properties are added into YSZ based thermal barrier coatings (TBCs) using an adapted laser cladding process for the deposition of thermocouple clads without degrading the TBC structure. Embedding is then achieved by a subsequent deposition on YSZ by an atmospheric plasma spraying process (APS).

Other sensors, such as strain sensors, can also be produced via this approach. Self-healing TBCs can be produced by adding specific MoSi$_2$ powders into the YSZ TBC layer. An adaptation of the APS process is necessary to avoid the decomposition of the MoSi$_2$ powder. This approach can also be used for other protective coating systems.

**STRAIN-TOLERANT COATING SYSTEMS**

The team is using suspension plasma spraying (SPS) and plasma spray physical vapor deposition (PS-PVD) techniques to develop columnar structured coatings with extreme strain tolerance.

**DENSE FUNCTIONAL COATINGS**

The team uses advanced thermal spray techniques to produce different functional coatings with high gas-tightness e.g. for applications as oxygen or hydrogen separation membranes, as electrolytes in solid oxide fuel cells (SOFCs) or as chrome evaporation barriers in SOFCs.

**CONTACT**

Prof. Dr. Robert Vaßen  
Tel: +49 2461 61-2455  
r.vassen@fz-juelich.de

IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany
The team develops Ceramic Matrix Composites (CMCs) for gas turbine components or other systems that operate at high temperature under harsh environmental conditions. The composites are based on MAX phases as matrices, a novel family of materials that bridges the gap between ceramics and metals. Among all the MAX phases, $\text{Cr}_2\text{AlC}$, $\text{Ti}_3\text{SiC}_2$, $\text{Ti}_2\text{AlC}$ and $\text{Ti}_2\text{AlN}$ are mainly used due to their excellent response at high temperature. SiC short fibers - but also $\text{Al}_2\text{O}_3$ and C fibers - are used as a reinforcing phase.

**PROCESSING OF COMPOSITES**

The first step for the processing of these novel composites is the synthesis of pure MAX phase powders, which are not commercially available. Pure MAX phase powders are obtained by two different synthesis routes: solid-liquid state reaction, and molten salt method. Scaling up these processes leads to kilograms of high-quality powder per batch, which is required to develop complex and large components. Processing of the composites is mainly carried out by colloidal processing since chopped fibers are used. As a result, the processing of CMCs is simple, cheap and allows homogeneous dispersion of the fibers within the matrix. Furthermore, as production of final components is one of the main objectives of the group, CMCs are processed by Ceramic Injection Molding (CIM) to manufacture complex near net-shaped components at affordable costs.

**HIGH TEMPERATURE RESPONSE**

Developed CMCs are tested under realistic and aggressive environmental conditions, similar to those that the final components will withstand. Due to the novelty of MAX phases, their oxidation and corrosion resistance under different environmental conditions has not been explored sufficiently. Long term experiments at high temperature (1000 °C – 1300 °C) using burner rigs, thermal shock tests, characterization of the interaction of the CMCs with Thermal Barrier Coatings (TBCs), and mechanical characterization – flexural strength, tension and compression creep – are thus among the interests of the team.

**CONTACT**

Jun.-Prof. Dr. Jesus Gonzalez  
Tel: +49 2461 61-96761  
j.gonzalez@fz-juelich.de  
IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany
Oxygen transport membranes (OTM) provide an efficient way to separate oxygen from air at elevated temperatures, i.e. 500 – 900 °C. It is possible to either generate pure oxygen for any purpose, e.g. combustion processes, metallurgy, or medical applications, or to utilize the separated oxygen directly in chemical reactions such as partial oxidation of hydrocarbons to produce commodity chemicals.

**OTM MATERIALS**
OTM materials are ceramics showing mixed ionic-electronic conductivity (MIEC). This process does not consume any energy, making it very efficient. However, temperatures above 500 °C are necessary to realize fast ion diffusion. The selection of a suitable material depends highly on the operation conditions (particularly temperature, pressure and atmosphere), which are defined by the target application. IEK-1 thus established a materials tool box.

Perovskite-type oxides often show MIEC behaviour (e.g. La_{1-x}Sr_xCo_{1-y}Fe_yO_{3-δ} or SrTi_{1-x}Fe_xO_{3-δ}). But the transport process relies on crystal defects creating a trade-off between permeability and stability. Therefore, composite materials composed of a pure ionic (e.g. Ce_{0.8}Gd_{0.2}O_{2-δ}) and a pure electronic conductor (e.g. FeCo_2O_4) are also under investigation, enabling the use of inherently stable material combinations.

**OTM COMPONENTS**
Optimized membranes should be as thin as possible, requiring a mechanically stable support with sufficient porosity in order to enable oxygen feed to the thin membrane layer. Ideally, fine porous surface activation layers at both sides of the membrane facilitate oxygen surface exchange. For this purpose, IEK-1 relies on ceramic manufacturing technology suitable for mass production, particularly tape casting and screen printing, complemented by modelling efforts. In addition, novel processing technologies such as freeze casting and 3D-printing are being explored. A novel thermal spray technology has been developed for the coating of OTM on robust metallic supports, which is exceedingly challenging.

**CONTACT**
Dr. Stefan Baumann  
Tel: +49 2461 61-8961  
s.baumann@fz-juelich.de

IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany
HYDROGEN-PERMEABLE MEMBRANES
HYDROGEN-PERMEABLE MEMBRANES

The team Hydrogen-Permeable Membranes develops ceramic membranes able to transport hydrogen, either in protonic (H⁺) or molecular form (H₂) by means of selected materials and advanced fabrication techniques. Different transport mechanisms, the chemical nature of membrane materials, or process conditions allow for various application areas ranging from separation tasks (extraction of highly pure H₂ from gas mixtures) to intensifying complex chemical reactions in catalytic membrane reactors using e.g. H₂ and CO₂ or N₂ to form bio-fuels, higher hydrocarbons, or ammonia, respectively. Apart from the H₂ separation performed both by dense and microporous membranes, CO₂/N₂ separation in post-combustion gases in power plants is another highly pursued and industrially driven task for microporous membranes. In addition to that, the team develops microporous membranes for dehydration of alcohols via pervaporation, or both dense and microporous membranes for catalytic decomposition of H₂-containing compounds (e.g. H₂S, NH₃ etc.).

FABRICATION TECHNIQUES AND MATERIALS
Membranes of different thicknesses (nm-µm range), microstructure and final geometries are fabricated on either ceramic or metallic substrates by means of advanced, reproducible and scalable fabrication techniques, e.g. tape casting, screen printing, spin and dip coating in a clean room, PS-PVD etc. In addition, their properties are thoroughly studied by various characterization methods. The selection of materials covers several structural classes, ranging from well proven conventional choices such as graphene or zirconates and cerates with perovskite structure to novel, patented compositions such as rare-earth tungstates with defective fluorite structure. Along with the development of defect-free and highly performing membranes for the targeted energy and environmental applications, the team carries out detailed fundamental research on the interplay between composition, microstructure, performance and stability, partnering with a strong network of universities and research institutions under numerous national and international projects or other collaboration initiatives.

CONTACT
Prof. Dr. Wilhelm A. Meulenberg
Tel: +49 2461 61-6323
w.a.meulenberg@fz-juelich.de

IEK-1: Materials Synthesis and Processing
Forschungszentrum Jülich GmbH
52425 Jülich, Germany
SOLID OXIDE CELLS
The department of Solid Oxide Fuel and Electrolysis Cells (SOFC and SOEC) concentrates on material development and manufacturing methods for solid oxide fuel and electrolysis cells, mainly based on ceramic powder processing. The main focus is the development of new materials and the optimization of the microstructure of functional components.

**BEING PART OF THE FUTURE ENERGY SYSTEM**

At IEK-1, SOC research focuses on cells, contact layers and interconnect protective layers. Research and development starts with the synthesis of suitable materials or the purchase of commercially available powders and their conditioning: ranging from raw materials and intermediate products (slips, pastes, suspensions), layers, components, and parts to scaling up in terms of component size, homogeneity, and reproducibility as appropriate for application in a pilot plant. For the manufacturing processes, mostly powder-based methods from metal and ceramic powder processing are applied, such as pressing, tape casting, screen printing, or wet spraying. If certain properties are required for functional layers, thin-film processes (PVD, sputtering), precursor-based techniques such as sol-gel processes (spin or dip coating, inkjet printing) and thermal spray technologies may also be applied. Studies on the degradation of SOCs and intensive post-test analyses of fuel cell stacks round out the research portfolio.

**ENABLING EASY ACCESS TO ENERGY FOR EVERYONE**

In addition to our long-standing expertise in SOFC research, IEK-1 works on high-temperature electrolysers to produce hydrogen in steam electrolysis or syngas in co-electrolysis and on high-temperature metal-air batteries, storing energy by oxidation/reduction of metal (e.g. iron) incorporated into the fuel compartment. The focus is on the development of adapted electrodes for cells, characterization and post-test analysis of solid oxide electrolysis stacks.

**CONTACT**

Dr. Norbert H. Menzler  
Tel: +49 2461 61-3059  
n.h.menzler@fz-juelich.de  

IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany
CHRISTIAN DOPPLER LABORATORY FOR METAL-SUPPORTED ELECTROCHEMICAL ENERGY CONVERTERS
Metal-supported fuel cells (MSCs) have some specific advantages over anode-supported fuel cells (ASCs) such as improved stability, better thermal management in the case of high heating rates, ease of joining and reduced production costs. These advantages make MSCs attractive for mobile applications such as auxiliary power units (APUs) for on-board power supply in trucks as well as range extenders for battery electric vehicles (BEVs). The Christian Doppler Laboratory for Metal-Supported Electrochemical Energy Converters pursues a research concept which deals with the key challenges of MSC technology. In close cooperation with our project partners TU Wien and the Austrian industrial companies Plansee SE and AVL List GmbH, the following work topics are addressed:

**IMPROVEMENT OF ELECTROCHEMICAL PERFORMANCE**

The range extender application requires further increase of MSC power density. To achieve this aim, we are mainly focusing on improved electrode design. Microstructure, materials and phase composition of MSC electrodes are optimized in a systematic manner. Dual phase electrodes like LSC/GDC cathodes or Ni/GDC anodes are promising candidates. This approach is accompanied by the development of related processing technologies, also considering scaling up of the technology to industrial scale.

**EXTENSION OF LIFETIME**

One key issue of fuel cell technology is extension of lifetime. MSC specific degradation phenomena such as oxidation of the metallic substrate at high fuel utilization, interdiffusion at interfaces and degradation of electrochemically active layers are investigated in detail. Furthermore, operation of MSCs in mobile applications leads to additional modes of MSC degradation, e.g. caused by sulfur contamination of fuels or chromium poisoning of cathode materials. New material concepts are developed to reduce or suppress these kinds of degradation. A specific focus lies on the tailoring of interfaces.

**CONTACT**

PD Dr. Martin Bram  
Tel: +49 2461 61-6858  
m.bram@fz-juelich.de

IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany
SOLID-STATE BATTERIES

Member of the Helmholtz Association
New fields of application in electro-mobility and stationary energy storage drive the development of battery technology while in established fields of application, requirements with respect to safety, energy and power density also increase steadily. Thus, the application-targeted investigation of new, disruptive concepts combined with strategies to ensure transferability of the results into industry are the focal points of the solid-state batteries team at IEK-1.

**SOLID ELECTROLYTES AND SEPARATORS**
One option to enhance the safety as well as the energy and power density is the shift from liquid or polymer electrolytes to ceramic ones. Scalable fabrication of ceramic materials with high electrochemical stability, ionic conduction at room temperature and compatibility with the other cell components is essential here.

Separators and multi-layered structures made from these materials can also be applied in other next-generation batteries, such as metal-air, metal-S, metal-ion, etc.

**HIGH CAPACITY MIXED CATHODES**
To obtain high energy densities on the cathode side, the processing of ceramic electrolytes with specific (high voltage) active materials needs to be optimized. Chemical stability during processing and low interface resistances are needed for superior cell performance.

**METAL ANODES**
Metal anodes are the goal for almost all next-generation battery systems, but can only be used at relevant current densities if dendrites are prevented. Intrinsic dendrite prevention by materials design and protective concepts (e.g. interlayers) are our main strategies to enable metal anodes.

**ANALYSIS AND MODELING**
For targeted cell development, advanced analysis methods are developed in the group and used in collaboration with simulation groups for fast design – performance optimization loops.

**CONTACT**
Dr. Martin Finsterbusch  
Tel: +49 2461 61-2877  
m.finsterbusch@fz-juelich.de

IEK-1: Materials Synthesis and Processing  
Forschungszentrum Jülich GmbH  
52425 Jülich, Germany