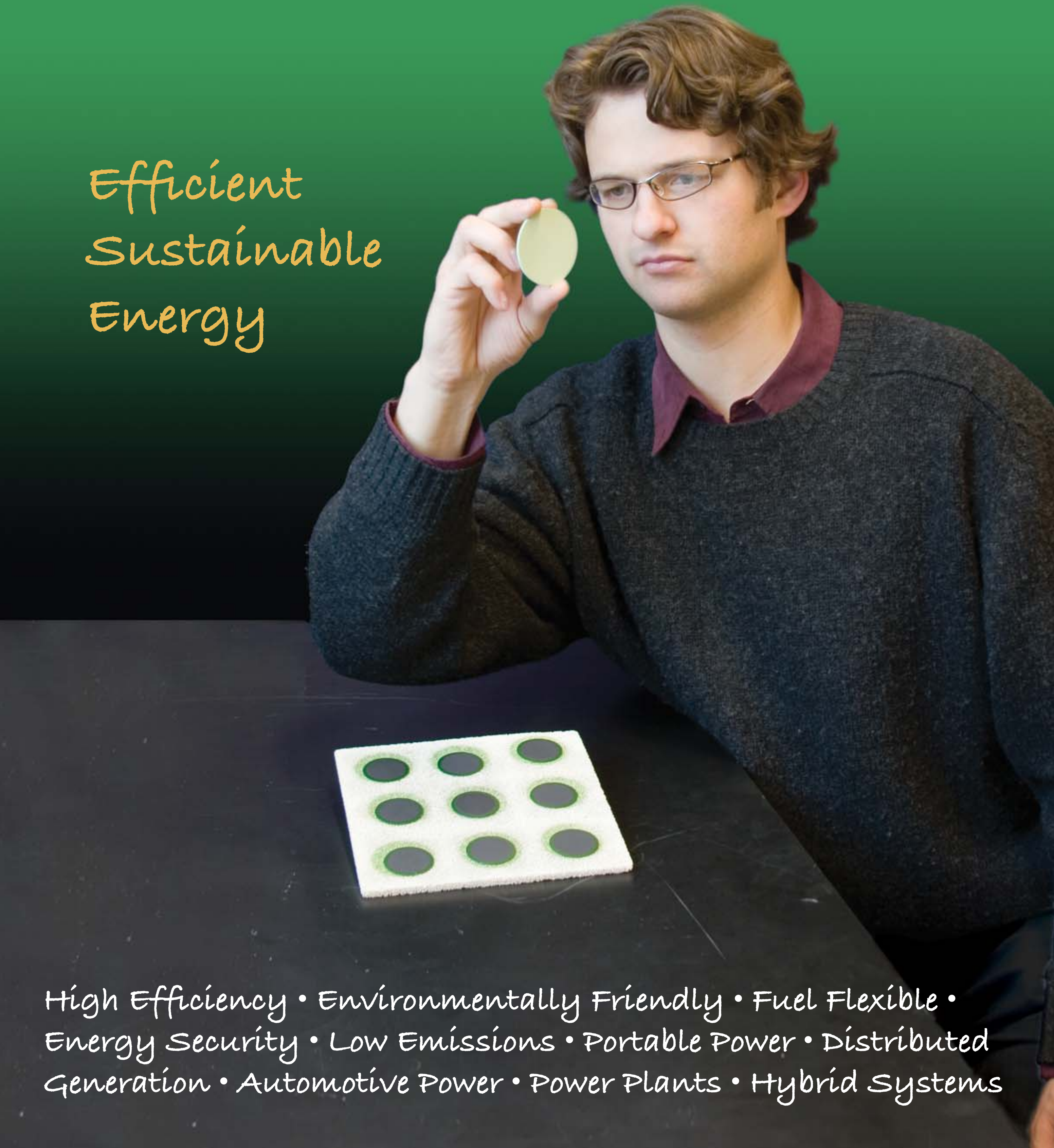
Colorado Fuel Cell Center

Research • Education • Collaboration



Efficient
Sustainable
Energy

High Efficiency • Environmentally Friendly • Fuel Flexible • Energy Security • Low Emissions • Portable Power • Distributed Generation • Automotive Power • Power Plants • Hybrid Systems

Internationally Recognized Experts in Fuel Cell Science and Technology

The Center's faculty members are established experts in fuel cell science and technology. This multidisciplinary group represents Materials Science, Chemical Engineering, Electrical Engineering, and Mechanical Engineering. The Colorado School of Mines has a long-standing mission and core expertise for research and teaching in the broad areas of Energy, Environment, and Materials Science. A critical element of the Center's mission is to educate a new generation of scientists and engineers, who are uniquely equipped to meet the nation's and world's challenges for sustainable and renewable energy.

Robert J. Kee
- Distinguished Professor
- Chemically reacting flow and electrochemistry

Andrew M. Herring
- Associate Professor
- Polymer electrolytes and fuel-cell systems

Anthony M. Dean
- Distinguished Professor
- Chemical kinetics and theoretical chemistry

Marcelo Simoes
- Associate Professor
- Power electronics and renewable energy

Kevin L. Moore
- Distinguished Professor
- Electrical engineering and control systems

Ryan O'Hayre
- Assistant professor
- Fuel-cell materials and system architectures

Neal P. Sullivan
- Assistant Professor
- Solid-oxide fuel cells and experimental diagnostics

Ivar E. Reimanis
- Full Professor
- Mechanical and structural behavior of ceramics

Mark Lusk
- Full Professor
- Ab-initio modeling of materials

Hans Carstensen
- Research Professor
- Theoretical chemistry and chemical kinetics

Huayang Zhu
- Research Professor
- Modeling reacting flow and electrochemistry

Robert J. Remick
- Adjunct Professor
- Center Director

Fuel cells will play a critical role in satisfying the world's rapidly growing energy demands. Direct electrochemical oxidation enables electricity production at nearly double the efficiency of conventional technology. Pollutant emissions are negligible and operation is nearly silent. Fuel cells can operate on many fuels, including hydrogen, hydrocarbons, and biomass. Systems are scalable from small portable units to large power plants. They integrate well into hybrid-power solutions. All these benefits promise sustainable energy production and energy security. The CFCC is extraordinarily well positioned to contribute the cutting-edge research and advanced education needed to develop and deploy this extraordinary technology.

Infrastructure

University Faculty and Students

The Center's primary assets are the participating faculty and students. They are all associated with home departments, where the faculty members teach core curricula and students earn degrees. The Center serves as a focal point, facilitating the pursuit of multidisciplinary research.

Dedicated Fuel-Cell Laboratory

The Center's 3500-square-foot laboratory facility, which was occupied in 2006, was designed and constructed specifically for fuel-cell research. The facility has complete fabrication and performance-testing equipment for both solid-oxide (SOFC) and polymer-electrolyte membrane (PEM) fuel cells. The capability to fabricate and evaluate new materials and combinations is especially important. Substantial complementary capabilities are also devoted to fuel processing and other supporting technologies.

In addition to dedicated fuel-cell laboratories, the Center is supported by critical facilities and expertise available elsewhere at the Colorado School of Mines. For example, advanced electron-microscopy equipment is available in the Metallurgical and Materials Engineering Department.

Modeling and Simulation Tools

We are leaders in developing state-of-the-art software capabilities to model all aspects of fuel-cell chemistry, electrochemistry, transport, and system integration. These simulation tools play a vital role in assisting the critical interpretation of experimental investigation. They also guide the design and optimization of advanced cell architectures and systems.

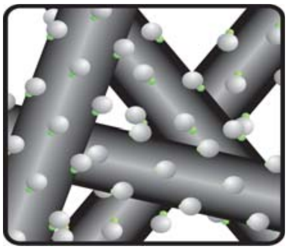
Research

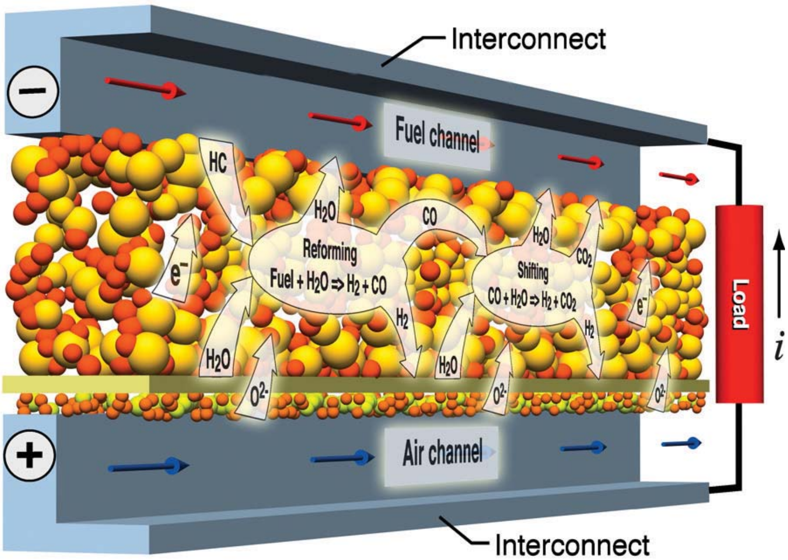
Scope and approach

The Center's research has broad scope, including SOFC and PEM fuel cells. Research initiatives are concerned with new materials as well as novel fuel-cell architectures. Critical materials include electrolytes, catalysts, current-collectors, and sealants. Evaluation criteria include electrochemical performance, mechanical behavior, and durability. In addition to fuel-cell-specific research, there is substantial research on complementary balance-of-plant technologies, such as reforming of hydrocarbon fuels. Most research projects involve a strong interactive combination of experiment, theory, and modeling. An important objective is to understand fundamental chemistry and physics across vastly disparate length scales, ranging from atomistic to full operational systems. The following paragraphs provide examples of a few research initiatives.

Electrocatalysts

All current fuel-cells will benefit from advances in the electrocatalysts that promote electron charge-transfer chemistry. The most-advanced PEM technology uses precious-metal nano-scale catalyst particles that are randomly incorporated onto supporting structures. Such a process provides little control over catalyst particle size and distribution. A current research project uses an intelligent-design approach to develop carbon nano-tubes that support the catalysts. These new materials are engineered with surface dopants that template the assembly and stabilize uniform arrays of catalyst nano-particles. The dopant-mediated growth and stabilization are expected to deliver more homogeneous, durable, active, and selective catalysts.





On-Anode reforming

In contrast to other fuel-cell types, SOFCs can directly accommodate hydrocarbon fuels. In fact, incorporating hydrocarbons into the fuel stream can improve performance compared to operating on hydrogen or syngas alone. To realize these benefits, anode materials must be designed to promote internal reforming and inhibit deleterious carbon-deposit formation. One current project focuses on the direct utilization of ethanol and other biofuels in SOFCs.

Chemical kinetics

Because SOFCs operate at high temperatures, hydrocarbon fuels (such as gasoline) may experience substantial gas-phase transformations. The decomposition products are the ones that ultimately react electrochemically. Current experimental and theoretical research focuses on pyrolysis and partial-oxidation chemistry. Results show significant hydrocarbon decomposition, even prior to entering the cell. The research also suggests approaches to minimize deposit formation.

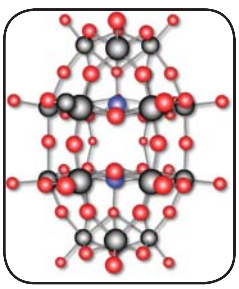
Ceramic materials

SOFC systems rely on ceramic and ceramic-metallic composite materials.

Performance, in turn, depends on tailored material properties. Current research is devoted to fabrication methods that deliver optimally structured electrode and electrolyte material combinations. For example, functionally graded porosity and catalytic activity improve performance. Ceramic membrane-electrode assemblies are fabricated in planar or tubular shapes.

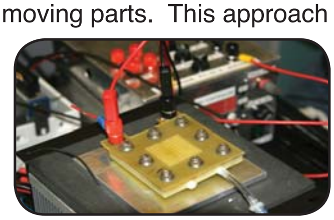
Polymer electrolytes

Today's PEM fuel cells operate below 100 ˚C, requiring fuel humidification and careful attention to the formation of liquid water. There is a recognized need to develop new polymers that operate above 120 ˚C. Our research concentrates on a class of polymers based on heteropoly acids, which facilitate "dry," high-temperature operation.



Passive fuel cells

Fuel cell systems typically require a number of ancillary components, such as humidifiers, pumps, compressors, fans, and heat sinks. Current research is focused on a new architecture for PEM cells that function without ancillary components and have no moving parts. This approach is expected to provide great advantages for small portable applications.

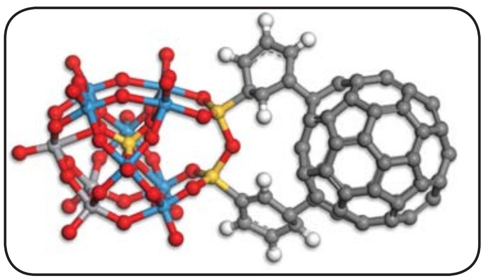


Power electronics

Fuel cells produce direct-current electricity, often at low voltage. Power-electronics components are needed to service a variety of practical loads, often at high voltage of alternating current. Additionally, there can be significant benefits to incorporating hybrid power-storage components, such as rechargeable batteries or ultracapacitors, into fuel-cell systems. These components can respond rapidly to load transients, enabling more stable fuel cell operation. Supervisory and feedback control systems are needed to coordinate fuel-cell and ancillary components during load-following transients.

Ab-initio materials modeling

Computational tools based on atomistic-level quantum mechanics provide theoretical guidance for identifying promising fuel-cell materials and structures. Such ab-initio inquiries can predict a material's structural stability and electro-chemical characteristics, prior to synthesizing the material in the laboratory. Additionally, these models predict materials properties that are needed in practical engineering models. Quantum chemical modeling is also used to predict gas-phase and heterogeneous thermodynamics and chemistry.

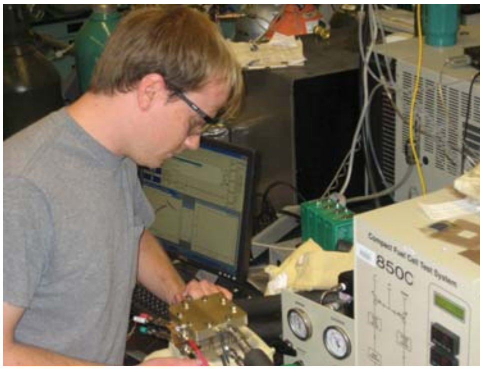


Modeling tools

A major element of our research focuses on fundamentally based modeling and simulation. Fuel cells are complex, requiring a coordinated multidisciplinary approach. Models must represent fluid flow, heat-transfer, chemical kinetics, porous-media transport, ion transport, and electrochemical charge-transfer. Validated predictive models form a strong basis for advanced cell and system design.

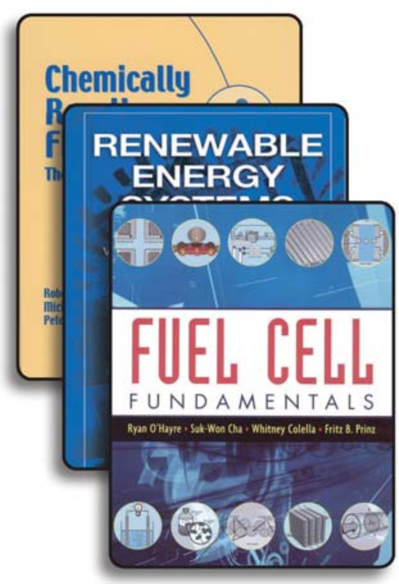
In addition to modeling the fuel cells, recent research focuses on coupling all balance-of-plant components, power electronics, and control systems. These models form the basis for finding optimal solutions for complete systems.

Education



The Center's education initiatives are multifaceted. Faculty members teach relevant classes in their home departments, including chemical, electrical, and mechanical engineering as well as materials science. Class projects and assignments often benefit from current research. There are numerous opportunities for undergraduate students, and great interest to participate. Senior-design projects provide multidisciplinary engineering teams a year-long experience in exciting areas of science and technology. Graduate students are supported to pursue leading-edge thesis research. Industrial interactions provide opportunities for summer jobs and internships.

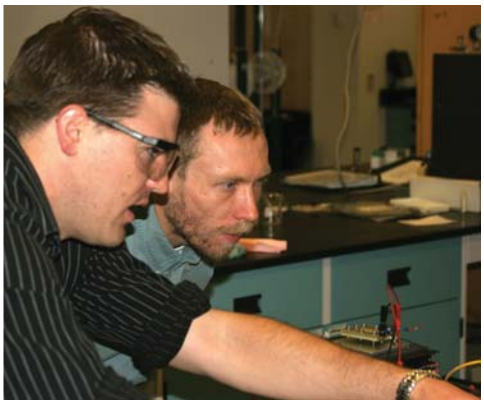
In addition to numerous scholarly papers, the faculty is also publishing textbooks that support teaching and research. Prof. Ryan O'Hayre's recent text on Fuel Cell Fundamentals is widely used worldwide.



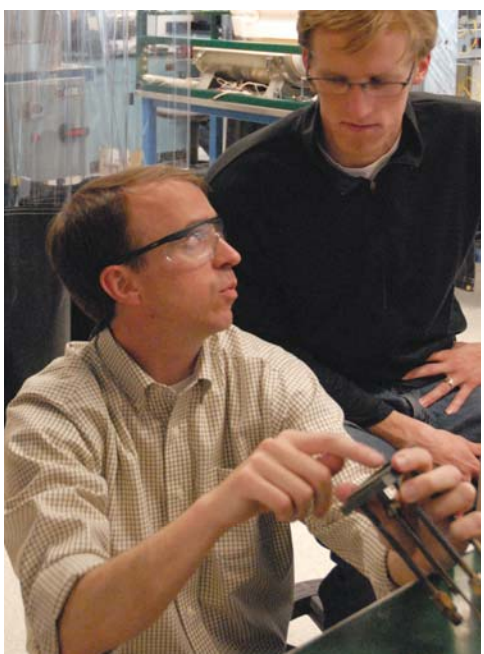
Collaboration

The Center benefits from active collaborations with industry, academia, and national laboratories. Current academic collaborators include faculty at Caltech, Case Western Reserve University, University of Maryland, University of Karlsruhe, and Northwestern University.

We also work closely with commercial fuel-cell and component developers. These include 3M, CoorsTek, Mesoscopic Devices, Innovatek, Versa Power Systems, and TDA Research.



Several of these businesses are located in Colorado, and benefit from the proximity of the Center. For example, Mesoscopic Devices is a leading developer of small, portable SOFC systems. CoorsTek is a worldwide leader in the manufacturing of technical ceramics.



Support

The Center's $3M physical plant was initiated in 2005 with a grant from the Governor's Office of Energy Management and Conservation, together with cost sharing from the School of Mines, National Renewable Energy Laboratory (NREL), and private industry.

Governor Bill Ritter visits the CFCC in March 2007.

The State is keenly interested in attracting and supporting local businesses in sustainable energy. Thus, one objective of the Center is to catalyze and support fuel-cell business clusters in Colorado.

Research in the Center is supported by a number of sources, including the Office of Naval Research, Air Force Office of Scientific Research, Army Research Office, the Department of Energy, as well as private industry. Research grants and contracts usually have specific tasks and deliverables as negotiated with the sponsor.

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Education
Collaboration

Colorado Fuel Cell Center

is located on the campus of the Colorado School of Mines, in Golden, Colorado.

CFCC seeks to advance fuel-cell research, development, and commercialization and to promote business opportunities in Colorado.

Visit CFCC online:
http://www.coloradofuelcellcenter.org

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CFCC

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