

Center for Clean Energy Engineering

Advancing Science to Systems

Prabhakar Singh
Director and UTC Endowed Chair Professor
Center for Clean Energy Engineering

Presented to DEEP, October 17, 2011

Outline

- **C2E2 Background**
- **Our Capabilities**
- **Research Highlights**
- **Accomplishments**



A Partnership in Excellence

Center for Clean Energy Engineering (C2E2)

A Public Private Partnership for Excellence in Education, Training, Innovation, R&D, Systems Engineering and Demonstration

Utility

Northeast Utilities

Industries

UTC & FCE

State

CEFIA (CCEF)

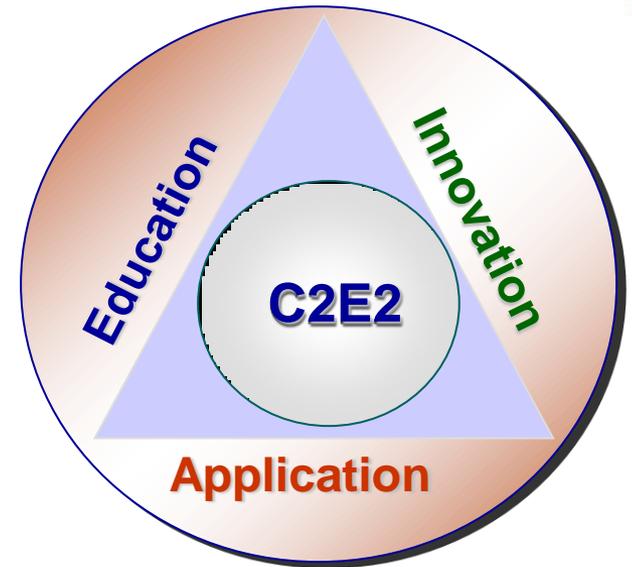
University

UConn

- Sustainable Energy Initiative
- Green Campus Initiative
- Industrial Collaborations
- Federal Agencies
- Industrial Consortium

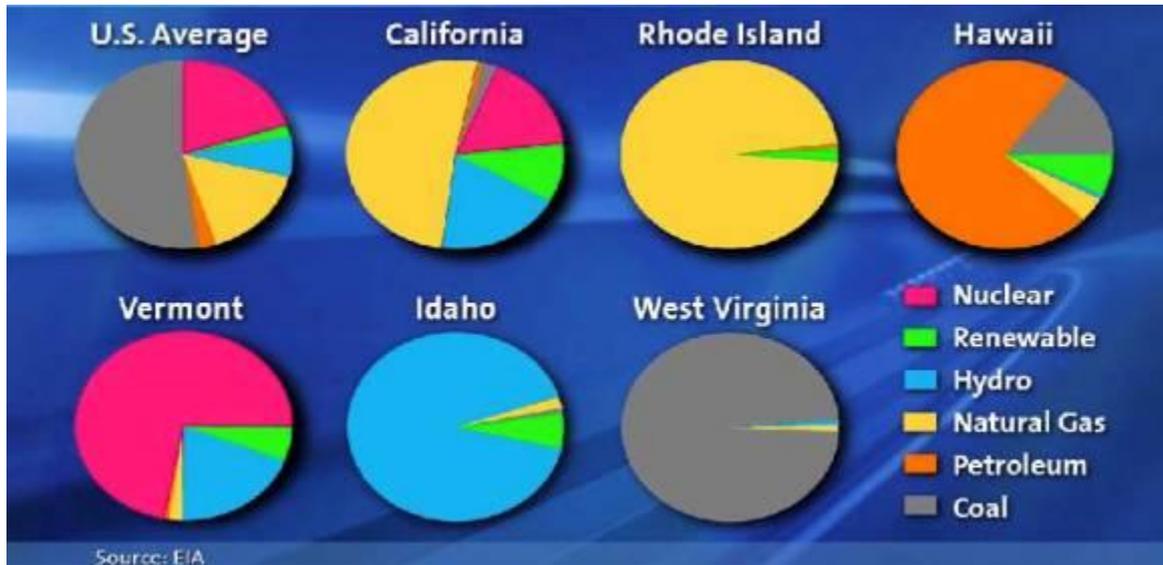
Our Mission

Center for Clean Energy Engineering (C2E2) will be recognized for world class education, research and training of scientists and engineers; for innovations in transforming “Science to Systems”; enabling industries and organizations in developing cost effective solutions for multi disciplinary problems in a timely manner; and for providing guidance and leadership in solving global societal issues ranging from sustainable energy to environment.



Enhancing Energy Security through Sustainability

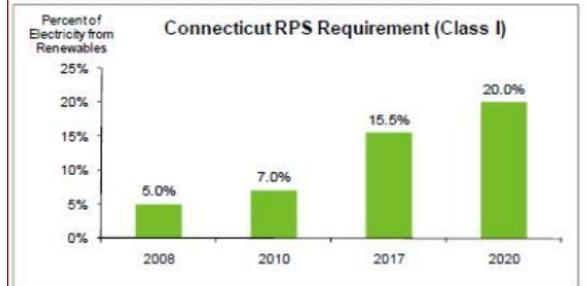
U.S. Power Generation – Diversity



Renewable Resources

Utilities and competitive suppliers must obtain specified percentages of the electricity they provide to customers from renewable sources to meet Connecticut's state-mandated renewable portfolio standard (RPS) requirements.

Connecticut has established three classes of renewable resources. Class-I renewable resources include certain types of solar, wind, biomass, hydro, landfill gas, and fuel cells. The Class-I RPS requirement increases to 20% in 2020, consistent with Governor Rell's goal to have 20% of the state's energy come from clean or renewable sources by 2020. ●●●



- Dictated by Policy, Environment, Technology, Fuel, and Market

Broader Focus

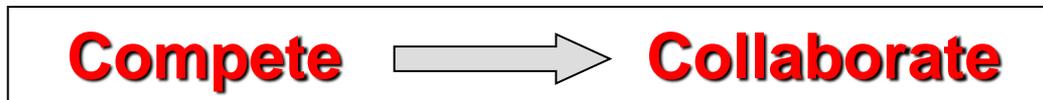
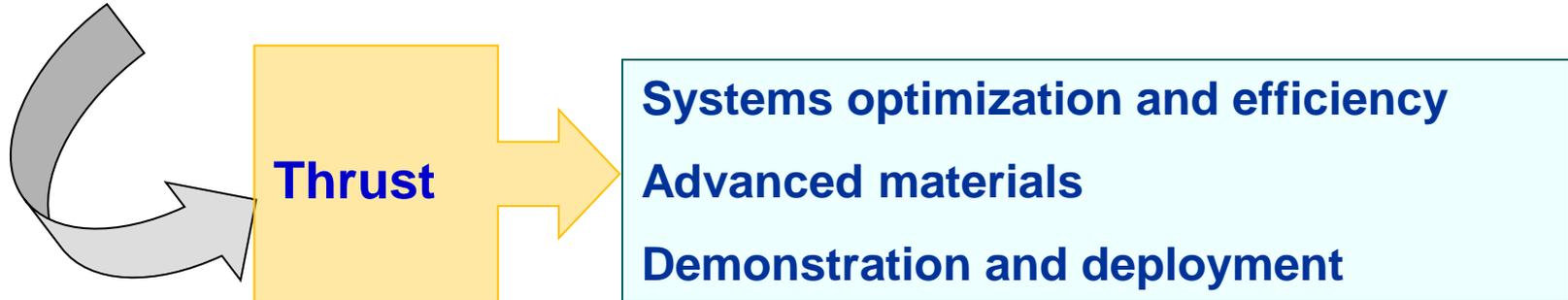
- ✓ Collaboration with fuel cell and energy industries in advancing basic scientific understanding.
- ✓ Participation in technology demonstration programs.
- ✓ Work with CT legislature, policy makers and industrial leaders.
- ✓ Provides technical input to the state clean energy fund.
- ✓ Coordinate and participate in K-12 out reach programs.



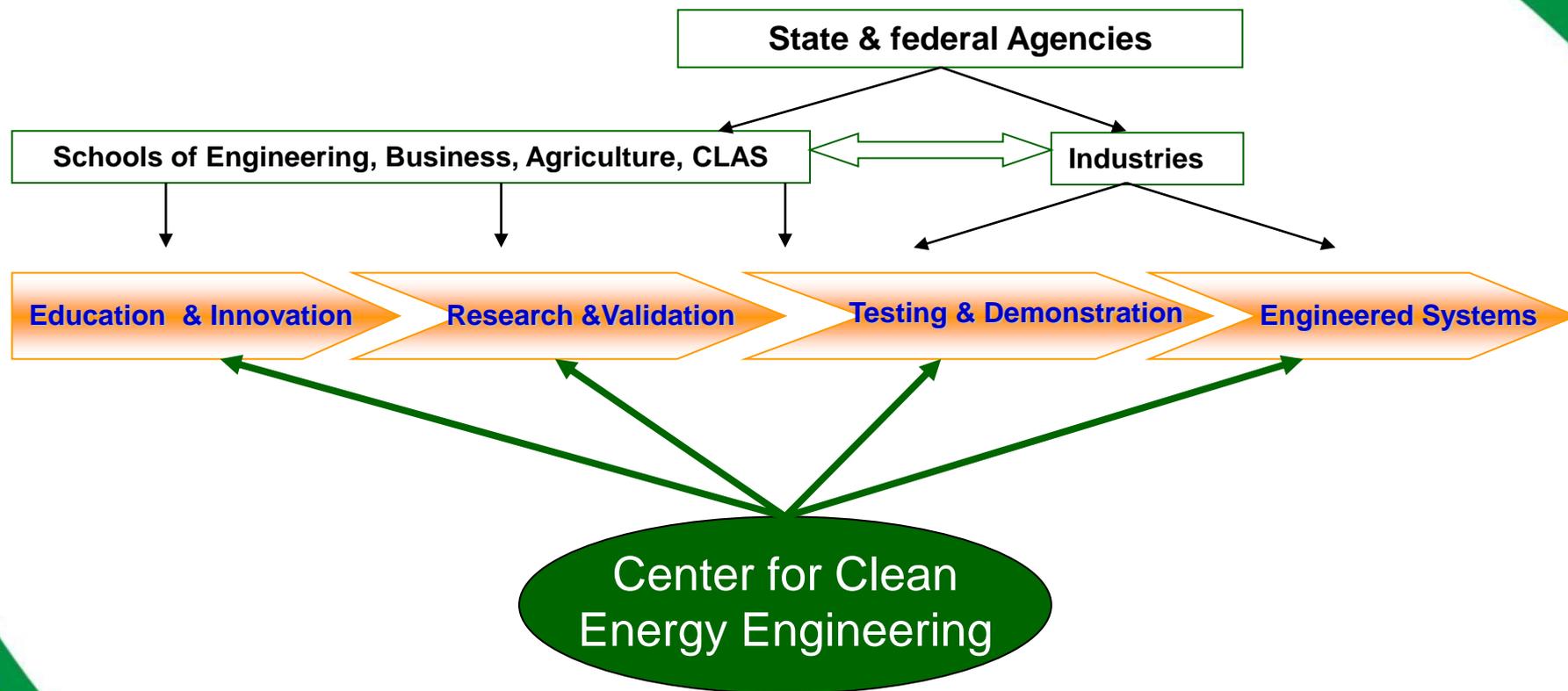
Broader Scope

Emerging Opportunities in:

- Energy Conversion Systems – Electrochemical to Renewables
- Fuels – Fossil to Biomass to Hydrogen
- Energy Storage – Batteries to Mechanical to Chemical
- Water - Mining effluent to post processing

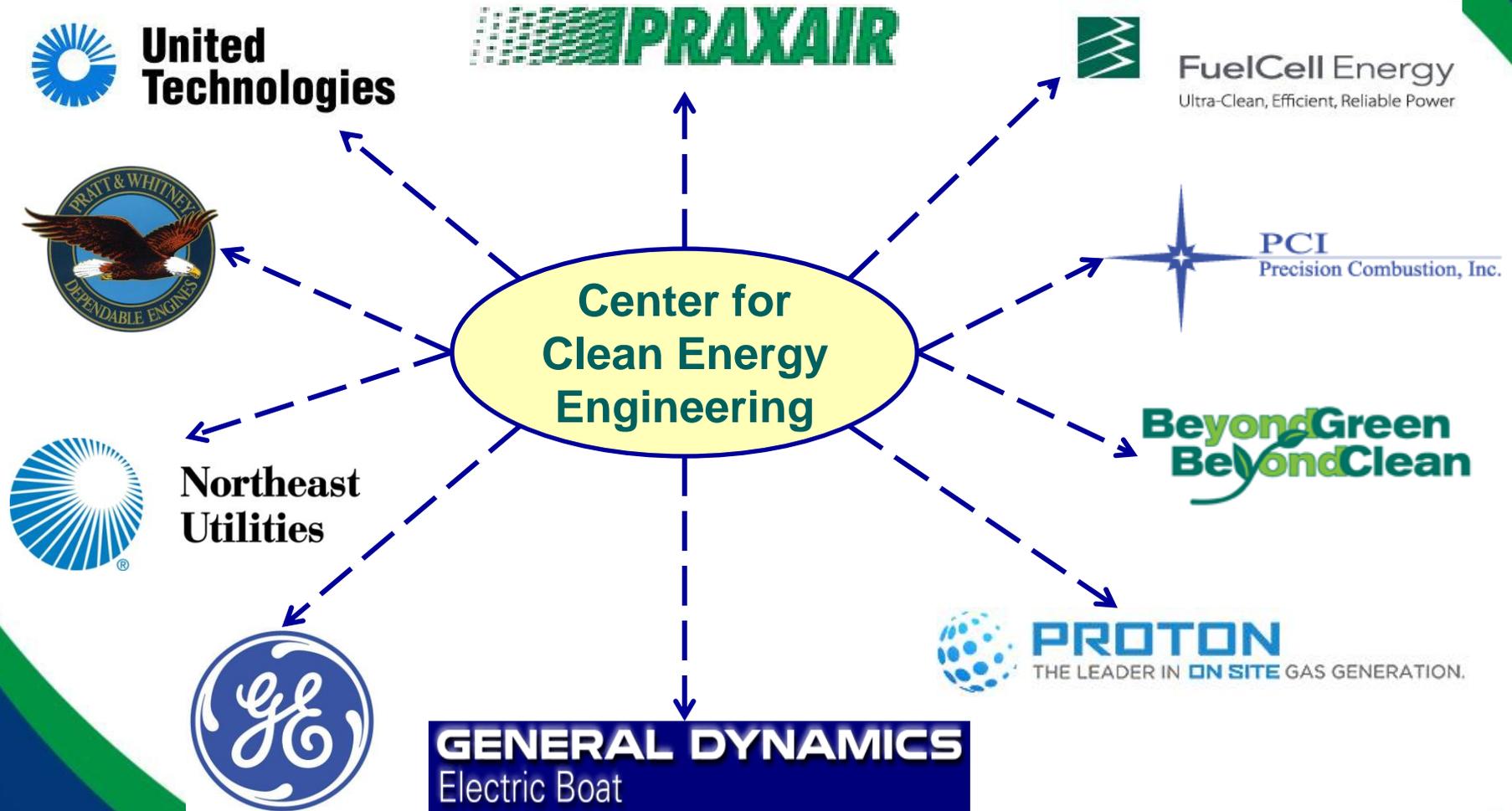


From “Idea” to “Implementation”

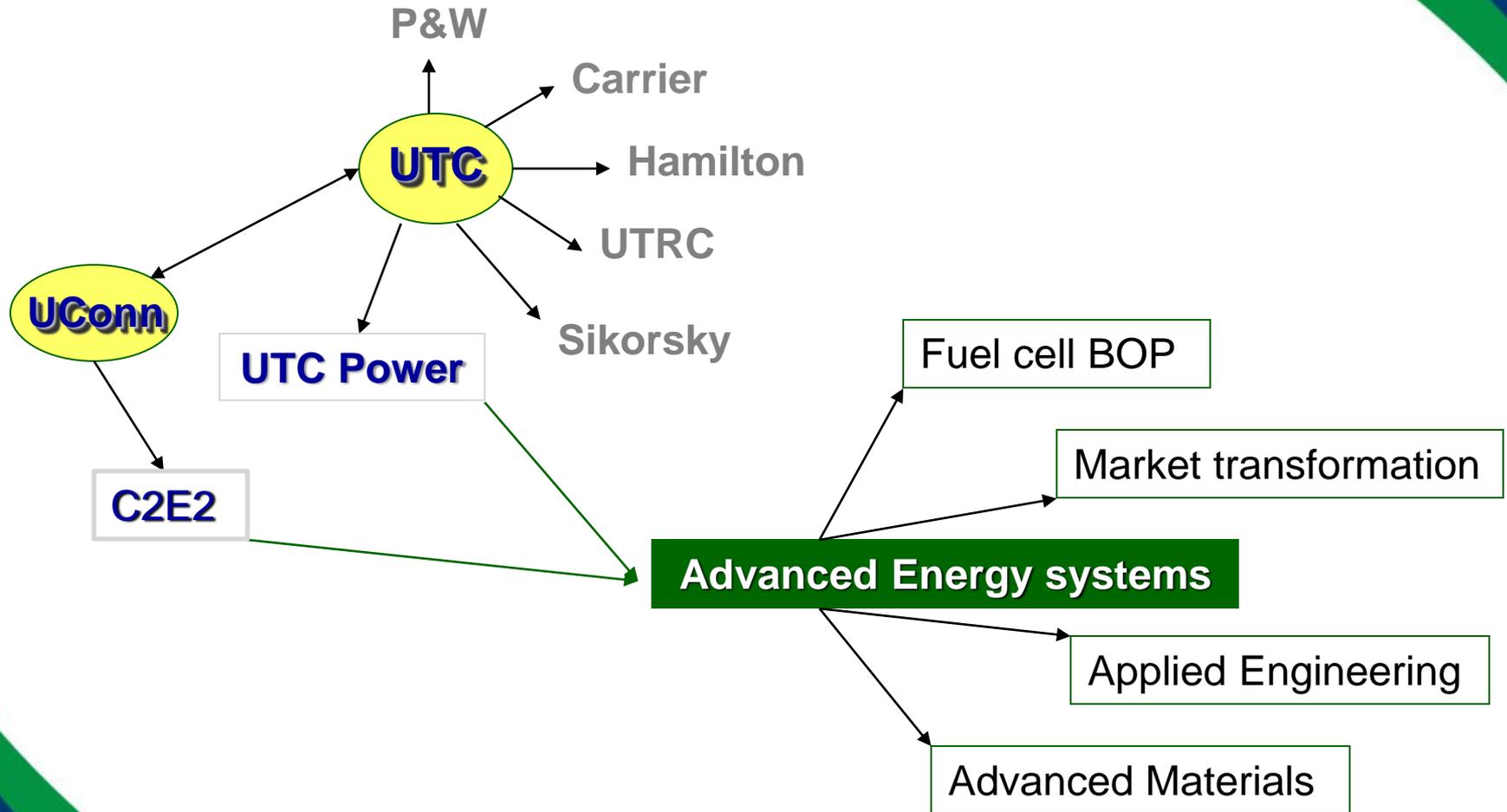


- > 20,000 Sq. Ft laboratory space
- 4 High Bay Area piped with Hydrogen for 24/7 Operation
- Well equipped laboratory – High temperature to Electrochemistry
- 20 resident Faculty and research Staff
- 75 Graduate Research Students

Innovating Technology for CT Companies



Collaboration in Clean and Sustainable Energy



Collaboration and International Partnerships



Federal Agency

Partners: US DOE, US Army, ONR, DARPA, NSF, USAF

C2E2: A portal for government and industrial partners to energy research expertise, capabilities, and relations.

National and International Industrial and Academic Partners:

Northrop Grumman, Rolls Royce, Siemens, Conoco Phillips, Nissan Automotive, Haynes International, Harvard, MIT, WR Grace, UMass Amherst, WPI, Boston Univ., University of Pittsburgh, U. Wyoming, UC Irvine, University of South Carolina, Ohio State University, Dalian, POSTECH, Tokyo Institute of Technology, Indian Institute of Science & many more

CT Industrial & Academic Partners:

United Technologies Corporation, FuelCell Energy, Northeast Utilities, CT Clean Energy Fund, Proton Energy Systems, Habco, nzymSys, PCI, DSTAR, Sonalysts, Yardney, Mystic Innovations Group, Yale, & many more

Research Laboratory Partners:

ORNL, ANL, PNNL, NRC Canada, Research Center Juelich – Germany, Institute of Nuclear Energy Research Taiwan, Council for Scientific & Industrial Research India and others

Leadership in Sustainability – From Community to Mobility

Center for Clean Energy Engineering

Sustainable Community

Sustainable Mobility

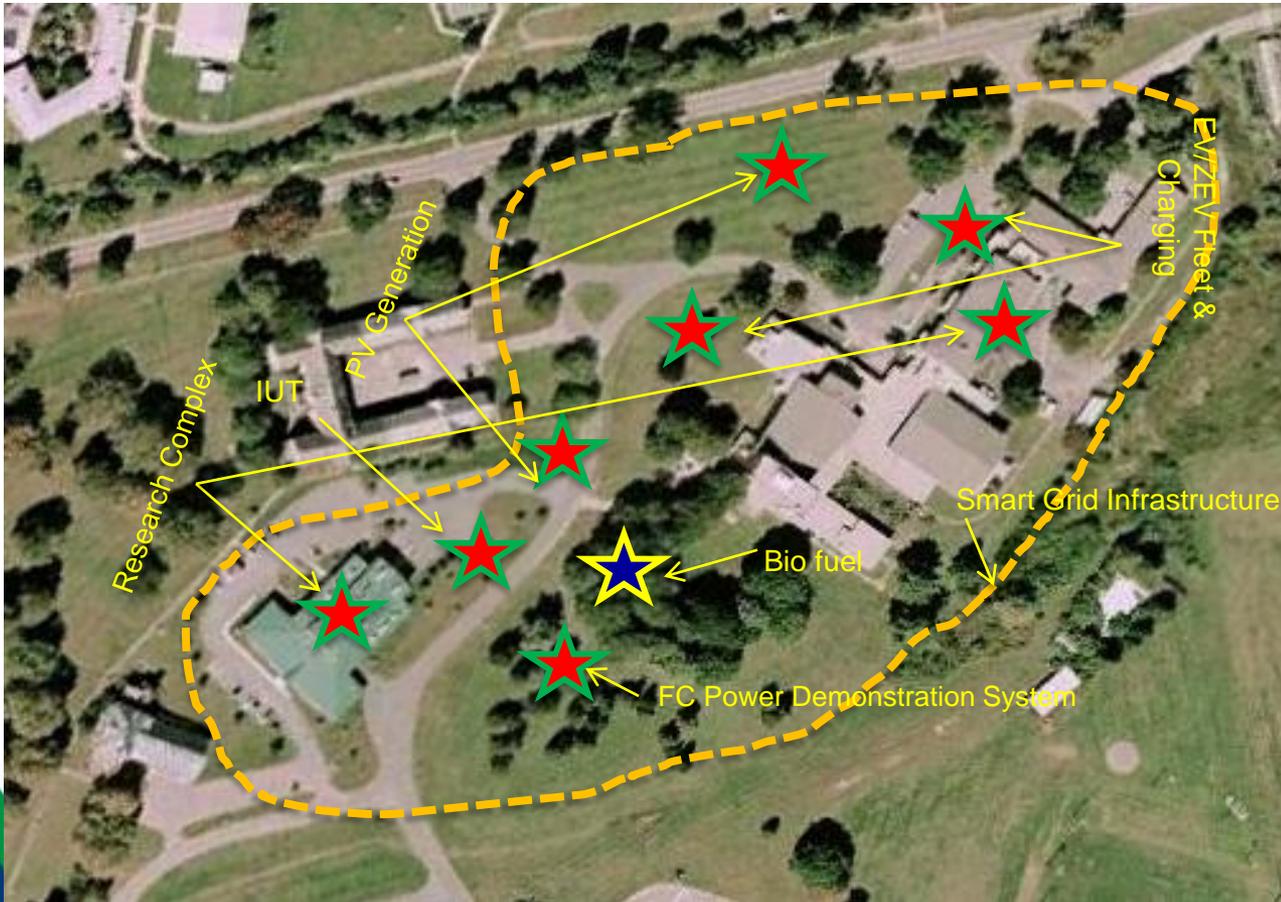
Smart Grid

Smart Efficient Buildings

Position UConn, and CT industries in identifying, testing, validating and implementing advanced technologies related to energy sustainability

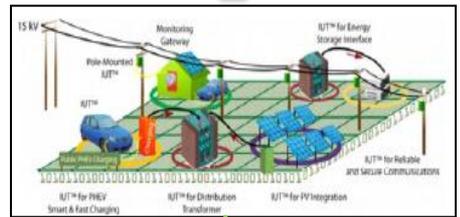
Develop Strategies for the Implementation of the Energy Sustainability Roadmap

CT Energy Hub – From Concept to Validation and Demonstration



- Sustainable Community
- Sustainable Mobility
- Smart Grid
- Smart Buildings

**CT resource
Technical Leadership
Unique Facility**



Moving Forward with Technology Demonstration & Deployment



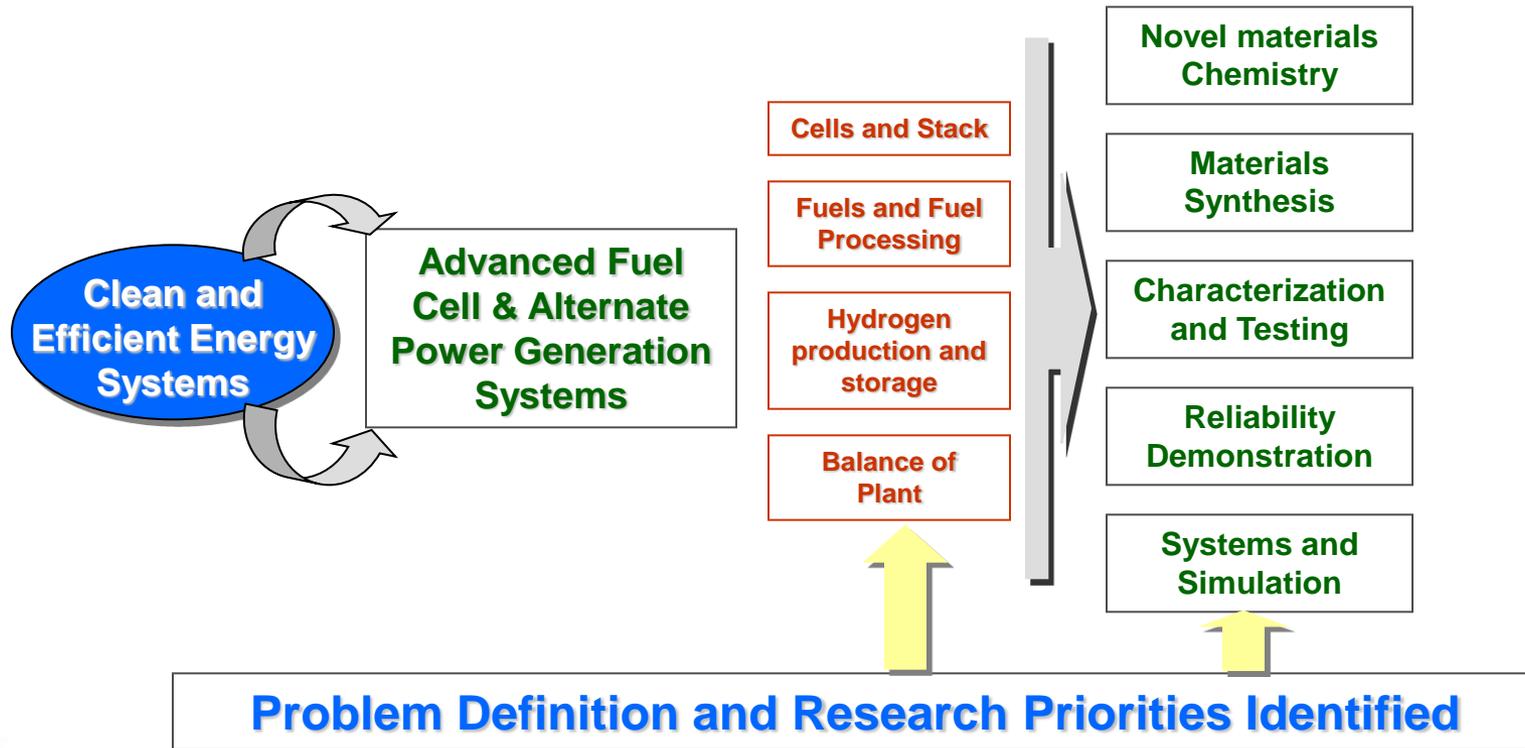
Leading to Sustainable Campus

C2E2 Research Initiatives

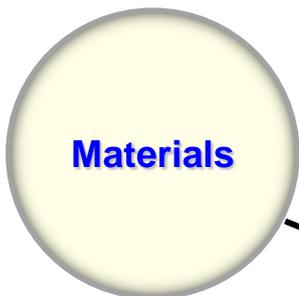
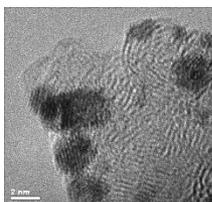
Emerging Energy Technologies

- **Fuel Cell Power Systems (PEMFC to MCFC to SOFC)**
- **Power plant and chemical process Simulation**
- **Bio- Fuels and Bio-Mass Gasification (Bio-Diesel to Bio-Solids)**
- **Renewable Energy systems (From Solar to Wind)**
- **Fuel Processing, Catalysis and Gas clean up (Hydrogen to Hydrocarbon)**
- **Carbon Capture (Efficient Adsorbents to Conversion)**
- **Combustion Research (Conventional to Oxy-fuel)**
- **Energetic Materials (Novel melting to Net Shape manufacturing)**
- **Thermal and Plasma Processing**
- **Energy Storage (Electrochemical to Thermal)**
- **Smart Grid and Efficient Buildings**

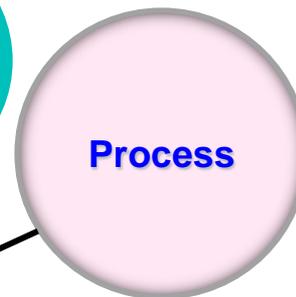
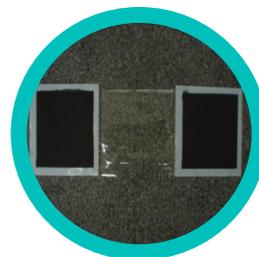
Reliability and Durability of Energy Systems



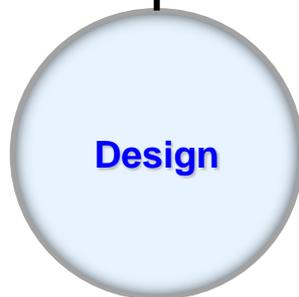
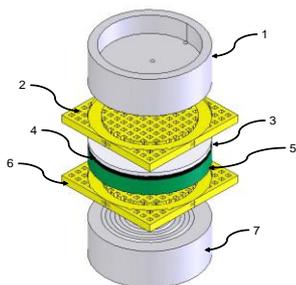
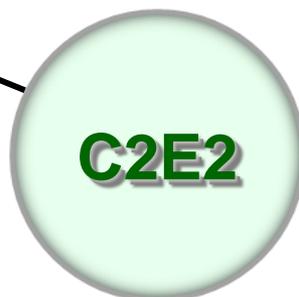
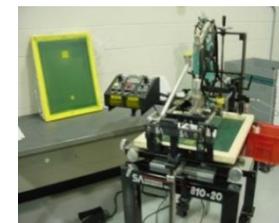
C2E2's Capabilities- Materials, Processes and Design



- Materials Characterization
- Materials Development
- Failure Investigation



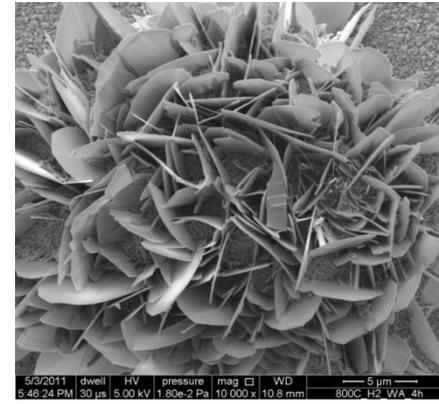
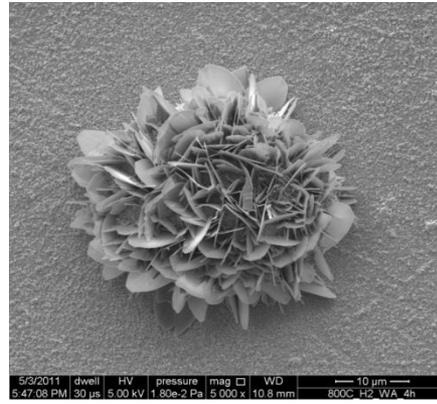
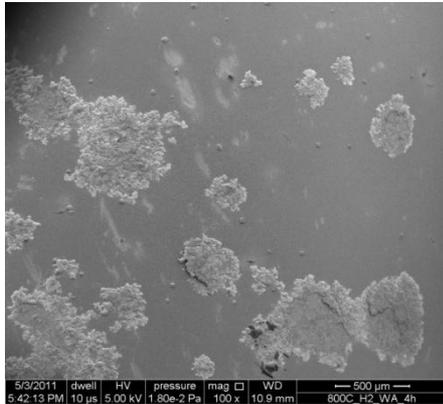
- Pilot Scale MEA Production
- Catalyst Process Development
- Process Modeling



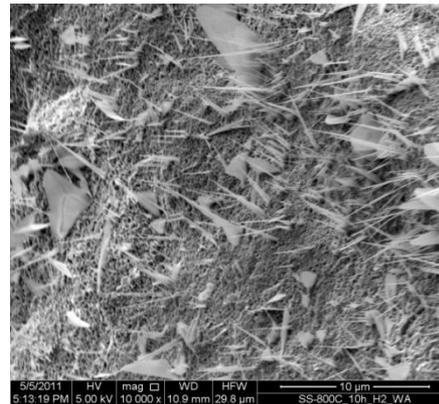
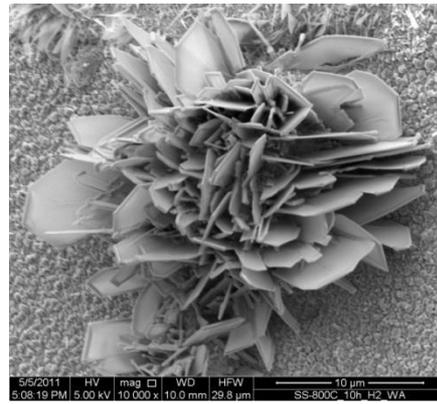
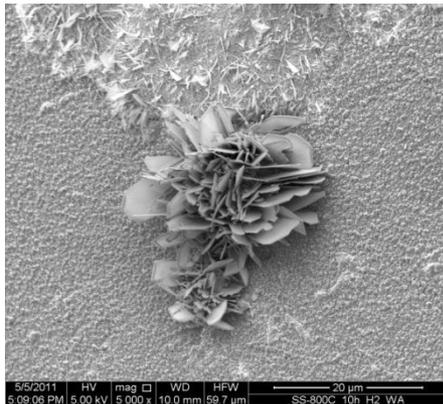
Courtesy of The National Renewable Energy Laboratory (NREL)

- Design of Laboratory and Production Cells
- Troubleshoot Production Cell Issues
- System Design
- System Performance Modeling

Advancing Metallurgy:



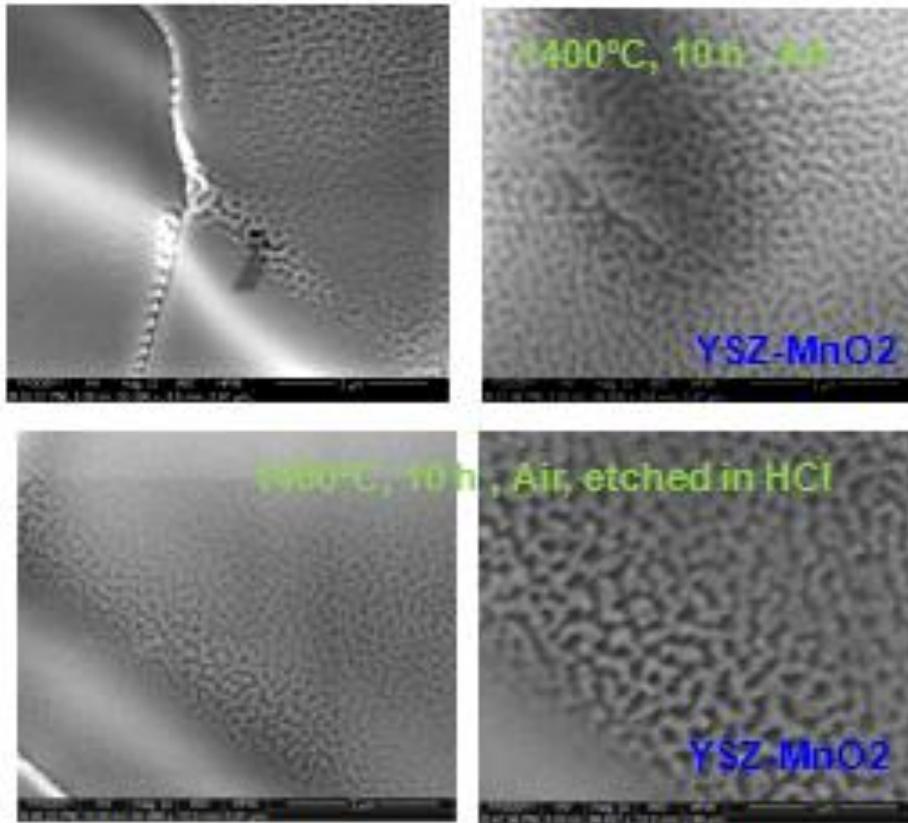
4 hr



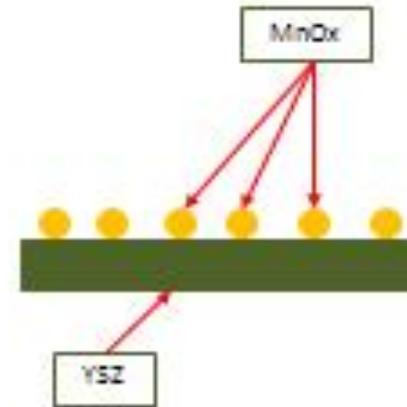
10 hr

Sample: SS-316L-tube; Temperature: 800°C, Time: 4 & 10 h; Atmospheres: Inside tube-Dry H₂ and Outside tube: Wet Air

Tailoring Surfaces to Interfaces

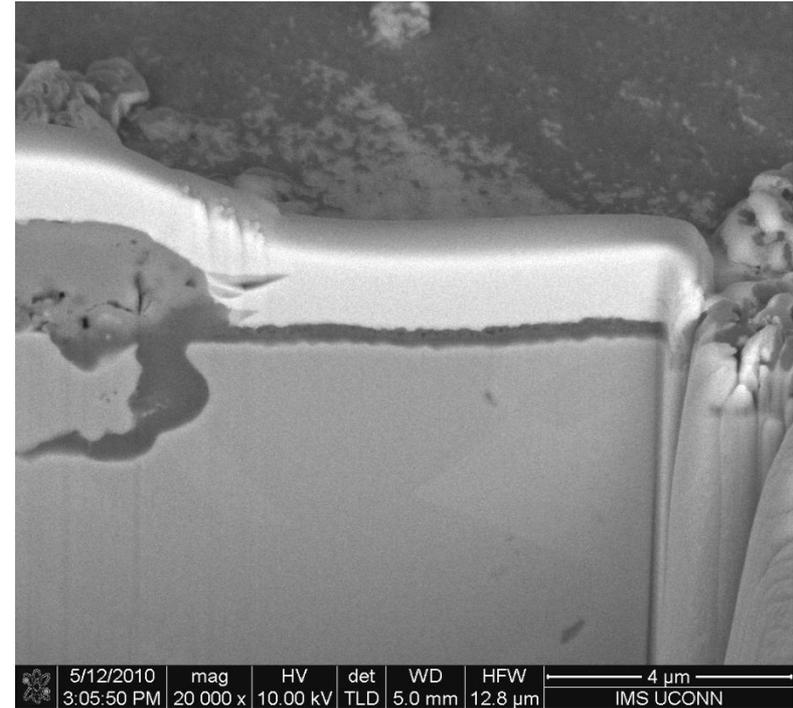
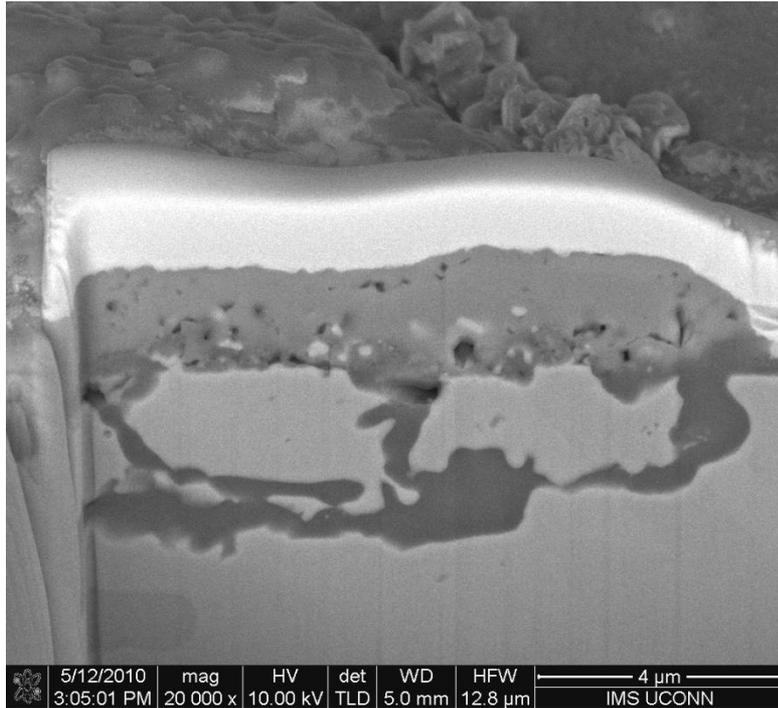


Planar surface changes to wavy surface



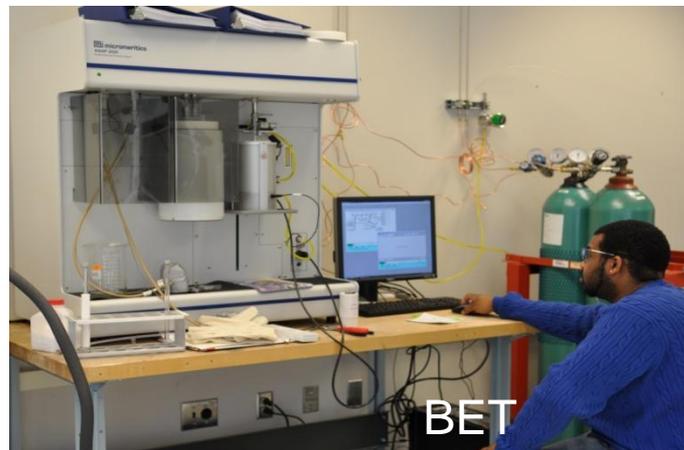
Controlled experiment: YSZ embedded in MnO₂ powder

Analytical Expertise – Key to Product Development



Porous thick Cr-oxide scale. Interesting contrast under Cr-oxide scale.

Test Facility - Examples



In-Situ Characterization



State of the Art HT-ESEM, TGA, DSC available for materials characterization and in-situ testing. Electrode stability, stoichiometry etc. will be studied.

In-Situ Characterization (HT-ESEM) and DSC/TGA



Xradia - X-ray Tomography



State of the Art characterization from 3D tomography to FIB-TEM are available for a wide variety of materials development including functional materials and catalysts for energy conversion and storage systems

High Temperature Processing and Characterization



A well equipped laboratory for electrochemical measurements

Our Continued Growth



Faculty and Staff at C2E2



2009	< 25
2010	- 55
2011-'12	> 120



Supports CT energy initiatives, UConn leadership and National needs

Inspired by Industrial, State, Federal and UConn Support

COMBUSTION SCIENCE & TECHNOLOGY



Baki Cetegen
Professor and Department Head,
Mechanical Engineering
Ph.D., California Institute of Technology
Research: In-situ fuel cell diagnostics, near infra-red laser absorption spectroscopy



Mun Y. Choi
Professor and Dean of Engineering,
Mechanical Engineering
Ph.D., Princeton University
Research: Combustion, heat transfer



Tianfeng Lu
Assistant Professor,
Mechanical Engineering
Ph.D., Princeton University
Research: Computational fluid dynamics with detailed chemistry, reduction of large chemical kinetic mechanisms, efficient simulation of complex multidimensional turbulent flows



Michael Renfro
Associate Professor,
Mechanical Engineering
Ph.D., Purdue University
Research: In-situ fuel cell diagnostics, near infra-red laser absorption spectroscopy, water, carbon dioxide, and carbon monoxide concentration



Chih-Jen Sung
School of engineering Professor in Sustainable Energy,
Mechanical Engineering
Ph.D., Princeton University
Research: Electrochemical modeling, fuel chemistry

FUELS & FUEL PROCESSING



Georgios Bollas
Associate Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Aristotle University of Thessaloniki
Research: Thermochemical and hybrid cycles, hydrogen economy, biomass gasification



Bakun Li
Assistant Professor,
Civil & Environmental Engineering
Ph.D., University of Cincinnati
Research: Biological hydrogen production as a sustainable environmental technology



Ashish Mhadeshwar
Assistant Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., University of Delaware
Research: Heterogeneous catalysis, fuel processing, energy generation, catalyst deactivation, and emission



Richard Parnas
Associate Professor and Director,
Chemical Engineering,
Chemical, Materials and Biomolecular Engineering
Ph.D., University of California, Los Angeles
Research: Optical fiber based sensors, monitoring in-situ membrane operating performance



Steven Subb
Board of Trustees Distinguished Professor and Head, Department of Chemistry
Ph.D., University of Illinois
Research: Development of CO tolerant

ADVANCED ENERGY MATERIALS, PROCESSES & SYSTEMS



Mark Aindow
Professor and Director,
Materials Science & Engineering
Chemical, Materials, and Biomolecular Engineering
Ph.D., University of Liverpool, England
Research: Diesel fuel reformulation, ammonia selective metal catalysts, hydrodesulfurization



Theodore Bergman
Professor,
Mechanical Engineering
Ph.D., Purdue University
Research: Thermal systems analysis, heat and mass transfer in fuel cell stacks



Leonard Bonville
Research Specialist,
Center for Clean Energy Engineering
B.S., Iowa College
Research: Process development, endurance, and cost reduction of fuel cell membranes, catalyst coated membranes, and MEAs for PEM and acid stacks



C. Barry Carter
School of Engineering Professor,
Department of Chemical, Materials, and Biomolecular Engineering
D. Phil Oxford University, Sc.D., Cambridge University
Research: Binding structure, chemistry and bonding of materials to properties, solubility reactions, organic materials, microscopy



Wilson Chiu
Associate Professor,
Mechanical Engineering
Ph.D., Rutgers University
Research: Electrochemical modeling and thermal control of undercatalyzed fuel cell systems



Chris Cornelius
Assistant Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Virginia Polytechnic Institute
Research: Understanding interrelationships of structure, property and function of materials related to energy technologies



Amir Faghi
United Technologies Chair Professor in Thermal Fluids,
Mechanical Engineering
Ph.D., University of California, Berkeley
Research: Thermal systems analysis and application of heat pipe technology to portable fuel cell stacks and systems



Puxian Gao
Assistant Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Georgia Institute of Technology
Research: Optimize nanomaterials design and synthesis in conjunction with technology and energy related applications.



Robert Gao
Prest and Whitney Endowed Chair Professor,
Mechanical Engineering
Ph.D., Technical University of Berlin, Germany
Research: Sensing and control, homecare



Hanchen Huang
School of Engineering Professor in Sustainable Energy,
Mechanical Engineering
Ph.D., University of California, Los Angeles
Research Interests: Advanced Materials Processing



Eric H. Jordan
Professor,
Mechanical Engineering
Ph.D., University of Wisconsin-Madison
Research: Advanced Materials Processing, temperatures



Joong-Ho Kim
Assistant Professor,
Civil & Environmental Engineering
Ph.D., University of Illinois at Urbana-Champaign
Research: PEM fuel cells, functionally graded electrodes' PEM Fuel Cells



Russ Kunz
Professor-in-Residence,
Center for Clean Energy Engineering
Ph.D., Renaissance Polytechnic Institute
Research: Fuel Cell technology and electrochemistry



Radenka Maric
School of Engineering Named Professor in Sustainable Energy
Chemical, Materials and Biomolecular Engineering
Ph.D., University of Kyoto, Japan
Research: Thin film and nanomaterials technology development



Trent Molter
Research Scientist,
Chemical, Materials, and Biomolecular Engineering
Ph.D., University of Connecticut
Research: Regenerative fuel cells, hydrogen production, electrochemical compressors, fuel cell materials and hydrogen electronics



William Mustain
Associate Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Illinois Institute of Technology
Research: New materials for gas-to-liquid exchange membrane fuel cells, molten carbonate fuel cells, reformer catalyzed biogas fuel cells



Kenneth Noll
Professor,
Molecular and Cell Biology
Ph.D., University of Illinois
Research: Microbial fuel cells, catalytic fuel oxidation, Computer modeling Methods



Ugur Pasaogullari
Assistant Professor,
Mechanical Engineering
Ph.D., Pennsylvania State University
Research: PEM Fuel Cells, Multi-phase transport phenomena



George Nelson
Assistant Professor,
Mechanical Engineering
Ph.D., Georgia Institute of Technology
Research: Modeling of multi-scale energy systems and the study of transport phenomena in porous media



Sanguthevar Rajasekaran
UTC Professor of Computer Science & Engineering and Director, BECAT
Ph.D., Harvard University
Research: Computer simulation of fuel cell systems, device modeling, multi-scale performance modeling and analysis



Rampi Ramprasad
Associate Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., University of Illinois, Champaign Urbana
Research: Modeling



George Rossetti, Jr.
Associate Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Pennsylvania State University
Research: Thermodynamic, kinetic, reaction processing, microstructure evolution, phenomena and phenomena materials and their applications in sensing, catalysis, energy conversion and storage



Montgomery Shaw
A.T. Dillaberto Distinguished Professor, Chemical, Materials and Biomolecular Engineering
Ph.D., Princeton University
Research: Phase behavior in polymer solutions and blends, aging of polymer electrolytes



Prabhakar Singh
Director, Center for Clean Energy Engineering and UTC Chair Professor of Fuel Cell Technology
Ph.D., University of Sheffield, England
Research: Solid oxide fuel cells: Systems operation, process optimization, hydrocarbon fuel processing, hydrogen separation and electrical management



Alevtina Smirnova
Assistant Research Professor,
Chemical, Materials, and Biomolecular Engineering
Ph.D., St. Petersburg State University
Research: Novel Materials (nanotubes, nanowires, nanorods and catalysts) for SOFC, PEMFC, and DMFC. Modeling of fuel cell system performance.



Jiong Tang
Assistant Professor,
Mechanical Engineering
Ph.D., Pennsylvania State University
Research: PEM Fuel Cells, system level dynamic modeling, control strategy



Atul Verma
Associate Professor,
Chemical, Materials, and Biomolecular Engineering
Ph.D., Marquette University
Research: Advanced SOFC, high temperature metallic and ceramic materials, conductive oxides and degradation mechanisms.



Mei Wei
Associate Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., University of New South Wales
Research: Nanoparticle deposition methods, interfacial integrity, turbulent SOFCs



Brian Willis
Associate Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Massachusetts Institute of Technology
Research: Tuning spectroscopy for molecular electronics and nanosensors, catalytic support materials for improved durability of electrocatalyst formulations in fuel cells



Bi Zhang
Professor,
Mechanical Engineering
Ph.D., Tokyo Institute of Technology, Japan
Research: Improved machining and manufacturing techniques for PEM fuel cell systems

RENEWABLE ENERGY & RESOURCES



Alexander Agrios
Assistant Professor,
Civil and Environmental Engineering
Ph.D., Northwestern University
Research: Solar energy, electron transport and recombination kinetics, electrochemistry



Joseph Bushey
Assistant Professor,
Civil and Environmental Engineering
Ph.D., Carnegie Mellon University
Research: Mercury cycling



Maria Chrysoschoou
Assistant Professor,
Civil and Environmental Engineering
Ph.D., Stevens Institute of Technology
Research: Mercury cycling



Harry A. Frank
Professor,
Biological and Physical Chemistry
Ph.D., Boston University
Research: Solar photo catalysis (conversion focus)



Vijaya Kumar
Assistant Professor,
Physical and Biological Chemistry
Ph.D., Indian Institute of Technology, Kanpur
Research: Solar photo catalysis (conversion focus)



Harris Marcus
Professor and Director,
Institute of Materials Science
Ph.D., Northwestern University
Research: Carbon methanoly and laser sintering, membrane fuel cell systems, low power applications



Jeffrey McCutcheon
Assistant Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Yale University
Research: Electro spun nanofiber networks webs for use as substrate for novel water filtration membranes



Fotis Papadimitrakopoulos
Professor,
Physical Chemistry
Ph.D., University of Massachusetts
Research: Processing PV, electrochromic devices, luminescent materials



James F. Rusing
Professor,
Analytical Chemistry
Ph.D., Clarkson College of Technology
Research: Solar Photo Catalysis



Leslie Shor
Assistant Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., Rutgers University
Research: Water



Gregory A. Sotzing
Associate Professor,
Polymer and Organic Chemistry
Ph.D., University of Florida
Research: Materials - Chemical sensing, polymer processing

UConn Energy Expertise



ENERGY STORAGE & POWER MANAGEMENT



Reda Ammar
Professor and Head,
Control Systems and Engineering
Ph.D., University of Connecticut
Research: Real-time systems, computer simulation of fuel cell systems, parallel processing, model-based performance modeling and analysis



Mehdi Anwar
Professor,
Electrical and Computer Engineering
Ph.D., Clarkson University
Research: Optimization & Minimization of power conditioning circuits for fuel cell systems



Eric Donkor
Associate Professor,
Electrical and Computer Engineering
Ph.D., University of Connecticut
Research: Distributed manufacturing, high power D.C. to A.C. converters, electrical energy storage and characterization of fuel cell systems



Yunsi Fei
Assistant Professor,
Electrical and Computer Engineering
Ph.D., Princeton University
Research Interests: Resiliency of energy systems against cyber attacks



Peter Luh
SNET Professor of Communications & Information Technologies
Department of Electrical and Computer Engineering
Ph.D., Harvard University
Research: Optimize generation & storage options, Modeling of energy efficient green buildings, Demand response



Sung Youl Park
Assistant Professor,
Electrical and Computer Engineering
Ph.D., Virginia Polytechnic Institute and State University
Research: Power conditioning, energy conversion, renewable energy, smart grid applications



Krishna Pattipati
Assistant Professor,
Electrical and Computer Engineering
Ph.D., University of Connecticut
Research: Optimization of generation and storage options, Li-ion battery, wind modeling (grid integration)



Leon Shaw
Assistant Professor,
Chemical, Materials and Biomolecular Engineering
Ph.D., University of Florida
Research: PEM fuel cells, bipolar plates, carbon/polymer composites



Peng Zhang
Assistant Professor,
Electrical and Computer Engineering
Ph.D., University of North Carolina
Research: Electromagnetic transient programs, power system reliability, power system planning & operation, renewable energy.

Thank You



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