Cornell Institute for Sustainable Energy Systems (Under construction)

- One of two private land grant universities (the other is MIT, Cornell includes agriculture and life sciences)
- National centers for nanofabrication, nanobiotechnology assets for CISES
- University structure & sustainable development initiative
Topical Clusters of the Institute for Sustainable Energy Systems

1. Energy systems and energy security;

2. Primary energy resources (biomass, wind, fossil, nuclear, solar);

3. Energy conversion devices and processes (hydrogen production, fuel cells, new prime movers, and related technology);

4. Energy storage and distribution (new grid technologies effectively integrating distributed energy production schemes, batteries, hydrogen fuel containment and distribution, disposal of energy waste products);

5. Environmental impact mitigation (carbon sequestration, siting of power production, interaction with atmospheric and oceanic dynamics and chemistry);

6. Energy efficiency and conservation (new indoor heating and cooling technology, new lighting technology).
Some Examples of Multi-Investigator Energy Research

Each involving at least 5 Cornell faculty

- Cornell Fuel Cell Institute
- Northeast Sun Grant
- Flexible Display
- Power Systems ERC - PSERC
- Computational Turbulent Combustion ITR

Francis J. DiSalvo¹ and Héctor D. Abrúña¹ (co-directors)
Paul F. Mutolo¹ (Associate Director)
R. Bruce VanDover², Ulrich Wiesner², Emmanuel Giannelis², Barry Carpenter² and Sossina Haile³
¹Dept. of Chemistry and Chemical Biology
²Materials Science and Engineering
³California Institute of Technology and Cornell Fuel Cell Institute
Baker Laboratory, Cornell University
Ithaca, New York 14853-1301
Materials Science Challenges to Fuel Cell Commercialization

Critical challenges remain at the materials level in the heart of the fuel cell, the MEA (membrane electrode assembly).

Empirically designed. Based on century old materials. Innovation Required.

requirements...

**Electrocatalysts: anode and cathode**
- Anode: improved poison tolerance, lower overpotential to fuel oxidation (for direct fuel fuel cells, e.g. DMFC)
- Cathode: lower overpotential to oxygen reduction
- Both: cost competitiveness, improved durability

**Electrolyte: conductivity and mechanical stability**
- Increased robustness to radical attack
- Decreased fuel permeability (for direct fuel cells, e.g. DMFC)
- Better matched coefficients of thermal expansion (for SOFC)

**Electrode: Structure and interface**
- More robust catalyst support (stable to oxidation)
- Designed porosity of the electrode layer
- Increased tolerance of interfaces to cycling, aging, manufacturing
CFCI’s Approach to Fuel Cell Materials Development

GOAL: Discover and develop improved materials for advanced MEAs.

TARGET: At present, CFCI’s materials development (e.g. catalyst, electrolyte, support) is aimed at improving MEAs for lower temperature polymer electrolyte membrane (PEM) fuel cells.

FUTURE: The techniques developed at CFCI can be applied to other fuel cell systems. In the near term, we are exploring materials for solid oxide fuel cells (SOFCs).

CFCI Strengths:
- Discovery and Design of new electrocatalyst materials
  - Solid-state synthesis + electrochemical understanding + high-throughput approach = impressive new catalysts based on intermetallic compositions
- Functionalizing the electrolyte membrane
  - Results in improved properties: manufacturability and fuel cell operation
- Designing electrode materials of defined architecture
- Exploiting self-assembly to ensure the electrode form enables its function
Ordered Intermetallic Electrocatalysts as Anodes

- 52 bulk materials synthesized so far
- 37 have been characterized (71% of the materials)
- 26 have shown some activity (70% of tested materials)
- Most promising candidates have been investigated in depth

CFCI: Abrúña / DiSalvo groups
High-Throughput Synthesis

on-axis sputter deposition of thin film composition spreads

>60% of ternary phase space sampled on a single wafer
Nafion®-Nanohybrid Membranes

- **Polymer**: Nafion®
- **Nanoparticle choices**:
  - Montmorillonite (H+MMT)
  - Sulfonated-SiO₂
  - Sulfonated Zirconium-Phosphonate

Cornell Institute for Sustainable Energy Systems

CFCI: Giannelis group
Block copolymer-metal nanoparticle hybrids: A route to porous intermetallic electrodes

We are developing nanoparticles of the most active metals as identified by the combinatorics group.

Platinum

Bismuth

Serves as catalyst and electron conductor

50 nm

30 nm
Northeast Sun Grant Center of Excellence

Basic Research

Genetic Resources

Education, Outreach, Business Opportunity

Applied Research

Development

Systems thinking

1 µm
BIOFUELS

Biofuels

Methane Production and Utilization

Cellulosic Ethanol

Biohydrogen

Biomass is the only renewable that directly reduces our dependency on liquid fuels.
Cornell Biomass Research Groups

Approximately 30 faculty (engineering, plant biology, microbiology, molecular biology, plant pathology)

From feedstocks to bioindustrial products

• Genomics and proteomics to control plant metabolic pathways - Manipulate plant genomes to produce quantitative and qualitative changes in organic constituents of plant biomass

• Key bioprocessing activities of agriculturally-based resources into raw materials for synthesis of new products include fractionation, extraction, depolymerization, and synthesis of intermediate products. For example, ligno-cellulosic materials must be fractionated into constituent biopolymers and modified to facilitate either enzymatic or microbial conversion.

• Protein engineering, metabolic engineering of microorganisms to increase enzyme copy number or to metabolize multiple carbon sources, improved bio-reactor performance, better biosensor-based controls are some of the key scientific and engineering issues addressed.
Next Generation Flexible Electronics For Energy applications

New Materials, Manufacturing and Use Paradigms
Large area flexible electronics

Systems level approach with collaborative university-industrial research centers

- Extensive ongoing flexible electronics activities – especially within the MS&E community at Cornell

- Leverage breadth of research activities across departments
  - Materials Science and Engineering
  - Electrical and Computer Engineering
  - Chemical and Biomolecular Engineering

- Engage geographically proximate industries
  - Foster more interactions between students / faculty / industry

- Incorporate key university collaborations to complement local capabilities

- Develop “large” collaborative center proposals with high impact to Cornell and NYS industries
Initial Concepts: Coupling of active electronics on flexible substrates for lighting

- Key issues associated with materials / interactions
- New manufacturing technologies (roll-to-roll)
- Strategic directions for local industry

Cornell Institute for Sustainable Energy Systems

- Strong background / interest
  - Ast, Thompson, Malliaras, Wiesner
- Processing / novel materials
  - Giannelis, Ober, Dieckmann, Baker
Internal and collaborative strengths

- Low-Temperature Si TFT growth/integration (Ast, Thompson)
- Organic materials
- Novel luminescence (Malliaras, Wiesner)
- Barrier technologies
- Advanced lithography
- Conducting oxides (Ober, Giannelis, Dieckmann)
- Linkage with external expertise
  - Tom Jackson (Penn)
  - Mike Rubner (MIT)
  - Antoine Kahn (Princeton)
Collaborative Activities

- Efforts focused on broad flexible electronics
  - Solar panels
  - Solid-state lighting
  - Low cost electronics (RF-ID tags, displays, etc.)
  - Unique flexible requirements (conformal sensors)
  - Low cost manufacturing (roll-to-roll enabling research)

- Develop key industrial partnerships to focus activities

- Develop focus on fundamental enabling sciences (broadly)
  - Materials issues
  - Manufacturing issues
  - System level integration and application

- Directed ultimately toward roll-to-roll processing capabilities
  - Synergy with Arizona Flexible Display center
  - Partner with USDC to site R2R prototype center locally
Power Systems Engineering Research Center

A National Science Foundation Industry / University Cooperative Research Center
Mission

PSERC helps engineer the future electric power infrastructure by:

- using collaboration among universities, industry, and government
- conducting research on challenges in providing customers with reliable, economical, and environmentally-acceptable electric energy
- informing policy-makers through research and education
- educating the next generation of engineers
Collaborating Universities

- Cornell University - Robert J. Thomas - Center Director
- Arizona State University - Gerald Heydt
- University of California at Berkeley - Shmuel Oren
- Carnegie Mellon University - Sarosh Talukdar
- Colorado School of Mines - P.K. Sen
- Georgia Institute of Technology - Sakis Meliopoulos
- Howard University - James Momoh
- University of Illinois at Urbana - Peter Sauer
- Iowa State University - Jim McCalley
- Texas A&M University - Mladen Kezunovic
- Washington State University - Anjan Bose
- University of Wisconsin-Madison - Chris DeMarco
- Wichita State University - Ward Jewell
Industry Members

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American Electric Power
American Transmission Co.
AREVA T&D
Arizona Public Service
British Columbia Trans. Co.
California ISO
CenterPoint Energy
Duke Energy
Entergy
EPRI
Exelon
GE Energy
FirstEnergy
Institut de recherche d’Hydro-Québec
(IREQ)
ISO New England
MidAmerican Energy
Midwest ISO
National Grid USA
New York ISO
New York Power Authority
NxtPhase
Pacific Gas and Electric
PJM Interconnection
PowerWorld Corp.
RTE – French TSO
Salt River Project
Siemens, EMA
Southern Company
Steel Tube Institute
TVA
Tri-State G&T
TXU Electric Delivery
U.S. DOE
Western Area Power Admin.

Cornell Institute for Sustainable Energy Systems
Researchers

- 40 researchers in 3 research areas
- Multidisciplinary, specializing in:
  - power systems, applied mathematics, non-linear systems, power electronics, control theory, computing, operations research
  - economics, industrial organization and public policy.
Cornell’s Involvement

- Multidimensional Market Design
  - Electric Market Design Principles
  - Optimal Electricity Market Structures to Reduce Seams and Enhance Investment
- Experimental Lab Program – POWERWEB
- Methods for Real-Time Market Monitoring
- Resource Adequacy: Incentives for Long-term Transmission and Generation Investments
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American Transmission Co.
AREVA T&D
Arizona Public Service
British Columbia Trans. Co.
California ISO
CenterPoint Energy
Duke Energy
Entergy
EPRI
Exelon
GE Energy
FirstEnergy
Institut de recherche d’Hydro-Québec
(IREQ)
ISO New England
MidAmerican Energy
Midwest ISO
National Grid USA
New York ISO
New York Power Authority
NxtPhase
Pacific Gas and Electric
PJM Interconnection
PowerWorld Corp.
RTE – French TSO
Salt River Project
Siemens, EMA
Southern Company
Steel Tube Institute
TVA
Tri-State G&T
TXU Electric Delivery
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