Global Climate and Energy Project Goals

- Discovering new scientific concepts for clean energy
- Developing breakthrough energy technologies
- Educating future energy thought leaders and research workforce
- ...to enable affordable, safe, secure and clean energy for everyone
GCEP: A CREATIVITY ENGINE FOR ONE OF THE WORLD’S GREATEST CHALLENGES

**Sponsors**
- Research funding
- IP licenses
- Pathways to commercialization
- Domain knowledge
- Commercial insight and experience
- University engagement

**GCEP Organization**
- Research opportunity identification
- Systems application analysis
- Outreach

**Results of Collaboration**

- Excellent science
- Breakthrough energy technologies
- Future energy thought leaders and research workforce
- Clean sustainable planet

**Universities**
- Research ideas, personnel, and facilities
- Research results and IP
- Fundamental research
- Industry engagement

**ExxonMobil**

**GE**

**Schlumberger**

**TOYOTA**

**DUPONT**
A Unique Partnership: Industry/Academia Engagement in the Discovery and Innovation Stage of the Development Cycle

- Scientific Invention
- Process Innovation
- Technical Product
- System Integration

GCEP Model

Typical Industry-Academic Engagement
GCEP Works with Universities Around the World

China
Peking University
China University of Geosciences

Japan
Research Institute of Innovative Technology for the Earth

Australia
University of New South Wales
University of Sydney

USA
Stanford University
Boise State University
Brigham Young University
California Institute of Technology
Carnegie Institution of Washington
Colorado School of Mines
Harvard University
Northeastern University
Northwestern University
Purdue University
Rensselaer Polytechnic Institute
Rice University
SRI International
University of California-Santa Cruz
University of Illinois at Urbana-Champaign
University of Montana
University of Texas at Austin
University of Texas at Dallas
University of Southern California
University of Tennessee
University of Wisconsin-Madison

Europe
Energy Research Centre of the Netherlands
Swiss Federal Institute of Technology
IRDEP/CNRS
Technical University of Delft
University of Dundee
Ghent University
Universite de Picardie Jules Verne
Universidad Politécnica de Madrid
Uppsala University
Utrecht University/FOM
GCEP Activities

Analysis
Assessing opportunities and challenges.

Research
Discovery and development of game changing technologies.

Outreach
Sharing knowledge with the industry, government and the public.
The solar and wind energy resources are very large compared to human energy use.
Global Depletable Energy Resources

Ratio of Resources to Annual Human Energy Use

- Geothermal Energy*
- Deuterium-tritium (from Li)
- Uranium
- Thorium
- Coal
- Gas Hydrates
- Oil
- Gas
ENERGY ANALYSIS SHOWS LONG LIVED STORAGE IS NEEDED FOR ELECTRICITY GRID APPLICATIONS

PERFORMANCE SPECIFICATIONS FOR GRID SCALE STORAGE
Sally Benson, Stanford University
Need to improve electrochemical storage cycle life by a factor of 5 or more for it to have a significant global impact as an energy storage technology

- Open framework of prussian blue analogues can enable:
  - fast ion transport
  - minimum strain
  - high cycle life

\[
ESOI = \frac{\lambda \eta D}{\epsilon_{gate}}
\]

\(\lambda\) : cycle life
\(\eta\) : round trip efficiency
\(D\) : depth of discharge
\(\epsilon_{gate}\) : embodied energy

Barnhart and Benson, 2013 (EES)

GRID-SCALE BATTERIES
Yi Cui and Robert Huggins, Stanford University

- Demonstrated 40,000 charging cycles using copper hexacyanoferrate

GCEP Has A Diverse Research Portfolio

Renewables
- Bioenergy
- Other Solar Conversion
- Solar Water Splitting
- Solar Photovoltaics
- Cost-Shared Research
- Exploratory Research

Carbon-Based Energy Systems
- Hydrogen Impacts
- Advanced Combustion
- Advanced Coal
- CO₂ Capture
- CO₂ Storage
- Batteries for Transportation
- Advanced Fuel Cells

Other
- Integrated Assessment
- Grid Storage
- Electrocatalysis
- Cells
- Grid Control

Electrochemistry and Electric Grid
A DECADE OF INNOVATION AND PROGRESS IN ADVANCED COMBUSTION

2002

Advanced Combustion

2012

Energy Efficient, Low CO₂-emitting Engines

Low-irreversibility engines

Advanced coal power generation systems

High efficiency engines at extreme states

Sootless diesel
A DECADE OF INNOVATION AND PROGRESS IN THE ELECTRIC GRID

Flat control of the electric grid for renewable integration

Chemistry for solid oxide fuel battery

Ability to Integrate New Energy Generation and Systems

2002

Electric Grid

2012

Designs and materials for flywheel storage

Electrode materials for safe, fast, inexpensive batteries
A DECADE OF INNOVATION AND PROGRESS IN CARBON CAPTURE AND STORAGE

Geologic studies of sequestration

Experiments and simulations of CO₂ storage

Linking CO₂ injection effects to geophysics

2002 Carbon Capture and Storage 2012

Molecular gates for gas separation

Mineralization with silicates

Biomimetic strategies for carbon capture

Effective Options for Addressing CO₂ Emissions from Fossil Fuels
A DECADE OF INNOVATION AND PROGRESS IN SOLAR ENERGY

 Nanostructured PV for thin film

 Si quantum dots to control band gap

 Photon-enhanced thermionic emission

 Hot carrier solar cells

 2002

 Solar Energy

 2012

 High Efficiency and Low Cost of Solar Energy Conversion

 Plasmonics enhance absorption

 Artificial photosynthesis

 Thermo-photovoltaic cells

 All carbon solar cell
A DECADE OF INNOVATION AND PROGRESS IN BIOENERGY RESEARCH

2002

- Fatty Acids
- Time
- Biodiesel from bacteria

2012

- Effective Use of Organisms for Production of Fuels and Energy Conversion
- Methane from microbes and electrical current
- Global potential of biomass
- Photosynthetic bioelectricity
- Optimizing plants for biofuels

2012

- Hydrogen from biomass
- Methane from microbes and electrical current
- Global potential of biomass
- Photosynthetic bioelectricity
- Optimizing plants for biofuels
A DECADE OF INNOVATION AND PROGRESS IN TRANSPORTATION RESEARCH

2002

Nanowire lithium ion batteries for electric vehicles

Hydrogen storage through C-H bonds

2012

Wireless power transfer to moving vehicles

Efficient Mobility Options with No or Low CO₂ Emissions

Catalysts for fuels from CO₂
A DECADE OF INNOVATION AND PROGRESS IN FUEL CELL RESEARCH

2002

Nanoscale architecture gives large surface area for improved fuel cell performance

Nanotubes and atomic layer deposition for enhanced low-temperature efficiency

Study kinetic behavior of nanostructured materials

Nanoscale fabrication for high power density

Enabling Electricity from Hydrocarbon Fuels with Low CO₂ Emissions

Fuel Cells
A DECADE OF EDUCATING FUTURE LEADERS

- GCEP’s major activity is to support student and faculty research
- Over 700 students have participated
- Student lecture series
- Poster sessions
- Industry/student engagement
- Recruiting
2002 - 2013
Cumulative GCEP Highlights

GCEP Milestones and Key Events

2002 – Launching of GCEP at Stanford with four Sponsors
2004 – First set of competitive research awards
2005 – First GCEP Symposium
2008 – First patent issued on GCEP technology
2010 – First license of GCEP technology

GCEP Statistics

165 Faculty PI’s
713 Grad Students and Post-docs
39 Research Institutions
80 Full-Scale Research Activities
515 Peer-Reviewed Publications
34 Patent Applications
4 Start Up Companies

GCEP
ExxonMobil
Schlumberger
TOYOTA
Potential of GCEP Research for Impact in the Developing World

• GCEP research uses breakthroughs in fundamental science to provide giant steps forward in new energy technologies.

• Explore options for applying these principles to develop technologies that can be used to improve the quality of life in developing countries, recognizing:
  - Economic development needs
  - Financial constraints
  - Institutional constraints
  - Environmental impact
  - Resource availability