Introduction to GCEP and Scope of Workshop

Lynn Orr

GCEP Fusion Energy Workshop
# The Grand Challenge

## Needs
- Growth in world population to 9 billion from 6 billion, of which 2 billion people currently have no access to modern energy systems
- Improved standard of living in growing economies of developing world
- Increased demands for energy, food, land, and materials.

## Component Challenges
- Water supply
- Agricultural systems (strongly linked to water supply)
- **Energy (with possible limits on CO₂ emission)**

## Protection, Restoration, and Improvement of the Planetary Biogeochemical Systems
Global Geochemical History

- Concentrations of GHGs have risen significantly over the preindustrial levels.

Source: IPCC Third Assessment Report, 2001
Atmospheric CO$_2$ Concentration
- Last Glacial Maximum to Present

Adapted from: http://www.climate.unibe.ch/gallery_co2.html
Four Glacial Cycles Recorded in the Vostok Ice Core

The oceans have taken up ~400 Gt of fossil fuel CO₂. Global surface oceans now remove 20-25 Mt CO₂/day.

Decline in pH (0.1 since industrial revolution) affects bicarbonate, carbonate ion concentrations, rates of fixation of CaCO₃ by assorted critters in the trophic chain, potential for feedbacks with temperature change.

Source: Oceanography Vol.17, No.3, Sept. 2004
Concerted Efforts to address Climate Change
The Need for Technology

Assumed Advances In:
- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

Gap Technologies:
- Carbon capture & disposal
  - Adv. fossil
- H₂ and Adv. Transportation
- Biotechnologies
  - Soils, Bioenergy, Adv. Biological Energy

Source: J. Edmonds, PNNL
The Global Climate and Energy Project (GCEP) was established to conduct fundamental research to develop the energy options needed to address the “gap.” It is a 10-year, $225M commitment for research on the fundamental underpinnings for technologies that could have a significant impact on a global scale. 

Mission

To Conduct Fundamental Research to Support Development of Technology Options for Energy Use With Reduced Greenhouse Gas Emissions

and others…
Step-Out Research

Progress

Scientific Challenge

Step-out Idea

Step back to fundamentals

Scientific Advance to Enable Development of a Game-changing Technology in Reduced Time

Energy Option

Present Time

Time
Resource Work Potential (TW)


Current Global Exergy Usage Rate ~ 15 TW (0.5 ZJ per year)
~80000/15 = ~5300

(1 ZJ = 10^{21}J)
GCEP Research Portfolio Areas

- CO₂ separation, capture, and storage
- Combustion science and engineering
- Hydrogen production, distribution, and use
- Renewable energy sources (wind, solar, biomass, geothermal)
- Advanced materials
- Advanced coal utilization
- Advanced transportation systems
- Advanced nuclear power technologies
- Electric power generation, storage, distribution
- Energy distribution systems and enabling infrastructures
- Geoengineering

Active research currently underway
Research proposals under review
Assessment in progress
Future consideration
Nanostructured Silicon-Based Tandem Solar Cells
Martin Green, Gavin Conibeer (UNSW)

- Fabrication of two- or three-cell tandem stack devices from silicon-based materials.
- Uses abundant, non-toxic, stable, and durable materials
- Control the bandgap of silicon through carrier confinement in nanoscale structures
  - Integrate silicon nanoparticles into matrices of silicon oxide, nitride, or carbide
  - Exploit quantum effects related to their size and distribution across the cell
- Optimize geometry of the nanoparticle networks to enhance carrier transport through resonant hopping between layers in a cell
- Areas of Activity:
  - Materials Preparation
  - Physical, Optical, and Electronic Characterization
  - Simulation and Modeling:
  - Device Fabrication
• Increase accumulation of cellulose and carbon uptake in biomass crops by genetic alteration of the regulation of cellulose synthesis
• Transgenic plants will be produced in which the components of the cellulose synthase complex are produced in increased amounts and at altered times during plant development.
Capture electricity directly from living biological cells by inserting nano-scale electrodes into their chloroplasts.

Light-driven charge separation generates high potential electrons in stroma, and O$_2$ and H$^+$ in lumen.

Energy is generated through a current that results in recombination of electrons from stromal side of the membrane with H$^+$ and O$_2$ on lumenal side of the membrane (at cathode) to generate H$_2$O.

Explore using unicellular alga Chlamydomonas reinhardtii.
Advanced Membrane Reactors in Energy Systems
Dan Jansen, Joop Schoonman ECN/TU-Delft

\[
\begin{align*}
\text{CH}_4 + \text{H}_2\text{O} & \rightleftharpoons \text{CO} + 3 \text{H}_2 \\
\text{CO} + \text{H}_2\text{O} & \rightleftharpoons \text{CO}_2 + \text{H}_2
\end{align*}
\]

- Removal of CO\textsubscript{2} or H\textsubscript{2} can shift equilibrium and lead to lower reaction temperature
- Will combine separation and reaction in membrane reactors
- Hydrogen membranes:
  - Use chemical vapor infiltration (CVI) and atomic layer deposition (ALD) to control pore size of a nanoporous ceramic membrane in a very controlled manner
- CO\textsubscript{2} membranes
  - e.g.: hydrotalcites, ionic liquids
- Improved catalysts
  - High activity at ~ 400 °C and integrated into membrane
• Create a suite of tools for design and implementation of geologic sequestration projects:
  ➢ Site selection and evaluation: effective methods to assess the integrity of geologic seals that limit CO₂ migration.
  ➢ Fluid migration: very efficient methods for predicting the flow paths and long-term fate of injected CO₂.
  ➢ Monitoring: appropriate tools for monitoring the state of injection projects at each stage.
Resource Work Potential (TW)

Current Global Exergy Usage Rate ~ 15 TW (0.5 ZJ per year)

$1 \times 10^{10} / 0.5 >$ the time for the Sun to become a red giant (5 billion years)!

Approaches to Fusion

Magnetic Confinement
- Tokamaks
- Stellarators
- and various alternative configurations

Inertial Confinement
- various configurations
Questions for the Workshop

- What are the scientific and technical barriers to the realization of fusion power at a significant scale?
- What scientific breakthroughs are still required for achieving reactor regime?
- What are the opportunities for fundamental research for developing these technologies and overcoming these barriers?
- How can GCEP, with its objectives and its relatively modest research project budgets, create additional options that would have a significant impact?
# Workshop Agenda

## Day 1

### Welcome and Introduction
- **8:30** GCEP Introduction and Workshop Purpose
  - Lynn Orr
- **9:00** Fusion Development Path
  - Rob Goldston

### Confinement Concepts
- **9:50** The Advanced Tokamak
  - Amanda Hubbard
- **10:30** Break
- **10:50** The Spherical Torus
  - Martin Peng
- **11:30** The Compact Stellator
  - Hutch Neilson
- **12:10** Alternative Confinement Concepts
  - Simon Woodruff
- **12:50** Lunch

### Turbulent Transport
- **1:50** Experimental Investigation of Turbulent Transport
  - George Tynan
- **2:30** Modeling of Turbulent Transport
  - William Dorland
- **3:10** Break

### Plasma Stability
- **3:30** Plasma Stability in Tokamaks and Stelleraltors
  - Gerald Navratil
- **4:10** Plasma Stability in Alternative Confinement Concepts
  - Bick Hooper

### Panel Discussion on Research Opportunities
- **4:50**
  - Reception

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## Workshop Agenda
### Day 2

### Energetic Particles and Plasma-Wall Interactions
- **8:30** Energetic Particles in Plasmas  
  Speaker: James Van Dam
- **9:10** Plasma-Wall Interactions  
  Speaker: Michael Ulrickson
- **9:50** Break

### Materials for Fusion
- **10:10** High Field Magnet Technology  
  Speaker: Joseph Minervini
- **10:50** Reduced Activation Materials  
  Speaker: Nadine Baluc

### Panel Discussion on Research Opportunities
- **11:30**
- **12:10** Concluding Remarks
- **12:30** Lunch
Thank You!

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