Energy and Greenhouse Gases: EMF 19 & GCEP

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The Grand Challenge

• The Issue
  Meeting the needs of a population of 10-11 billion people at the end of this century implies greater production and consumption of goods and services, and increased demands for energy, food, land, and materials. The challenge is to meet these needs while protecting and restoring the planet’s life support systems (ecological, air, water, and climate).

• Component Challenges
  – Water supply
  – Agricultural systems (strongly linked to water supply)
  – Energy (with possible limits on CO₂ emission)
Global Geochemistry

- CO₂ concentration in the atmosphere has increased from 280 to 370 ppm since 1860.
- pH of the upper ocean has decreased by 0.1
- Continuing debate about the magnitude and timing of impacts of greenhouse gases on global climate.
- But there is no doubt that human activities are interacting with planetary geochemistry on a global scale.
- We should be working now on research to create energy options with very low greenhouse emissions.

So what do we do?

- Reduce energy use?
- Find new energy sources?
- Find someplace to put the CO₂ (other than the atmosphere)?
- All of the above?
How fast can we do all this?

- Autos: a decade to change the population significantly.
- Buildings: multiple decades as buildings are replaced, upgraded.
- Industry: plants typically last 30 years or more.
- New energy sources: also decades.
- Big capital investments will be required (though some will pay for themselves).
- Big challenge, so let’s get started!

Imagine …

… a set of global energy systems that emit very small amounts of greenhouse materials (CO$_2$, CH$_4$, N$_2$O, black soot, and others)
Questions

• What will be the primary energy sources?
• How will supplies be deployed, distributed, and used?
• What technologies and systems can be applied effectively in developing countries?
• What barriers to implementation will have to be overcome?
• How will we deal with questions of safety, environmental impact, market acceptance, cost?
• What technologies can help eliminate these barriers?

Global Climate and Energy Project (GCEP)

• A new project has been established at Stanford, with industry support (ExxonMobil, Schlumberger, GE, and Toyota), to investigate how to reduce emissions of greenhouse materials.
• The approach: look broadly across primary energy sources, transformations, and uses.
• Ask where university-based pre-commercial research can reduce barriers to implementing energy systems that have substantially lower greenhouse emissions.
Extensions and limitations

Current approaches omit important dynamics of technological change. A broader framework for analyzing technological change is needed.

Portfolio Areas

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

- For each of the energy areas, assess opportunities for reductions in greenhouse emissions, barriers to implementation, and opportunities for university research to reduce barriers.
- Assessments are the basis for proposal to release blocks of funding for each area.
- Work with research groups inside and outside Stanford to put in place projects that fit within the areas.

Initial Research Projects

- Integrated assessment of technology options
- Hydrogen production and utilization
- Advanced combustion systems
- Geologic sequestration of CO₂

These initial projects will involve 14 faculty in 7 departments (5 in Engineering, 2 Earth Sciences).
Integrated Assessment of Technology Options

Develop comprehensive analysis system for:

- Assessments of probable significance of technologies
- Assessments of options to speed up diffusion of technologies
- Estimation of greenhouse emissions, evaluations of potential reductions

Faculty: Sweeney, Weyant (Mgmt Sci & Eng/Energy Mod. Forum)
Hydrogen Production and Use

- Genetically engineering hydrogen production in photosynthetic microbes
  - Sunlight is the direct energy source
  - Use breakthroughs in microbial genomics, bioinformatics, protein engineering, metabolic engineering

- Hydrogen fuel cells and monitoring bioconversion
  - Use thin film fabrication methods to build high performance fuel cells
  - Build sensors to monitor and control bioconversion

Faculty: Swartz (Chem Eng), Spormann (Civil & Env Eng), Prinz (ME)
50 Nanometer Membrane on Porous Substrate

Science: QM Simulations Implanted Ion Highways

Biological Hydrogen Production: Complete Pathway in Each Cell

Goal: Develop Probes for Intracellular Redox Potential
Advanced Combustion Systems

- Low irreversibility engines – combustion of highly vitiated reactant streams with simultaneous work extraction
- Coal and biomass char reactivity – design for lower CO$_2$, NO$_x$ emission
- Sensors for advanced combustion systems
- Process informatics – construct computationally tractable models of combustion chemistry, heat and mass transfer and fluid mechanics

Faculty: Bowman, Edwards, Golden, Hanson, Mitchell (Mech Eng)

Controlled Combustion

- In conventional combustion devices, chemical conversion of fuel and oxidizer to products occurs rapidly in an uncontrolled and highly irreversible process (flame).
- In controlled combustion, the rate of the fuel conversion process is varied by imposing prescribed initial conditions (temperature and mass fractions of the oxidizer and diluents), leading to potential reductions in irreversibilities in energy conversion (improved efficiency) and reduced emissions of pollutants and greenhouse gases.
**Controlled Combustion**

The Concept:

- **Controlled Combustion Concept**
- **Air Temperature > 800°C**

- Dilution by combustion products, N₂ or CO₂

**Geologic Storage of CO₂**

- Use CO₂ to recover methane in coal beds.
- Dissolve CO₂ in deep aquifers that contain salt water.
- Inject CO₂ to recover oil and gas.
- Volumes are very large: 1 GtCO₂/yr = 25 million B/D.
Geologic \( \text{CO}_2 \) Sequestration

- Develop a suite of tools for design, monitoring of \( \text{CO}_2 \) injection projects
- Geologic systems: oil and gas reservoirs, coalbeds, deep saline aquifers
- Develop fast, accurate method for flow prediction
- Develop low-cost monitoring methods (passive seismic, InSAR, in-well sensors)
- Develop seal integrity assessment tools

Faculty: Harris, Zoback (Geophys), Kovscek, Orr (Pet Eng)

Conclusions

- No single solution to energy/\( \text{CO}_2 \) challenge.
- Need research on a wide-ranging portfolio of energy sources and conversion methods.
- Conservation and energy efficiency are very important, but additional effort needed to create deep reductions in emissions.
- Sequestering enough \( \text{CO}_2 \) to have an impact is a daunting challenge, but it is one that will require the skills of many engineers and scientists across disciplines.
Conclusions

- The energy/CO$_2$ challenge is a global one that will require a sustained, long-term, international effort that blends science, engineering, economics, policy, and much more international cooperation than has been in evidence so far.

Summary

We now have a remarkable opportunity to unleash the talents of our creative students and faculty to work on one of the grand challenges of this century. If we succeed, we can change the world!