Stanford University

Global Climate & Energy Project

May 1–2, 2006

Introduction to GCEP and Scope of Workshop

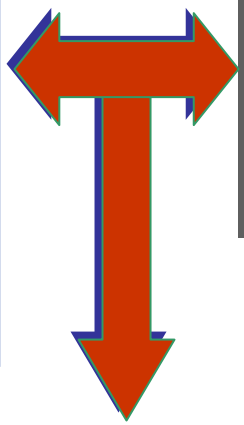
Lynn Orr

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.

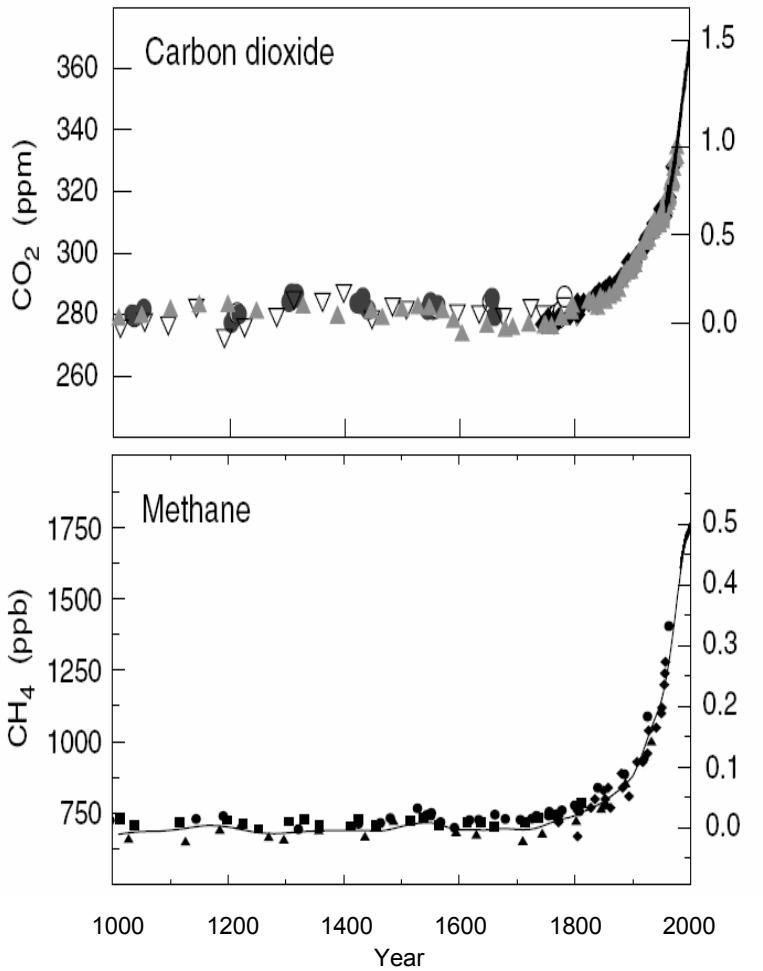


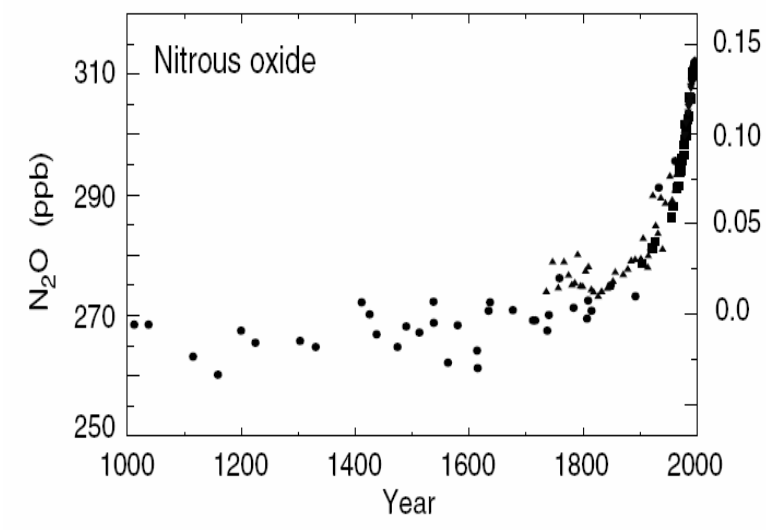
Protection, Restoration, and Improvement of the Planetary Biogeochemical Systems

Component Challenges

- Water supply
- Agricultural systems (strongly linked to water supply)
- **Energy (with possible limits on CO_2 emission)**

Global Geochemical History

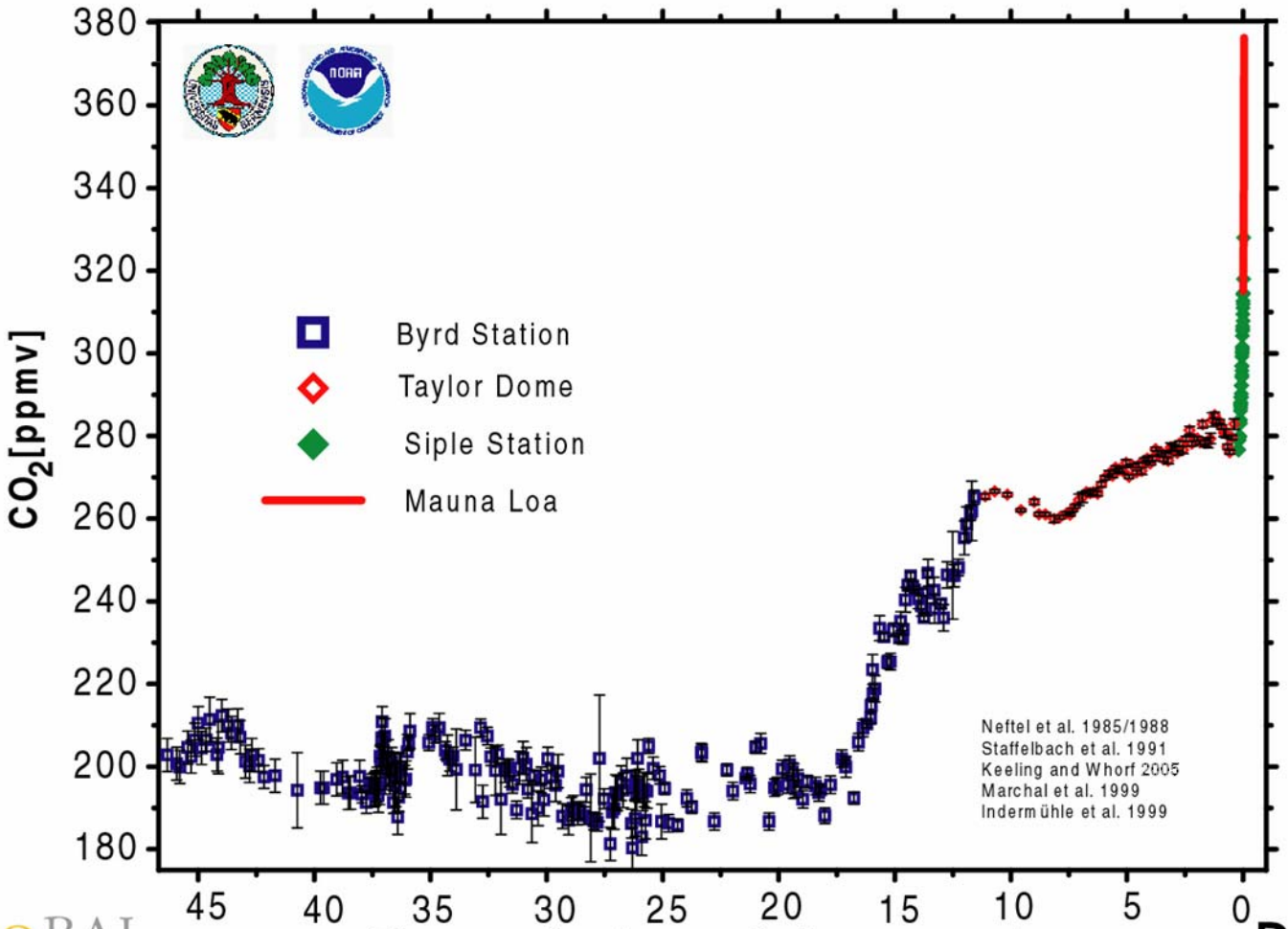




- Concentrations of GHGs have risen significantly over the preindustrial levels.

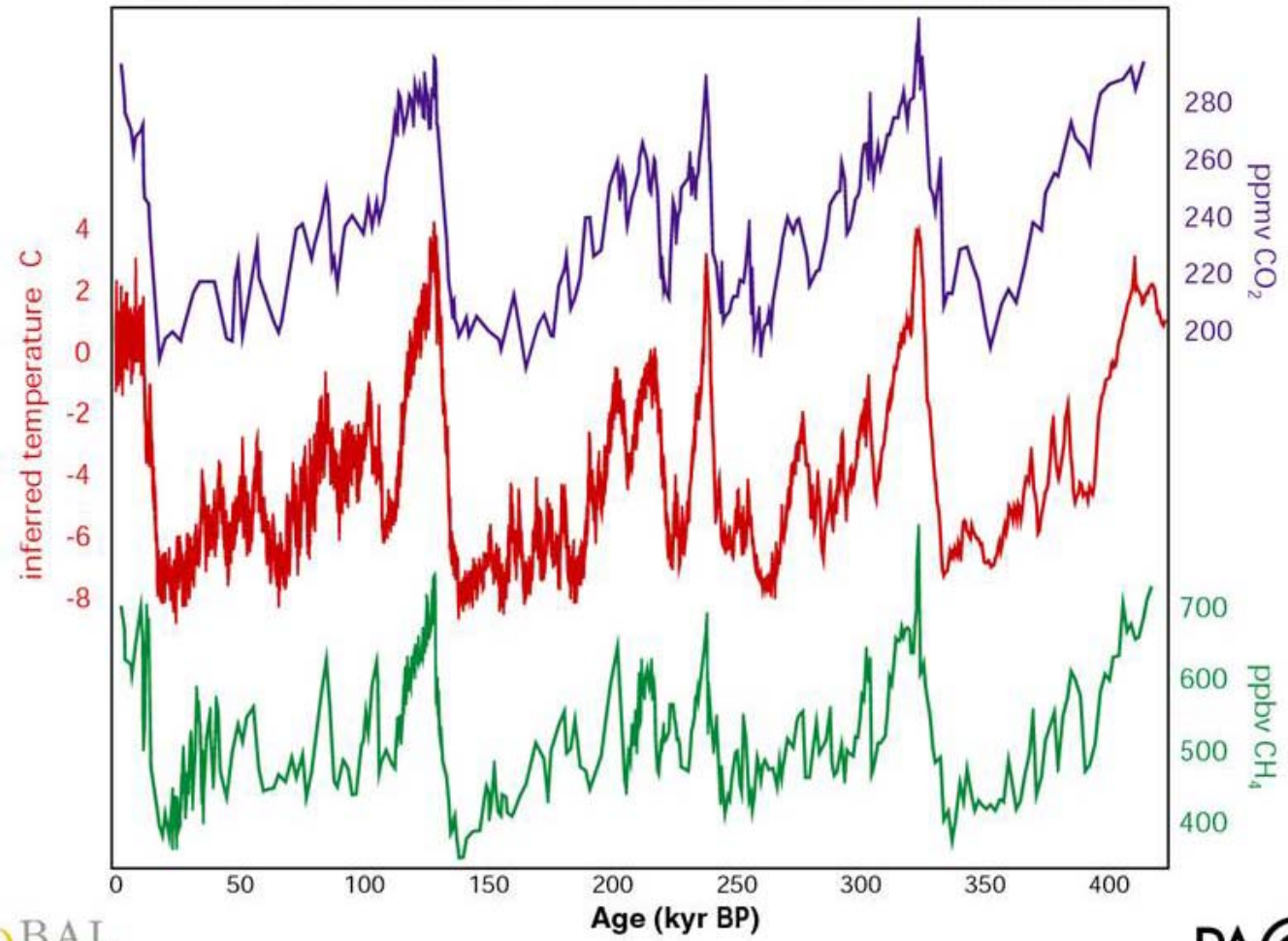
Source: IPCC Third Assessment Report, 2001

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



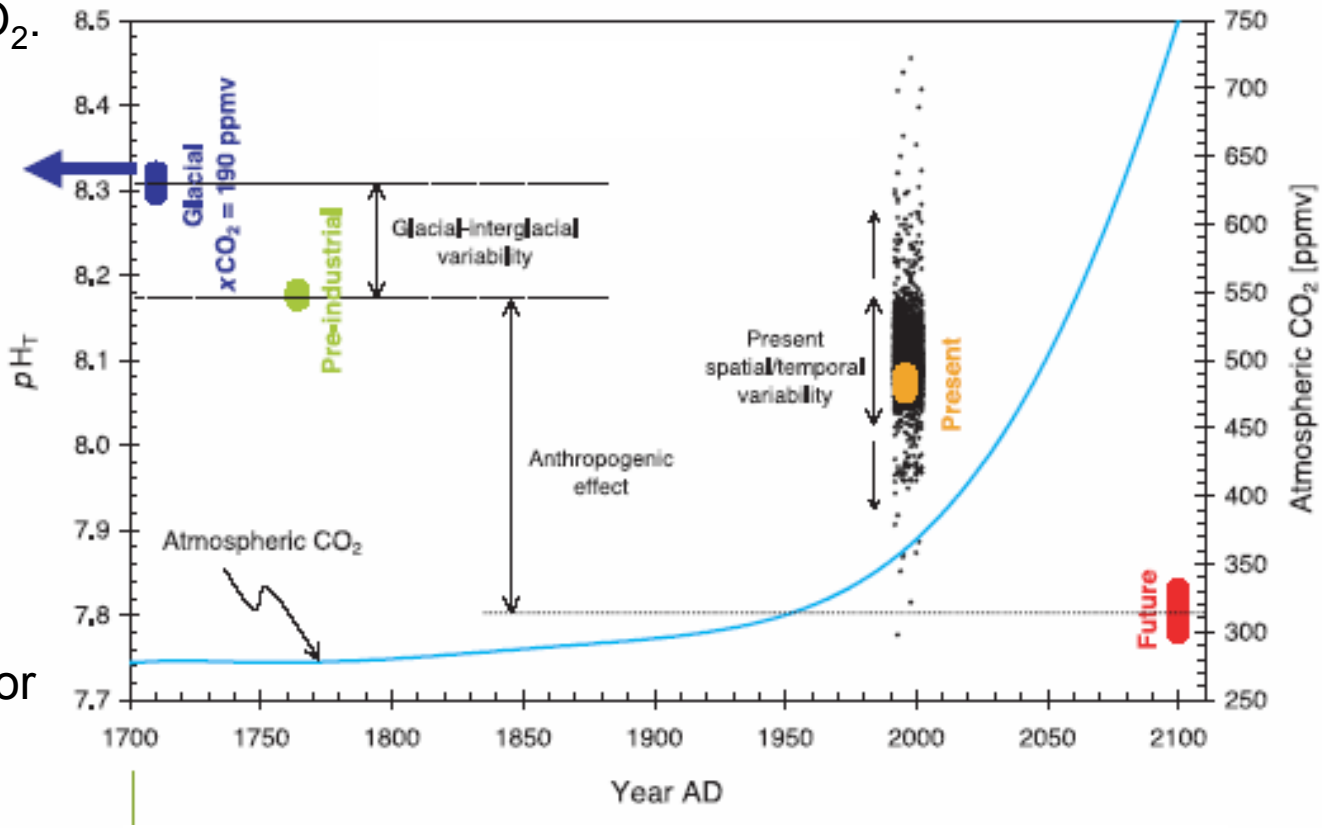
J.R. Petit et al., *Nature,* **399**, 429–36, 1999.

The Oceans in a High CO_2 World

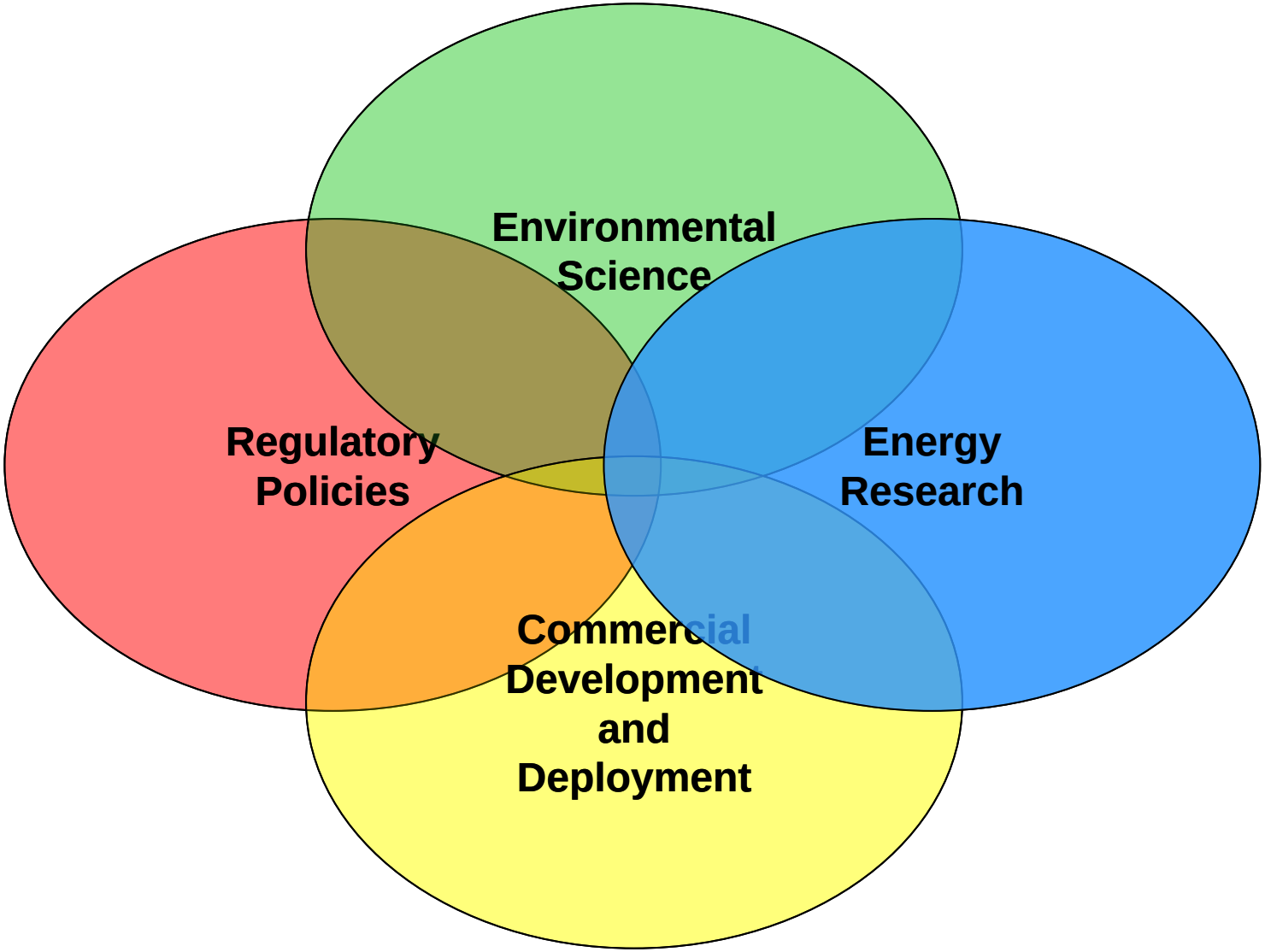
The oceans have taken up ~400 Gt of fossil fuel CO_2. Global surface oceans now remove 20-25 Mt CO_2/day.

Decline in pH (0.1 since industrial revolution) affects bicarbonate, carbonate ion concentrations, rates of fixation of $CaCO_3$ by assorted critters in the trophic chain, potential for feedbacks with temperature change.

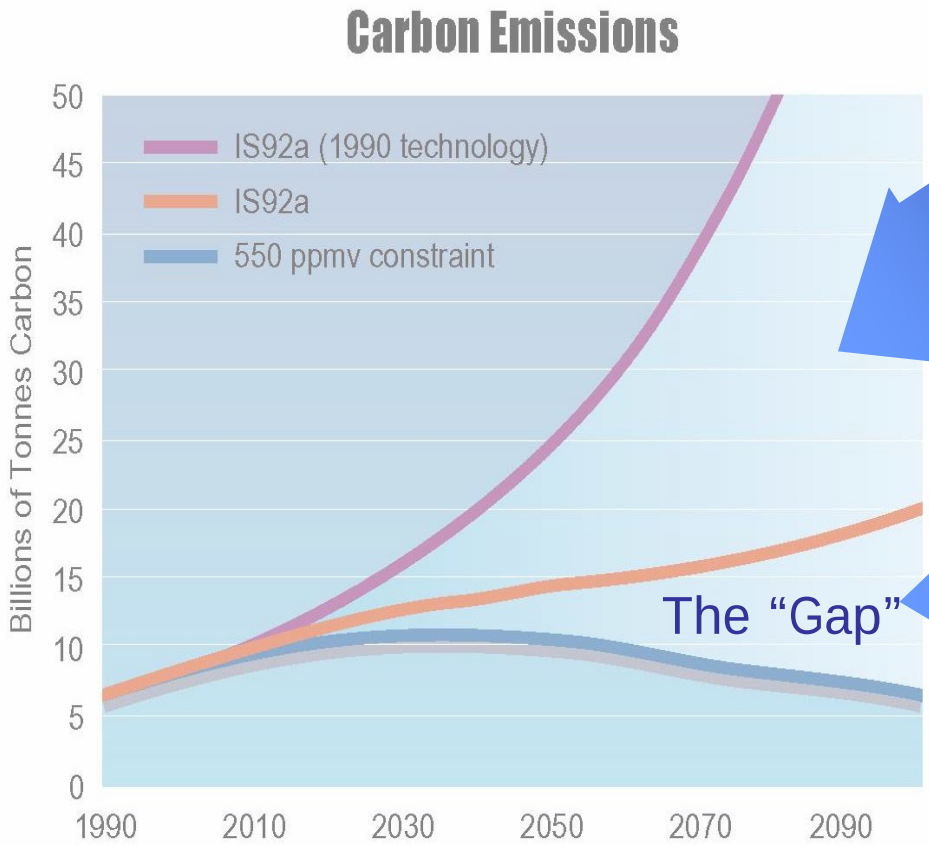
Source: Oceanography Vol.17, No.3, Sept. 2004



Concerted Efforts to address Climate Change



The Need for Technology



Assumed Advances In:

- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

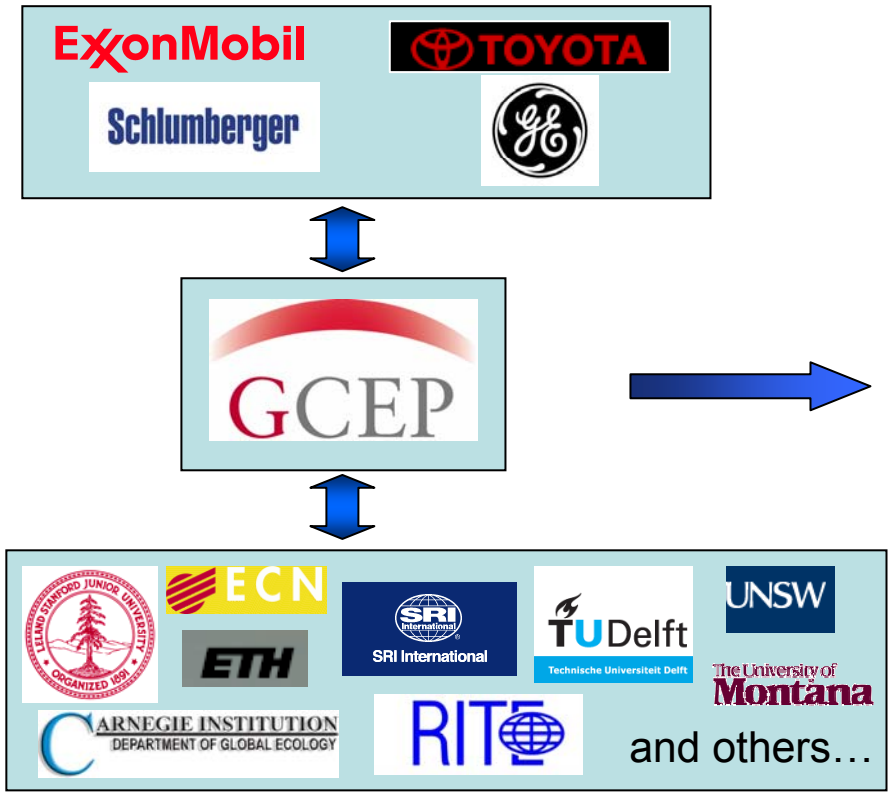
Gap Technologies:

- Carbon capture & disposal
  - Adv. fossil
- H_2 and Adv. Transportation
- Biotechnologies
  - Soils, Bioenergy, Adv. Biological Energy

Source: J. Edmonds, PNNL

The Global Climate and Energy Project

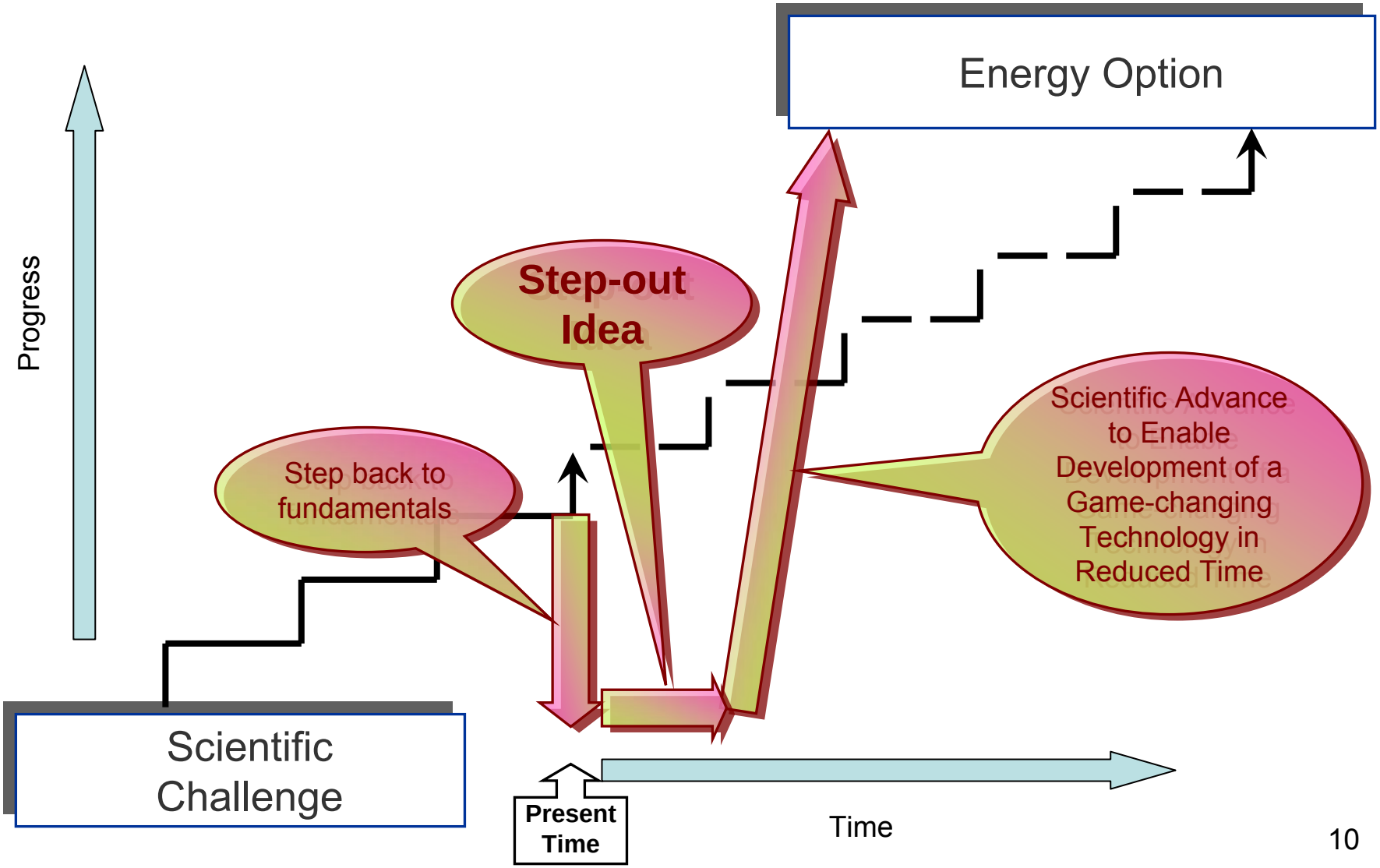
- The Global Climate and Energy Project (GCEP) was established to conduct fundamental research to develop the energy options needed to address the "gap"
- It is a 10-year, $225M commitment for research on the fundamental underpinnings for technologies that could have a significant impact on a global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



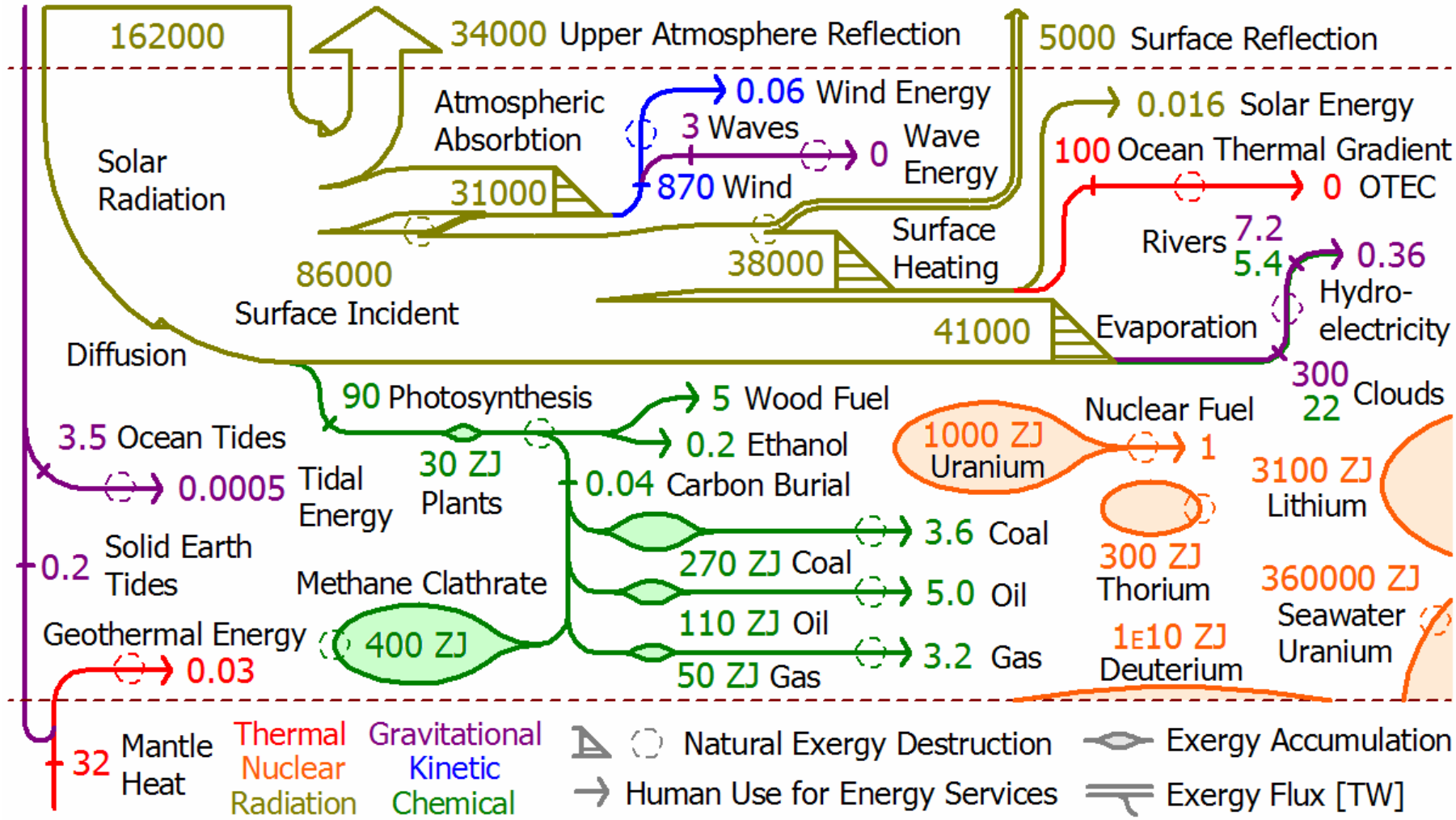
Mission

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

Step-Out Research



Resource Work Potential (TW)



(1 ZJ = 10^{21}J)

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

~80000/15 = ~5300

Source: W. Hermann, GCEP Systems Analysis Group 2004.

GCEP Research Portfolio Areas

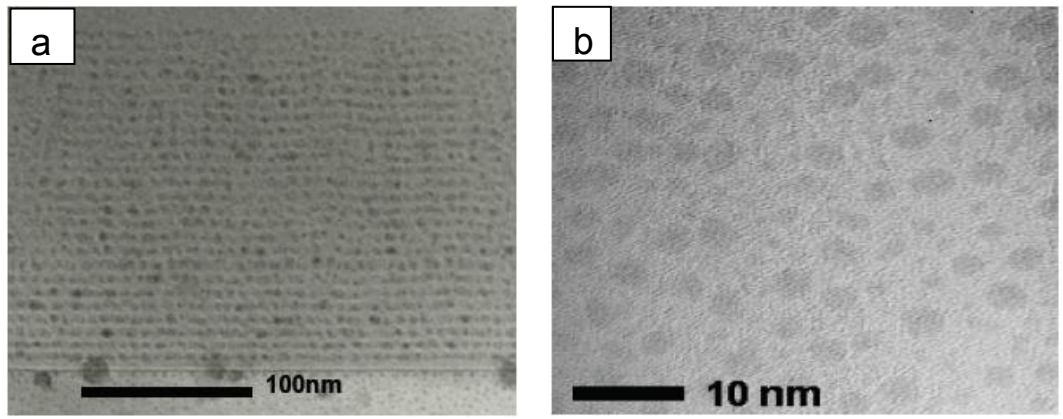
- **CO_2 separation, capture, and storage**
- **Combustion science and engineering**
- **Hydrogen production, distribution, and use**
- **Renewable energy sources (wind, solar, biomass, geothermal)**
- **Advanced materials**
- **Advanced coal utilization**
- **Advanced transportation systems**
- **Advanced 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)

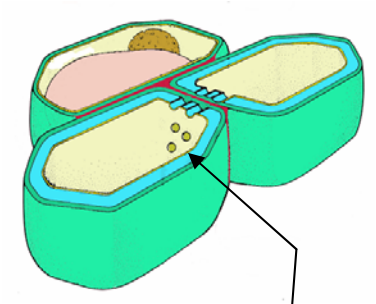
- Fabrication of two- or three-cell tandem stack devices from silicon-based materials.
- Uses abundant, non-toxic, stable, and durable materials
- Control the bandgap of silicon through carrier confinement in nanoscale structures
  - Integrate silicon nanoparticles into matrices of silicon oxide, nitride, 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



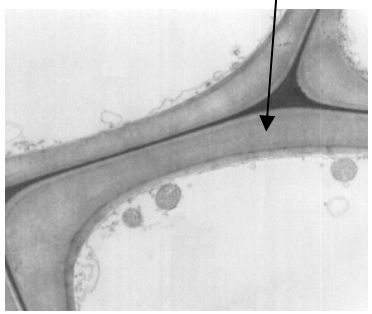
Genetic Engineering of Cellulose Accumulation

Chris Somerville

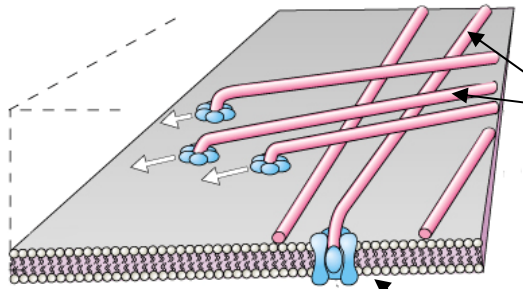
- Increase accumulation of cellulose and carbon uptake in biomass crops by genetic alteration of the regulation of cellulose synthesis
- Transgenic plants will be produced in which the components of the cellulose synthase complex are produced in increased amounts and at altered times during plant development.



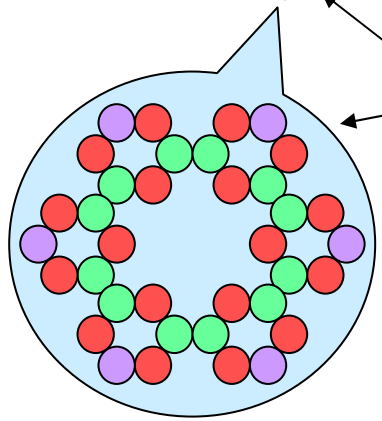
Cell walls



Electron micrograph of a cell wall



Cellulose fibrils



Cellulose Synthase

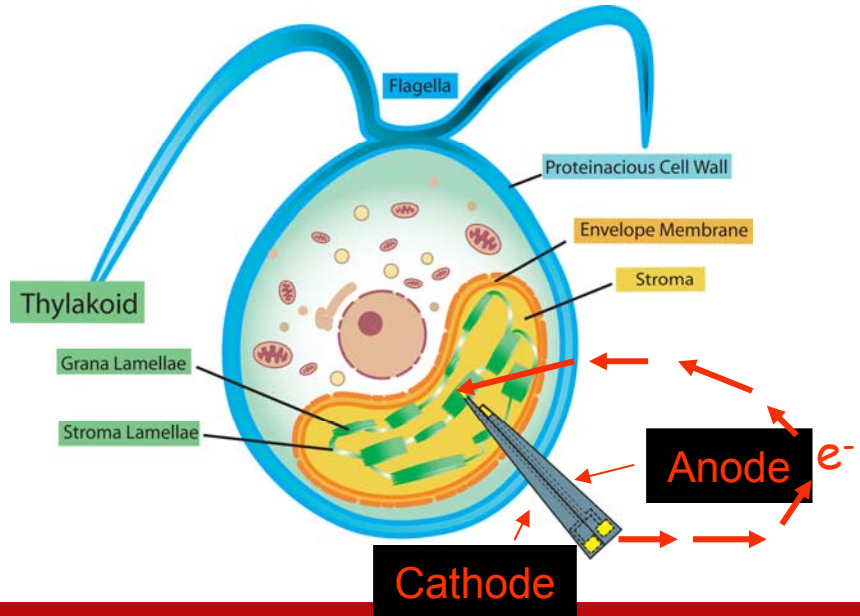
Monitoring and Accessing Cellular Photosynthesis for Bioelectricity

Fritz Prinz and Arthur Grossman

- 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_2O
- Explore using unicellular alga Chlamydomonas reinhardtii

$h\upsilon$

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$



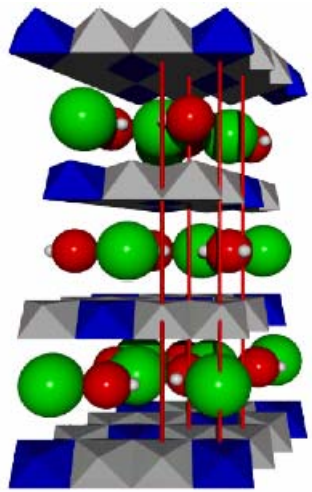
Advanced Membrane Reactors in Energy Systems

Dan Jansen, Joop Schoonman ECN/TU-Delft

$$CH_4 + H_2O \rightleftharpoons CO + 3\,H_2$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

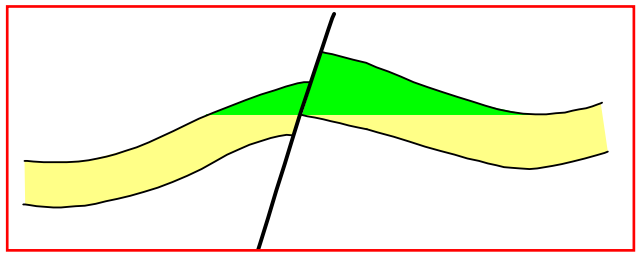
- Removal of CO_2 or H_2 can shift equilibrium and lead to lower reaction temperature
- Will combine separation and reaction in membrane reactors
- Hydrogen membranes:
  - Use chemical vapor infiltration (CVI) and atomic layer deposition (ALD) to control pore size of a nanoporous ceramic membrane in a very controlled manner
- CO_2 membranes
  - e.g.: hydrotalcites, ionic liquids
- Improved catalysts
  - High activity at ~ 400 °C and integrated into membrane

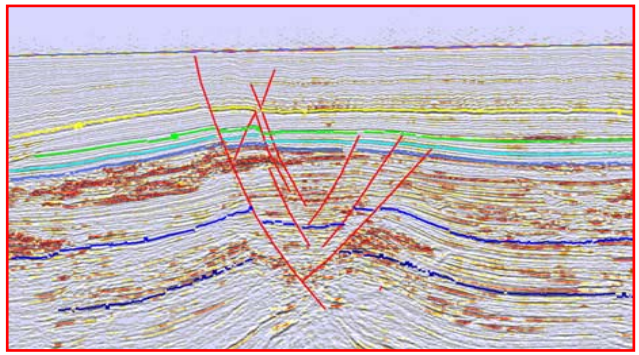


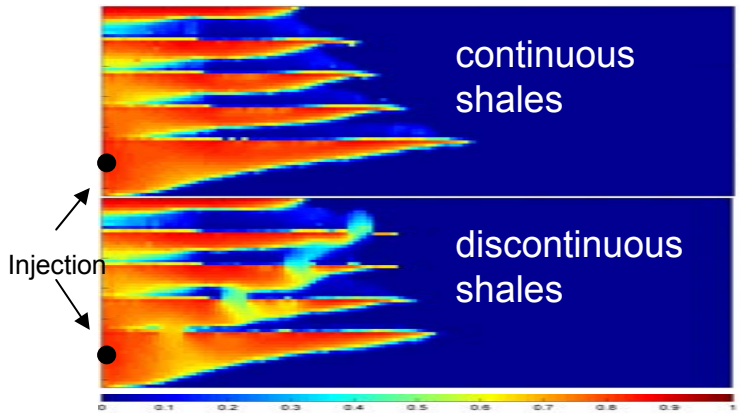
Geologic Storage of CO_2

Mark Zoback, Jerry Harris, Tony Kovscek, Lynn Orr

- 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 CO_2 migration.
  - Fluid migration: very efficient methods for predicting the flow paths and long-term fate of injected CO_2.
  - Monitoring: appropriate tools for monitoring the state of injection projects at each stage.







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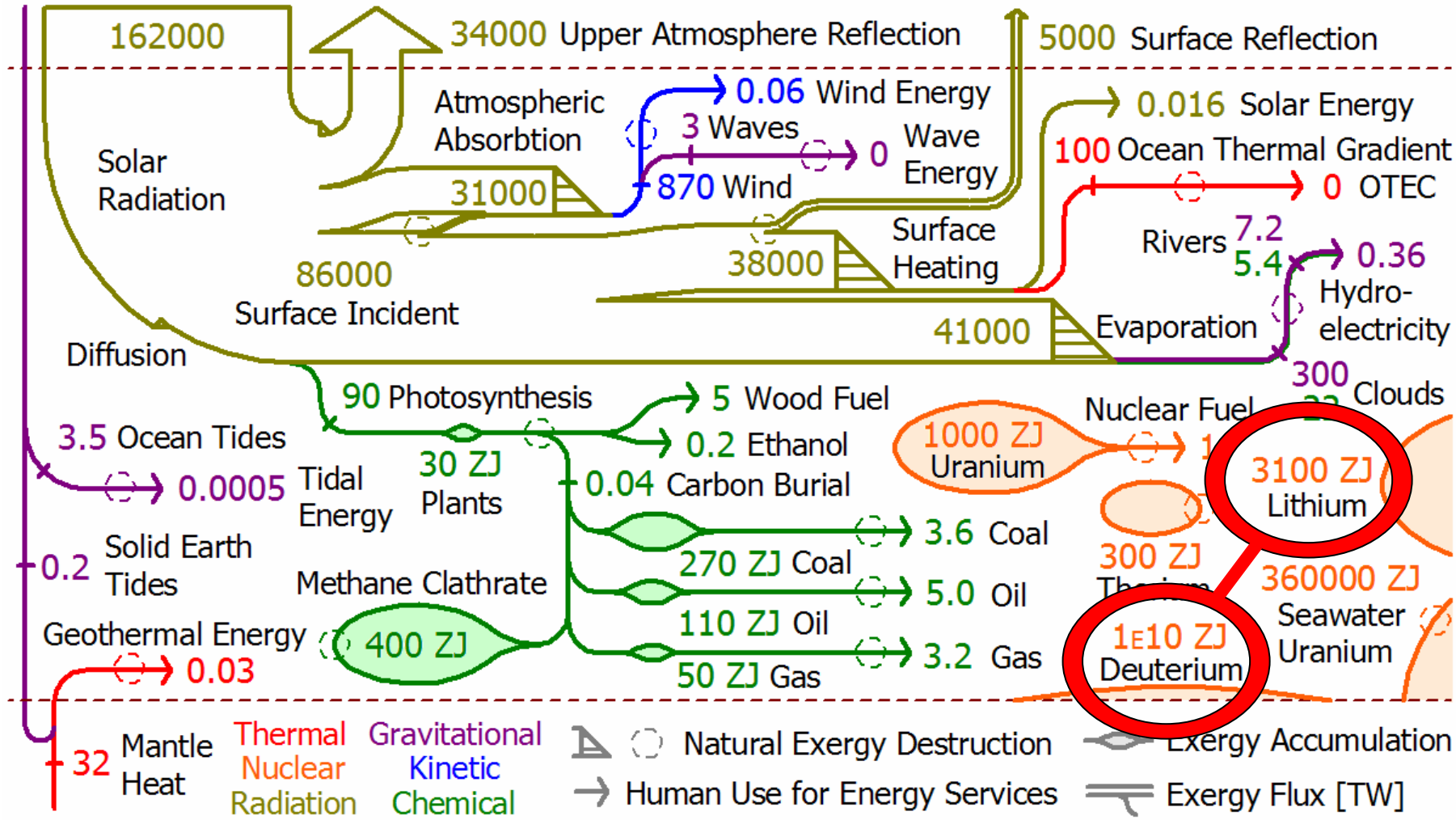


(1 ZJ = 10^{21}J)

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

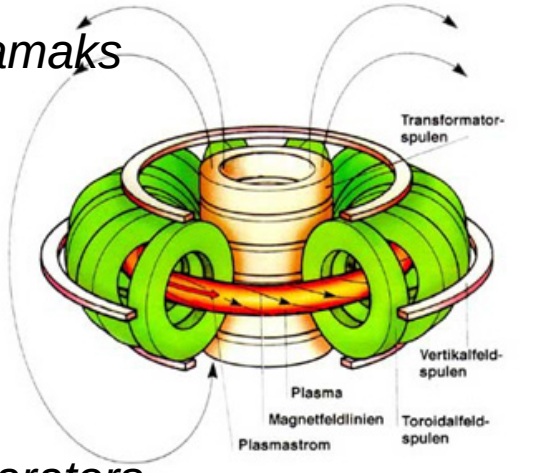
1E10 / 0.5 > the time for the Sun to become a red giant (5 billion years) !

Source: W. Hermann, GCEP Systems Analysis Group 2004.

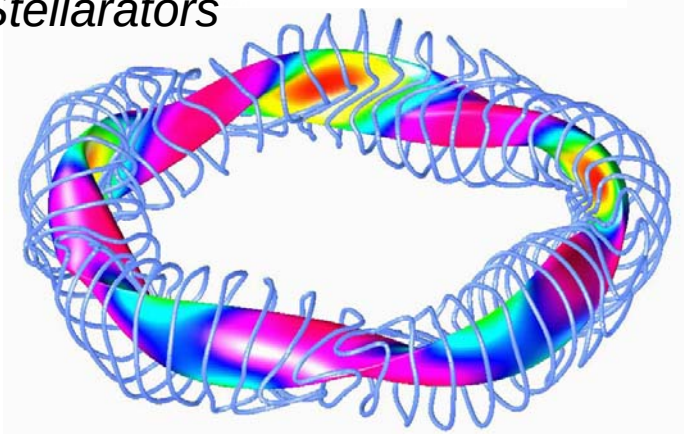
Approaches to Fusion

Magnetic Confinement

Tokamaks

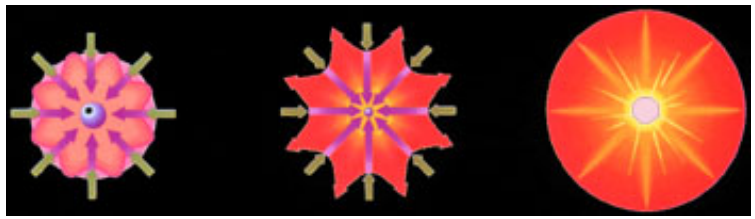


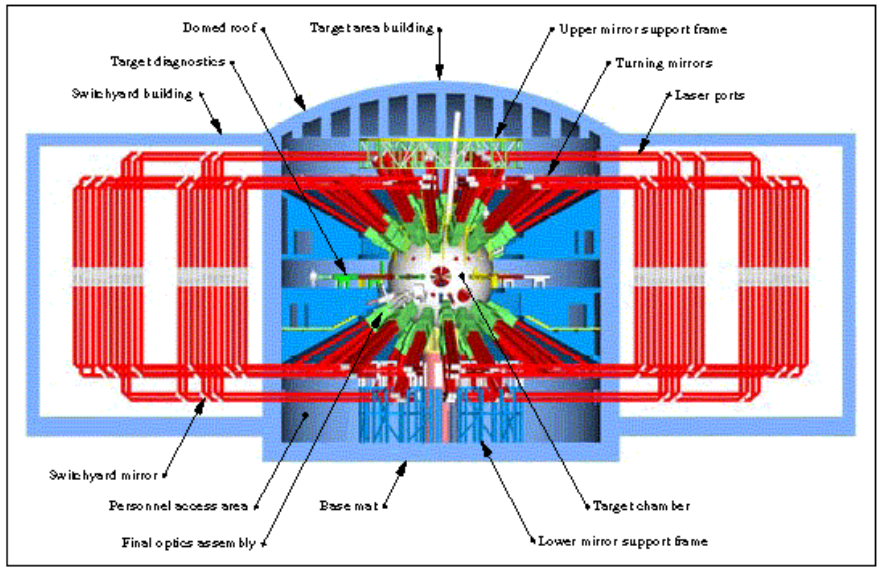
Stellarators



and various alternative configurations

Inertial Confinement





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 Stellerator	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 Stellerators	Gerald Navratil
4:10	Plasma Stability in Alternative Confinement Concepts	Bick Hooper
4:50	**Panel Discussion on Research Opportunities**	
5:30	*Reception*	

Workshop Agenda

Day 2

	Energetic Particles and Plasma-Wall Interactions	
8:30	Energetic Particles in Plasmas	James Van Dam
9:10	Plasma-Wall Interactions	Michael Ulrickson
9:50	*Break*	
	Materials for Fusion	
10:10	High Field Magnet Technology	Joseph Minervini
10:50	Reduced Activation Materials	Nadine Baluc
11:30	**Panel Discussion on Research Opportunities**	
12:10	Concluding Remarks	
12:30	*Lunch*	

Thank You!

Rob Goldston and PPPL

- for all the useful discussions and your help with the organization of this meeting in Princeton

Paolo Bosshard

- for the technical organization of the workshop

Kersti Miller and Nancy Sandoval

- for organizing everything else

Our Sponsors

- for making this project possible

Our Speakers

- for sharing your time, expertise, and opinions with us

The Energy Community

- for taking time to participate in our discussions