Stanford University

Global Climate & Energy Project

October 18-19, 2004

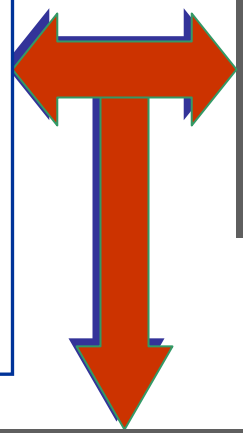
GCEP Solar Energy Workshop
Welcome and Introduction

Lynn Orr

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.

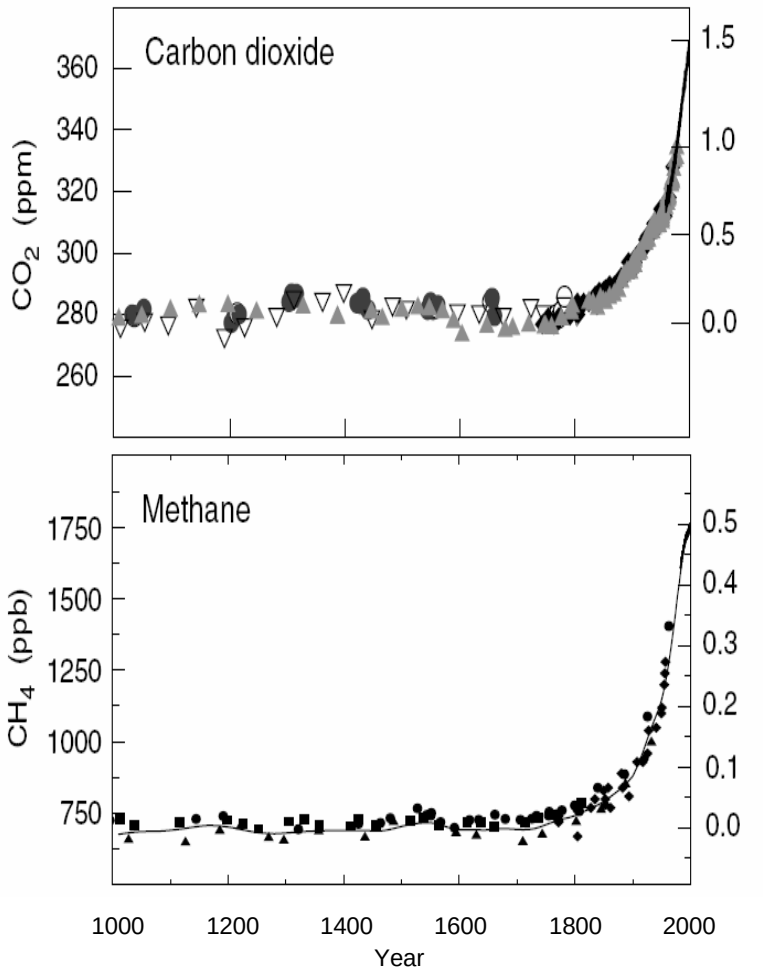


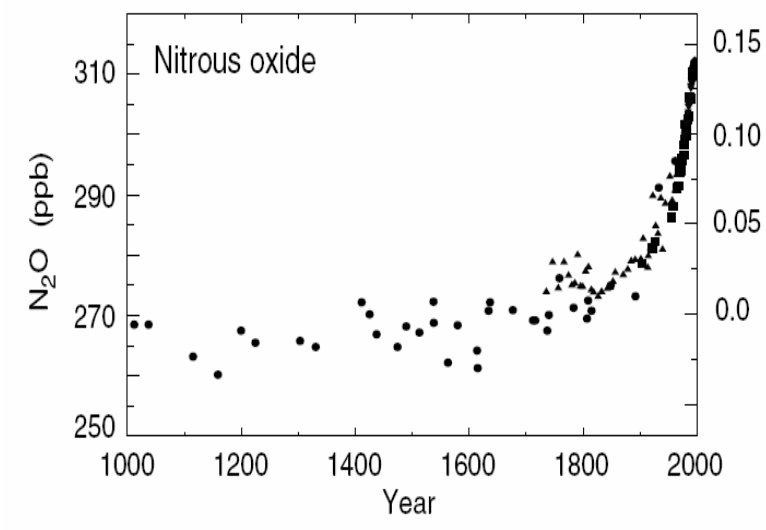
Protection, Restoration, and Improvement of the Planetary Biogeochemical Systems

Component Challenges

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

Global Geochemical History



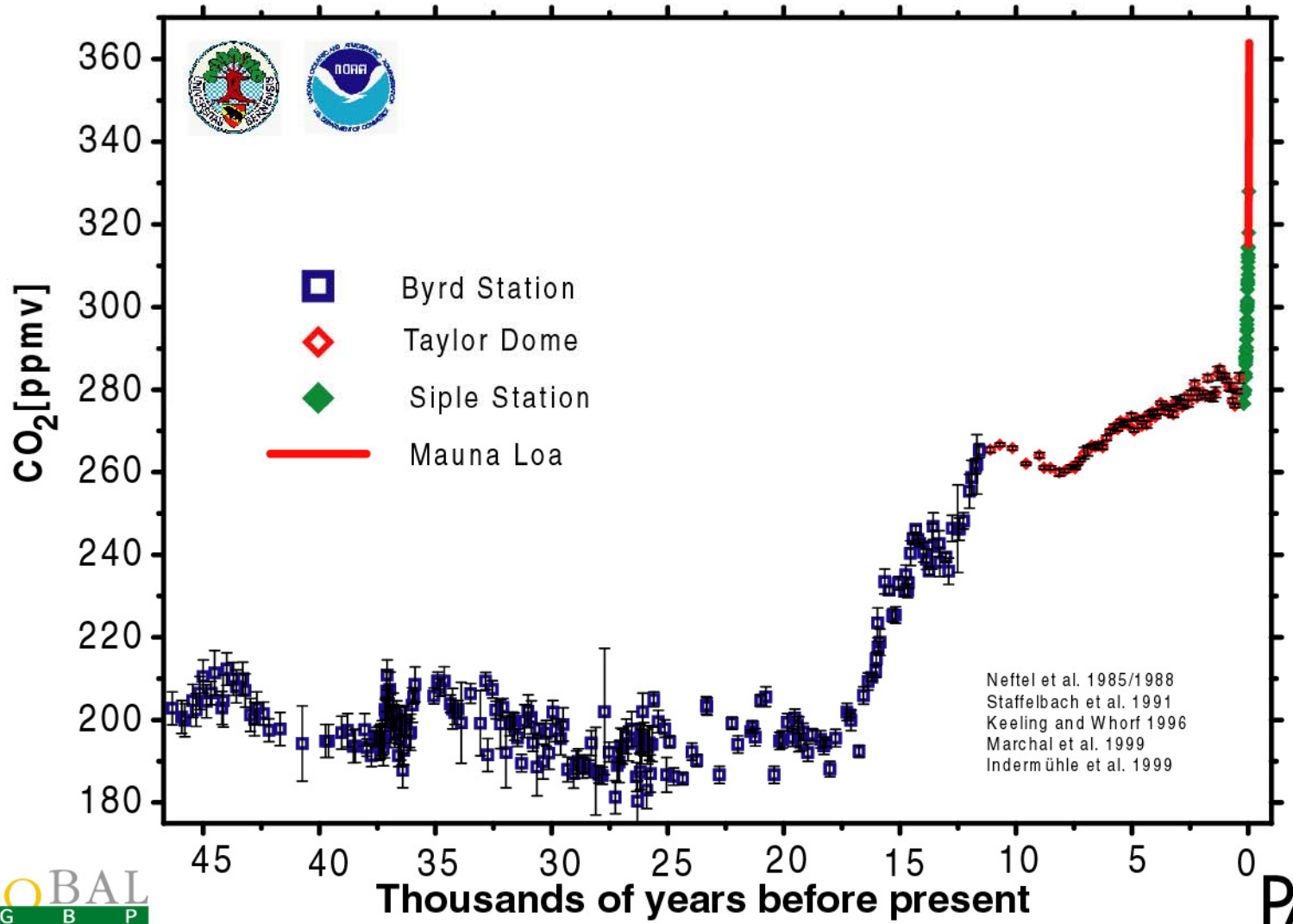


- Concentrations of GHGs have risen significantly over the preindustrial levels.

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

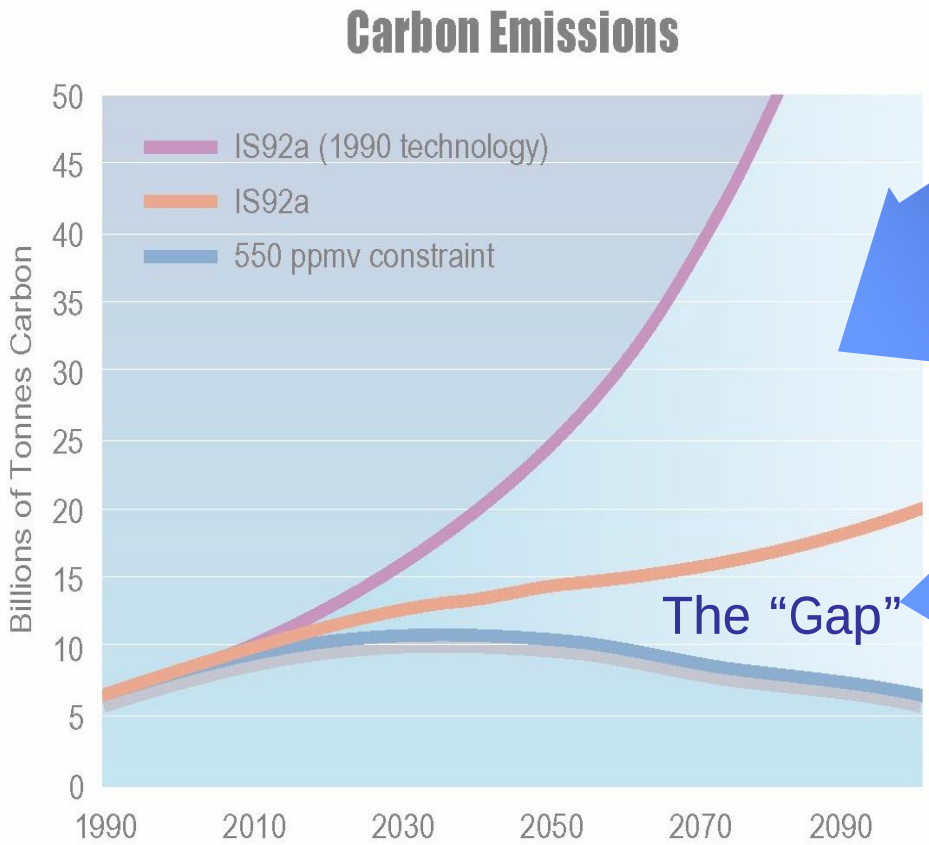
GLOBAL CHANGE IGBP

PAGES PAST GLOBAL CHANGES

Potential Impacts of High CO_2 Concentrations

- Global average temperature, regional climates
- Reduced saturation state of aragonite ($CaCO_3$) in the upper ocean, which would reduce net accumulation of $CaCO_3$ in reefs, for example (Kleypas et al., Science, April 1999)
- pH of the upper ocean has declined by 0.1 since 1800 – with unrestricted carbon emissions, the decline will be 0.3-0.4 by 2100. Example biological impacts at 560 ppm include (Yoshihisa – SCOR IOC Paris 2004):
  - Reduced survival rates of snails, sea urchins
  - Reduced growth rates of sea urchins, slightly reduced for snails

The Need for Technology



Assumed Advances In:

- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

Gap Technologies:

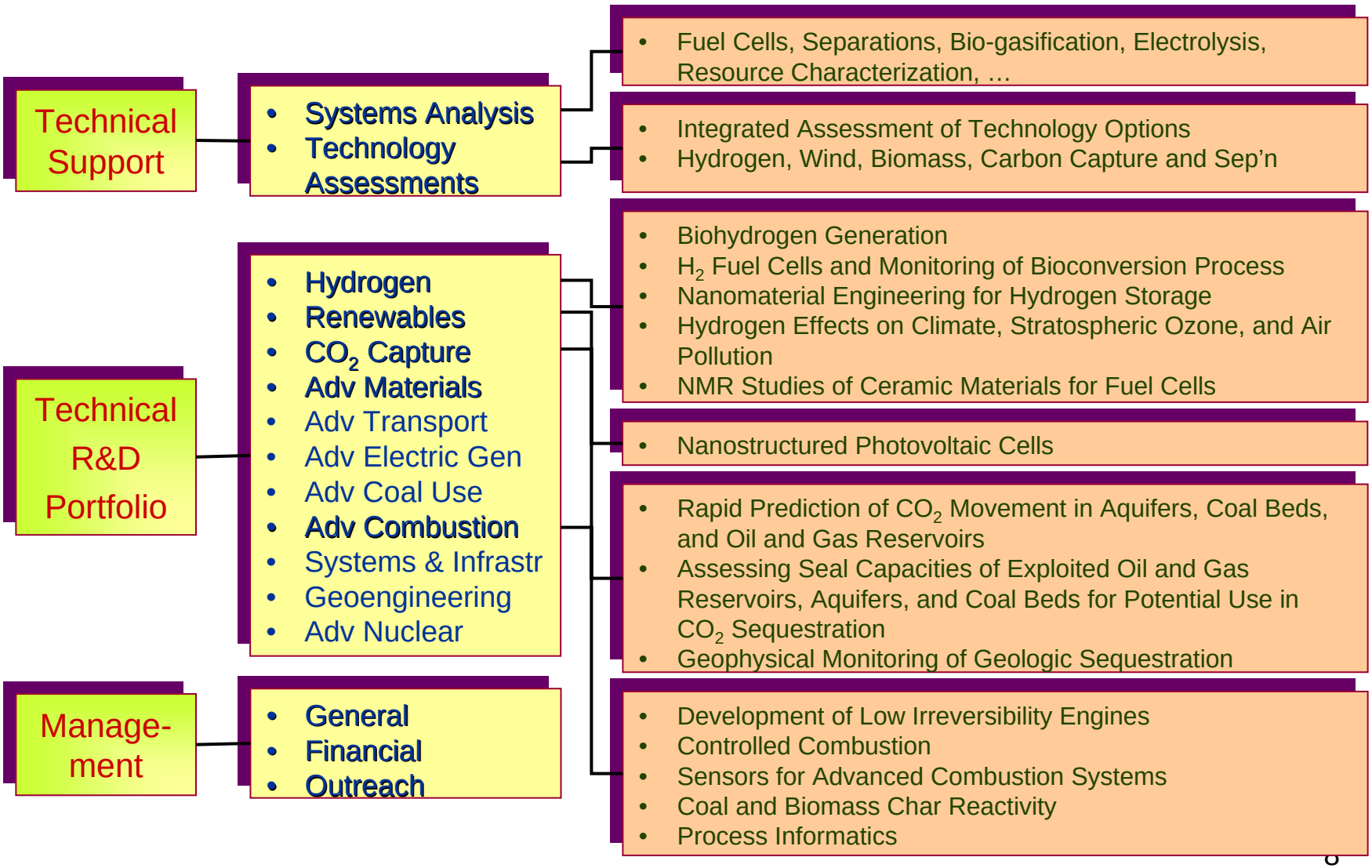
- Carbon capture & disposal
  - Adv. fossil
- H_2 and Adv. Transportation
- Biotechnologies
  - Soils, Bioenergy, Adv. Biological Energy

Source: J. Edmonds, PNNL

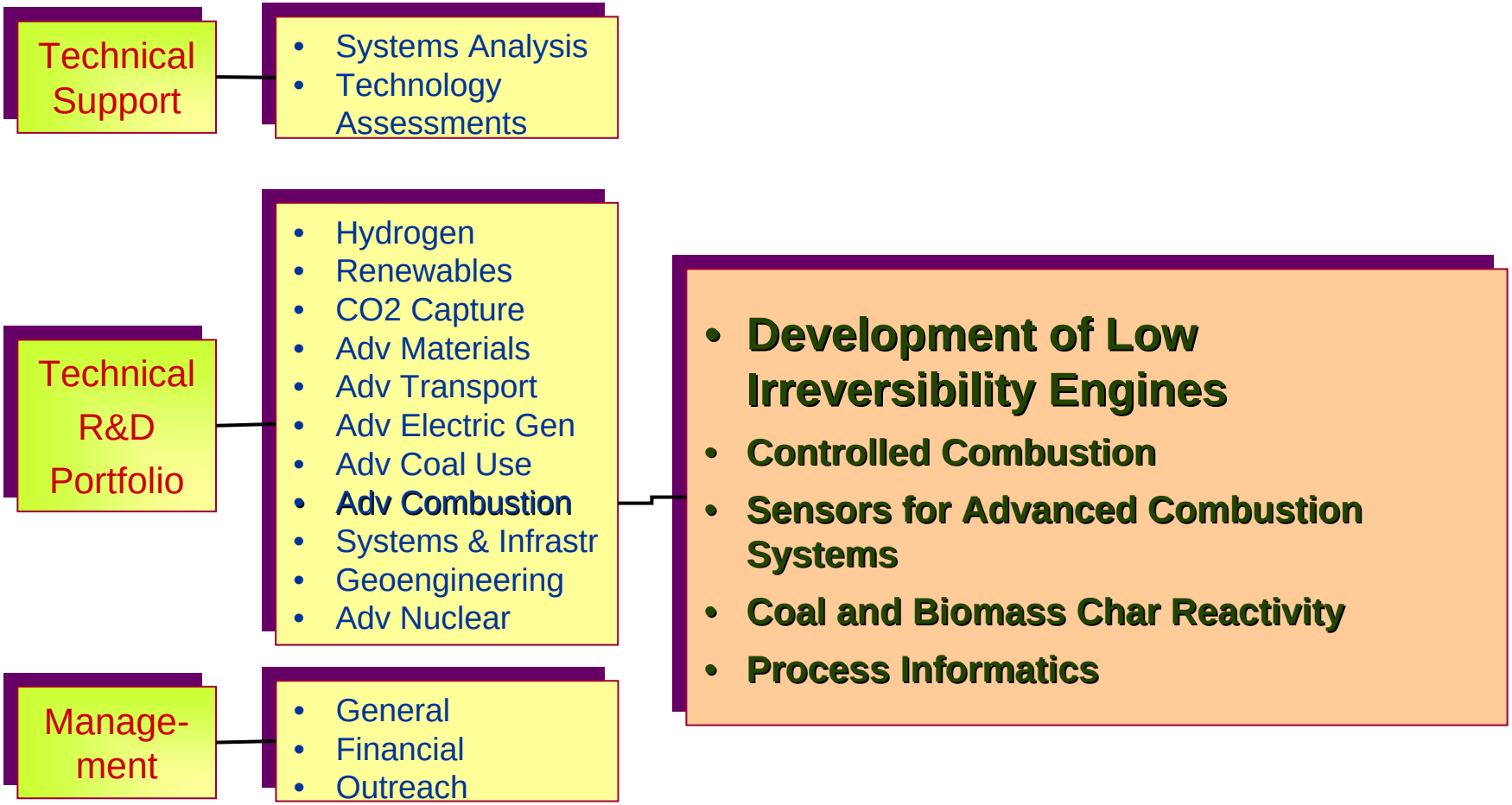
Global Climate & Energy Project

- A research project to develop new technology options for a low GHG future.
- Industrially sponsored: ExxonMobil, General Electric, Toyota, Schlumberger
- Ten-year project seeking options for the 10-50 year time frame.
- Defining what is possible now and on the horizon is a key element of developing ideas for new options.
- The objective of this meeting is to consider what is possible for future use of solar energy to meet the need for carbon-free energy use.

Current GCEP Portfolio



GCEP Advanced Combustion Projects
- Step-out Technology Example

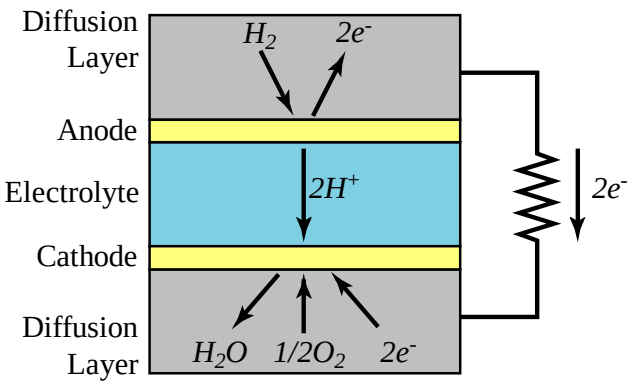


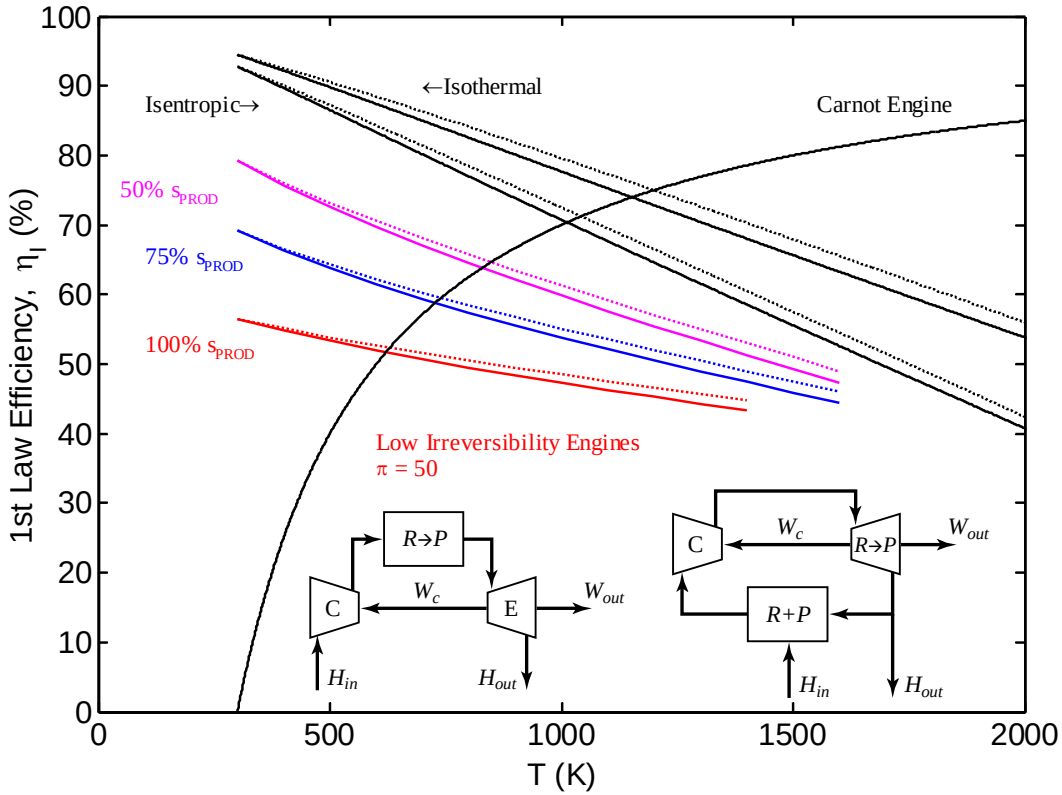
Low-Irreversibility Engines

Chris Edwards

Two approaches are being pursued to develop reactive engines with significantly improved efficiency.

1. Reduction of irreversibility by energy extraction during reaction. Requires dilute reaction during expansion.
2. Exploration of the possibility to develop a reversible expansion analog of the fuel cell.





Low-Irreversibility Engines
- Step-Out Concept

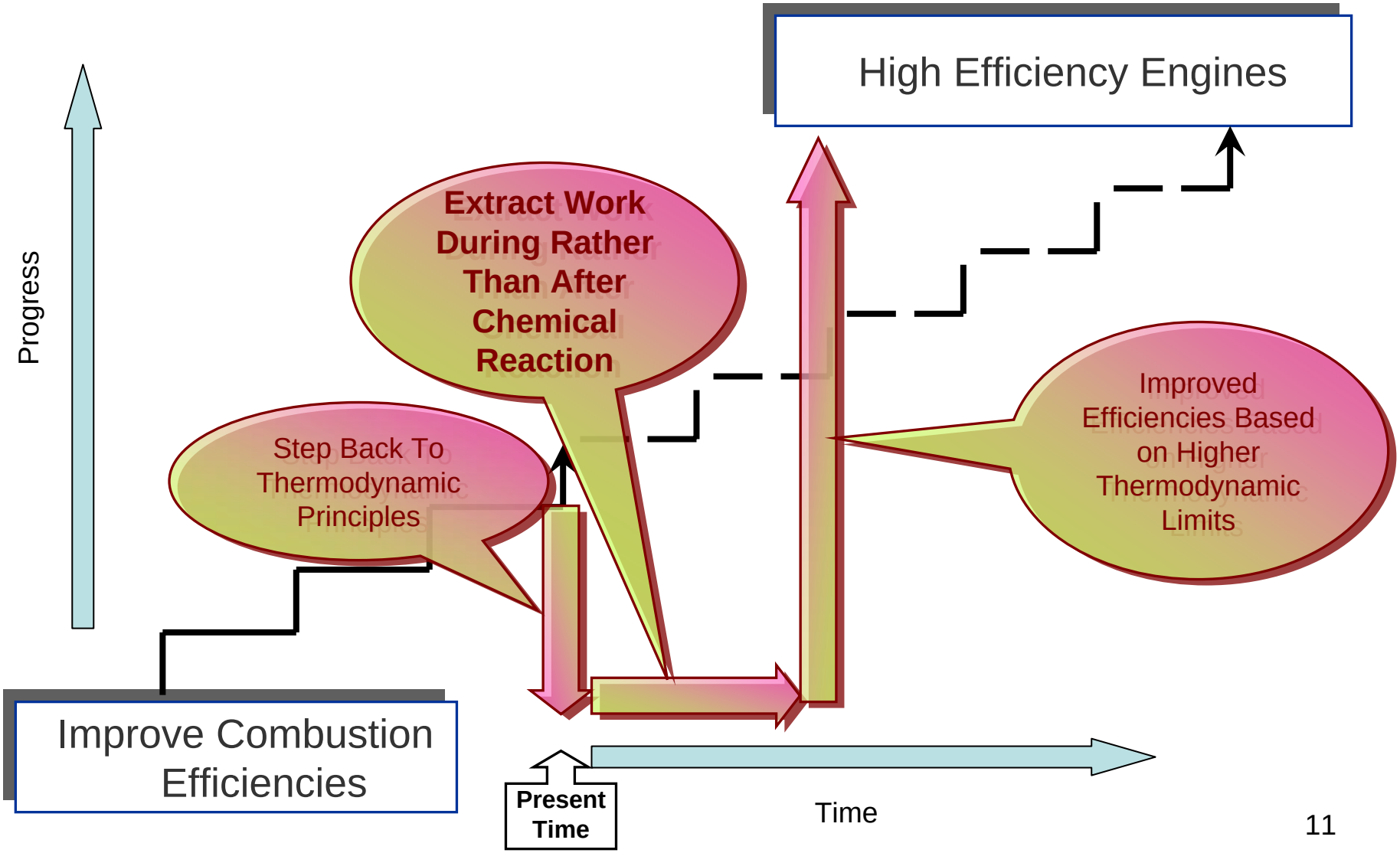
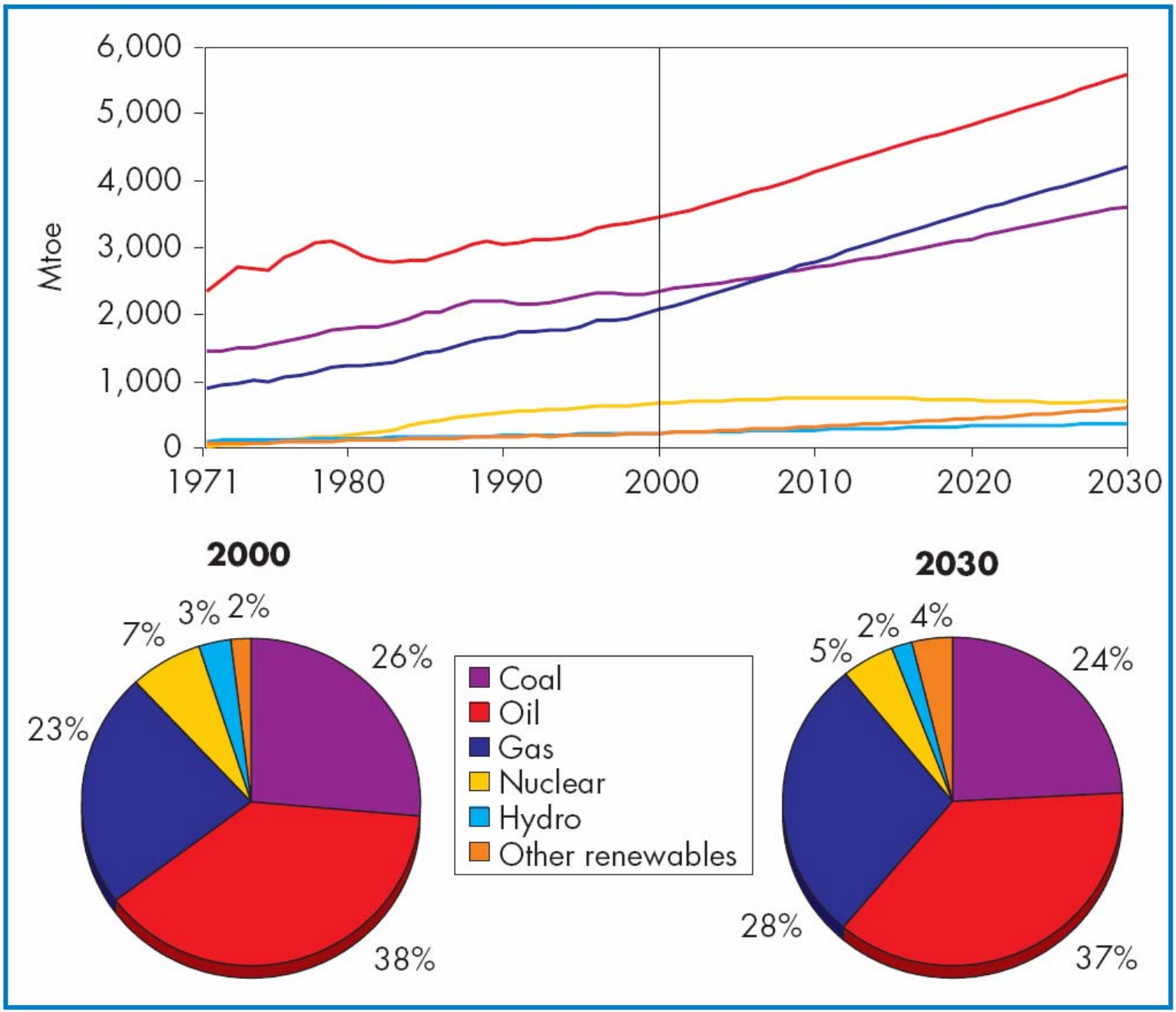
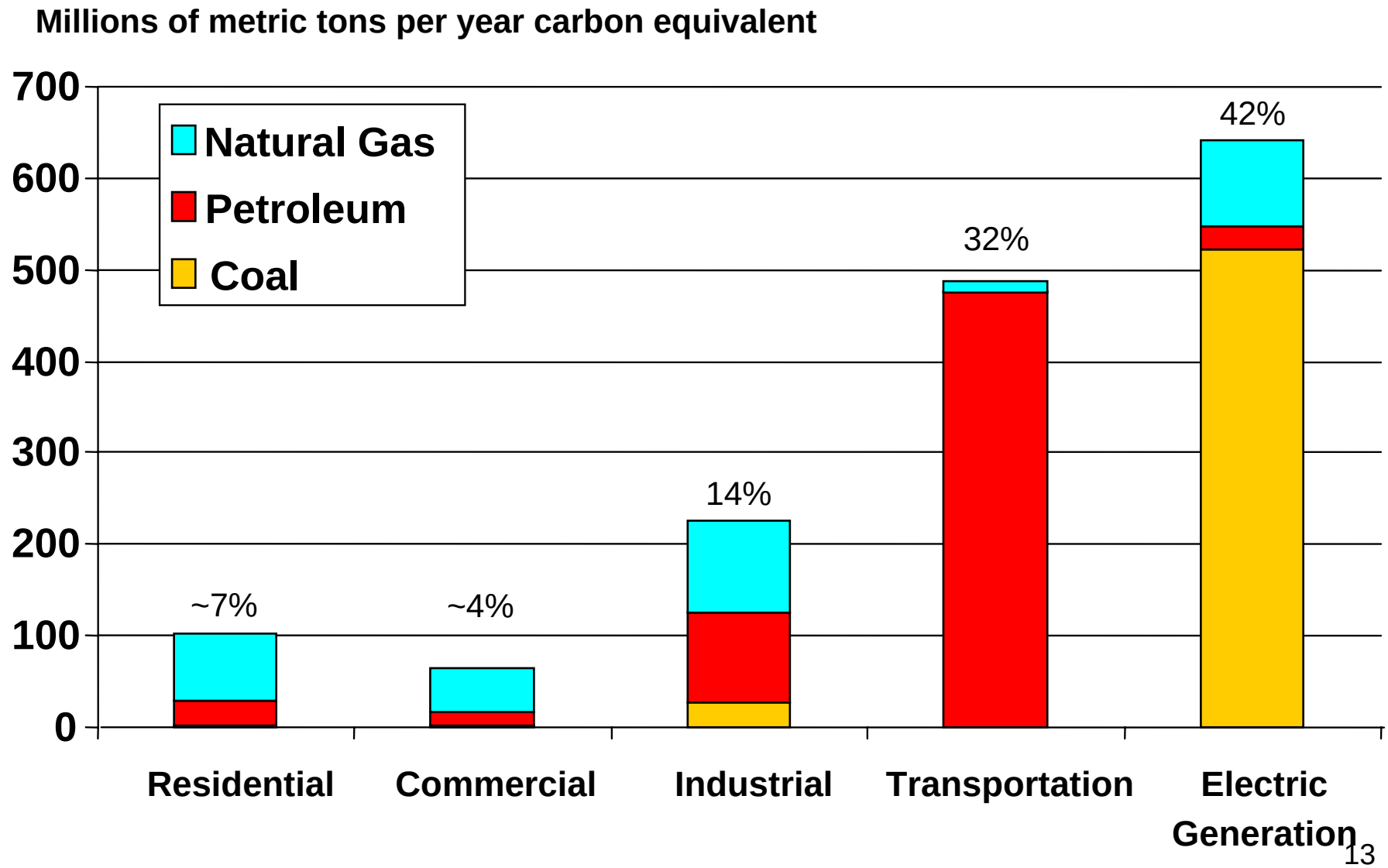


Figure 2.1: **World Primary Energy Demand**



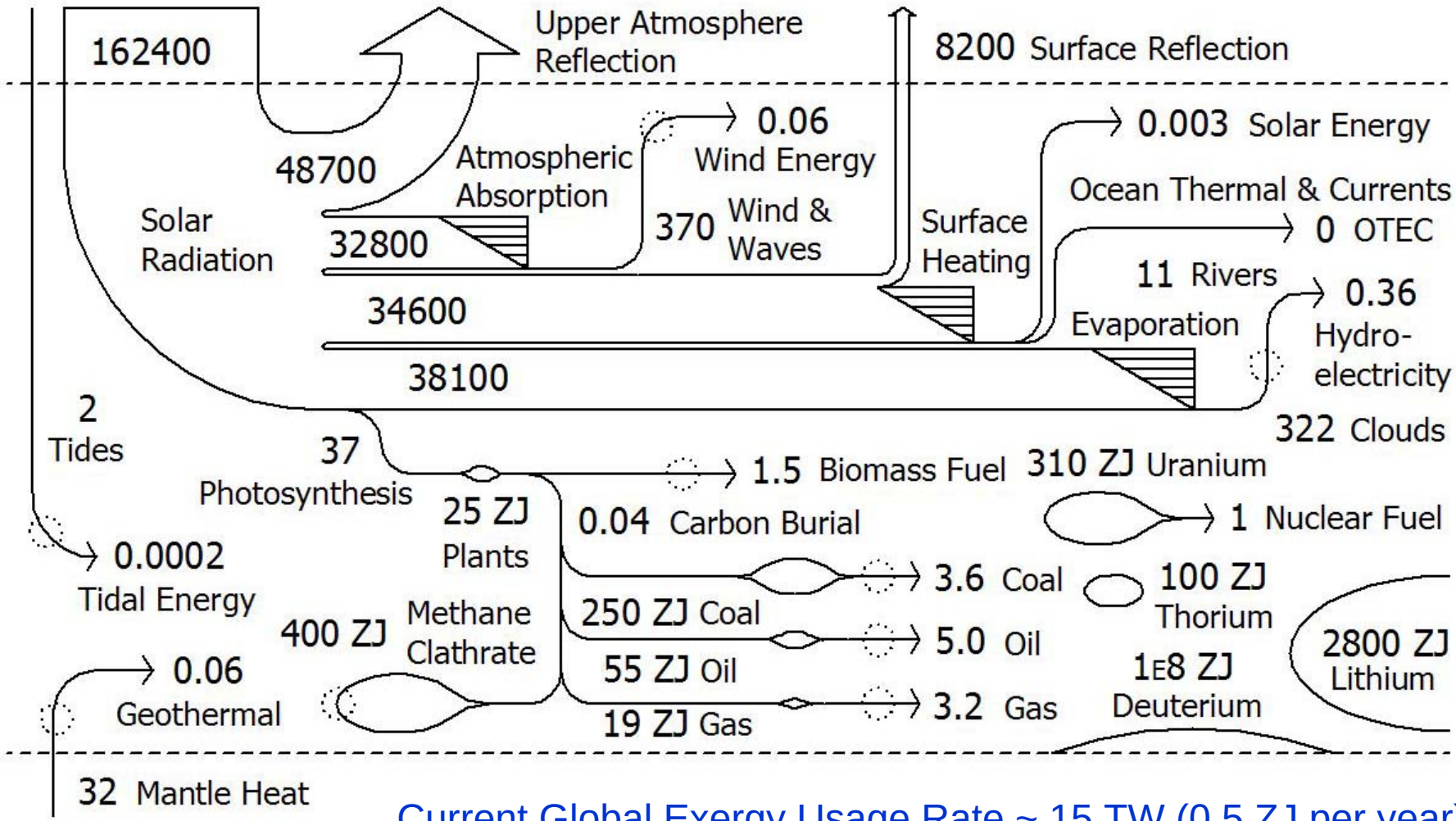
Source: OECD/ IEA, Paris, *World Energy Outlook 2002*, Second Edition, November (2002)

United States CO_2 Emissions in 2000



Source: U.S. EPA Inventory of Greenhouse Gas Emissions, April 2002

Global Exergy Balance (TW)



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

Source: J.T. Szargut, *Energy* 28, 2003 as modified by W. Hermann, 2004. (1 ZJ = 10^{21}J)

Research Questions Concerning Solar Energy

- What are the technological barriers and challenges to greater implementation of solar energy?
- Which key technologies, if developed, could change the game for solar?
- What are the research opportunities for developing these technologies?
- How can GCEP best contribute to solving the problems and expanding the opportunities and benefits?

Thank You!

- to our sponsors—for making this project possible
- to our speakers—for sharing your time, expertise, and opinions with us
- to our faculty—for considering how you can contribute to this problem of global importance in your research groups
- to the energy community—for taking time to participate in our discussions
- to our students—for providing the ideas, energy, and implementation needed to meet this challenge.

And special thank you to

- Paolo Bosshard – for working hard to bring us all here at the same time!
- Kersti Miller and Nancy Sandoval for organizing everything else!

And now, let's get to work …

Day 1: Nanostructured Organic Solar Cells

8:30 – 9:30	**Welcome and Introduction**	
8:30	GCEP Introduction and Workshop Purpose L. Orr, *Global Climate and Energy Project*	
9:00	Solar Technologies & Global Potential of Solar Energy M. Green, *University of New South Wales*	
9:30 – 12:00	**Improving Light Absorption**	**Chair: Michael McGehee**
9:30	Quantum Dot Sensitization T. Toyoda, *University of Electro-Communications*	
10:00 – 10:30	**BREAK**	

Day 1
Nanostructured Organic Solar Cells

10:30	High Efficiency Carrier Multiplication in PbSe Quantum Dots V. Klimov, *Los Alamos National Laboratory*	
11:00	Light-Harvesting Host-Guest Antenna Materials D. Brühwiler, *University of Bern*	
11:30	Panel Discussion	
12:00 – 1:00	**LUNCH**	
1:00 – 3:00	**Transport and Kinetics**	**Chair: Zhenan Bao**
1:00	Exciton Diffusion L. Siebbeles, *Technical University of Delft*	
1:30	Molecular Wires M. Wasielewski, *Northwestern University*	
2:00	Electron Transfer Kinetics J. Durrant, *Imperial College*	
2:30	Design of Photoactive Complexes P. Dutton, *University of Pennsylvania*	

Day 1
Nanostructured Organic Solar Cells

3:30 – 5:00	**Overall Cell Performance**	**Chair: Peter Peumans**
3:30	Optimization of Conjugated-Polymer-Based Bulk Heterojunctions J. Hummelen *Groningen University*	
4:00	Stability of Organic Materials A. Hagfeldt, *Uppsala University*	
4:30	Panel Discussion	
5:30 – 6:30	**RECEPTION**	

Day 2

Inorganic PV, Solar Thermal, Solar Technologies

8:30 – 10:00	**Thin Film Photovoltaics**	**Chair: James Harris**
8:30	Extremely Thin Absorbers–EU Program Overview F. Lenzmann, *Energy Research Centre of the Netherlands*	
9:00	Inorganic Thin Films: Future Perspectives J. Benner, *National Renewable Energy Laboratory*	
9:30	Third Generation Photovoltaics, M. Green, *University of New South Wales*	
10:00 – 10:30	***BREAK***	
10:30 – 12:30	**Matching the Solar Spectrum**	**Chair: James Harris**
10:30	Impurity Photovoltaic Effect W. Walukiewicz, *Lawrence Berkeley National Laboratory*	
11:00	Metamorphic Multijunctions R. King, *Spectrolab, Inc.*	
11:30	Non-Lattice-Matched III-V Heterostructures H. Atwater, *California Institute of Technology*	
12:00	Panel discussion	

Day 2
Inorganic PV, Solar Thermal, Solar Technologies

1:30 – 2:30	**Solar Thermal**	**Chair: Shanhui Fan**
1:30	Novel Heat Transfer Fluids and Thermal Storage L. Moens, *National Renewable Energy Laboratory*	
2:00	Power Towers: Solar Two, Solar Tres S. Jones, *Sandia National Laboratory*	
2:30 – 3:00	***BREAK***	
3:00 – 4:30	**Solar Technologies**	**Chair: Mark Brongersma**
3:00	Diamond Solar Converters T. Fisher, *Purdue University*	
3:30	Space Solar Power M. Hoffert, *New York University*	
4:00	Panel Discussion	