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.

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 CO₂ Concentration
Last Glacial Maximum to present

Adapted from: http://www.climate.unibe.ch/gallery_co2.html
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
• H₂ 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

Technical Support
- Systems Analysis
- Technology Assessments

Technical R&D Portfolio
- Hydrogen
- Renewables
- CO₂ Capture
- Adv Materials
- Adv Transport
- Adv Electric Gen
- Adv Coal Use
- Adv Combustion
- Systems & Infrastr
- Geoengineering
- Adv Nuclear
- Biohydrogen Generation
- H₂ Fuel Cells and Monitoring of Bioconversion Process
- Nanomaterial Engineering for Hydrogen Storage
- Hydrogen Effects on Climate, Stratospheric Ozone, and Air Pollution
- NMR Studies of Ceramic Materials for Fuel Cells
- Nanostructured Photovoltaic Cells
- Rapid Prediction of CO₂ Movement in Aquifers, Coal Beds, and Oil and Gas Reservoirs
- Assessing Seal Capacities of Exploited Oil and Gas Reservoirs, Aquifers, and Coal Beds for Potential Use in CO₂ Sequestration
- Geophysical Monitoring of Geologic Sequestration
- Development of Low Irreversibility Engines
- Controlled Combustion
- Sensors for Advanced Combustion Systems
- Coal and Biomass Char Reactivity
- Process Informatics

Management
- General
- Financial
- Outreach
GCEP Advanced Combustion Projects
- Step-out Technology Example

Technical Support
- Systems Analysis
- Technology Assessments

Technical R&D Portfolio
- Hydrogen
- Renewables
- CO2 Capture
- Adv Materials
- Adv Transport
- Adv Electric Gen
- Adv Coal Use
- Adv Combustion
- Systems & Infrastr
- Geoengineering
- Adv Nuclear

Management
- General
- Financial
- Outreach

- Development of Low Irreversibility Engines
- Controlled Combustion
- Sensors for Advanced Combustion Systems
- Coal and Biomass Char Reactivity
- Process Informatics
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.

![Diagram showing the comparison between Carnot Engine and Low Irreversibility Engines.](image-url)

- **Carnot Engine**:
  - High efficiency at high temperatures.
  - Linear relationship between efficiency and temperature.

- **Low Irreversibility Engines**:
  - Efficiency starts low at low temperatures and increases as temperature increases.
  - Efficiency is higher than Carnot at low temperatures, indicating reduced irreversibility.

The diagram illustrates the performance of these engines as a function of temperature, with the isothermal and isentropic lines showing the theoretical maximum efficiencies.
Low-Irreversibility Engines
- Step-Out Concept

- Improve Combustion Efficiencies
- Extract Work During Rather Than After Chemical Reaction
- Step Back To Thermodynamic Principles
- Improved Efficiencies Based on Higher Thermodynamic Limits
- High Efficiency Engines
Figure 2.1: World Primary Energy Demand

United States CO₂ 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)

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>3:30 – 5:00</td>
<td>Overall Cell Performance</td>
<td>Chair: Peter Peumans</td>
<td></td>
</tr>
<tr>
<td>3:30</td>
<td>Optimization of Conjugated-Polymer-Based Bulk Heterojunctions</td>
<td>J. Hummelen</td>
<td>Groningen University</td>
</tr>
<tr>
<td>4:00</td>
<td>Stability of Organic Materials</td>
<td>A. Hagfeldt</td>
<td>Uppsala University</td>
</tr>
<tr>
<td>4:30</td>
<td>Panel Discussion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5:30 – 6:30</td>
<td>RECEPTION</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Day 2
Inorganic PV, Solar Thermal, Solar Technologies

8:30 – 10:00 Thin Film Photovoltaics

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

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Chair</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:30 – 2:30</td>
<td><strong>Solar Thermal</strong></td>
<td><strong>Chair: Shanhui Fan</strong></td>
</tr>
<tr>
<td>1:30</td>
<td>Novel Heat Transfer Fluids and Thermal Storage</td>
<td>L. Moens, <em>National Renewable Energy Laboratory</em></td>
</tr>
<tr>
<td>2:00</td>
<td>Power Towers: Solar Two, Solar Tres</td>
<td>S. Jones, <em>Sandia National Laboratory</em></td>
</tr>
<tr>
<td>2:30 – 3:00</td>
<td><strong>BREAK</strong></td>
<td></td>
</tr>
<tr>
<td>3:00 – 4:30</td>
<td><strong>Solar Technologies</strong></td>
<td><strong>Chair: Mark Brongersma</strong></td>
</tr>
<tr>
<td>3:00</td>
<td>Diamond Solar Converters</td>
<td>T. Fisher, <em>Purdue University</em></td>
</tr>
<tr>
<td>3:30</td>
<td>Space Solar Power</td>
<td>M. Hoffert, <em>New York University</em></td>
</tr>
<tr>
<td>4:00</td>
<td>Panel Discussion</td>
<td></td>
</tr>
</tbody>
</table>