Stanford University

GCEP Global Climate & Energy Project

ETAAC Meeting
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Stanford University

Science and technology for a low GHG emission world

http://gcep.stanford.edu/

The Grand Challenge

Needs

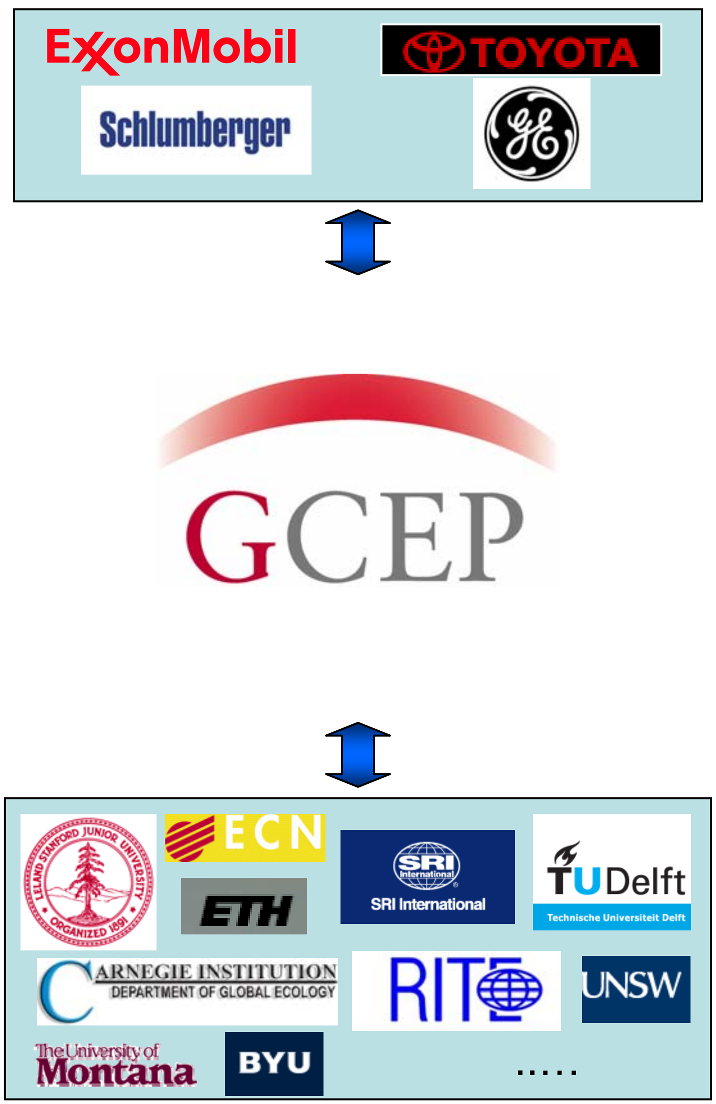
- Growth in world population to 9 billion from 6.5 billion, of which 2 billion people currently have no access to modern energy systems
- Improved standard of living in growing economies of developing world
- Increased demands for energy, food, land, and materials.

Protecting, Restoring, and Sustaining Planetary Biogeochemical Systems

Component Challenges

- Water supply
- Food supply (strongly linked to water supply)
- **Energy – The Focus of GCEP**

The Global Climate and Energy Project



Mission

- Fundamental and pre-commercial research
- Novel technology options for energy conversion and utilization
- Impact in the 10-50 years timeframe

Strategy

- No incremental research: revisit the fundamentals and explore new approaches
- High risk / high reward

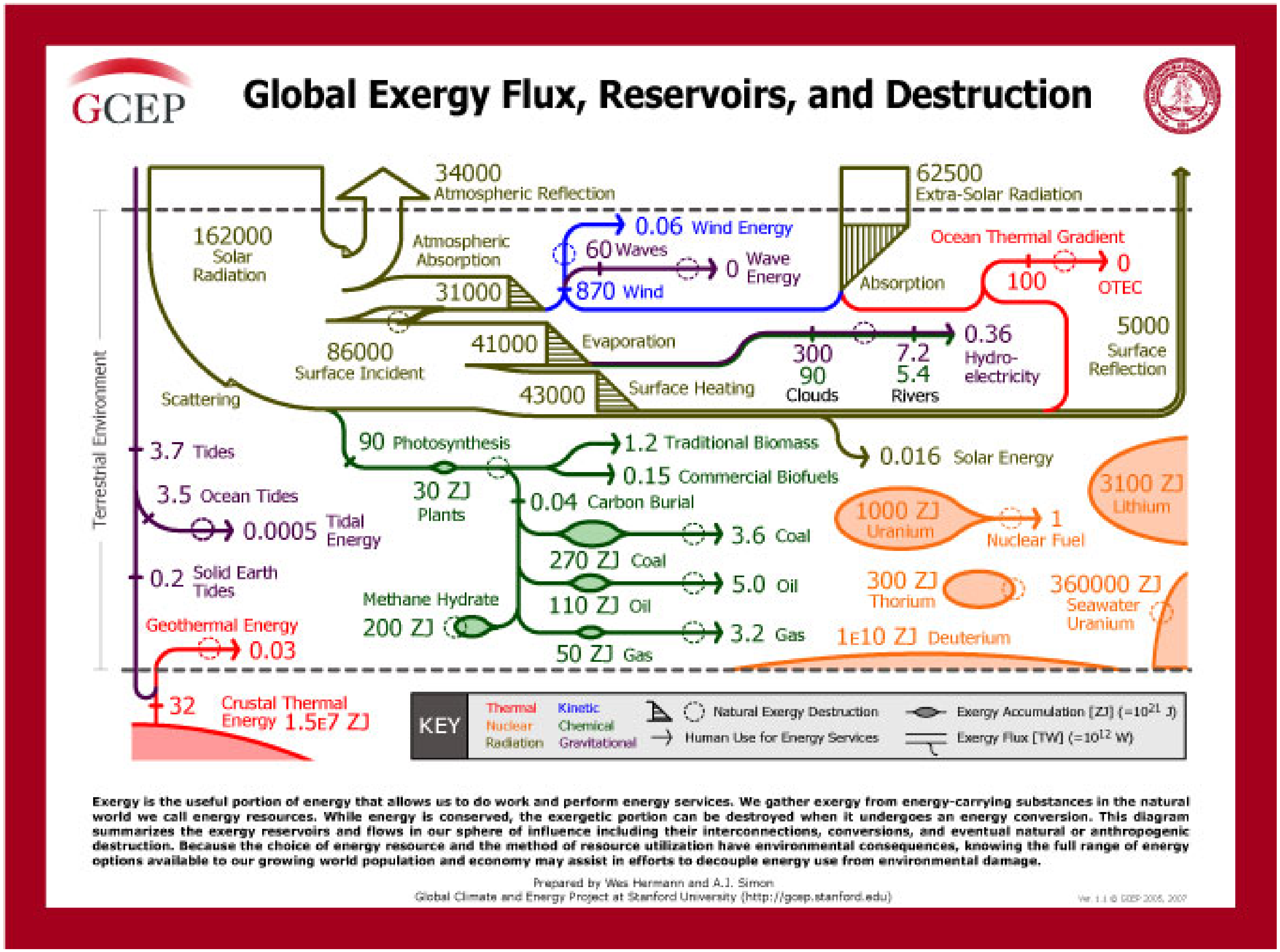
The players

- Industrial sponsors
- Academic institutions

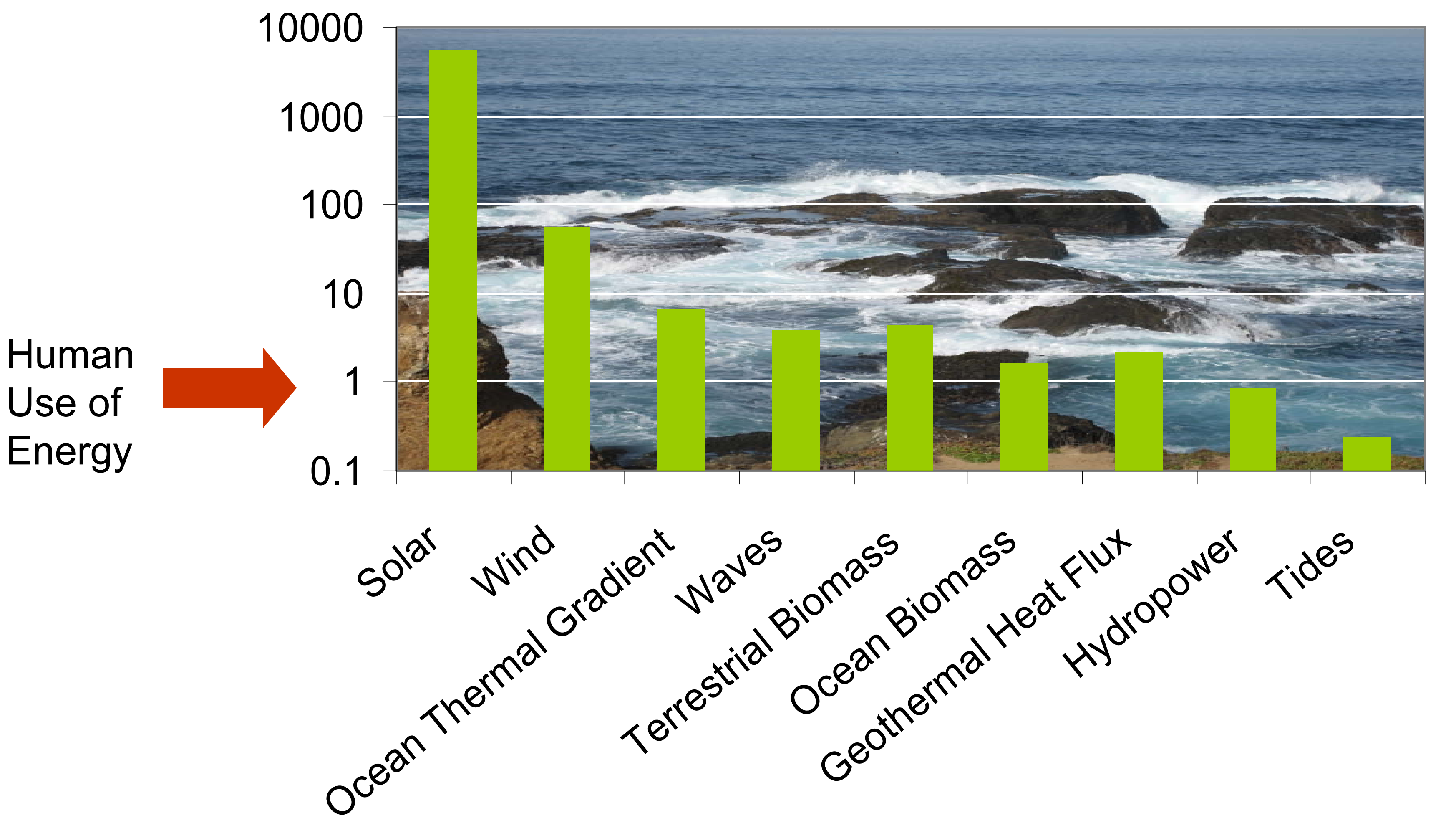
Schedule and Budget

- 10 years (2003 – 2013+)
- $225 M

Assessment of Global Exergy Sources and Flows



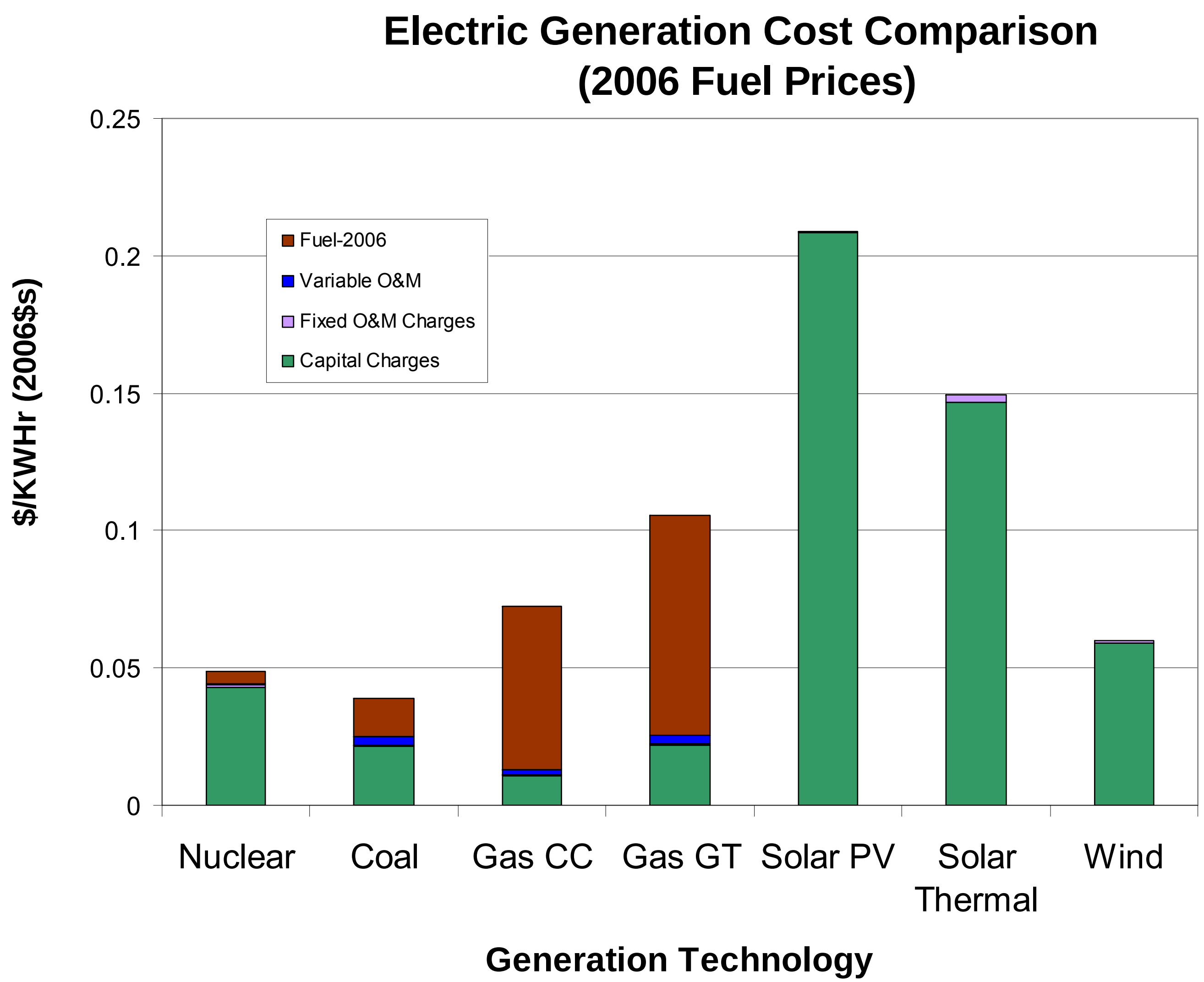
Renewable Global Exergy Flows



Exergy sources scaled to average consumption in 2004 (15 TW)

From Hermann, 2006: Quantifying Global Exergy Resources, Energy 31 (2006) 1349–1366

Cost of Electricity



Source: J. Weyant, Energy Modeling Forum, Stanford University

Solar Energy Projects

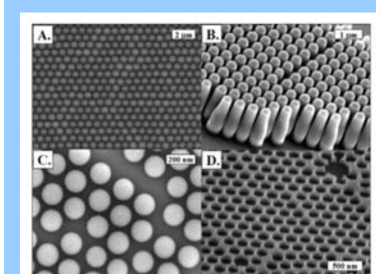
Solar Energy

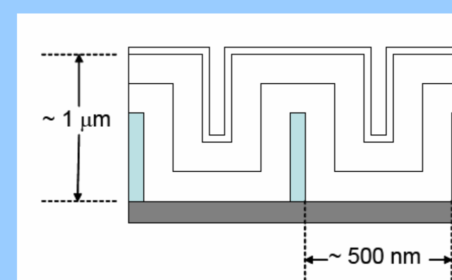
- Nanostructured Photovoltaic Cells, *McGehee*
- Monitoring and Accessing Cellular Photosynthesis Electrical Energy for Bioelectricity, *Prinz, Grossman (CIW)*
- Nanostructured Metal-Organic Composite Solar Cells, *Brongersma, Peumans, Fan*
- Inorganic Nanocomposite Solar Cells by Atomic Layer Deposition, *Bent, Harris, McGehee*
- Nanostructured Silicon-Based Tandem Solar Cells, *Green, Conibeer (UNSW)*
- Advanced Materials and Devices for Low-Cost and High-Performance Organic Photovoltaic Cells, *Bao, McGehee*
- Artificial Photsynthesis: Membrane Supported Assemblies That Use Sunlight to Split Water, *Lewis, Gray, Atwater (Cal Tech)**
- Molecular Solar Cells, *Peumans*

Inorganic Nanocomposite Solar Cells by Atomic Layer Deposition

Stacey Bent, James Harris, Michael McGehee

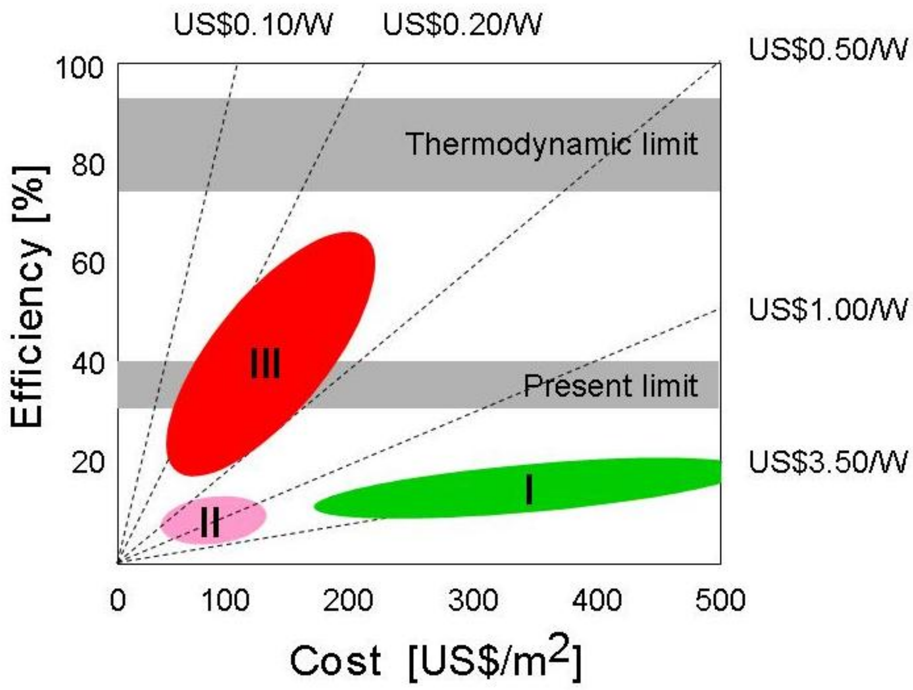
- Fabricated sub-micron pillar and hole geometries:
- Identified Cu_2ZnSnS_4 (CZTS) as a material with the appropriate bandgap (1.4 – 1.5 eV)
- Designed CZTS-specific ALD reactor





High Efficiency Solar Electricity

… increase the light-to-electricity conversion efficiency towards a 75% efficiency limit under global illumination conditions.



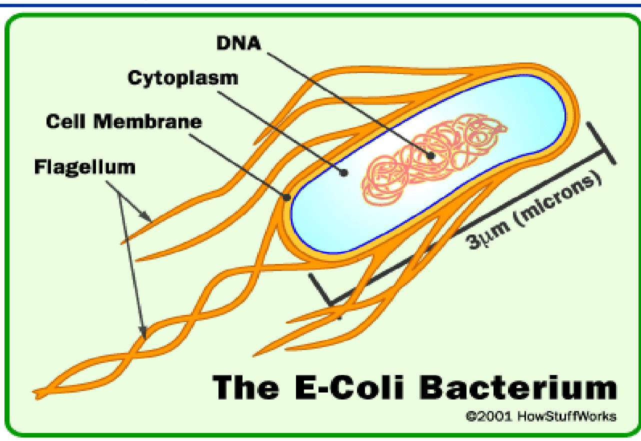
GCEP Criteria

- Meets or exceeds light-to-electricity energy conversion efficiency of 45% under global illumination conditions.
- Utilizes non-toxic, inexpensive, and abundant elements. Indium and germanium are examples of materials that can be considered scarce.
- Demonstrates a pathway to low-cost manufacture and economy of scale.
- Demonstrates a pathway to meeting or exceeding lifetime requirements of thirty years.

Biofuels Projects

Biomass

- Genetic Engineering of Cellulose Accumulation, *Somerville*
- Directed Evolution of Novel Yeast Species, *Sherlock, Rosenzweig (U. Montana)*
- Microbial Synthesis of Biodiesel, *Khosla*
- Technology Potential of Biofuels: Feasibility Assessment, *Field, Naylor*



Direct biodiesel production from biomass feedstock using engineered microorganisms could have both a potentially high yield and the high energy density of a hydrocarbon

Microbial Synthesis of Biodiesel

Chaitan Khosla

Objective:

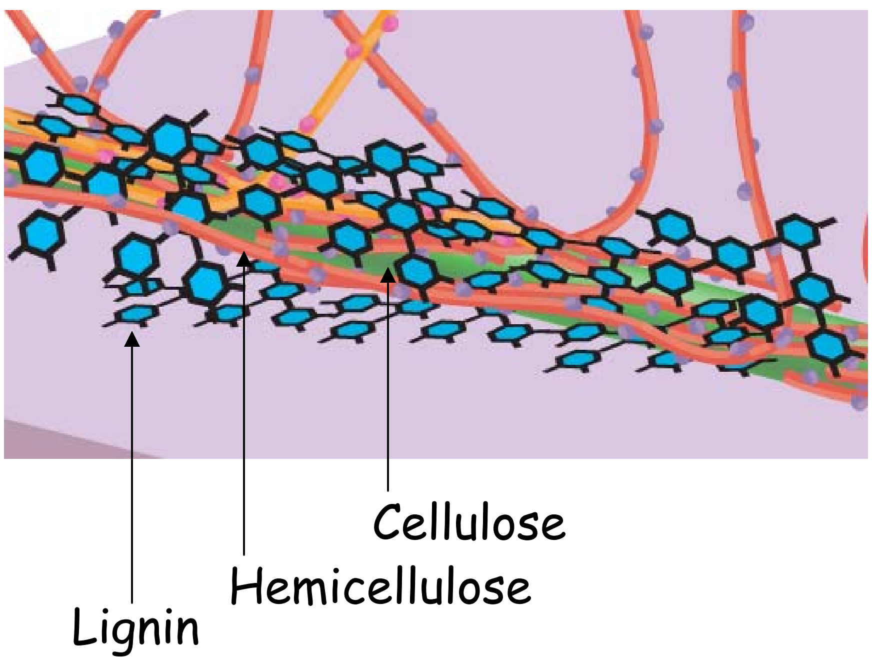
Engineer *E. coli* as a microbial factory for production of fatty acids.

Approach:

- Increase carbon flux (acetyl-CoA) to fatty acid biosynthesis synthesis (malonyl-CoA) by expressing genes from two key control enzymes
- Co-express plant oleosin genes to accumulate higher concentrations of fatty acids
- Biosynthesize fatty acid alternatives (e.g. aldehydes, esters and lactones), using existing fatty acid pathways and heterologous enzymes, and evaluate their quality and potential as biodiesel fuels

Request for Proposals: Lignin Management in Biofuels

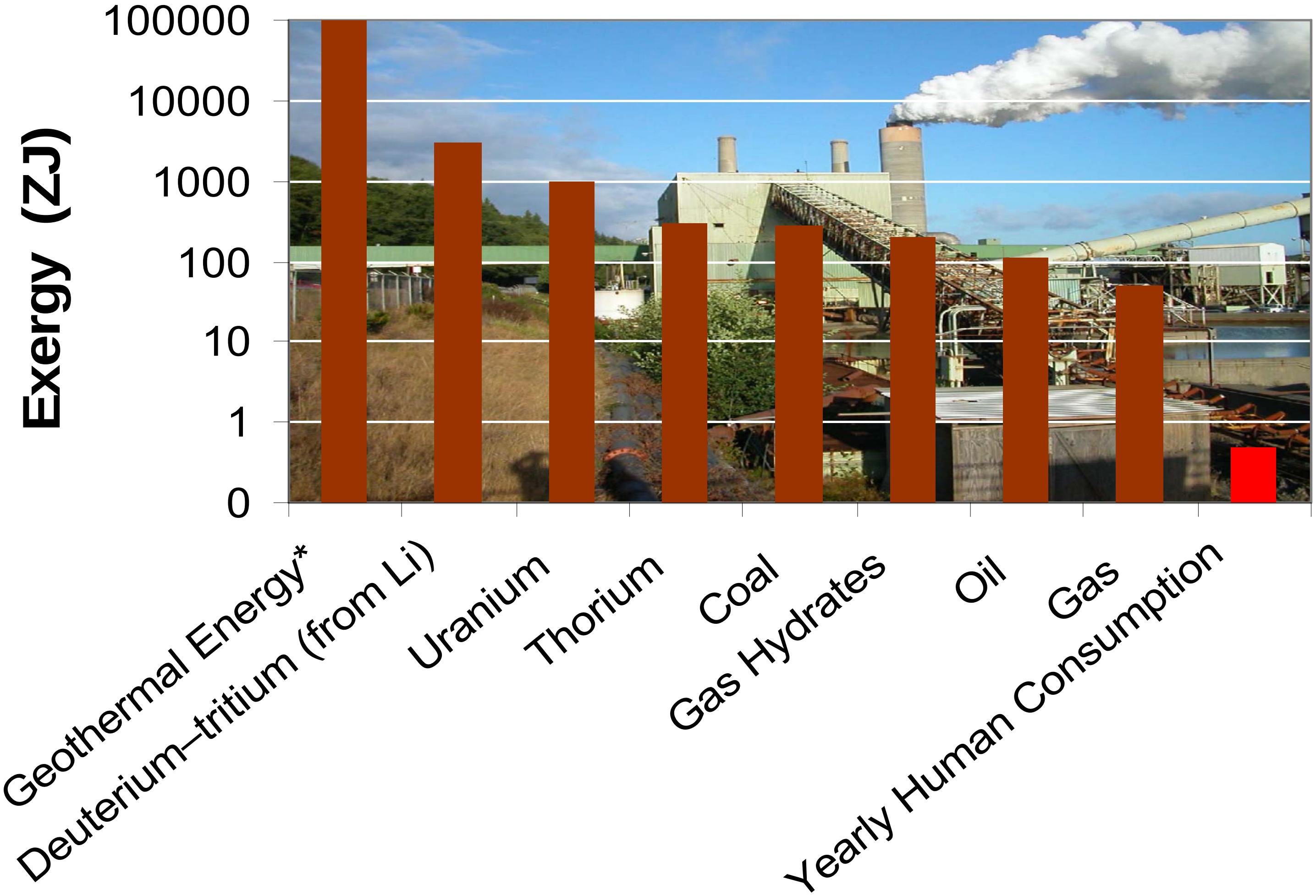
…enable an environmentally sustainable method of creating novel lignin compositions that enzymes or catalysts can hydrolyze into a liquid fuel such as ethanol, alkanes or oxygenates.



GCEP Criteria

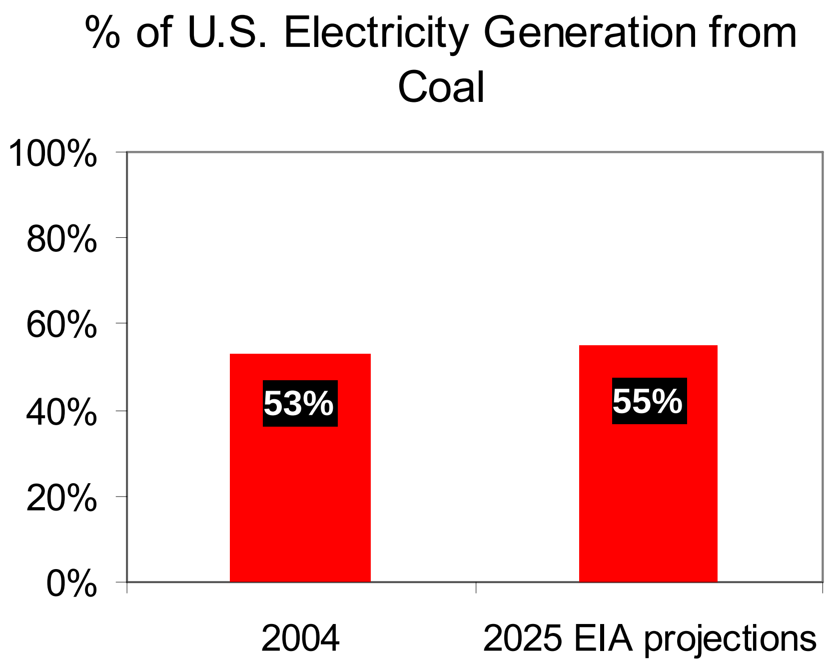
- Two-fold increase in the amount of sugars produced
- 50% increase in cellulosic ethanol production
- Maintain the structural and vascular integrity of the plant
- Large-scale deployment in crops that minimize environmental stress and resources.

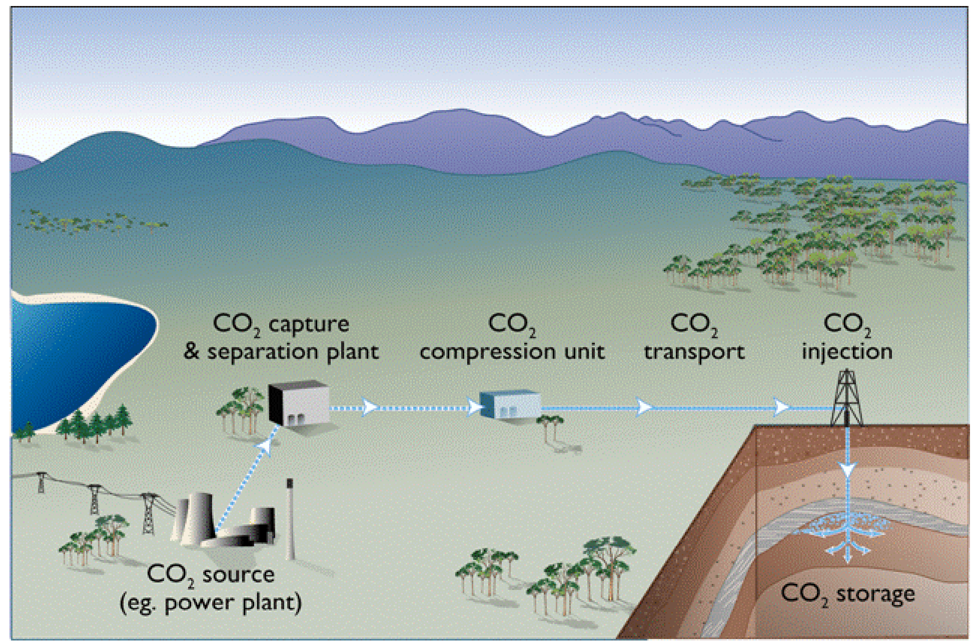
Global Exergy Stores



From Hermann, 2006: Quantifying Global Exergy Resources, Energy 31 (2006) 1349–1366

Capture and Geologic Storage of CO_2 Avoids Emissions from Fossil Fuels





CO_2 Capture and Storage: A Four Step Process

Capture → **Compression** → **Pipeline Transport** → **Underground Injection**

Carbon Dioxide Capture and Storage Projects

GCEP

CO_2 Capture

- Advanced Membrane Reactors in Energy Systems: A Carbon-Free Conversion of Fossil Fuels, *Jansen, Haije, Dijkstra, van den Brink, Pex, Schoonman, Peters (ECN-TU-Delft)*
- Development of Innovative Gas Separation Membranes Through Sub-Nanoscale Materials Control, *Yamada, Kazama, Yogo (RITE)*

CO_2 Storage

- A Numerical Simulation Framework for CO_2 Sequestration in Subsurface Formations, *Tchelepi, Durlofsky, Aziz*
- Geologic Storage of Carbon Dioxide in Coal, *Harris, Kovscek, Orr, Zoback*
- Increasing Carbon Storage within Soils by Controlling Key Microbial Respiration Processes, *Fendorf, Benner (Boise State)**
- Rapid Prediction of CO_2 Movement in Aquifers, Coal Beds, and Oil and Gas Reservoirs, *Orr, Kovscek*
- Assessing Seal Capacity of Exploited Oil and Gas Reservoirs, Aquifers, and Coal Beds for Potential Use in CO_2 Sequestration, *Zoback*
- Geophysical Monitoring of Geologic Sequestration, *Harris*

Development of Innovative Gas Separation Membranes Through Sub-Nanoscale Control

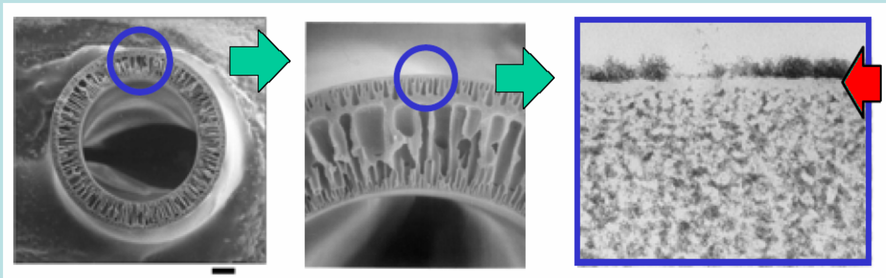
Koichi Yamada, Shingo Kazama, Katsunori Yogo (RITE)

Goal

- Optimize hollow fiber cardo polymer membranes for both CO_2 permeability and selectivity

Approach

- Create a thin layer of functional cardo polyimide material supported by a porous structure allows high permeability
- Carbonize outer surface of membrane restricts the thermal motion of the polymer chain to enhance the molecular gate function of the polymer.
- Functionalize the polymer can change its morphology at the sub-nanoscale level, allowing for fine tuning of the pore space.



100µm

50 nm

Fossil Fuel: Current and Completed GCEP Research Projects

Advanced Combustion

- Optimization of Synthetic Oxygenated Fuels, *Bowman, Golden, Hanson, Pitsch*
- Low Exergy Loss Chemical Engines, *Edwards*
- Controlled Combustion, *Bowman*
- Process Informatics, *Golden*
- Development of Low-Irreversibility Engines, *Edwards*
- Coal and Biomass Char Reactivity, *Mitchell*
- Sensors for Advanced Combustion Systems, Hanson

Advanced Coal Utilization

- Coal Energy Conversion with Aquifer-Based Carbon Sequestration: An Approach to Electric Power Generation with Zero Matter Release to the Atmosphere, Mitchell, Baxter (BYU), Pugmire (U Utah)*
- Integration of Coal Energy Conversion with Aquifer-based Carbon Sequestration (Stanford), *Mitchell*
- Integration of Coal Energy Conversion with Aquifer-based Carbon Sequestration (BYU), *Baxter, Tree (BYU)*

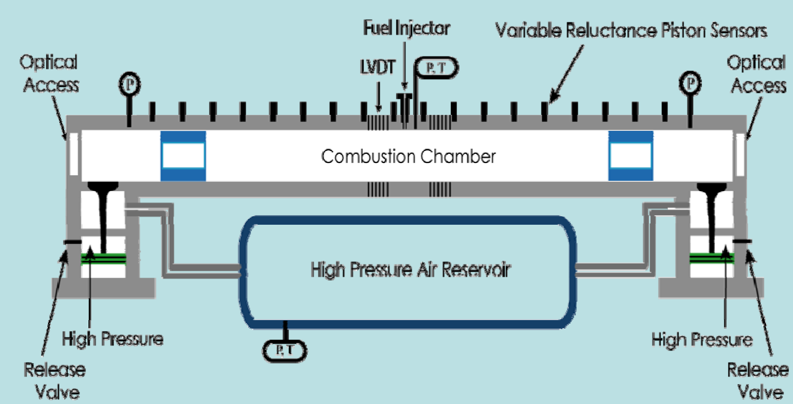
Development of Low-Exergy-Loss High-Efficiency Chemical Engines
Chris Edwards

Goal

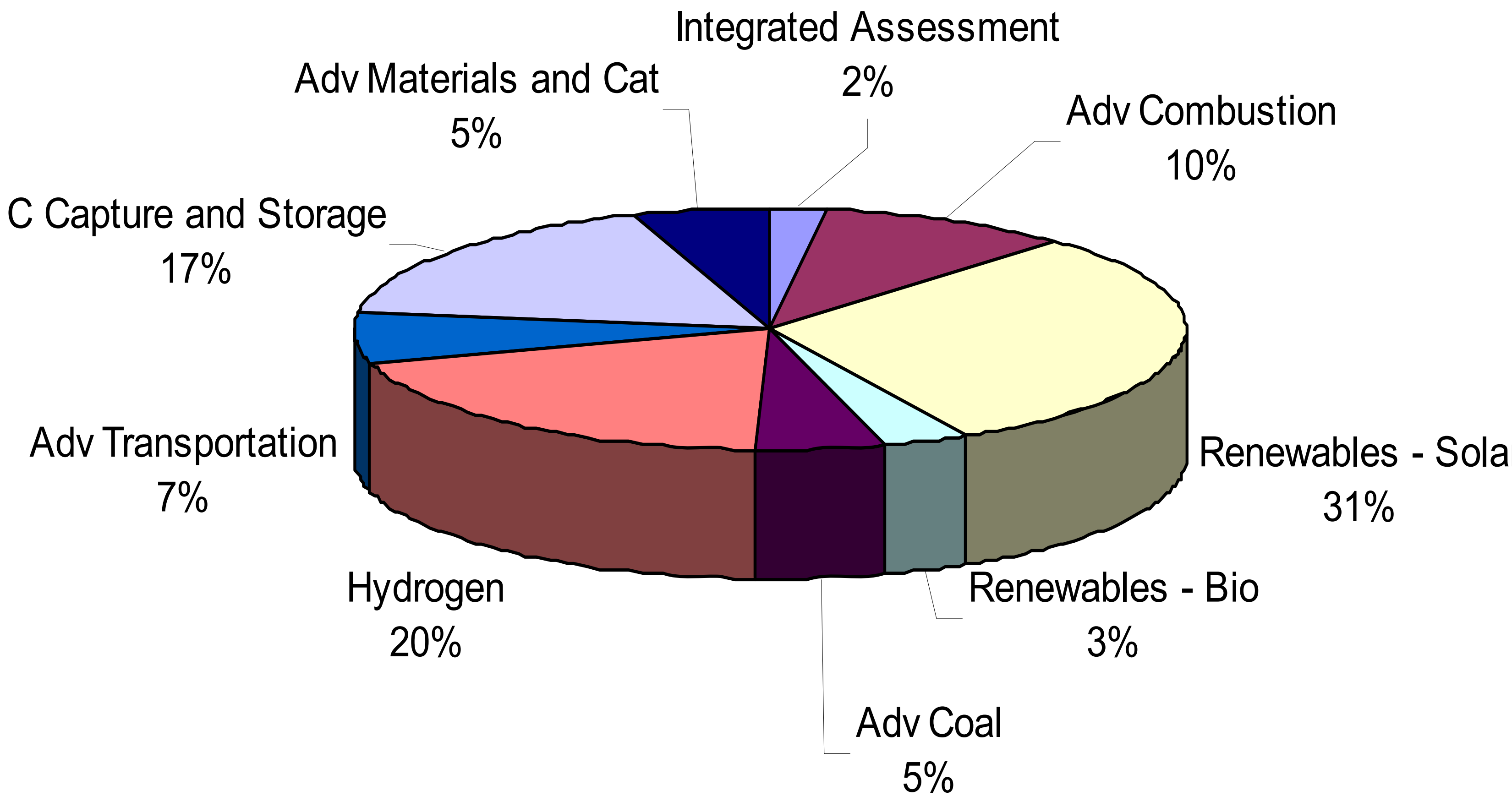
- Goal is to demonstrate the processes needed to enable simple-cycle engines with ~60% efficiency

Approach

- Combustion is conducted at very high speed with extreme compression



Overall Distribution of GCEP Research Funding



Total Research Funds Committed: $72.1M

Conclusions

- There is no silver bullet to solve this challenge. Multiple approaches must be pursued to best match different geographical and socioeconomic needs.
- A broad portfolio of fundamental research is needed to create novel, more efficient technology options with potential for large-scale impact.
- Investment in fundamental science is needed to provide breakthrough technologies – to keep the innovation pipeline full.
  - ❖ *We are in this for the long haul.*
- GCEP's high-risk / high-reward strategy fills a research niche that is complementary to what is traditionally supported by industry and governments.