Some Perspectives on Likely Future Energy Technologies

John P. Weyant
Stanford University

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Outline

- What's Likely and What's More Speculative
- Three Time Frames to Consider
- Synergies, Options, and Risk Management
- The Money
- A Focus on the Medium Term
- Some Interesting Things to Watch
  - Solar PV
  - Batteries and Other Storage Systems
  - Smart Grids, Smart Buildings, Smart Houses
  - Solid Oxide Fuel Cell for Generators, and Customers
  - Plug in Hybrid and Electric Vehicles

What’s More Likely and What’s More Speculative?

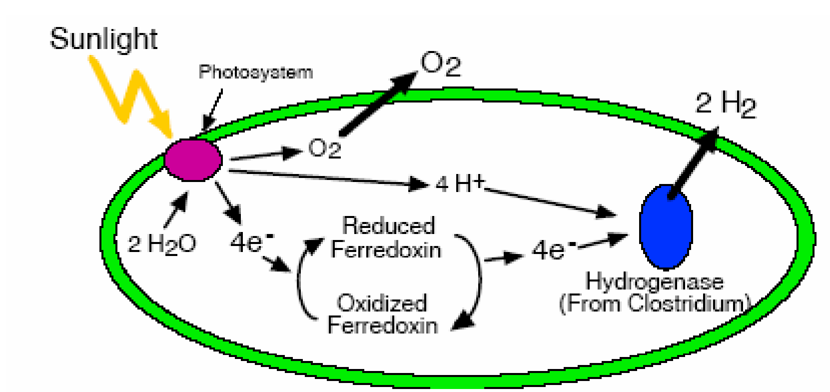
- What’s More Likely
  - Things that result from simple learning, or
  - that result from being able to see and measure things at the nano level, but
  - do not involve changing things at the atomic/genetic level
- What’s More Speculative
  - Things that do not result from simple learning, or
  - that do involve changing things at the atomic/genetic level

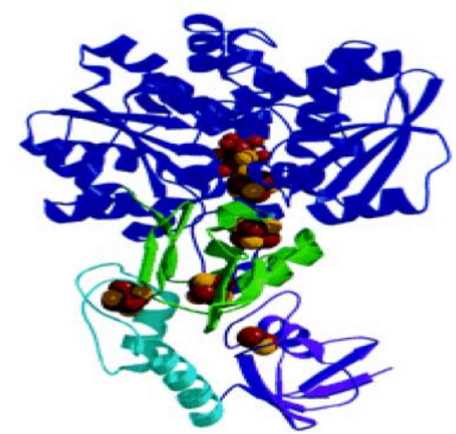
Three Time Frames for Thinking About Advanced Technology

- Today (Zero Through Less Than Five Years)
  - Smart Metering
  - Wind
  - Solar Thermal
  - First Generation PVs
- The Distant Future (Over 20 Years)
  - Biological Hydrogen
  - Advanced Third Generation PVs
  - Genetically Modified Energy Crops With Advanced Biofuels Conversion
- The Interesting Technology Planning Horizon (5-20 Years)
  - Advanced Second Generation/Early Third Generation PVs
  - Advanced Storage – Grid Scale Batteries, etc.
  - Smart and Micro Grids
  - Smart Buildings/Houses
  - Integrated System Control and Pricing
  - Home Scale Solid Oxide Fuel Cells
  - Plug in Hybrid/Electric Cars
  - Integrated System Control and Pricing
  - LEDs/OLEDs for Lighting, TVs and Computer Displays

Long Term Technology 1-
Direct Solar Biohydrogen
Jim Swartz, GCEP, Stanford

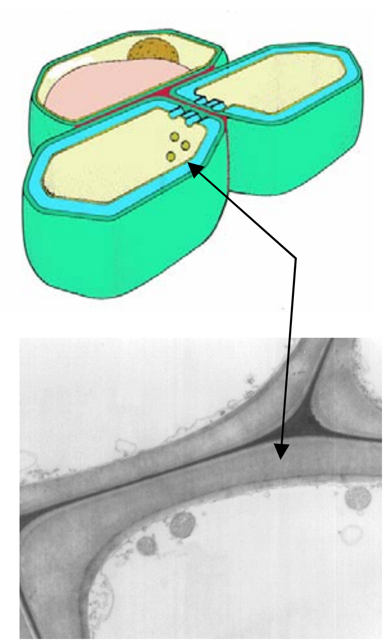
- Engineer *Synechocystis* organism to demonstrate photobiological production of hydrogen
- Modify protein structure of hydrogenase enzyme to exclude oxygen from active site while still allowing protons to enter and hydrogen to exit
- Use a cell-free protein evolution approach to:
  - Express and activate hydrogenase enzyme
  - Produce an uncoupler protein to aid flow of protons
  - Optimize organism for resistance to light exposure and to infection
- Test hydrogen production in photobioreactor set-up.

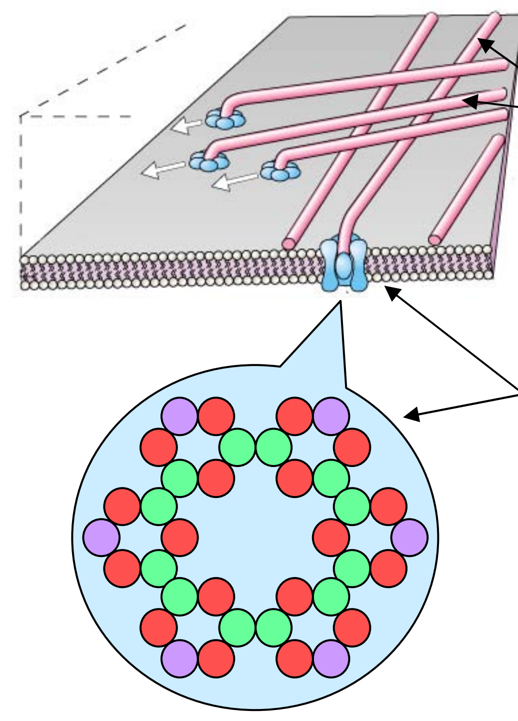




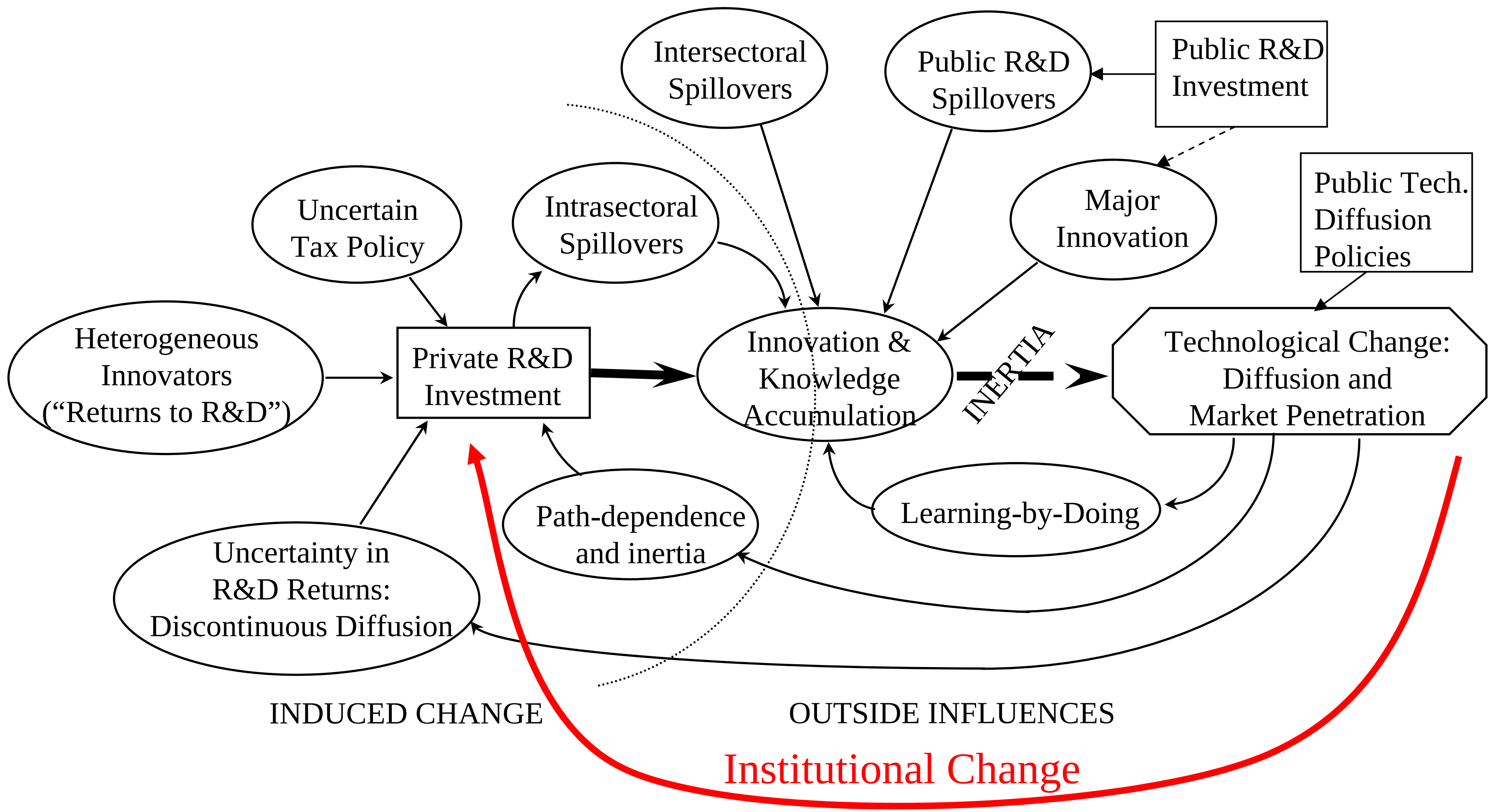
Long Term Technology 2-Genetic Engineering of Cellulose Accumulation
Chris Somerville, GCEP, Stanford University

- 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.



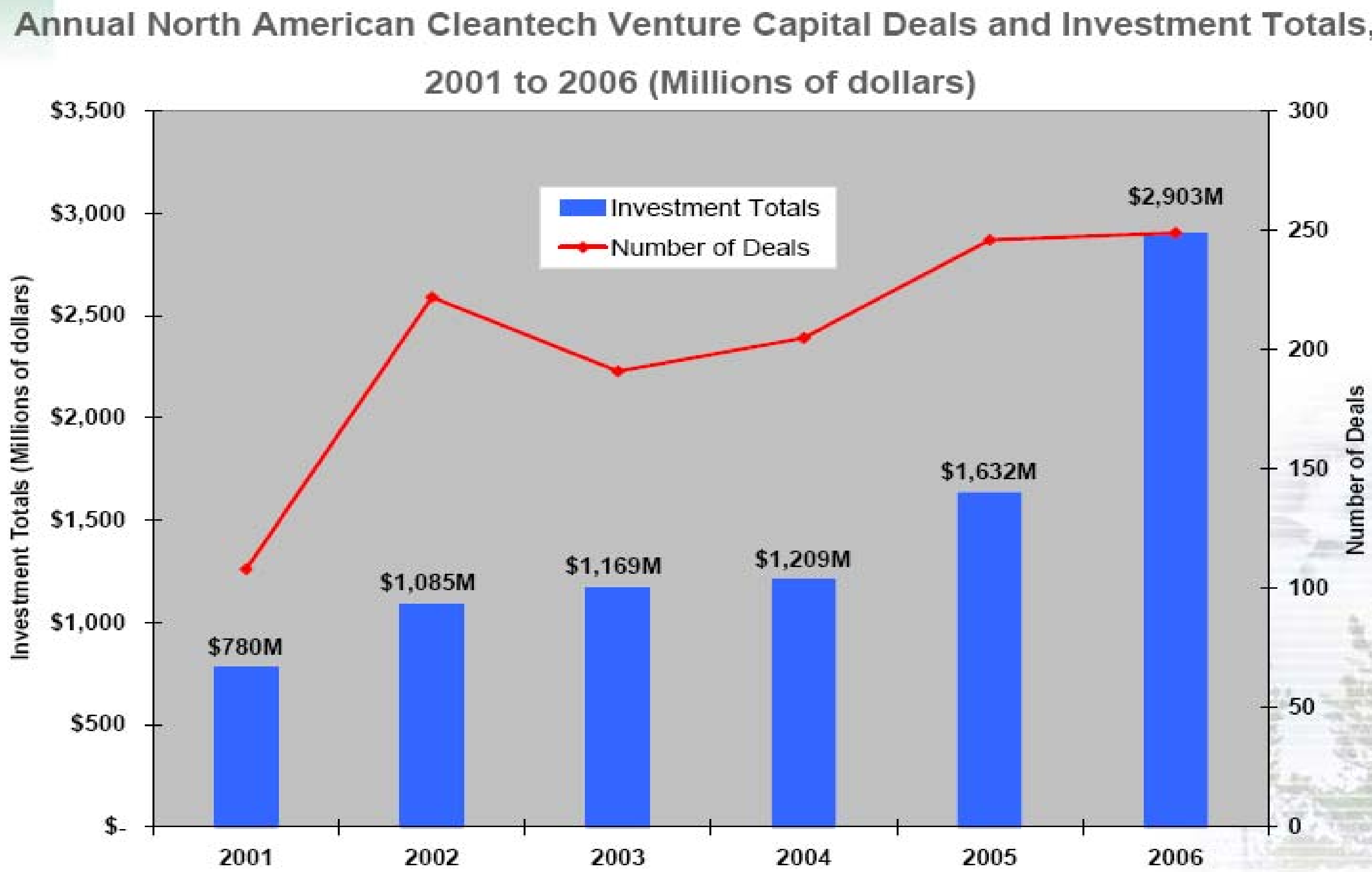


An Overview of The Process of Technological Change: Synergies, Options and Risk Management

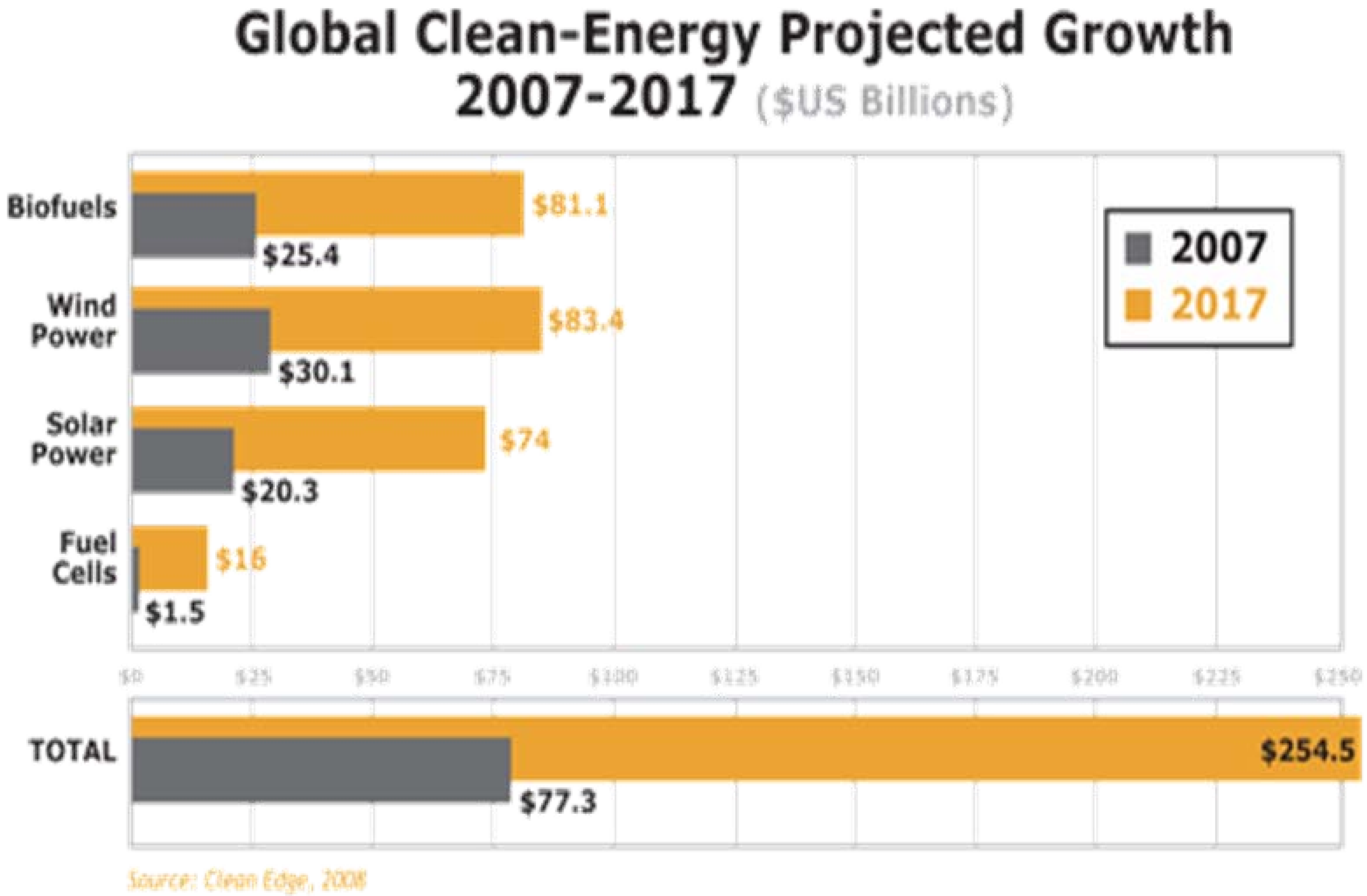


The Money I

Cleantech Venture Capital Trend



The Money - II


Global Clean-Energy Projected Growth
2007-2017 ($US Billions)
Biofuels
$81.1
$25.4
Wind Power
$83.4
$30.1
Solar Power
$74
$20.3
Fuel Cells
$16
$1.5
2007
2017
$0
$25
$50
$75
$100
$125
$150
$175
$200
$225
$250
TOTAL
$254.5
$77.3
Source: Clean Edge, 2008

A Focus on the Intermediate Term

- Advanced Second Generation/Early Third Generation PVs
- Advanced Storage – Grid Scale Batteries, etc.
- Smart and Micro Grids
- Smart Buildings/Houses
- Integrated System Control and Pricing
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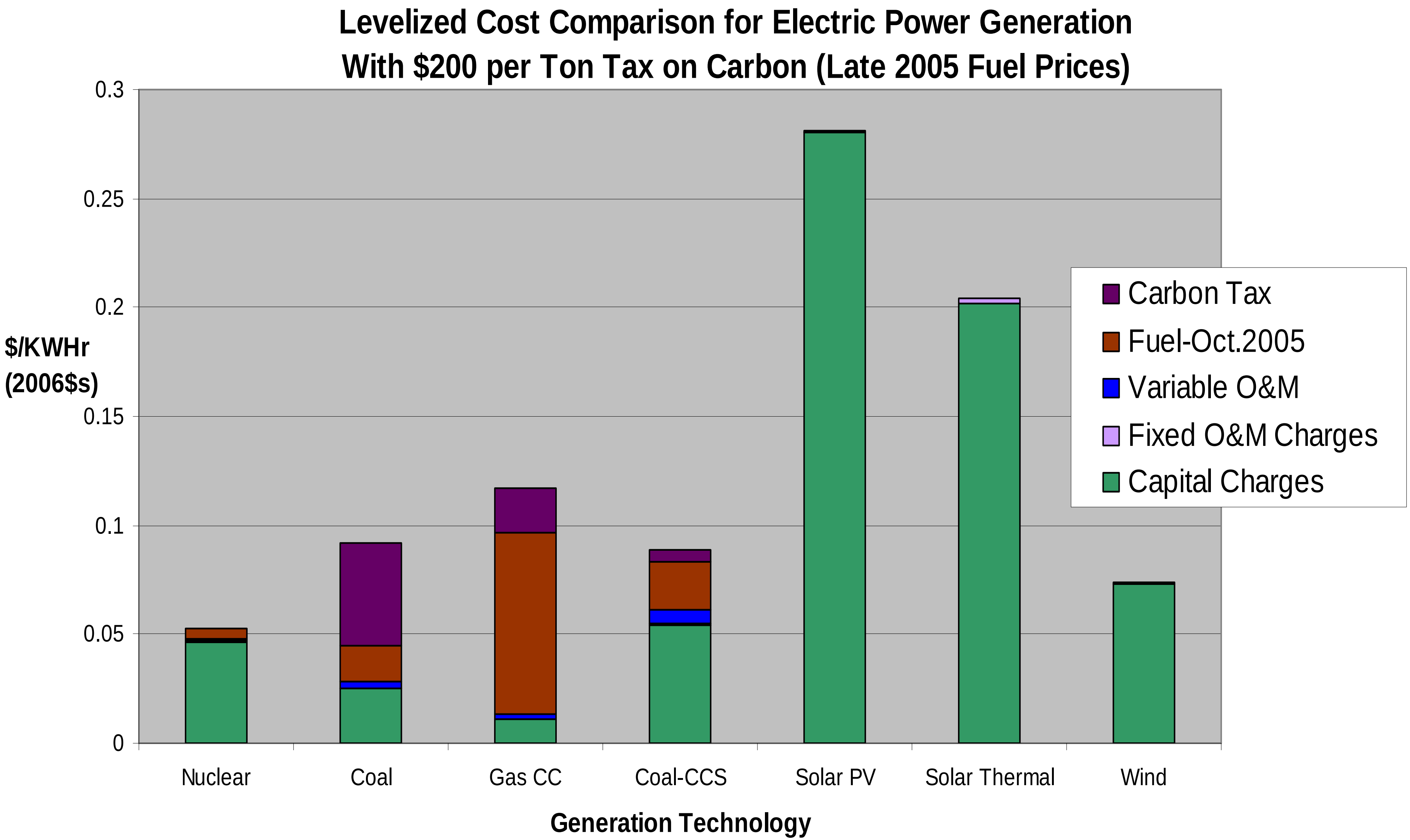
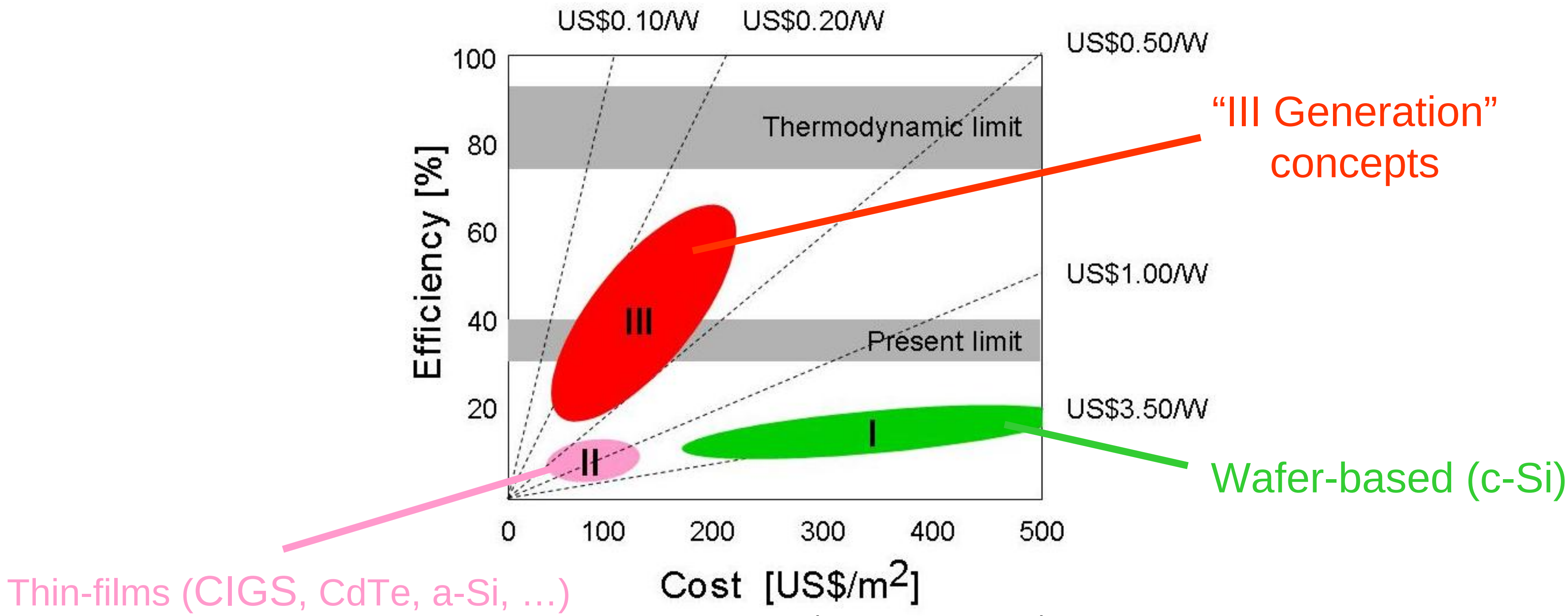

Levelized Cost Comparison for Electric Power Generation
With $200 per Ton Tax on Carbon (Late 2005 Fuel Prices)
$/KWHr
(2006$s)
0.3
0.25
0.2
0.15
0.1
0.05
0
Nuclear
Coal
Gas CC
Coal-CCS
Solar PV
Solar Thermal
Wind
Generation Technology
Carbon Tax
Fuel-Oct.2005
Variable O&M
Fixed O&M Charges
Capital Charges

But, We Have Many Energy Supply Risks

- Coal
  - Carbon dioxide releases and global climate change
  - Issues regarding technology, costs, and public acceptance of CCS
- Natural gas
  - Limited supply
  - Large price variability over time
- Nuclear power
  - Disposition of spent fuel
  - High capital cost
  - International proliferation: may mask nuclear weapons
- Renewables
  - High cost
  - Quantities to replace fossil fuel are huge

Reducing Cost and Increasing Efficiency of Photovoltaic Systems



(M. Green, UNSW)

Cost ↓

- Cheaper Active Materials (abundant inorganic or organic)
- Lower Fabrication Costs (low-cost deposition / growth)
- Cheaper BOS Components (substrates, encapsulation, …)

Efficiency ↑

Reduce the Thermodynamic Losses at Each Step of the Photon-to-Electron Conversion Process

- Light Absorption
- Carrier Generation
- Carrier Transfer and Separation
- Carrier Transport

Inorganic Thin-Film Photovoltaics

Materials

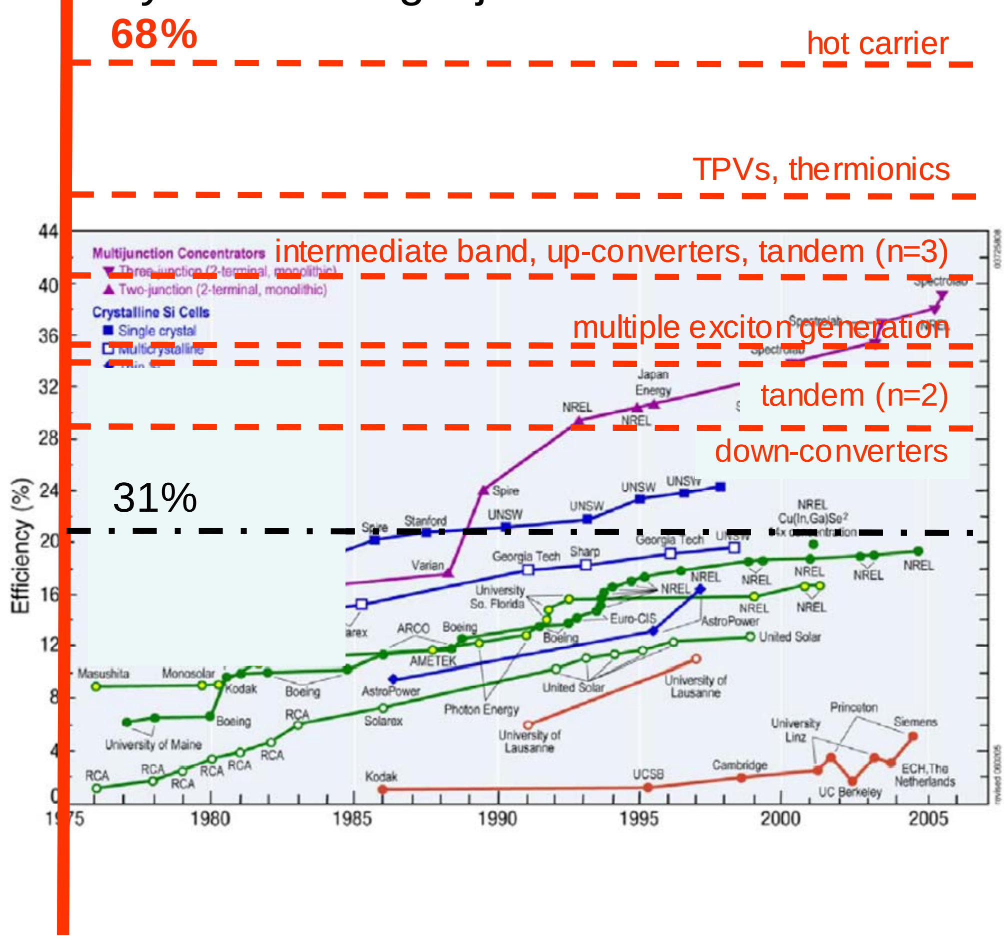
- (Novel) low-cost, abundant, non-toxic, and stable semiconductor materials
- Thin films: low volumes and lower requirements for charge transport
- Low-cost deposition processes

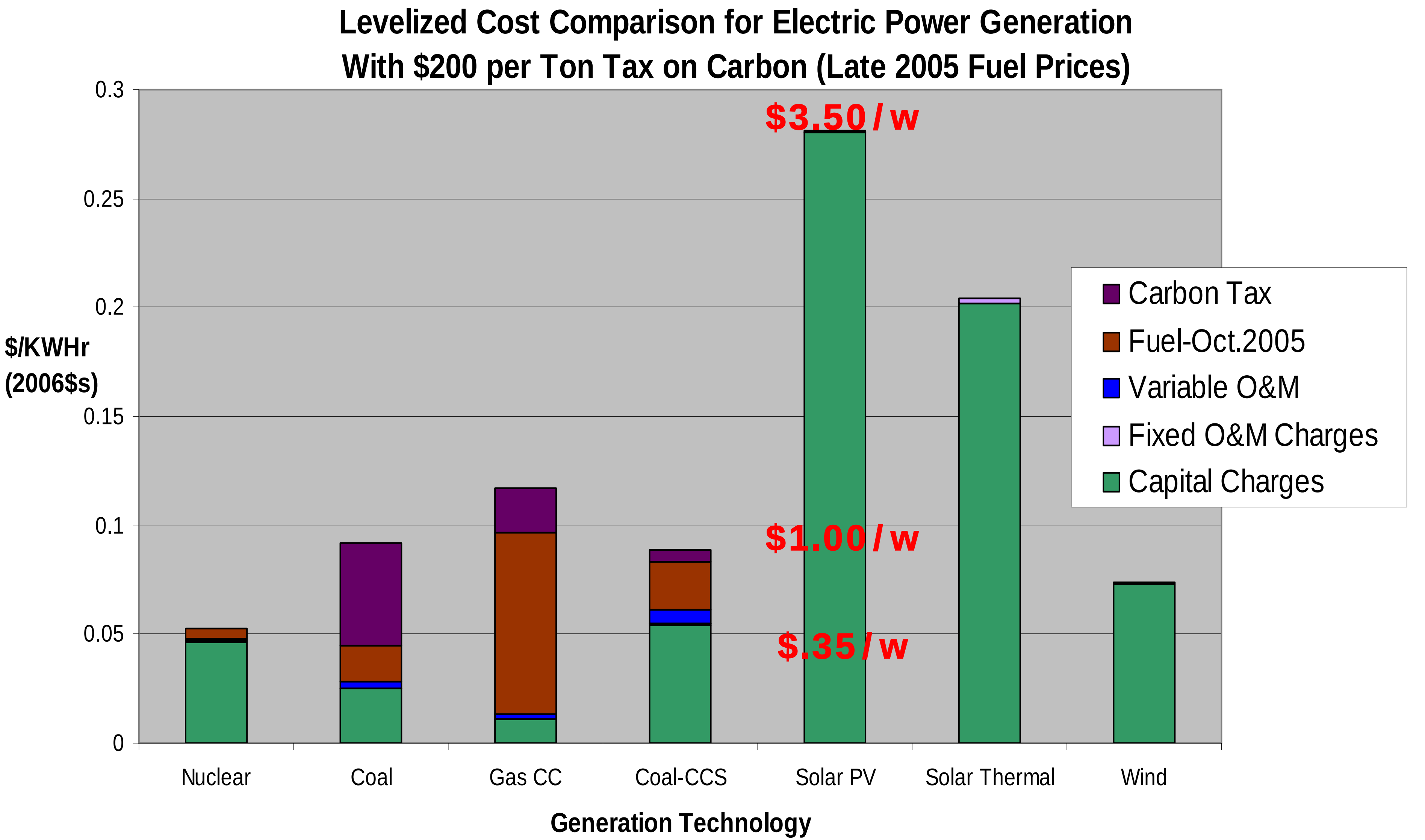
Nanoscale morphology

Performance enhancement through
- optimized geometry
- quantum effects

High efficiency

III generation concepts with efficiency limits beyond the single junction limit of 31%

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Nuclear
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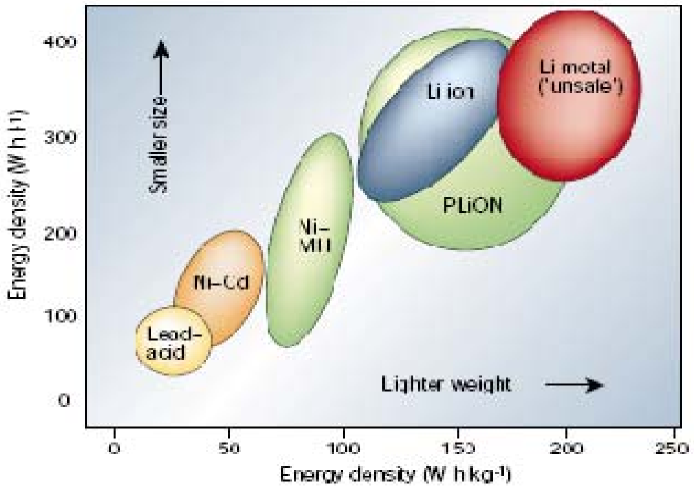
Solar Thermal
Wind
Generation Technology

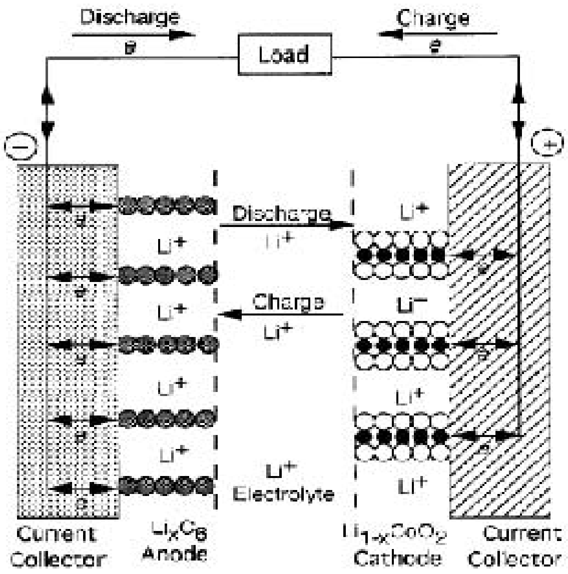
Batteries With Ultra High Capacity Si Nanowire Anodes

Yi Cui, Stanford University

Li Battery Technology



J.-M. Tarascon & M. Armand. Nature. 414, 359 (2001).



Battery parameters:

- Energy density: cathode and anode
- Power density: ion intercalation and electron transport
- Cycle life: strain relaxation

Example: Si as Anode Materials

C anodes: the existing anode technology.

$$C_6 \leftrightarrow LiC_6$$

Theoretical capacity: 372 mA h/g

Si anodes:

$$Si \leftrightarrow Li_{4.4}Si$$

Theoretical capacity: 4200 mA h/g

Problem for Si: 400% volume expansion.

Batteries With Ultra High Capacity Si Nanowire Anodes

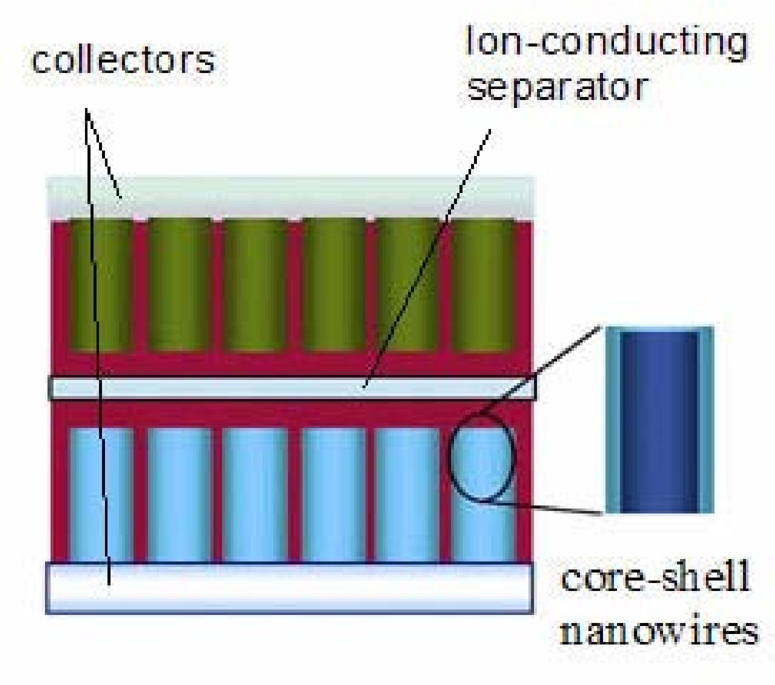


Figure 1: Schematic diagram of a nanowire battery cell.

Batteries With Ultra High Capacity Si Nanowire Anodes

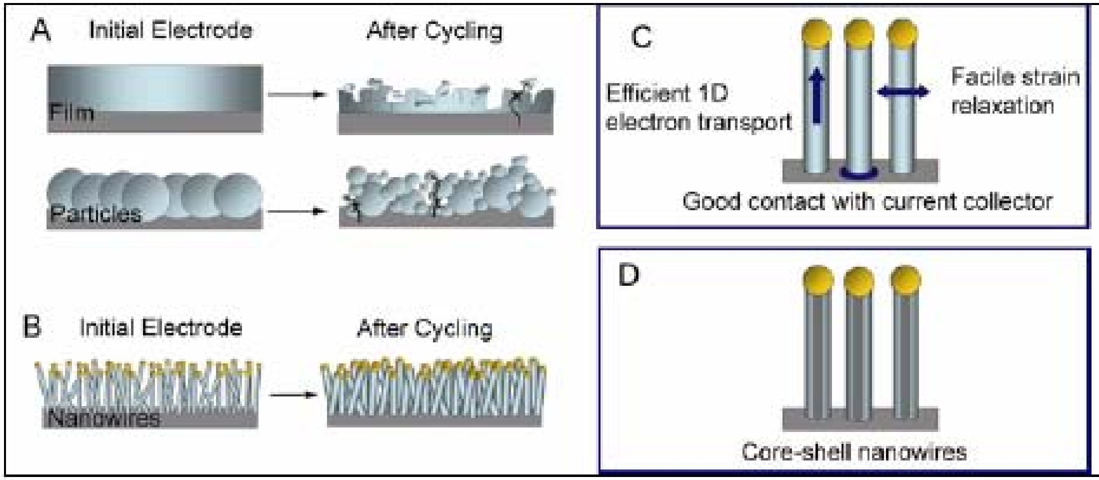


Fig. 1 A) Battery electrode made of bulk film or particles. B) NW battery electrode. C) Advantages of NW electrodes. D) Core-shell NW electrodes.

Ultra High Capacity Si Nanowire Anodes

- Si nanowires show 10 times higher capacity than existing carbon anodes
- Si nanowires show much better cycle life than bulk, particle and thin film geometries
- Si is abundant, the industry has a mature infrastructure and there is no need for high purity in this application
- There are several other competing concepts
- These can be used in cars, homes or at grid scale

A Focus on the Intermediate Term Revisited

- Advanced Second Generation/Early Third Generation PVs
  - Where/how would you use them if they get much cheaper
- Advanced Storage – Grid Scale Batteries, etc.
  - Where/how would you use them if they get much cheaper
- Smart and Micro Grids
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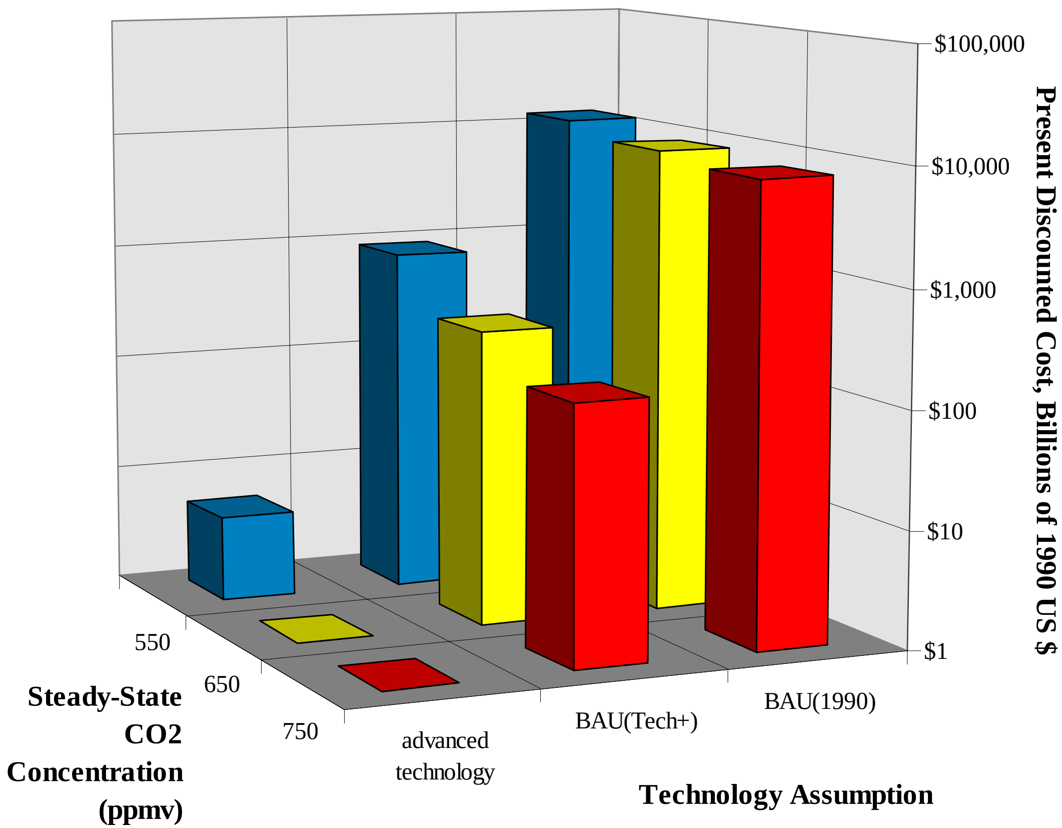
The End

3. How Flexibility

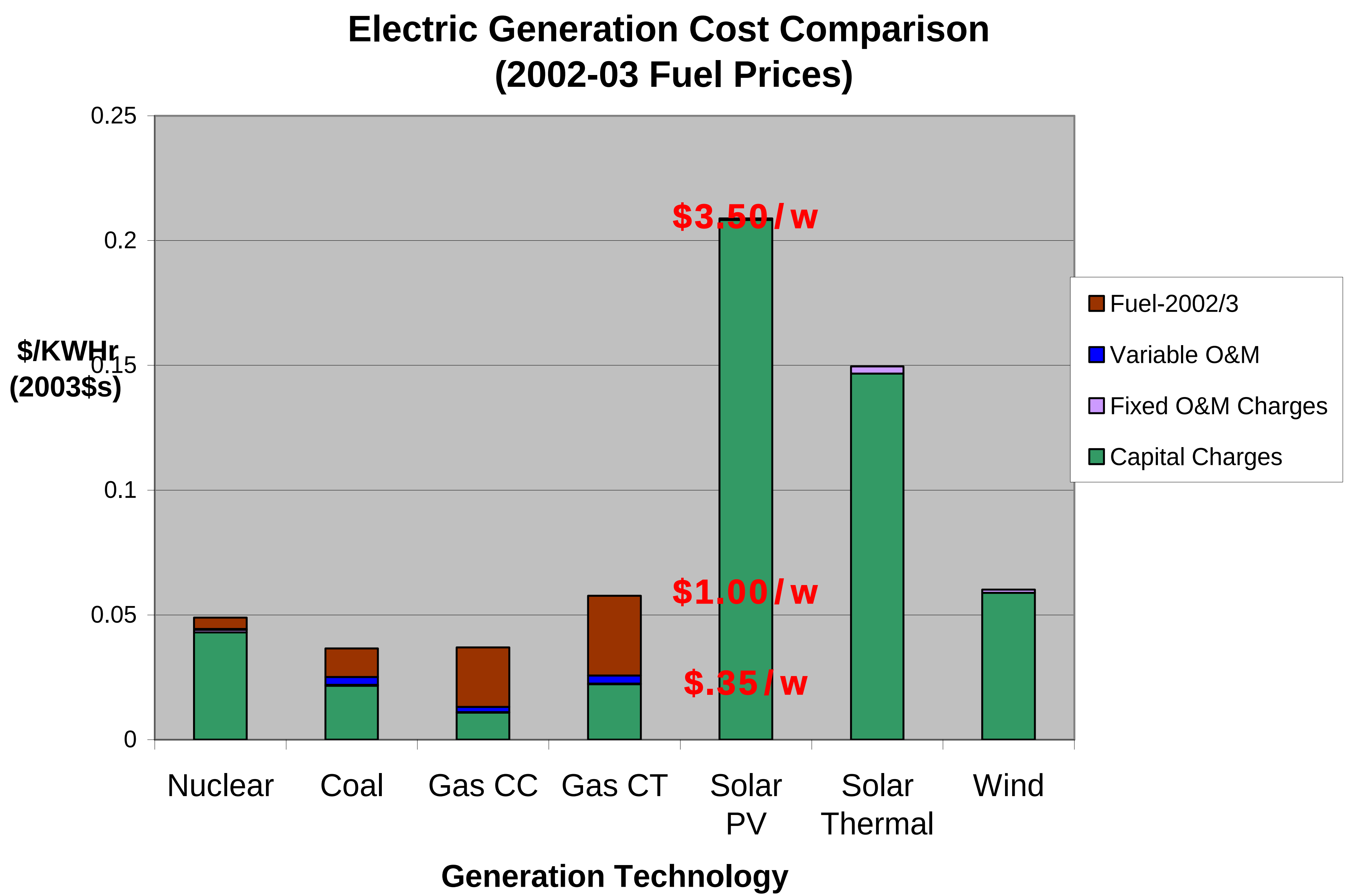
The VALUE OF DEVELOPING NEW ENERGY TECHNOLOGY

(Present Discounted Costs to Stabilize the Atmosphere)



Minimum Cost Based on Perfect Where & When Flexibility Assumption. Actual Cost Could be An Order of Magnitude Larger.

Battelle Pacific
Northwest Laboratories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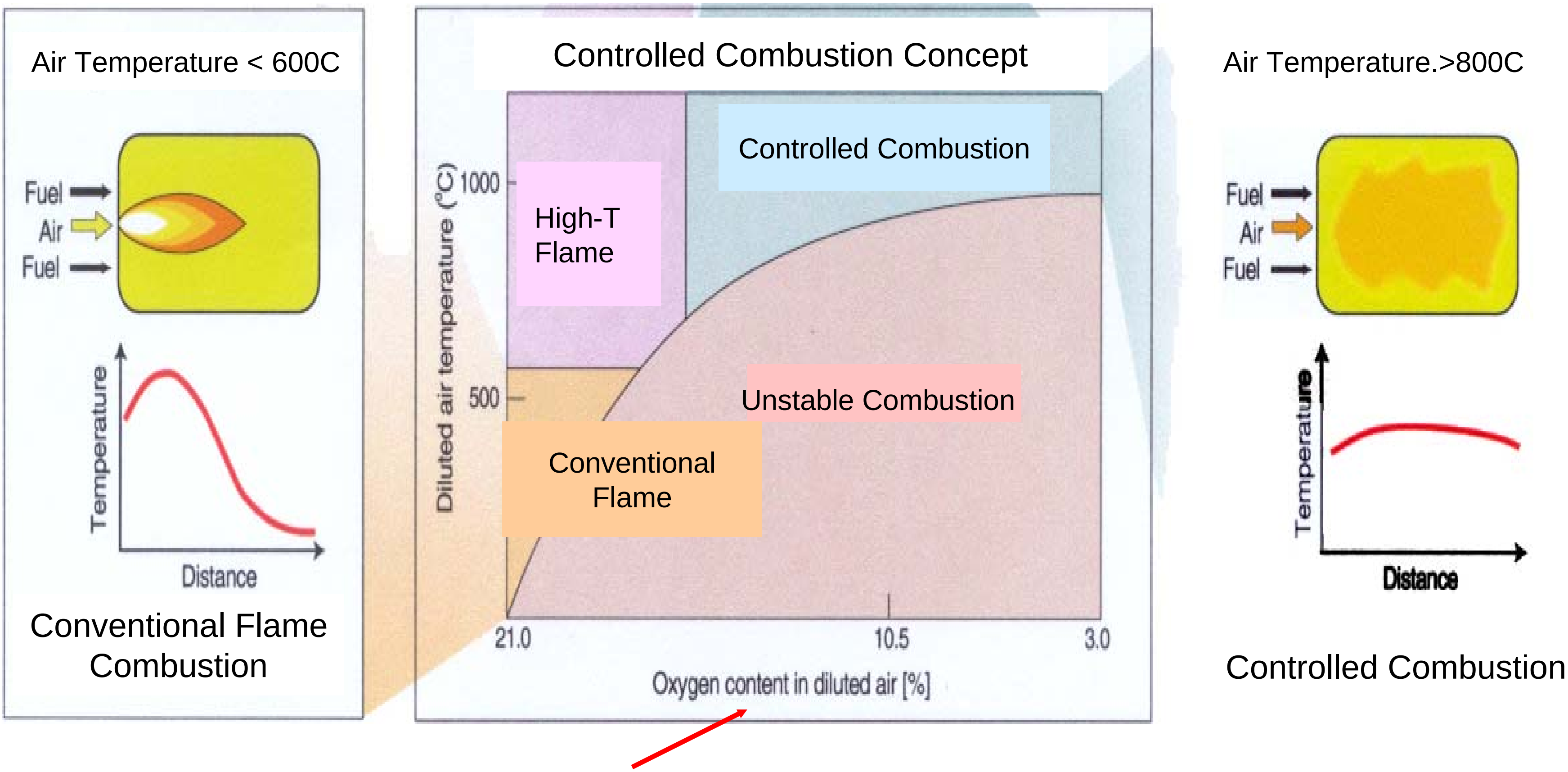
Fixed O&M Charges
Capital Charges
Nuclear
Coal
Gas CC
Gas CT
Solar PV
Solar Thermal
Wind
Generation Technology

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.

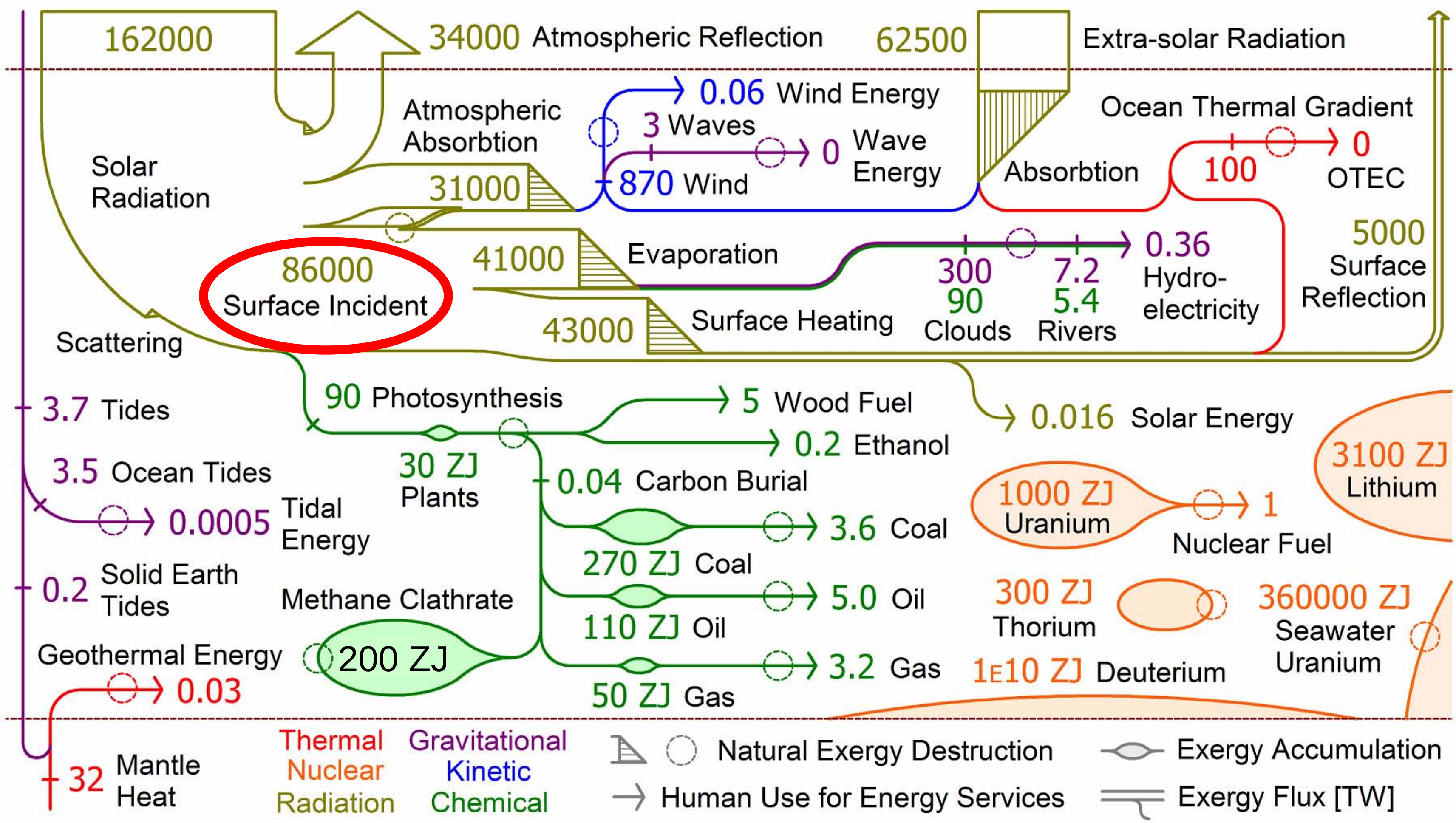
Controlled Combustion

The Concept:



Dilution by combustion products, N_2 or CO_2

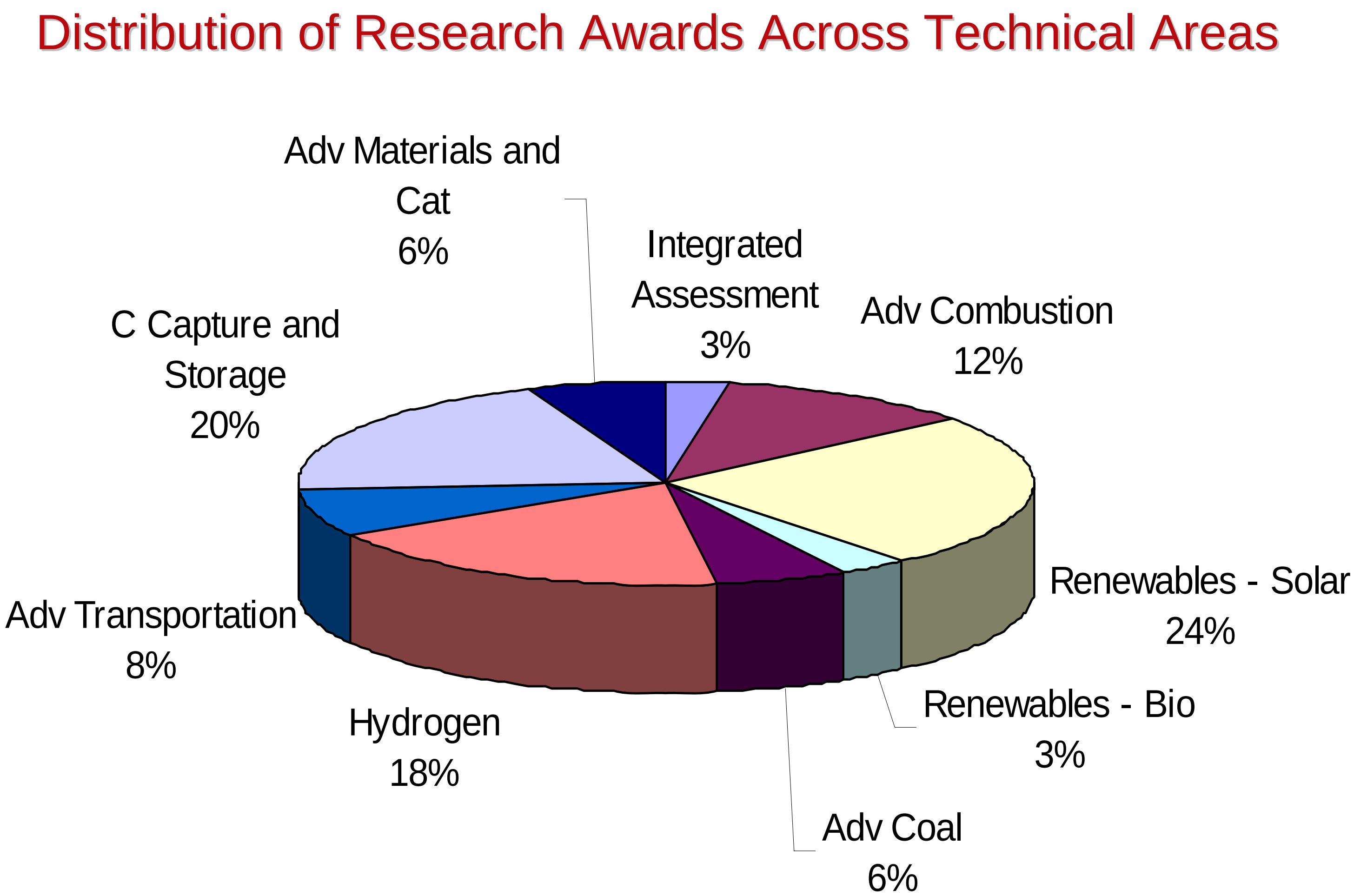
Exergy Flow of Planet Earth (TW): Solar Resource



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

(1 ZJ = 10^{21}J)

GCEP Research Funding



Total Research Funds: $61.2M