Energy for Sustainability

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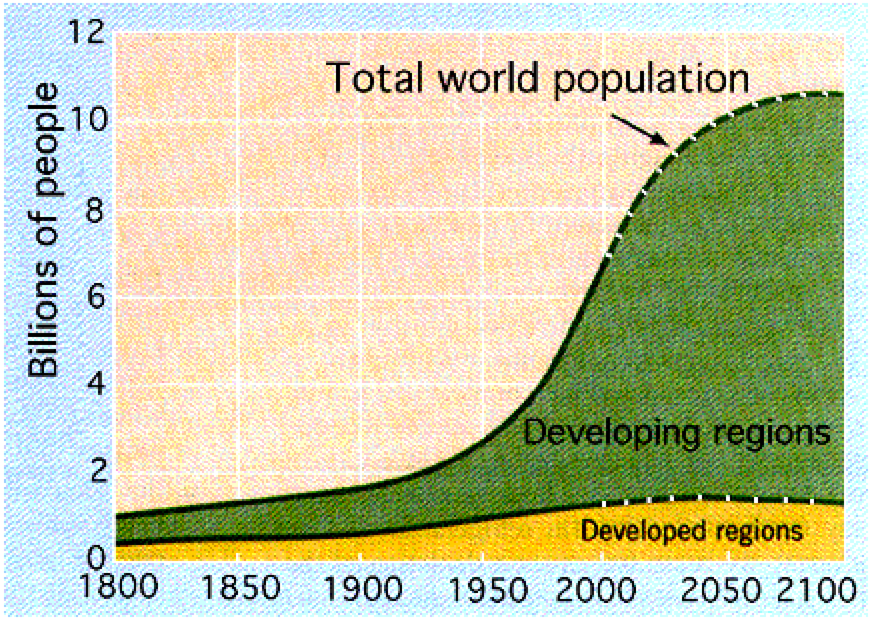
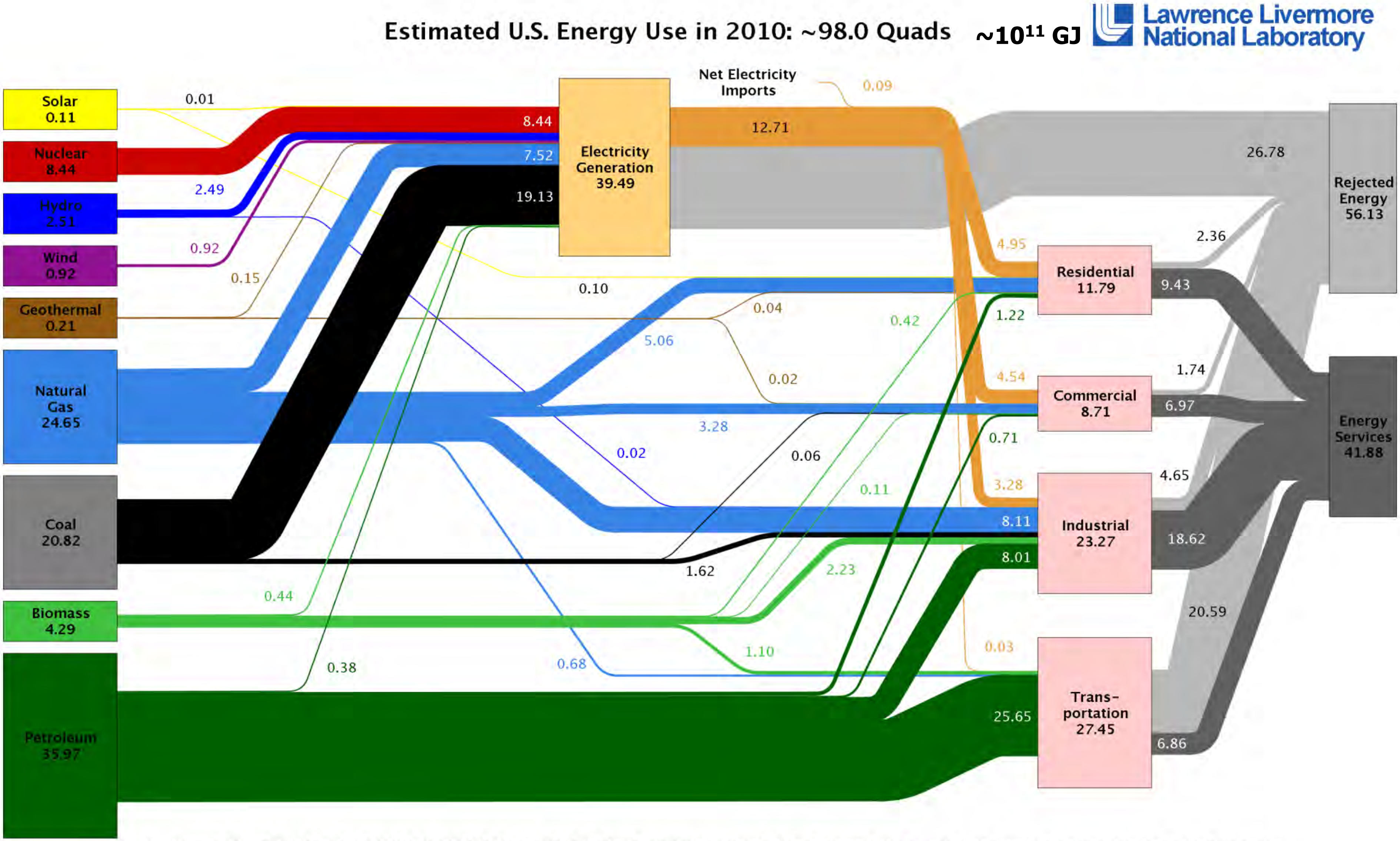
World Population

- Currently we need to design Food + Fuel supply for **7 10^9 people**
- Over next 50 years, increase the supply to support **10.5 10^9 people**



(World Populations: Fundamentals of Growth, 1990, gumption.org)

Energy Use in the United States



Source: LLNL 2011. Data is based on DOE/EIA-0384(2010), October 2011. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for hydro, wind, solar and geothermal in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." (see EIA report for explanation of change to geothermal in 2010). The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Energy Use in the United States

1. Electricity → Too much CO_2 emission

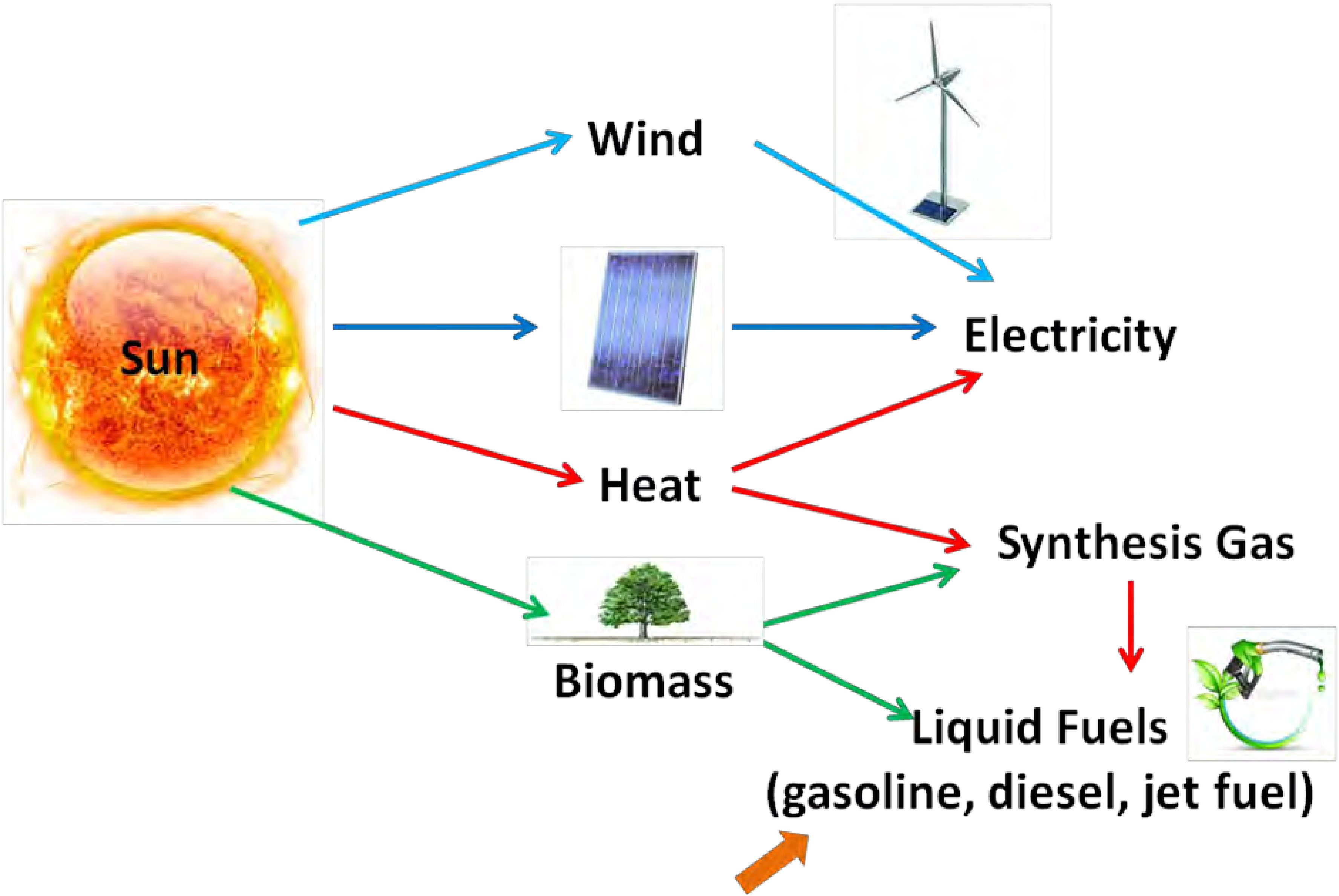
2. Natural Gas → Plenty from Gas Shales
(Some environmental concerns)

3. Petroleum → Most painful import!

$4.7 \quad 10^9$ barrels/year

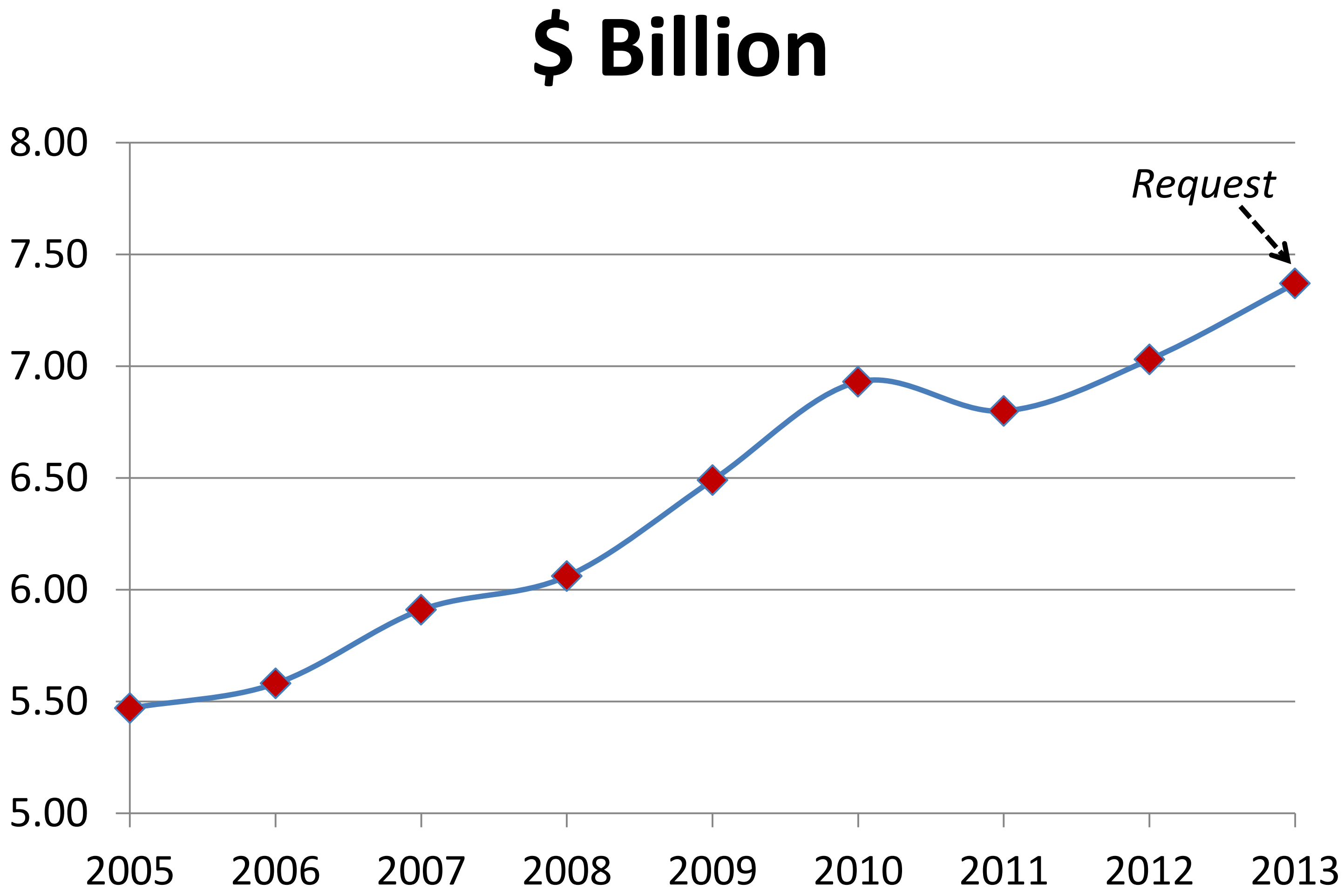
= **$460 billion/year**

One Sustainable Source of Energy



Progress in this area will have an immediate impact

National Science Foundation Budget



Merit Review Process

Steps 1-3

- Proposal Preparation and Submission
- 3 Months

Steps 4-7

- Proposal Review and Processing
- 6 Months

Steps 8-9

- Award Processing
- 1 Month

1 Opportunity Announced

2 Proposal Submitted

3 Proposal Received

4 Reviewers Selected

5 Peer Review

6 Program Officer Recommend-ation

7 Division Director Review

8 Business Review

9 Award Finalized

Merit Review Criteria

- What is the **intellectual merit** of the proposed activity?
  - Is the proposed research potentially **transformative**?
- What are the **broader impacts** of the proposed activity?
  - Advance discovery and understanding while promoting teaching, training and learning
  - Enhance infrastructure for research and education
  - Broad dissemination to enhance scientific and technological understanding
  - Benefits to society
  - Broaden participation of underrepresented groups

Selected Programs related to energy research:

1. **Sustainable Energy Pathway**

2. **Emerging Frontiers in Research and Innovation**

   Photosynthetic Biorefineries

3. **Energy for Sustainability (ongoing)**

Sustainable Energy Pathways
(A part of SEES Portfolio)

National Science Foundation

Science, Engineering, and Education for Sustainability (SEES)

To advance science, engineering, and education to inform the societal actions needed for environmental and economic sustainability and sustainable human well-being

Support interdisciplinary research and education that can facilitate the move towards global sustainability

Build linkages among existing projects and partners and add new participants in the sustainability research enterprise

Develop a workforce trained in the interdisciplinary scholarship needed to understand and address the complex issues of sustainability

GOALS

Fiscal Year 2012 Priorities

- Advance a clean energy future
- Nurture the emerging SEES workforce
- Expand research, education, and knowledge dissemination
- Develop interdisciplinary research networks
- Engage with global partners

Tremendous opportunity to build on NSF strengths and efforts

Current SEES Portfolio

Currently Active

SEP
Sustainable Energy Pathways

CNH
Coupled Natural Human Systems

SRN SEES
Sustainability Research Networks

RCN SEES
Research Coordination Networks

PIRE SEES
Partnerships for Int. Rsrch & Edu

SEES Fellows
Preparing New Researchers

WSC
Water Sustainability and Climate

OA
Ocean Acidification

Past – not available

EASM
Modeling Earth Systems

DBD
Dimensions of Biodiversity

CCE
Climate Change Education

Common SEES Solicitation Requirements

Must be interdisciplinary by design

- Proposals fundable by core program of directorates not suitable.
- Integration of multi-disciplinary parts is important

Must promote interdisciplinary education & training

- Integrating multi-disciplinary education into core curriculum
- Enhancing cross disciplinary interaction
- Creation of infrastructure for multidisciplinary research
- Enhancing public's understanding of sustainable energy future

Must go beyond just creating technologies – need to consider social, economic, and environmental aspects

- Proposals require only consideration, not in-depth treatment.
- Depth of treatment depends on proposal scope

Sustainable Energy Pathways

NSF 11-590

Amount

$34M for 15 -20 awards

Awards

Up to $500K/year

Up to 4 years

Requirements

At least 3 PIs (one lead, 2 co-PIs)

Represents 2 or more disciplines

Restrictions

Max 3 proposals per organization

Max 1 proposal per PI, Co-PI, Senior personnel

To develop efficient pathways towards sustainable energy, from starting points to ending points, via a systems approach in the priority areas of

- Sustainable Energy Harvesting, Conversion, and Storage
  - Energy harvesting and conversion
  - Energy storage solutions
  - Critical elements and materials
  - Nature inspired processes
  - Reducing carbon intensity
- Energy Transmission, Distribution, Efficiency, and Use
  - Transmission and distribution
  - Energy efficiency and management

Due Date, Feb 01, 2012

SEP Requirements and Review Criteria

The extent to which the proposal articulates SEP vision

- Embraces the overarching theme of sustainability,
- Develops and integrates scientific knowledge & technological innovation, with environmental, societal, & economic aspects.

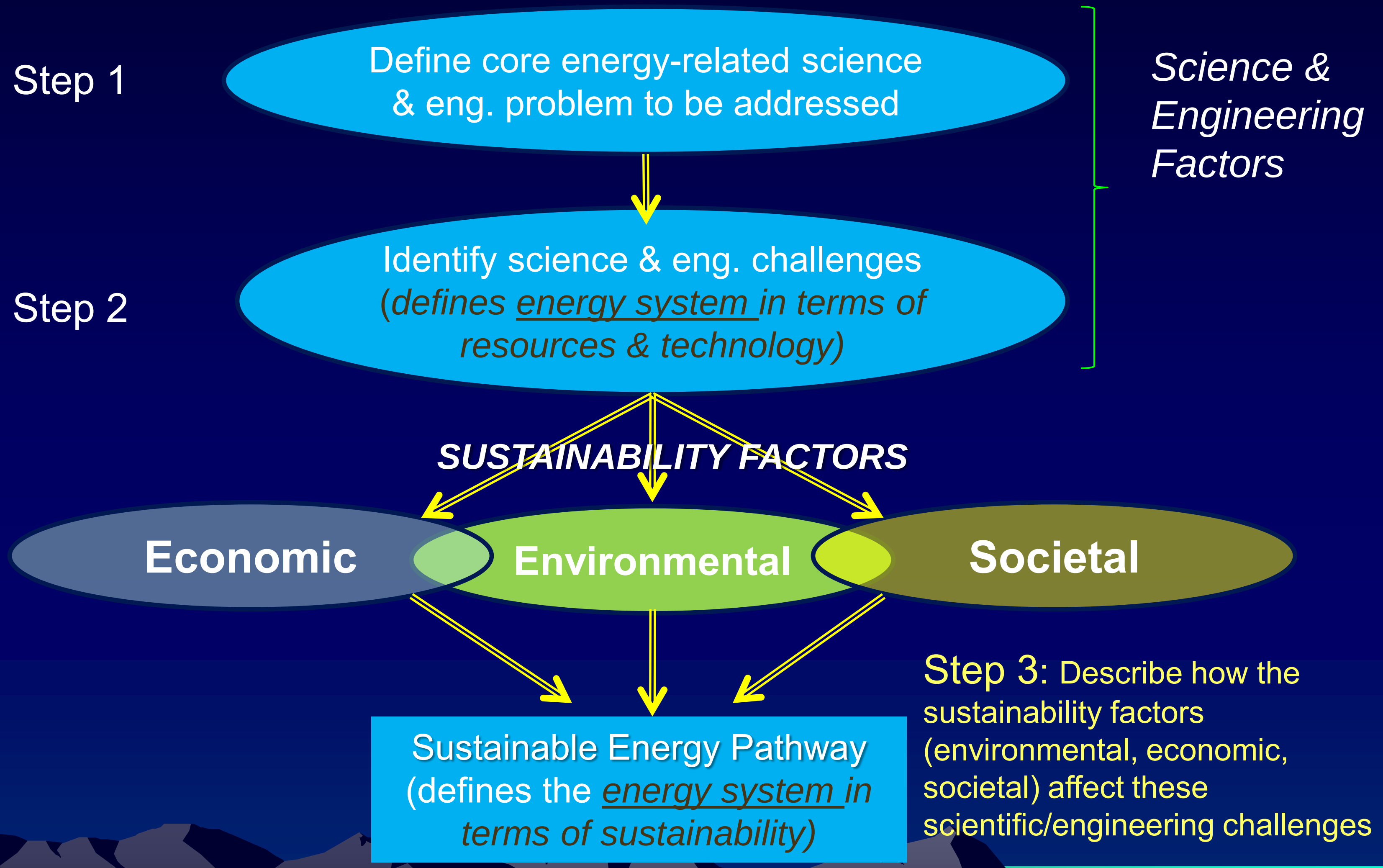
Synergistic engagement of multiple disciplines

As reflected in the research plan, expertise/roles of PIs, and the project management plan

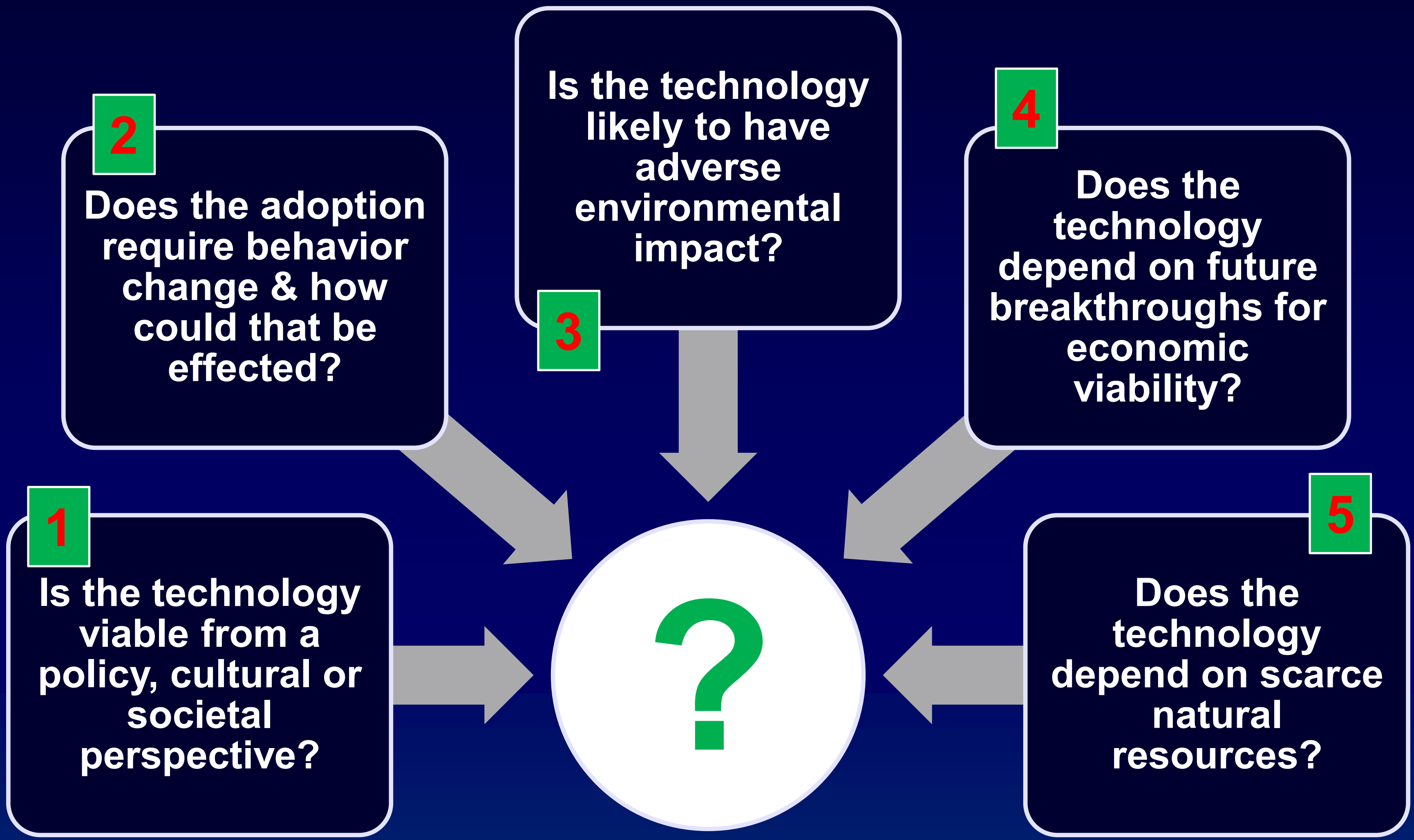
Integration of education & workforce development in research

As reflected in the potential effectiveness and impact in educating students and promoting public understanding of sustainable energy

Steps for Preparing a SEP Proposal



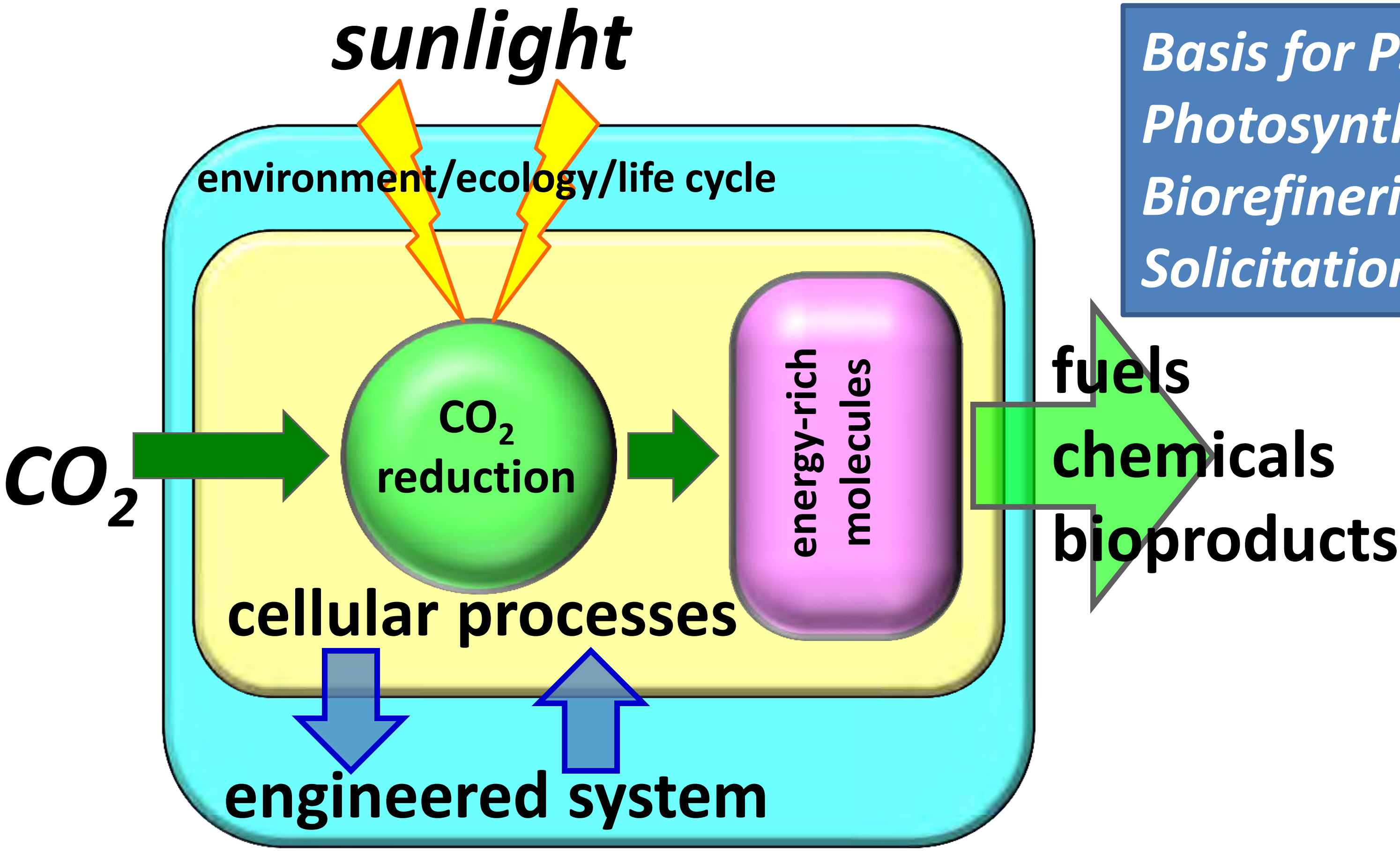
Key Considerations in SEP Vision



EMERGING FRONTIERS IN RESEARCH AND INNOVATION 2012 (NSF 11-571)

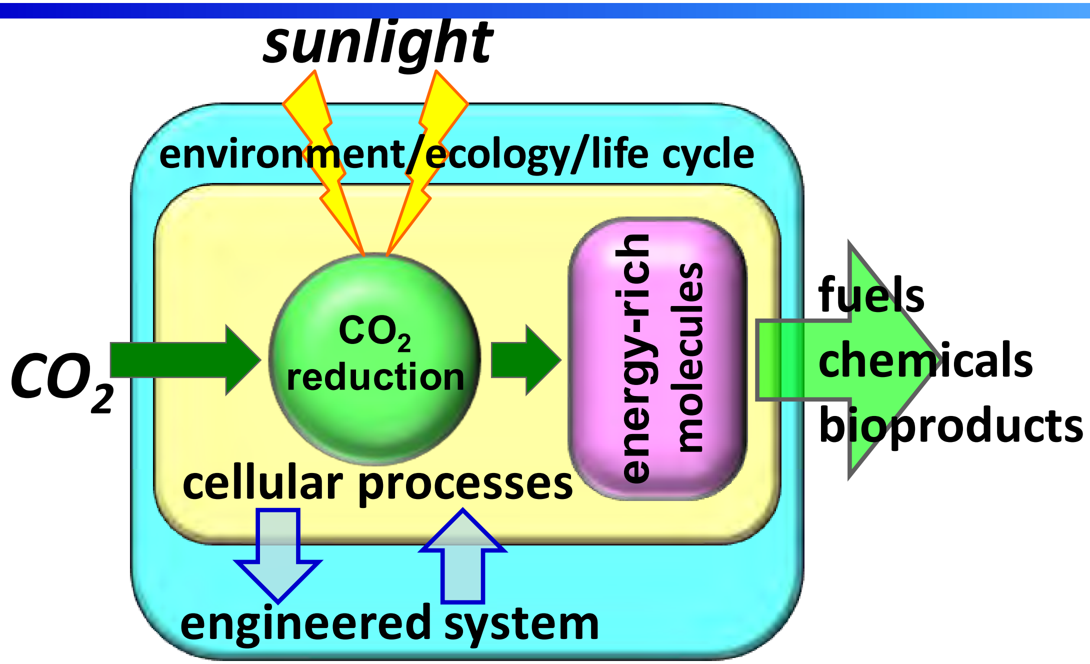
Photosynthetic Biorefineries

Basis for PSBR
Photosynthetic
Biorefineries
Solicitation



EFRI-PSBR

Upscaling Photobiological Processes: the Sustainable Photosynthetic Biorefinery



Objective: Establish the fundamental principles which efficiently deliver light and CO_2 to photosynthetic micro-organisms in scalable platforms for the sustainable & flexible production of fuels, chemicals, and bio-products

Expected Transformative Impact

- New paradigms for the rational/sustainable design and upscaling of photosynthesis-based, bio-manufacturing platforms that use sunlight and atmospheric CO_2 as inputs
- Advances in the basic science of flexibly transforming atmospheric CO_2 to complex and/or energy-rich molecules through metabolic processes
- Novel engineered systems for the emerging bio-economy

Teams and Submissions Must Address All 5 PSBR Elements

- Based on Fundamental Knowledge Generation and Based on Micro-organisms
- Innovative Modes of Delivery of Separated, Energy-Dense Compounds, preferably Fuels
- Multi-Scale Systems Approach at All Levels from Feed Development to Product Delivery
- Process Must be Demonstrably Scalable and Economic
- Process must be Sustainable in all Aspects

Award Size and Information

- Team Proposals Only:
  - 3 or more PIs
- Award size will depend on the type of research program proposed
- Up to 4 years in duration
- Up to $2M spread over 4 years (direct plus indirect cost)
- Up to $31M in FY 2012 for entire competition, pending the availability of funds

3. Energy for Sustainability program

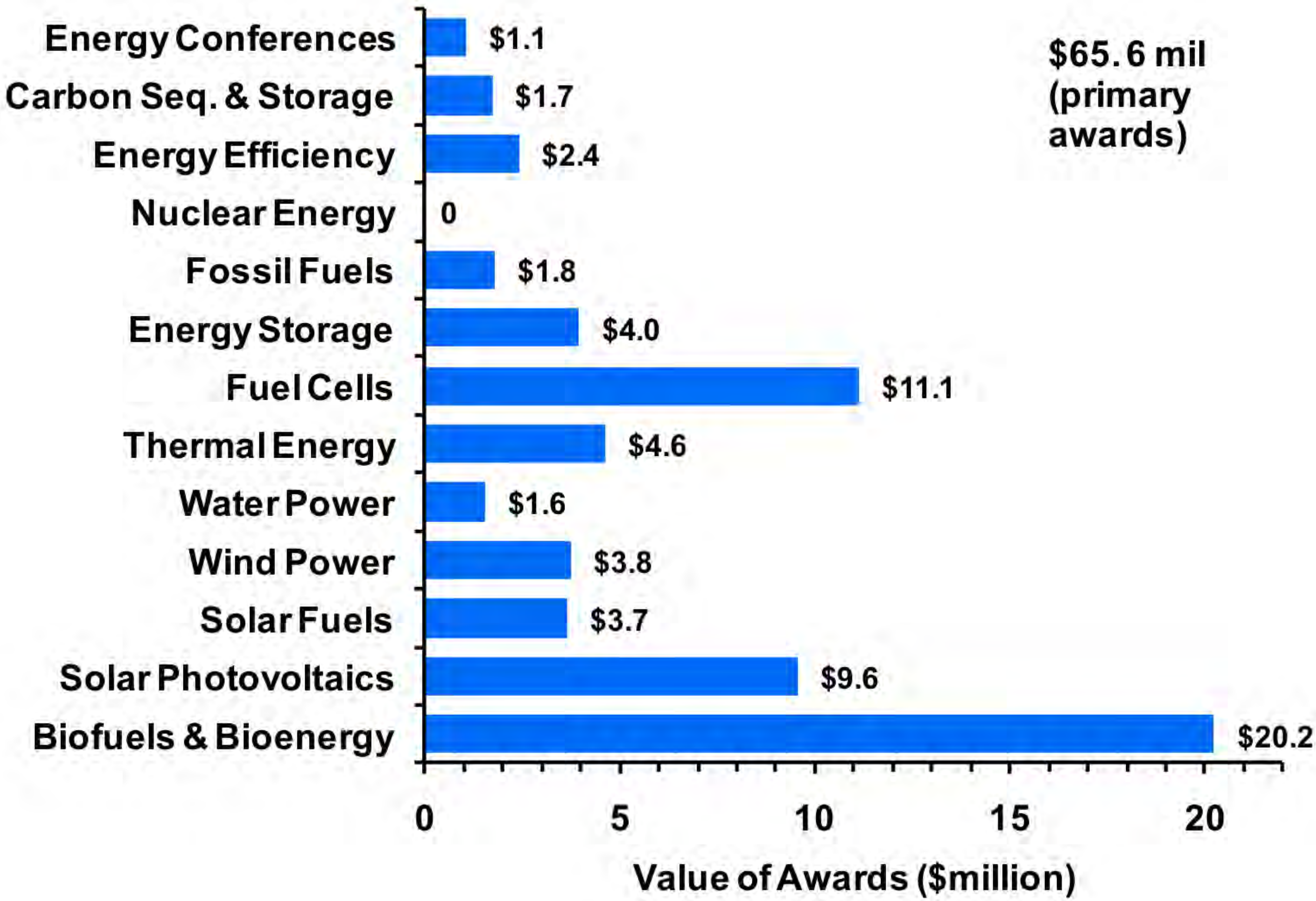
Within

Chemical, Bioengineering, Environmental, and Thermal Systems (CBET) Division

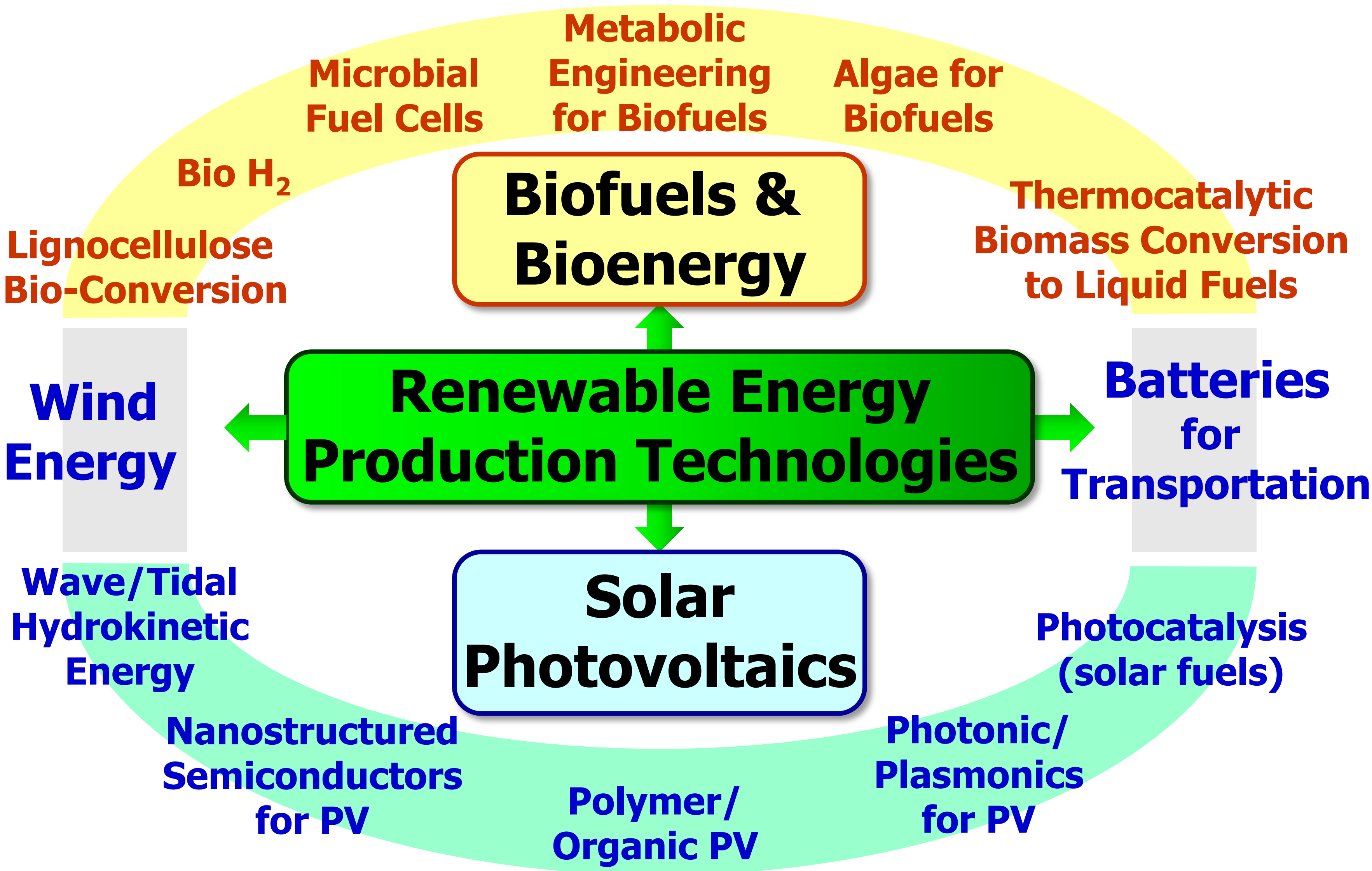
CBET Energy for Sustainability Program support:

- Fundamental engineering research and education that will enable innovative processes for the sustainable production of electricity and transportation fuels. The processes must be environmentally benign, reduce greenhouse gas emission, and utilize renewable resources.

CBET Clean Energy Current Awards By Technology



ENG/CBET Energy for Sustainability Program: Current Emphasis Areas



CBET Energy for Sustainability Program Current Investments: Biofuels & Bioenergy

Plant biomass conversion

- Pretreatment & enzymes
- Thermal-catalytic conversion to liquid hydrocarbons

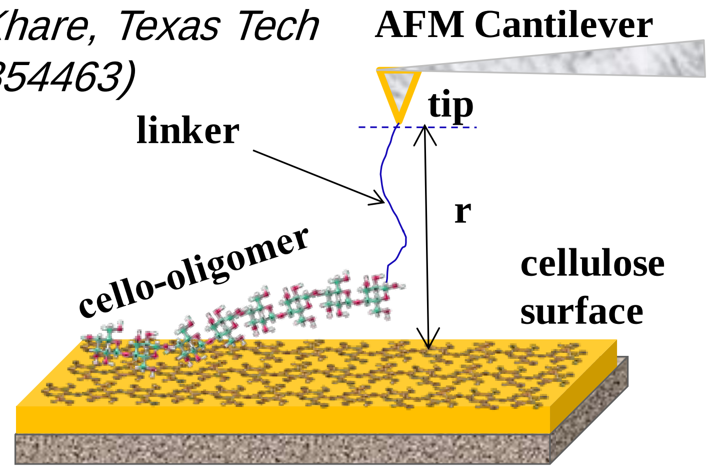
Advanced biofuels

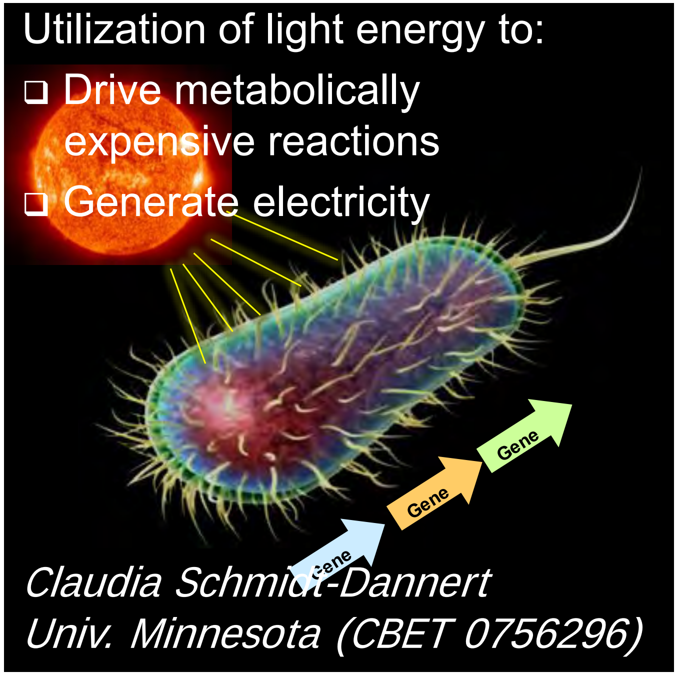
- Biofuels via metabolic engineering
- Energy-rich metabolites from algae
- Fuels from CO_2

Bioenergy

- Microbial/enzyme fuel cells
- Direct carbohydrate fuel cells
- Hydrogenase water-splitting to H_2

Rajesh Khare, Texas Tech (CBET0854463)





CBET Energy for Sustainability Program
Current Investments: Wind & Wave Energy

Modeling & simulation (wind)

- Turbine aerodynamics & control
- Wind turbine farm interactions with atmospheric boundary layer

Advanced concepts (wind)

- Gas-expanded lubricants
- Piezoelectric systems
- Floating structures
- Tethered systems

Wave/Tidal/Hydrokinetic

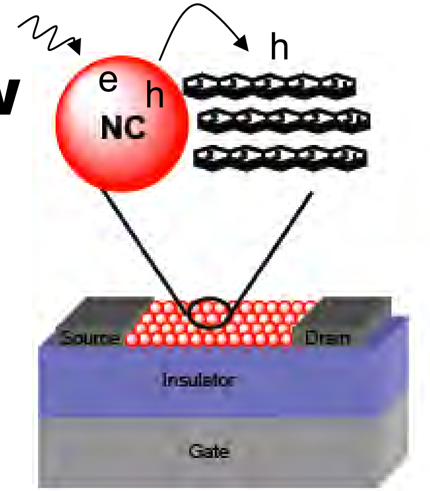
- Bio-inspired systems

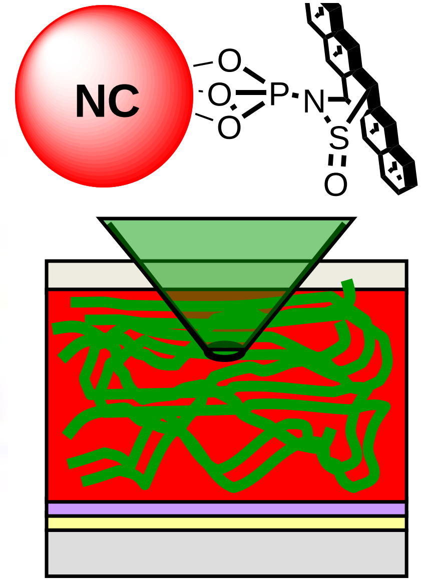
Marilyn Smith, Georgia Tech (CBET 0731034)
Advances in Wind Turbine Analysis and Design for Sustainable Energy

NSF Engineering Investments in Solar Photovoltaic (PV) Materials & Devices

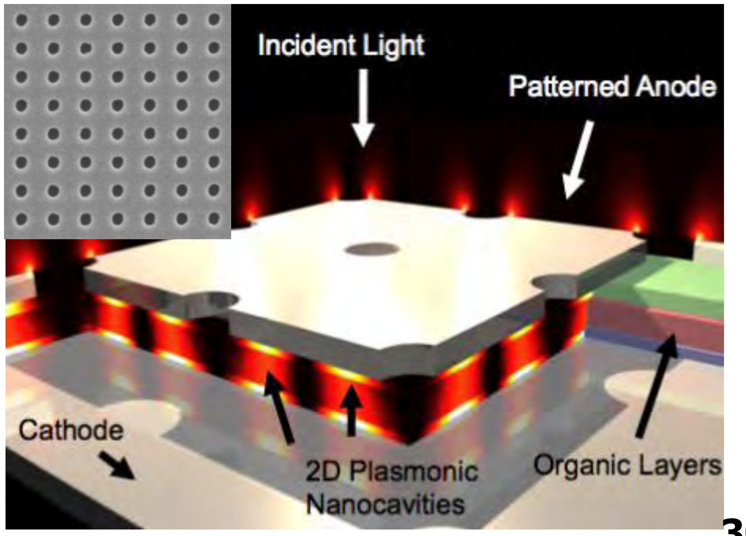
Innovative integration of new materials & devices for 3rd generation PV

- Nanowires, nanotubes
- Nanocrystalline/thin film
- Earth-abundant materials
- Multi-junction/hybrid stacks
- Plasmonic structures
- Photonic structures
- Dye-sensitized solar cells
- Polymer-based photovoltaics
- Self-assembled systems
- Biomimetic/bioinspired systems





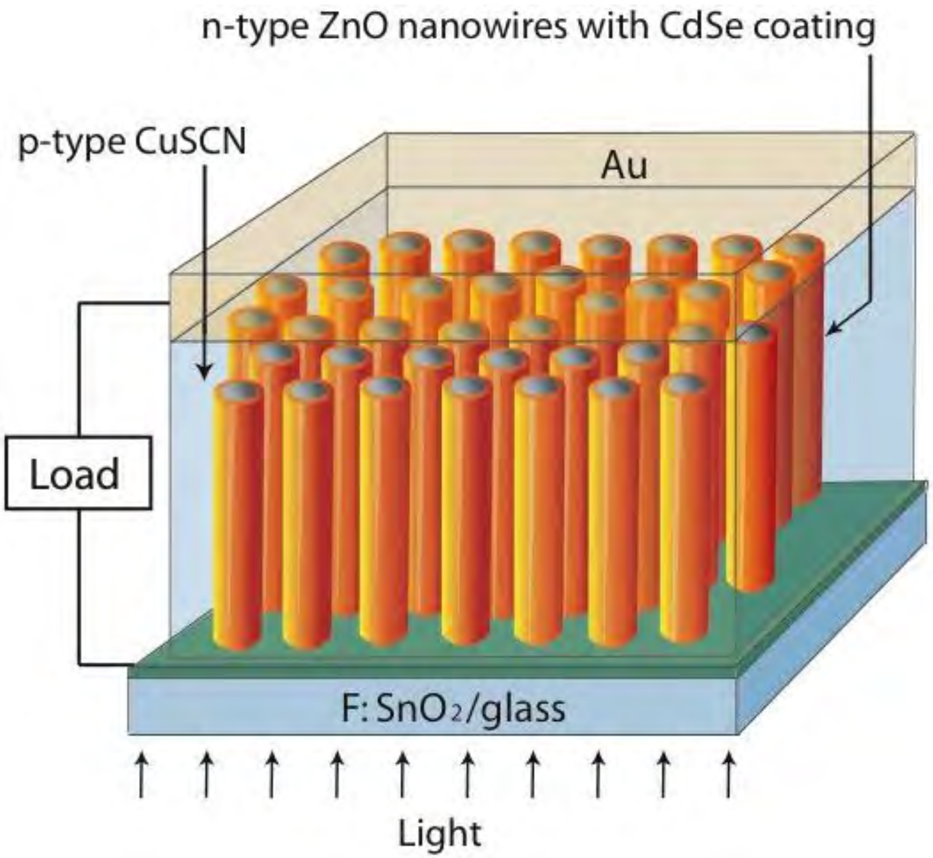
Cherie R. Kagan
Univ. of Pennsylvania



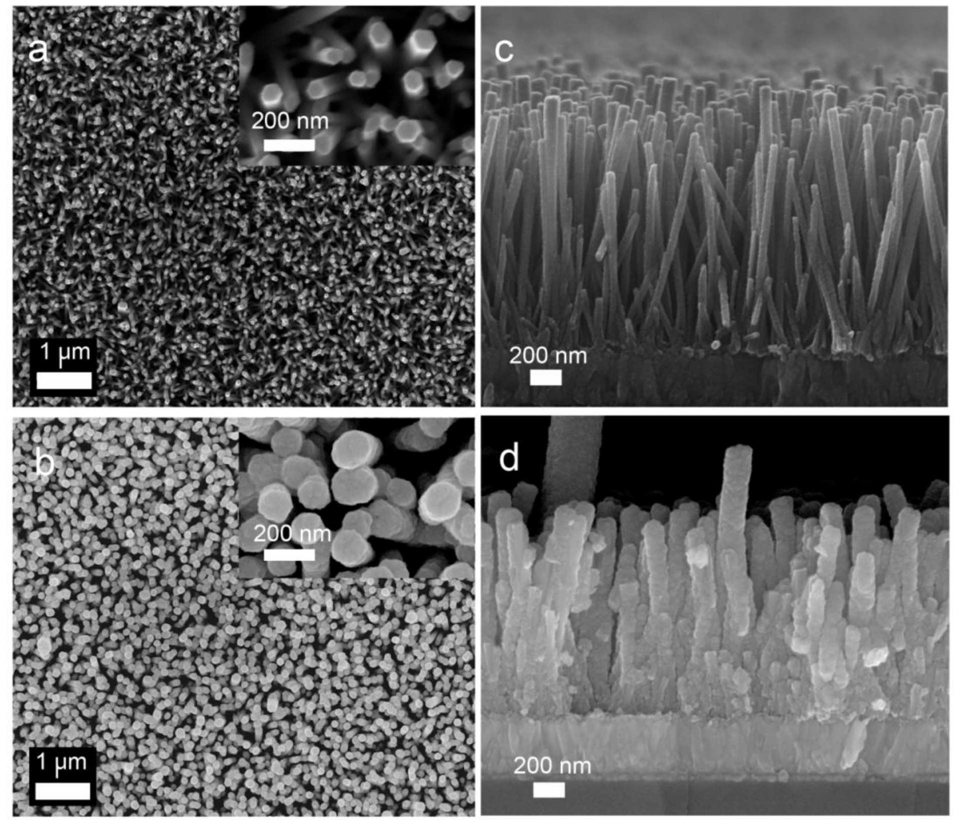
Russel Holmes,
University of Minnesota

CAREER: Interfaces and Their Effect on Charge Transfer in Extremely Thin Absorber Solar Cells

Jason B. Baxter, Drexel University, Award # 0846464



Extremely thin absorber (ETA) solar cells have been fabricated. Light is absorbed in the CdSe coating, where the photoexcited electron is injected into the ZnO and the hole is injected into the CuSCN.

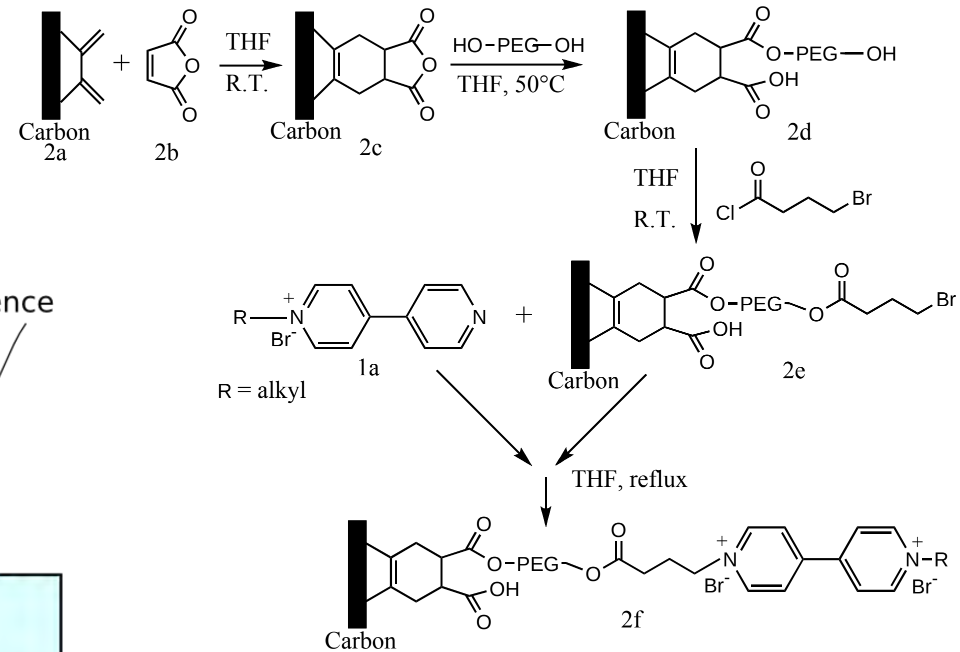


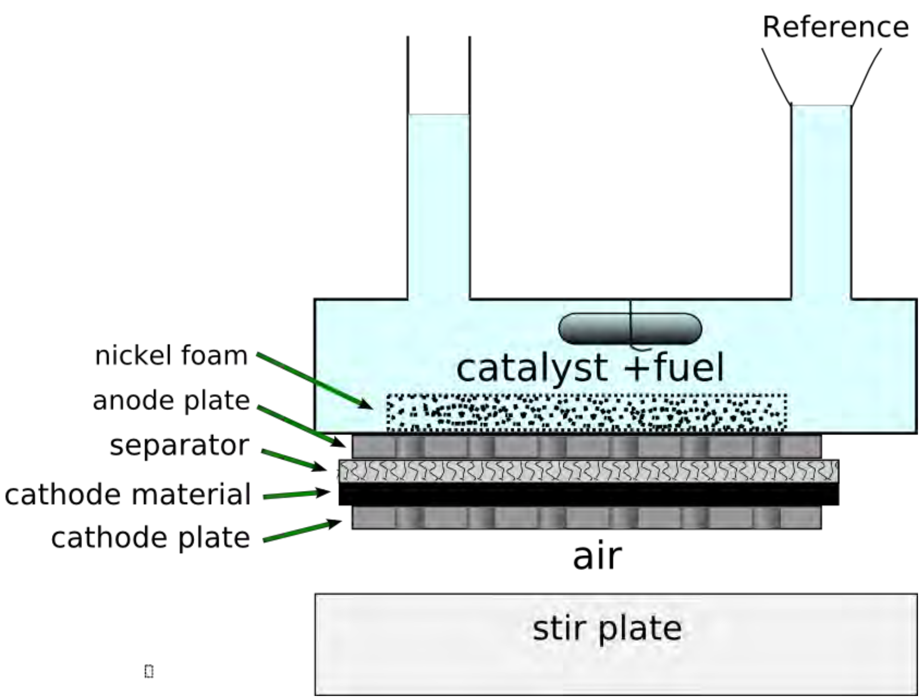
Scanning electron micrographs of (top) bare ZnO nanowire array, and (bottom) nanowires conformally coated with CdSe. 40 nm CdSe thickness is optimal for efficient charge separation in ETA cells.

Viologen-Based Oxidation of Carbohydrate Fuels for a New Type of Low-Temperature Fuel Cell

Dean Wheeler, Brigham Young University, CBET- 1034547

Viologen-based catalysts can be used to make a sugar-powered alkaline fuel cell with high efficiency compared to enzymatic types.

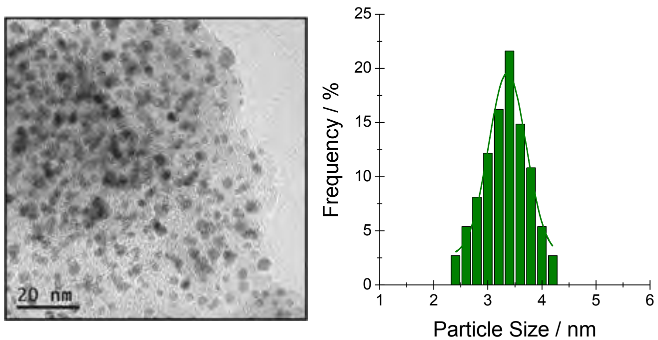




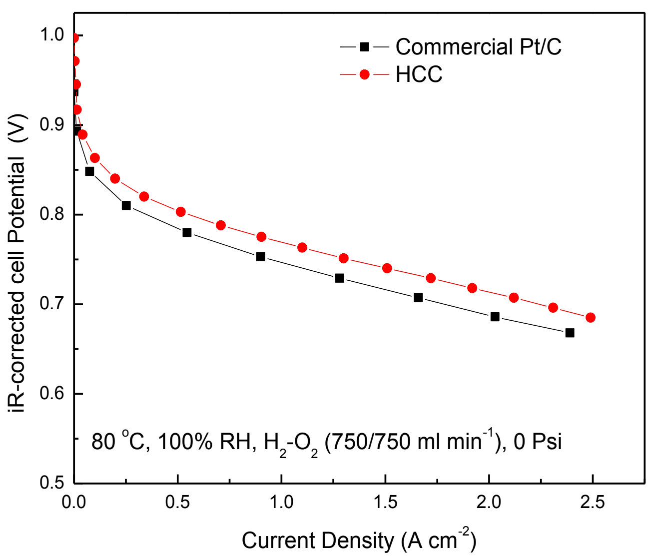
Developed new schemes to covalently attach the organic catalyst to electrode surfaces, which are currently being tested for electrochemical activity.

Development of Ultra-low Loading Platinum Alloy Cathode Catalysts for PEM Fuel Cells

Branko N. Popov, University of South Carolina, CBET- 0966956



←Hybrid cathode catalyst (HCC). Showing a uniform particle size distribution over the carbon composite catalyst (CCC) support.



← Performance comparison of commercial Pt/C and HCC catalysts. The HCC catalyst shows better fuel cell performance than the commercial Pt/C catalyst due to (i) contribution from the carbon composite catalyst support and (ii) the formation of Co-core Pt-shell structure particles.

Anode: Commercial Pt/C (0.1 mg_{Pt} cm^{-2})
Cathode: HCC-1 and commercial Pt/C (0.1 mg_{Pt} cm^{-2})
Membrane: Nafion® NRE 212

(a)

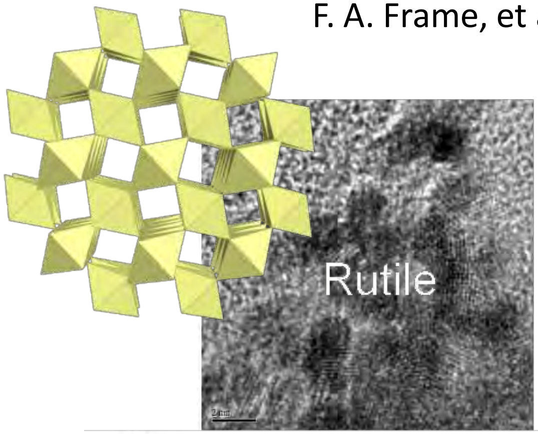
(b)

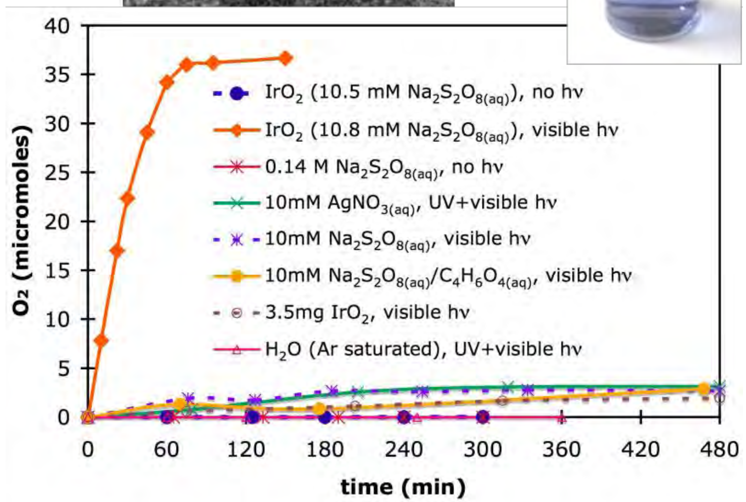
Simulation results of the effect of catalyst layer structure (Pt loading & porosity) on the peak power density for the cathodes employing (a) 20% Pt/C & 35% Nafion® and (b) 30% Pt/C & 35% Nafion®

Modular Construction of Nanostructured Catalysts for Solar Hydrogen Generation from Water

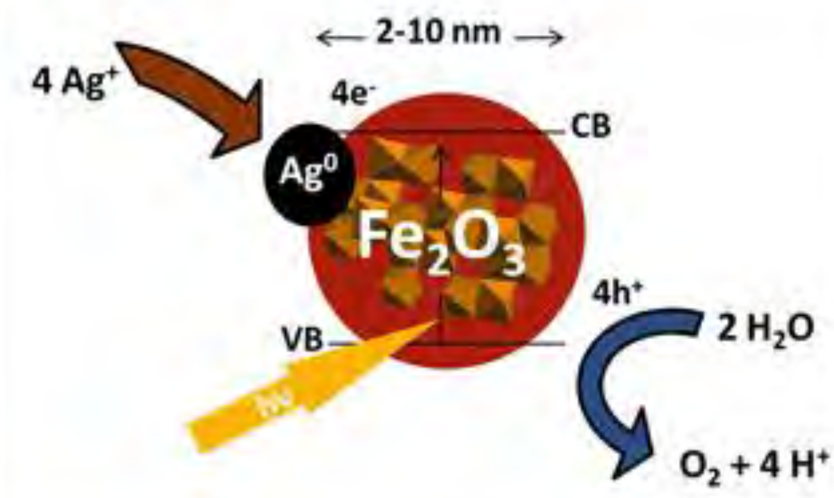
Frank E. Osterloh, University of California, Davis, CBET 0829142

F. A. Frame, et al. JACS 2011





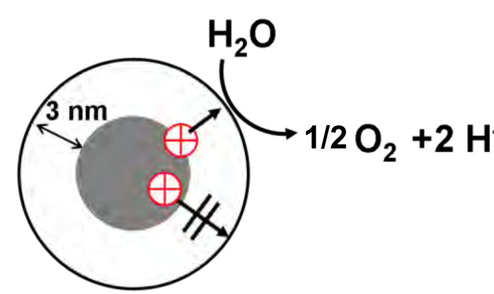
T. K. Townsend, EES 2011



Fraction of extractable holes to total holes

$F = V_{shell} / V_{total}$

F = 14.26% for Bulk-Fe_2O_3
F = 35.6% for Sonic-Fe_2O_3
F = 100% for Nano-Fe_2O_3



Nanoscaling activates iridium dioxide for photocatalytic oxygen formation from water

Nanoscaling activates alpha-iron oxide for photocatalytic oxygen formation from water

Measurements and Modeling of Multiple Wake Interactions in Large Wind Farms

Barthelmie/Pryor, Indiana University, Award # 1067007

Objectives

i) Reduce uncertainty in modeling wind turbine wake losses
ii) Optimize power output and layout for large wind farms

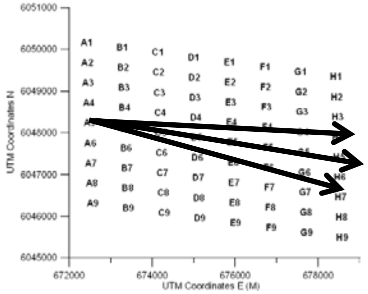
Highlights

For large on- and offshore wind farms:
i) Wind farm measurement with lidar
ii) Access and analyze wind farm data
iii) Develop new wind farm model

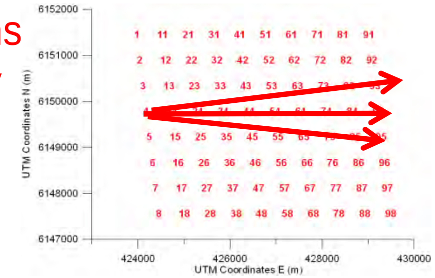
Parameter	Wind farm Δ efficiency from average	Range
Wind speed	+1.73 to 2.39% for 1 ms^{-1} increase	U=5-15 ms^{-1}
Turbine spacing	+1.06 to 1.49 % for 1 D spacing increase	4-20 D, U=5-15 ms^{-1}
Turbulence intensity	0.98 to 1.40% for 1% increase	5-13% TI, U=7-8 ms^{-1}
Atmospheric stability	-8.13 to 9.71% over range of stabilities	U=5-15 ms^{-1}

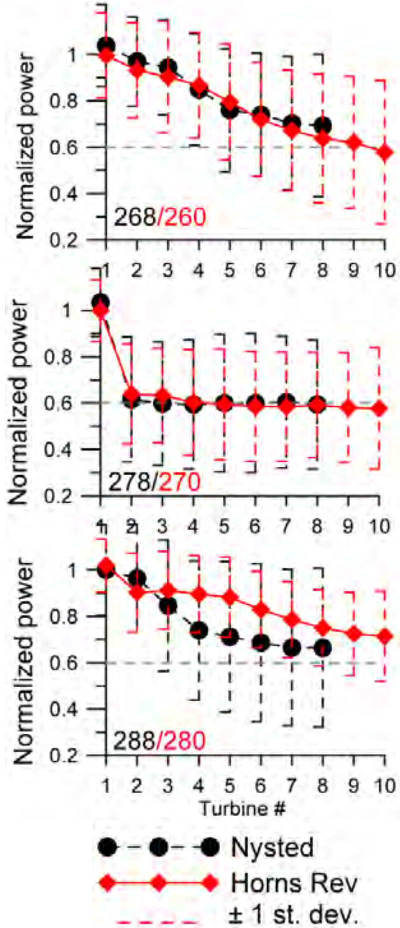
For a narrow range of wind speeds/directions:

Nysted 10.5 D



Horns Rev 7 D

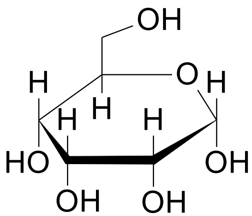




Reference: Barthelmie, Hansen & Pryor 2011. Submitted to IEEE Special Issue on Marine Energy and Environments Sep 2011. ID 0176-SIP-2011-PIEEE.

Towards Sustainable Hydrocarbon Biorefineries: Deoxygenation of Biomass Oxygenates to Hydrocarbons via Methane

Sandun D. Fernando, Texas A&M university, CBET- 0965772

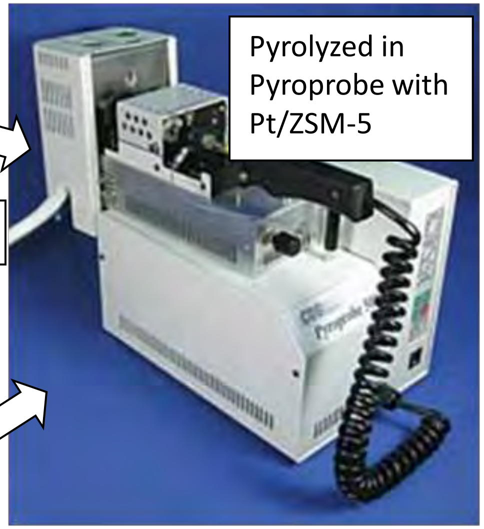


C^{12} glucose/ C^{13}glucose

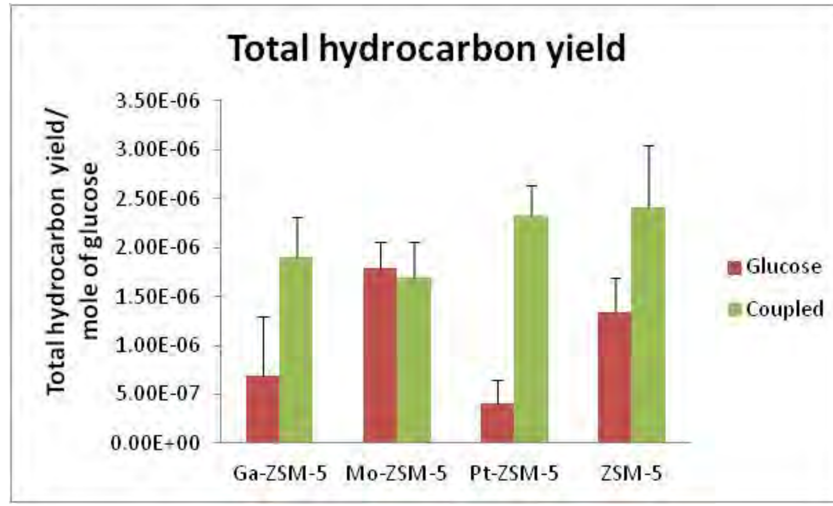
+

CD_4 / CH_4

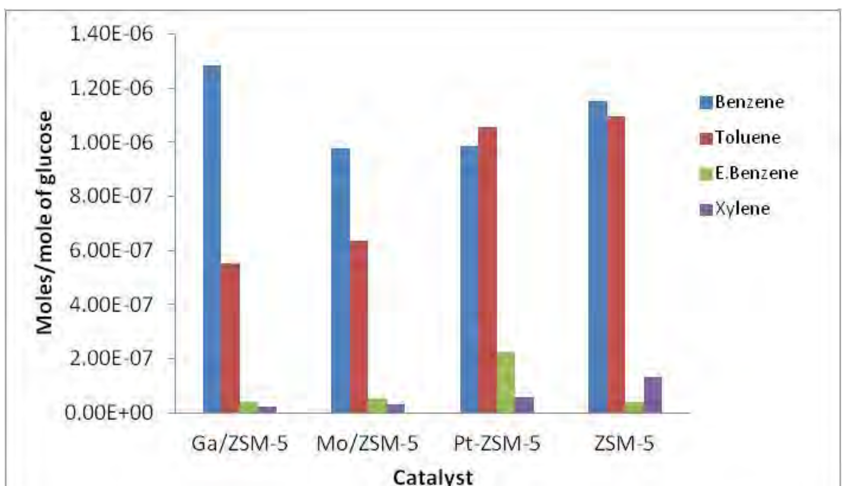
Dutarized / Regular methane



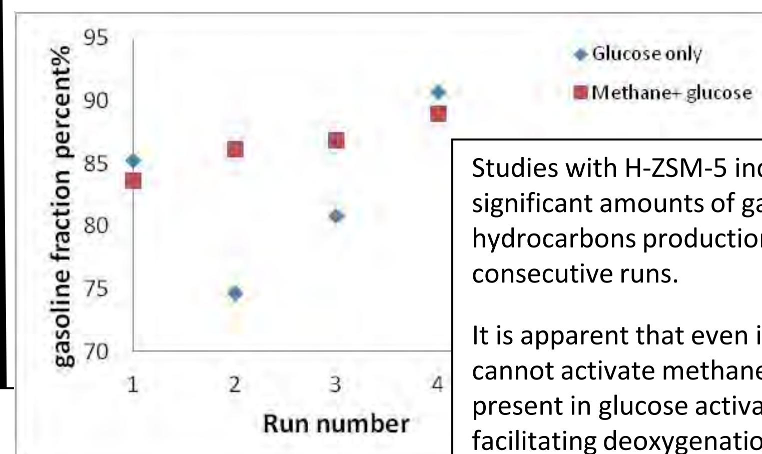
Pyrolyzed in Pyroprobe with Pt/ZSM-5



Mo-ZSM-5 is the best catalyst for deoxygenation of pure glucose. When methane is used as the proton donor for deoxygenating glucose, H-ZSM-5 and Pt-ZSM-5 performed better. The analysis shows that the yield of total hydrocarbons are significantly higher when glucose is catalytically pyrolyzed in the presence of methane.



BTEX yield with metal incorporated ZSM-5 when glucose is pyrolyzed in the presence of methane (BTEX:benzene, toluene, ethylbenzene, and xylene)



Studies with H-ZSM-5 indicate significant amounts of gasoline grade hydrocarbons production in four consecutive runs.

It is apparent that even if H-ZSM-5 alone cannot activate methane, oxygen present in glucose activates methane facilitating deoxygenation inside ZSM-5 .

Energy for Sustainability Program awards:

Thanks for your attention

NSF-funded researchers have won more than 180 Nobel Prizes!