The Sustainable Energy Challenge

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Outline

• the challenges: oil, the economy and carbon dioxide
• what is sustainability?
• sustainable energy alternatives and roadblocks
• UIC Summer Institute on Sustainability and Energy
Controlling the Functionality of Materials for Sustainable Energy
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http://www.annualreviews.org/journal/conmatphys

http://www.americanenergyinnovation.org/
The Problem: Dependence on Imported Oil

Unpredictable supply threatens economy, lifestyle, national security

find alternatives to imported oil
biofuels, electricity, solar fuels

Cost to economy
$350 B/yr at current prices transferred to foreign oil producers

http://tonto.eia.doe.gov/energy_in_brief/foreign_oil_dependence.cfm
The Problem: Greenhouse Gases and Climate Change

2/3 of carbon dioxide emissions come from power plants and autos.

Permanent changes in weather patterns, agricultural networks and coastal geography.

Cost of accommodation may be higher than preventive cost of reducing emissions.
Performance: fossil is cheaper

Sustainable energy technologies are in their infancy. They perform far below their ultimate potential.

Dramatic improvements are needed - incremental tuning of the present state of the art is not sufficient

Breakthroughs needed understand and control materials and chemistry at molecular and nanoscale levels
What is Sustainability?

- Lasts a long time
  - Oil in 1900
  - Coal in 2011

- Does no harm
  - Nuclear electricity: no $CO_2$
  - Ethanol: reduced $CO_2$

- Leaves no change
  - Closed chemical cycle
  - Electricity, hydrogen
Sustainable Next-Generation Energy Technologies

Sustainability Profile
- lasts a long time 😊
- does no harm 😊
- leaves no change 😊

Solar electricity: a fully sustainable energy chain
- manufacture and end-of-life impact must be considered

breakthroughs needed
- lower cost, higher efficiency photovoltaics
- third generation materials and nanostructures
- electricity storage
Carbon Sequestration

**Sustainability Profile**
- lasts a long time
- does no harm
- leaves no change

- emissions
- sequestration

- depletes coal resource
- 100s of years

- breakthroughs needed
  - chemical reactivity with rocks in extreme environments
  - migration through porous rocks
  - geologic monitoring and predictive modeling
  - leakage routes to atmosphere

~ 1000 years
Nuclear Electricity

Sustainability Profile

- lasts a long time
- does no harm
- leaves no change

- emissions
- nuclear waste

- depletes uranium resource 100s of yrs

breakthroughs needed
- materials for extreme environments
- high temperature, high radiation flux
- high corrosivity
- geologic monitoring and modeling

spent fuel 10 000s yrs

usgs
Replace Conventional Oil

- Cellulosic biofuel
  - Solar chemical fuel
  - Lasts a long time 😊
  - Does no harm 😊
  - Leaves no change 😊

- Oil sands and shale, coal to liquid
  - Lasts a long time 😞
  - Does no harm 😞
  - Leaves no change 😞

- Recycles CO₂

Switchgrass ethanol plant

- Cellulosic biofuel: recycles carbon dioxide
- Solar fuel without biology: thermo- or photo-chemistry
- Oil sands and shale, coal to liquid: → 50% more carbon dioxide
  → More pollutants

Breakthroughs needed

Cellulosic breakdown to sugar or fuel
Chemistry of carbon dioxide to fuel
Electrify Transportation

Sustainability Profile
- lasts a long time
- does no harm
- leaves no change

renewable electricity production

renewable hydrogen production

hydrogen storage

breakthroughs needed
- x2-5 higher energy density in batteries
- catalysts, membranes and electrodes in fuel cells

electric motor replaces gasoline engine

tesla motors

battery

catalysts, membranes and electrodes in fuel cells

fuel cell

H2, O2, e-

H2O

E2

H2

H2
Sustainable Energy Enabling Technologies: The Grid

breakthroughs needed
long distance reliable, efficient delivery of electricity
Enabling Technologies: Storing Energy

- Store intermittent solar and wind electricity
- Electrify transportation with plug-in hybrids and electric cars

**batteries:**
30-50x less energy density than gasoline
impossible dream: x10 improvement

**beyond batteries:**
chemical storage + fuel cells = electricity

**breakthroughs needed**
x2-5 increase in battery energy density
x10-20 increase through chemical storage + fuel cells

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- Electrical storage
- Electro-chemical storage
- Energy Storage Density
  - Hydrogen compounds (target)
  - Methanol
  - Chemical + fuel cells = electricity
  - Ethanol combustion
  - Gasoline

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**Energy/weight**
- MJ/kg system

**Energy/volume**
- MJ/L system
sustainable energy requires controlling complex, functional, high tech materials and chemistry
We are at the dawn of a new era

• build materials with atom-by-atom chemical precision
• predict behavior of materials that have not been made
• design new materials and chemistries for specific tasks

breakthroughs to next-generation sustainable energy technologies are within reach
Complexity Equals Functionality

Levels of Complexity

- compositional
- structural
- functional unit
- architectural
- connecting
- functional units
- temporal
- connecting
- sequential steps
- many interacting degrees
- of freedom

Artificial light-gathering and reaction center complex


The Energy and Science Grand Challenges

BESAC and BES Reports

- Secure Energy Future, 2002
- Hydrogen Economy, 2003
- Solar Energy Utilization, 2005
- Superconductivity, 2006
- Solid-state Lighting, 2006
- Advanced Nuclear Energy Systems, 2006
- Clean and Efficient Combustion of Fuels, 2006
- Electrical Energy Storage, 2007
- Catalysis for Energy, 2007
- Materials Under Extreme Environments, 2007
- New Science for a Secure and Sustainable Energy Future, 2008
- Science for Energy Technology, 2010
- Computational Materials Sciences and Chemistry, 2010

http://science.energy.gov/bes/news-and-resources/reports/basic-research-needs/
And Policy

A multidimensional, interactive challenge
What Do We Need to Do?

Research and Develop new more sustainable technologies
  • materials and chemistry of greater complexity and functionality

Educate the next generation for energy literacy
  • scientists and engineers
  • regulators, government officials, business people, urban planners
  • private citizens - the ultimate decision makers

Policy encourage new technologies through policy and planning
  • evaluate and incentivize the most suitable options

Entrepreneuership sustain a culture of innovation and risk taking
  • deploy technologies through small companies
UIC SUMMER INSTITUTE ON SUSTAINABILITY AND ENERGY
The world is undergoing an historic transition. Get on board.

Intense immersion in energy and sustainability
Lectures, tours of energy and sustainability sites
Team “challenge projects” solving real-world problems

Summer 2012
http://sise.phy.uic.edu
**Perspective**

Energy is making an historic transition from fossil to alternative, clean, sustainable.

The transition will take decades.

The bottleneck for many alternative energy technologies is basic science understanding of materials and chemistry.

Embracing the transition requires education - energy literacy for decision makers, research and development of new technologies, implementation through policy, planning, entrepreneurship.