The Sustainable Energy Challenge

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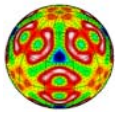
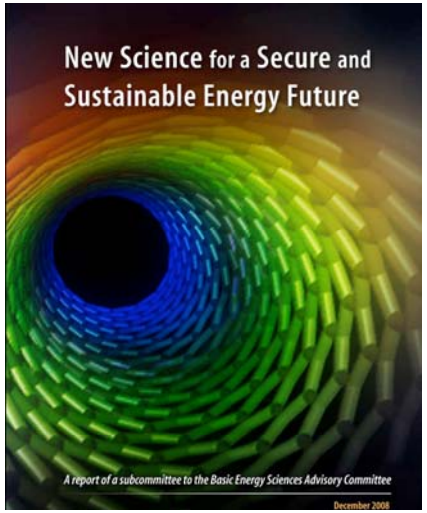
Outline

- the challenges: oil and carbon dioxide
- sustainable energy alternatives and roadblocks
- new era of science: controlling materials and phenomena
- meeting the challenges

APS Energy Research Workshop
Portland, OR
March 14, 2010





http://www.sc.doe.gov/bes/reports/list.html

physicsworld.com
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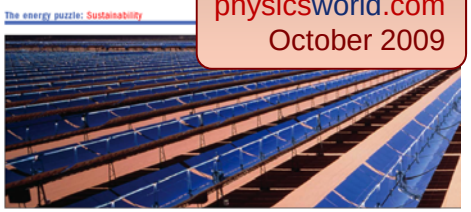
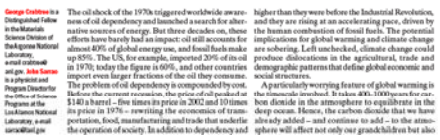


The road to sustainability

George Crabtree and John Sarrao



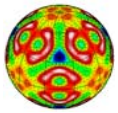
New Science for a Secure and Sustainable Energy Future

December 2008

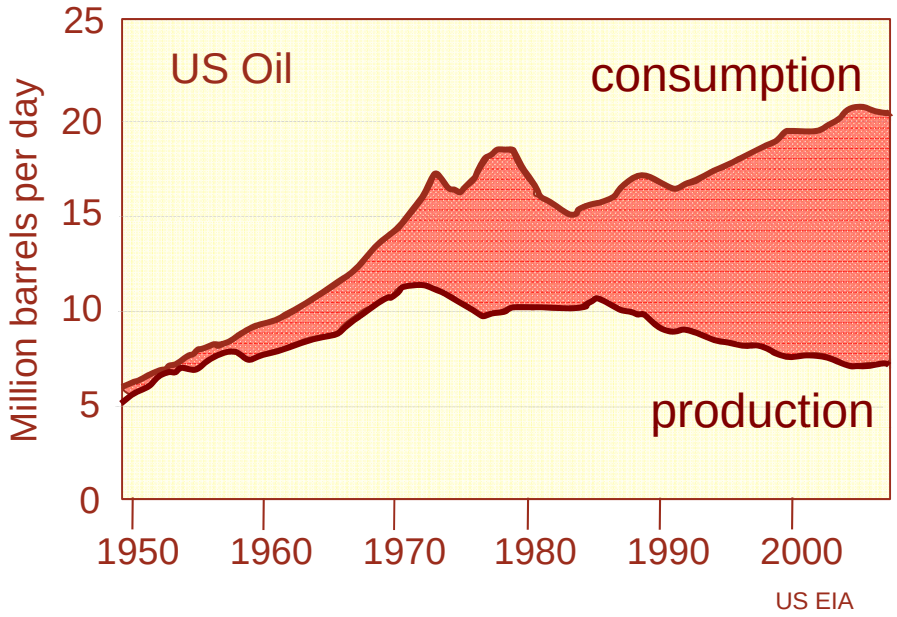
George Crabtree, Marc Kastner

Michelle Buchanan, Thomas Mallouk, John Sarrao, Michael Klein, Arthur Nozik, Julia Phillips, Sue Clark, Frank DiSalvo, Don DePaolo, Simon Bare, Wayne Hendrickson, Wolfgang Eberhardt, Franz Himpsel, Michael Norman, Andrea Cavalleri, Carl Lineberger, Yet-Ming Chiang, Pat Looney

Technical Support: Roger Klaffky, Michael Casassa, Jim Horwitz



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

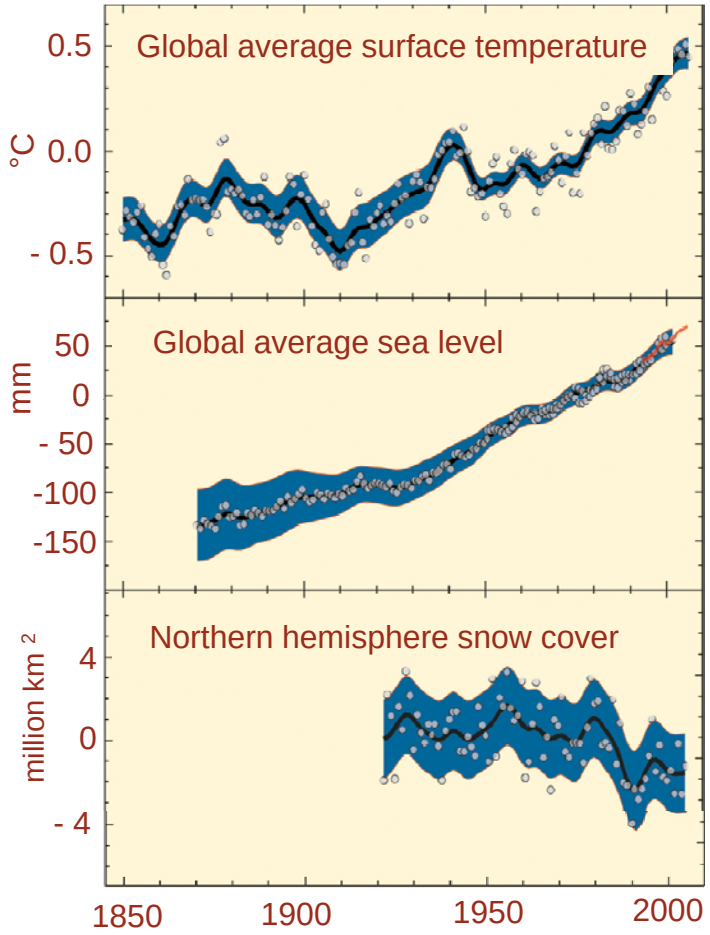
$700 B/yr
at recent peak prices

$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



IPCC Fourth Assessment 2007
http://www.ipcc.ch/graphics/gr-ar4-syr.htm SPM1

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

Oil and Carbon Dioxide: Woven into the Fabric

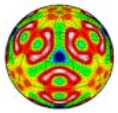
Driving our cars on imported oil

Unfettered emission of CO_2

Foundations of decades-long economic success

Alternatives require transformational change to business as usual

more sustainable
next-generation energy technology



What is Sustainability?

Lasts a long time

Oil in 1900

Coal in 2010

Does no harm

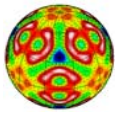
Nuclear electricity: no CO_2

Ethanol: reduced CO_2

Leaves no change

Closed chemical cycle

Electricity, hydrogen



Roadblocks to Sustainable Energy Technologies

Performance: fossil is cheaper

Sustainable energy technologies are in their infancy.

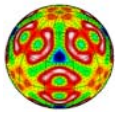
They perform far below their ultimate potential.

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



Sustainable Next-Generation Energy Technologies

Sustainability Profile

lasts a long time

does no harm

leaves no change

Solar electricity: a fully sustainable energy chain

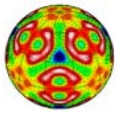
manufacture and end-of-life impact must be considered

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

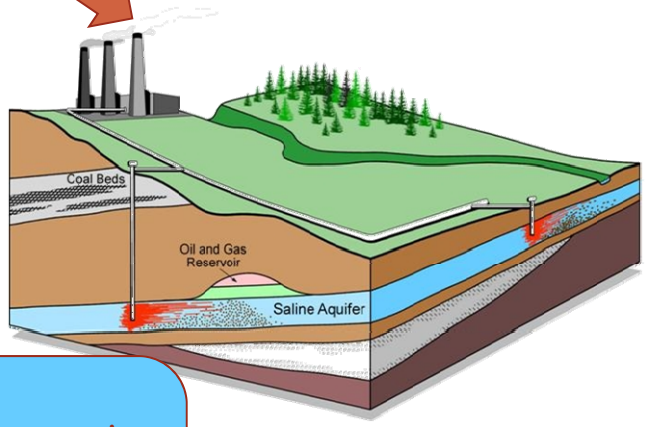
emissions

sequestration

carbon dioxide

depletes coal resource

100s of years



~ 1000 years

breakthroughs needed

chemical reactivity with rocks in extreme environments

migration through porous rocks

geologic monitoring and predictive modeling

leakage routes to atmosphere

Nuclear Electricity

Sustainability Profile

lasts a long time

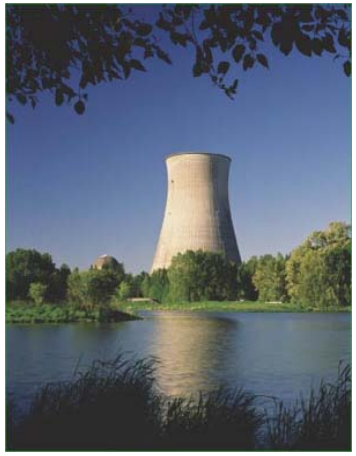
does no harm

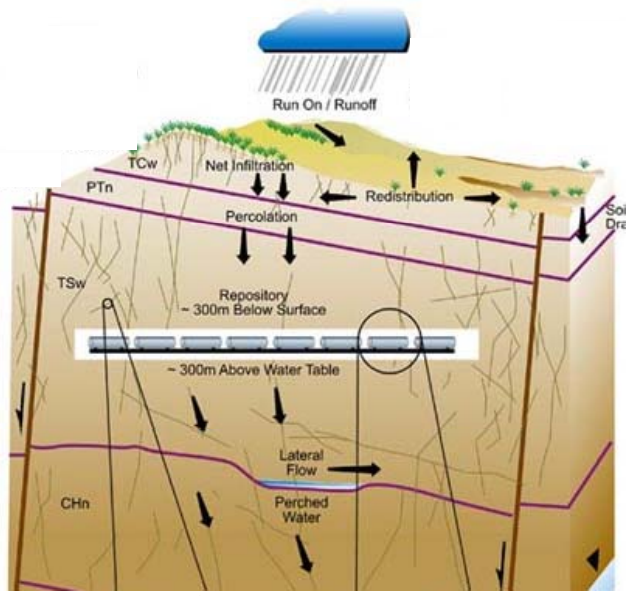
leaves no change

emissions

nuclear waste

depletes uranium resource
100s of yrs





nuclear waste
100 000s yrs

usgs

breakthroughs needed

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

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 CO_2

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

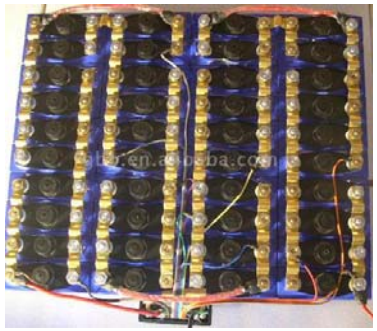
Sustainability Profile

lasts a long time

does no harm

leaves no change

renewable electricity production

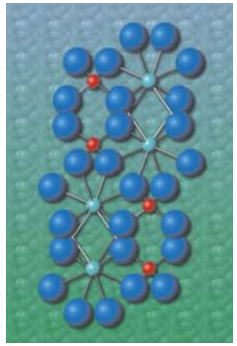


battery

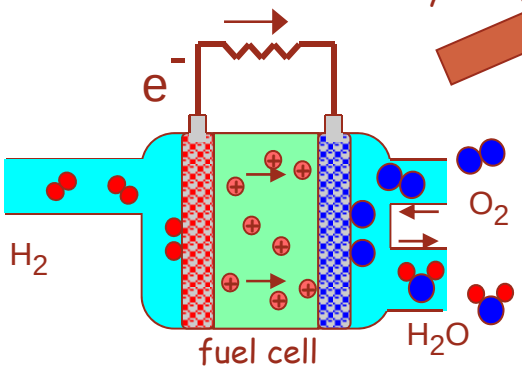
electric motor replaces gasoline engine

tesla motors

renewable hydrogen production



hydrogen storage

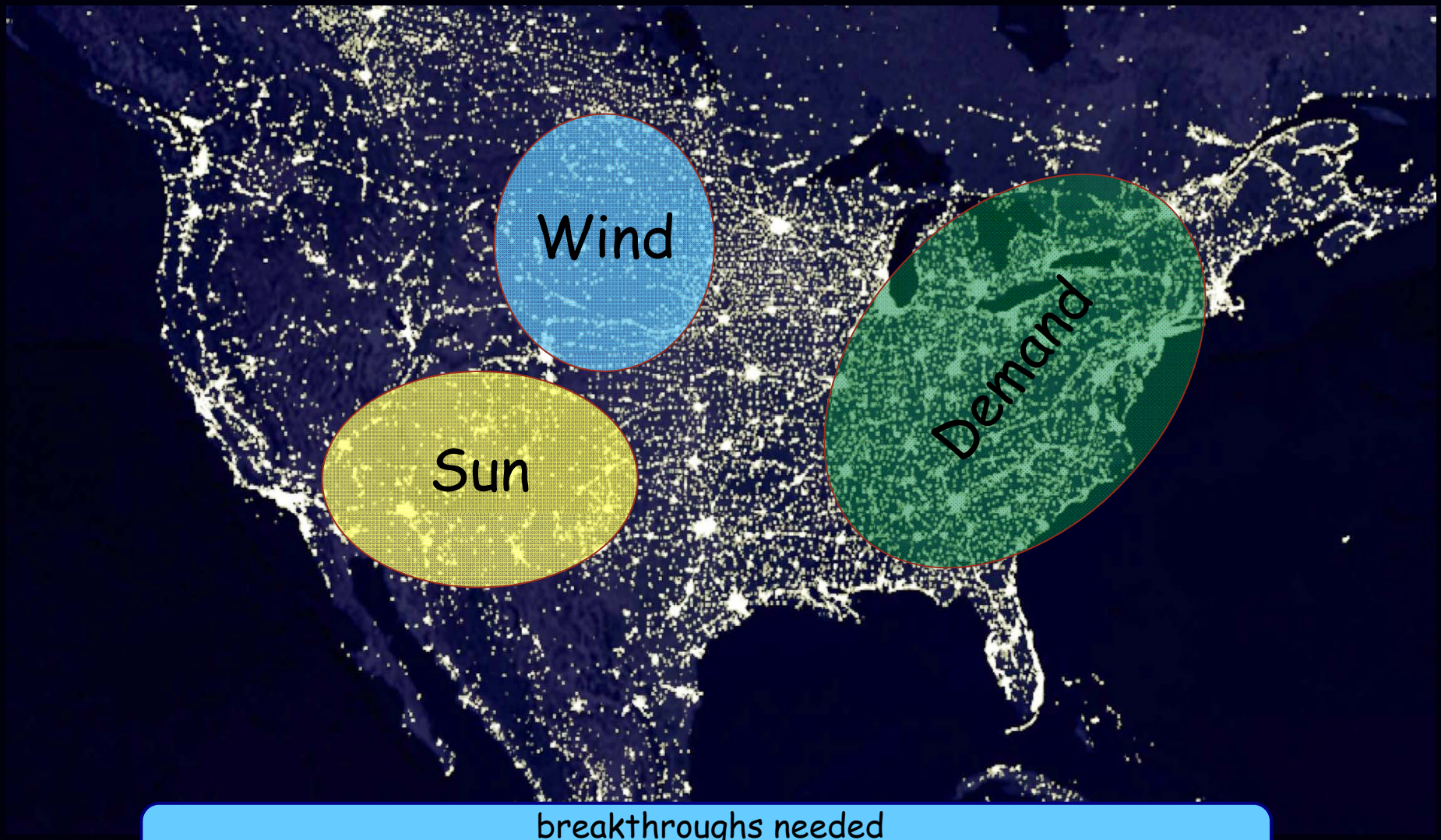


breakthroughs needed

x2-5 higher energy density in batteries

catalysts, membranes and electrodes in fuel cells

Sustainable Energy Enabling Technologies: The Grid



breakthroughs needed
long distance reliable, efficient delivery of electricity

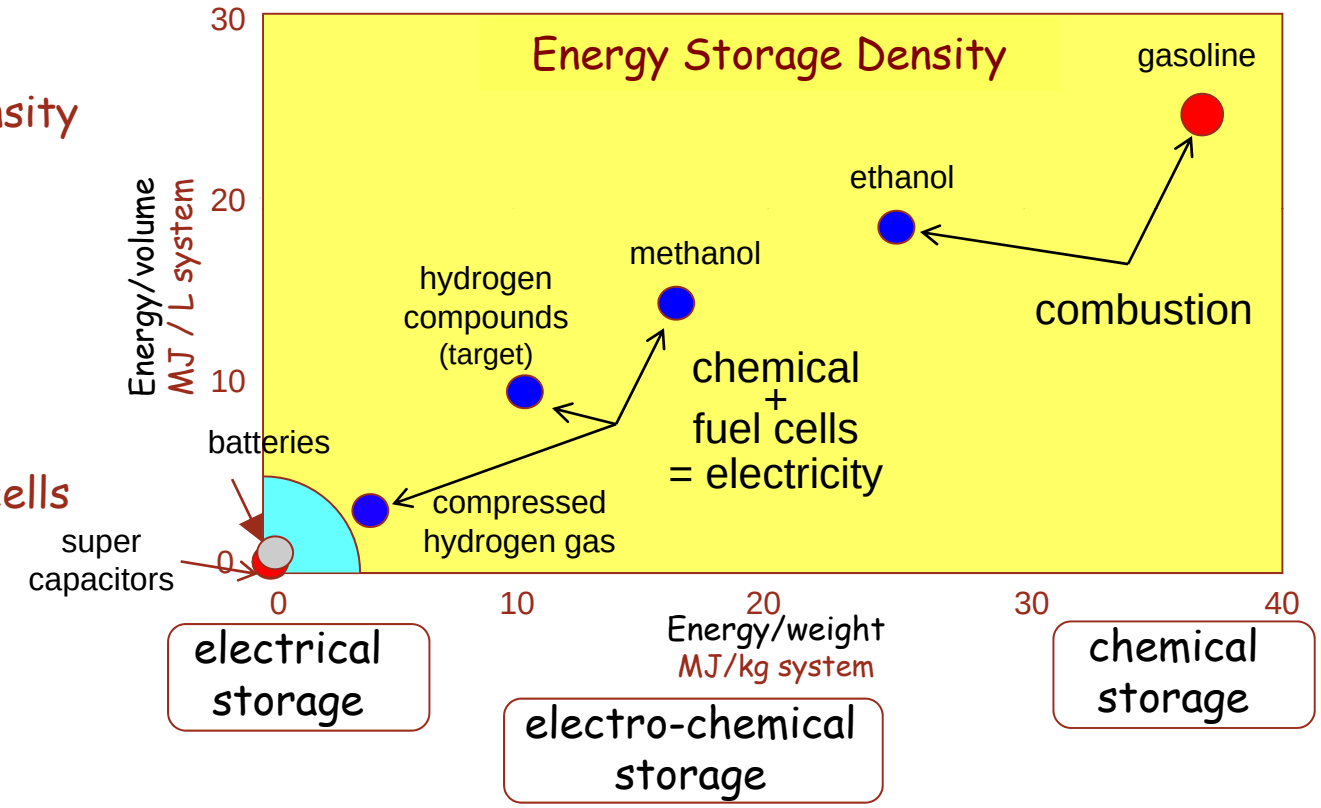
Enabling Technologies: Storing Energy

- 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

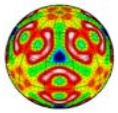
Which More Sustainable Technologies to Develop?

The problem is big – likely to need most or all of them

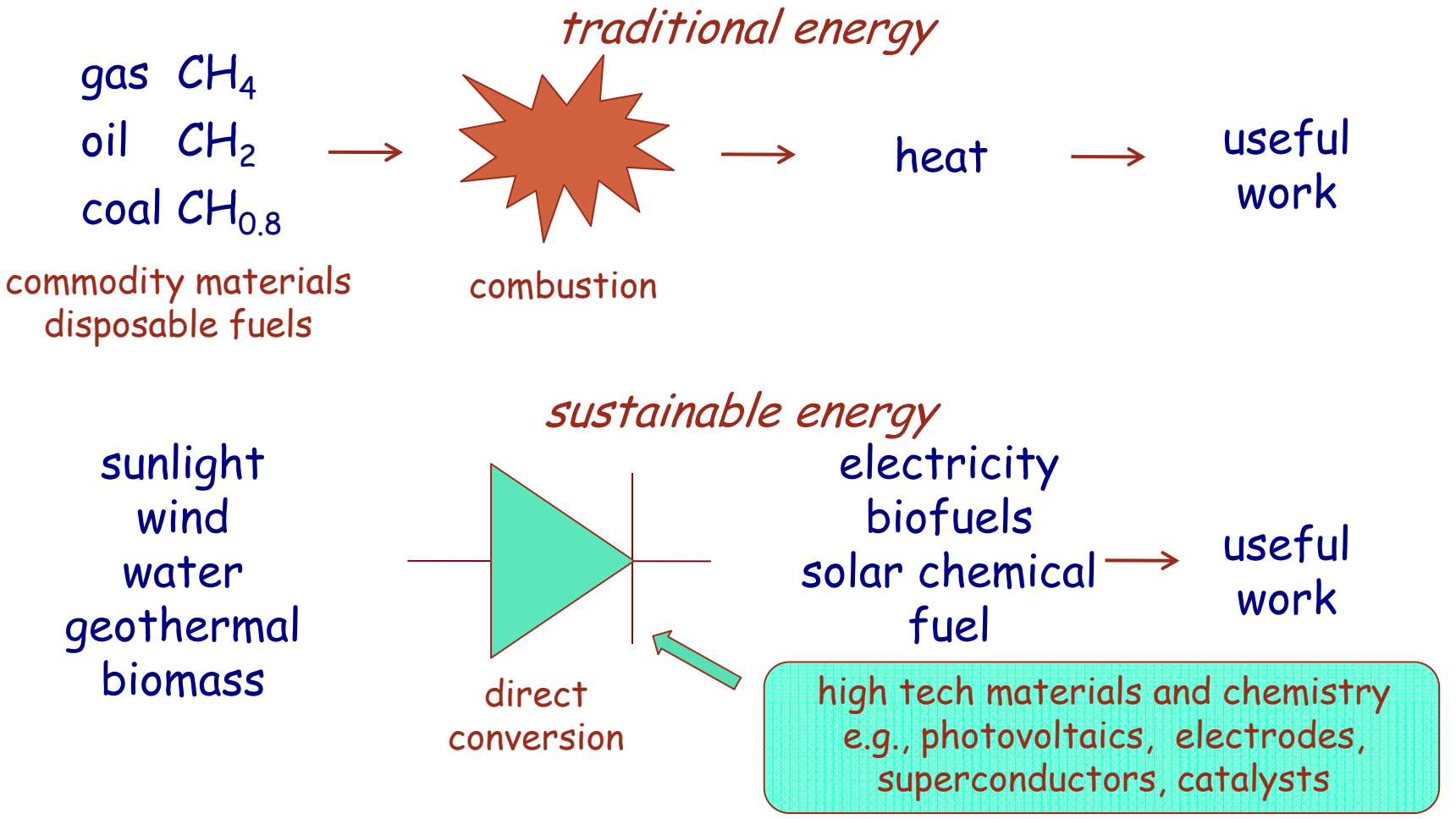
We don't know which will emerge as most effective

None can be implemented quickly – economics and market inertia

Successful sustainable energy requires controlling materials and chemical change in ultrasmall and ultrafast regimes

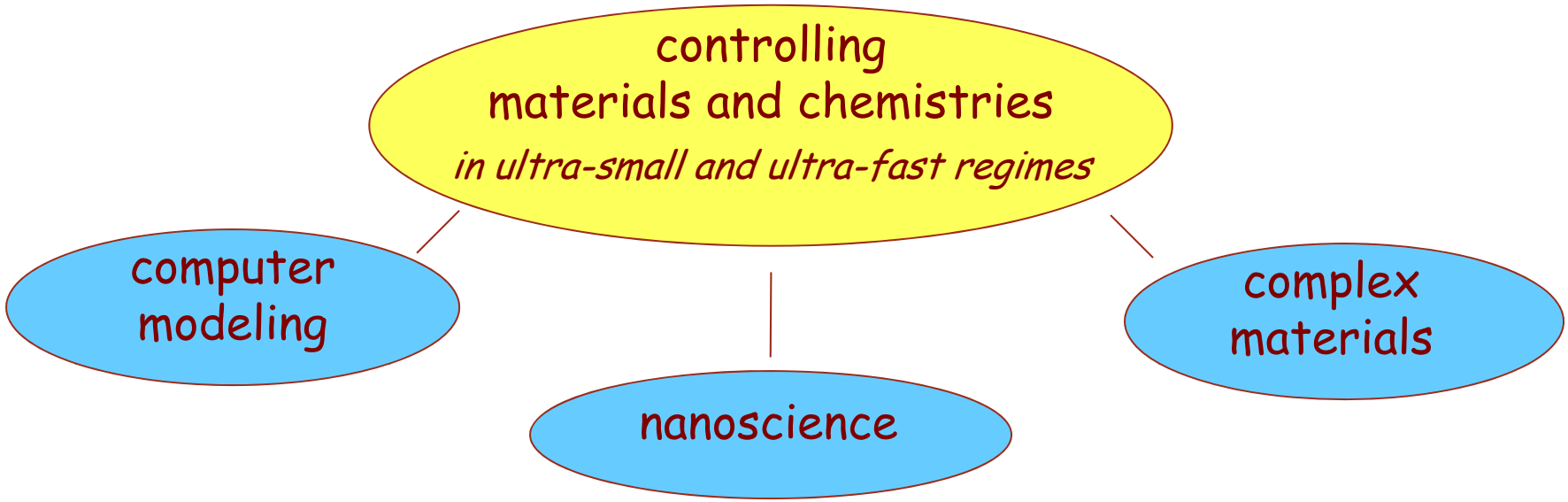


The Transition to Sustainable Energy: High Tech Materials and Chemistry



sustainable energy requires controlling complex, functional, high tech materials and chemistry

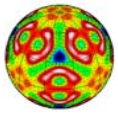
New Science: Controlling Complexity



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

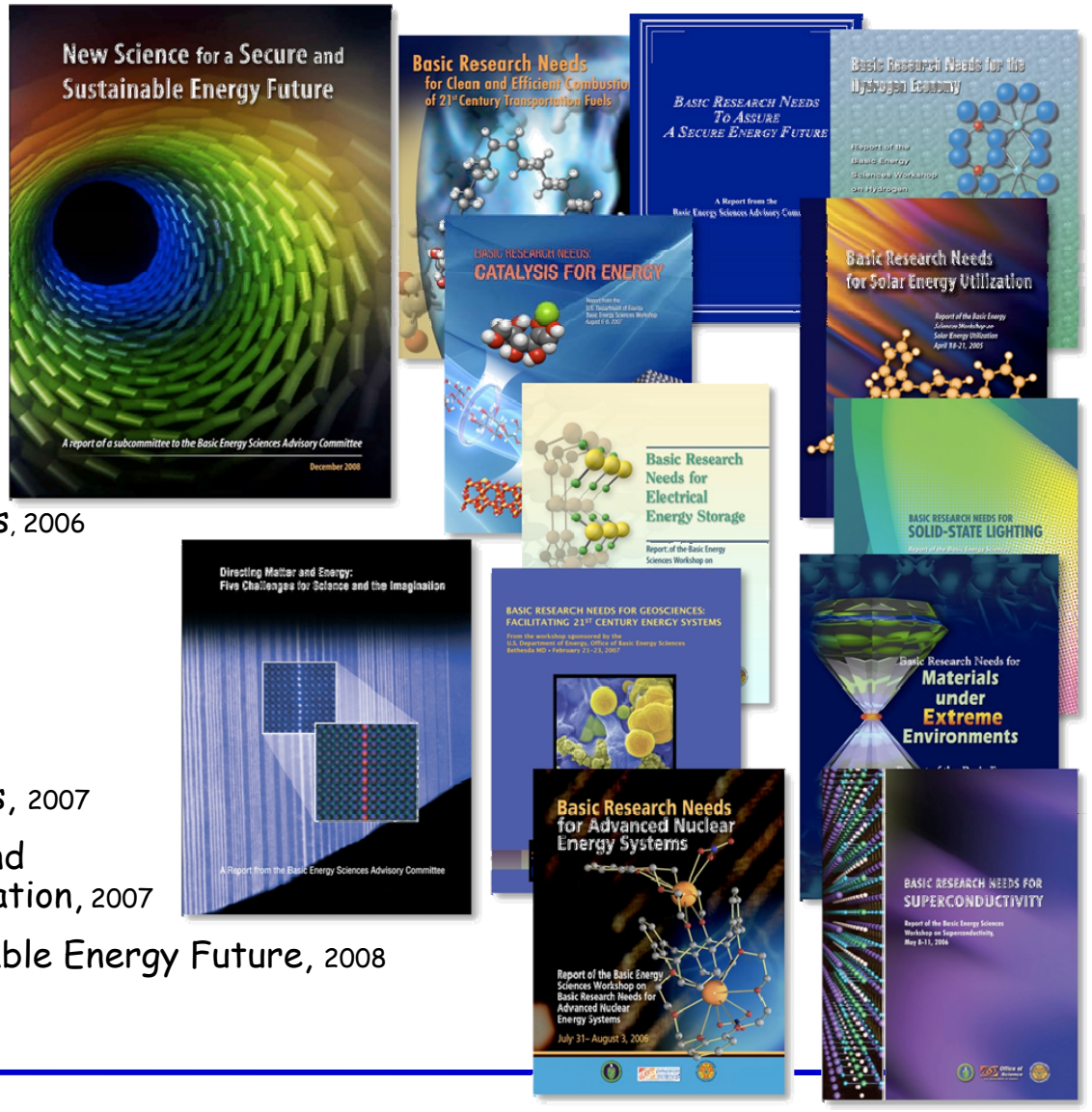
breakthroughs to next-generation sustainable energy technologies are within reach



The Energy and Science Grand Challenges

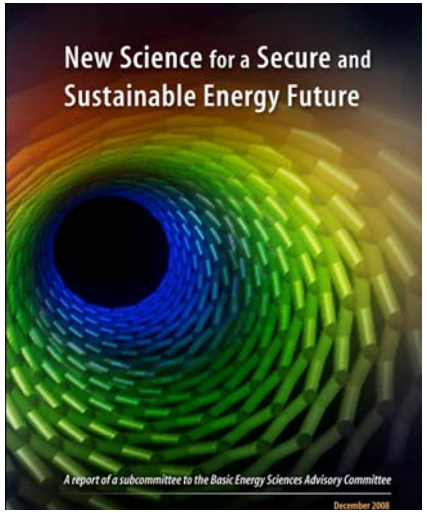
BESAC and BES Reports

- 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
- Geosciences: Facilitating 21st Century Energy Systems, 2007
- Materials Under Extreme Environments, 2007
- Directing Matter and Energy: Five Grand Challenges for Science and the Imagination, 2007
- New Science for a Secure and Sustainable Energy Future, 2008



http://www.sc.doe.gov/bes/reports/list.html

How Do We Get There?



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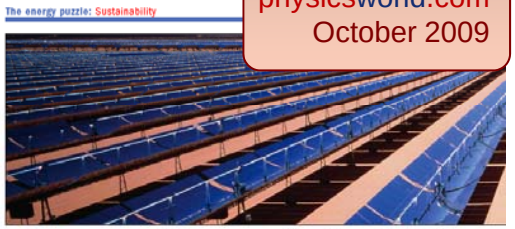
Dream Teams of the best scientists working with the best tools and focused on the most important problems are needed to achieve breakthroughs and transformational change.

The BES Energy Frontier Research Centers will launch these teams: an essential first step

We must launch an aggressive program to recruit and train the best and the brightest students and early career scientists.

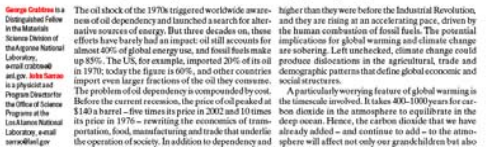
A massive and sustained investment in basic energy science is needed immediately, to achieve the breakthroughs in materials and chemical change needed for next-generation energy technologies.

physicsworld.com
October 2009



The road to sustainability

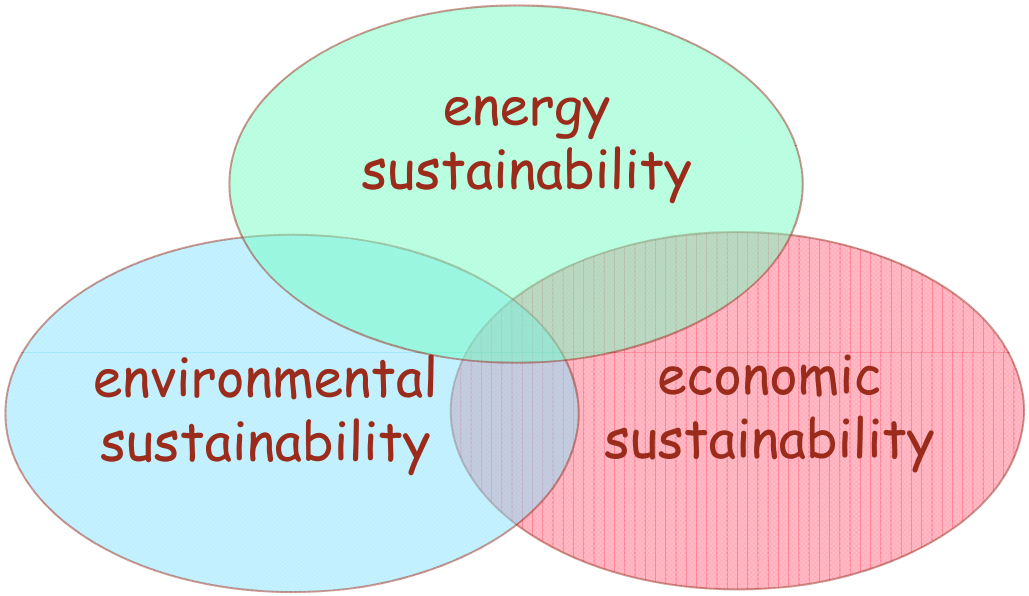
George Crabtree and John Sarrao



http://physicsworld.com/cws/article/indepth/40527

Back up Slides

The Goal: Sustainability



a multidimensional, interactive challenge

Perspective: Challenges and Opportunities

Weaning ourselves from imported oil and carbon dioxide emission requires structural change- not a refinement of business as usual

Next-generation sustainable energy technologies must operate at far higher performance

→ far more complex, functional, high tech materials

Developing these materials requires scientific breakthroughs

→ control materials performance and chemical change at atomic, molecular lengths scales and femtosecond time scales

→ replace the economic drain of imported oil with economic growth from exporting next-generation energy technologies