
The Sustainable Energy Challenge

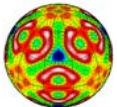
George Crabtree

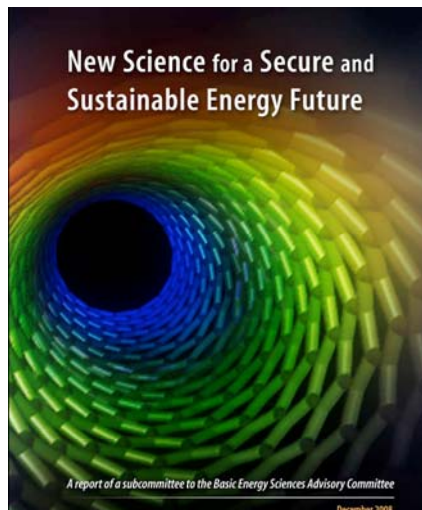
Materials Science Division
Argonne National Laboratory

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





New Science for a Secure and Sustainable Energy Future

A report of a subcommittee to the Basic Energy Sciences Advisory Committee

December 2008

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

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 Himpfel, Michael Norman,

Andrea Cavalleri, Carl Lineberger, Yet-Ming Chiang, Pat

Looney

Technical Support: Roger Klaffky, Michael Casassa, Jim

Horwitz

The energy puzzle: Sustainability



physicsworld.com

October 2009

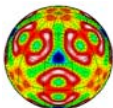
The road to sustainability

George Crabtree and John Sarrao

George Crabtree is a Distinguished Fellow in the Center for Science and Technology at Sandia National Laboratories. **John Sarrao** is a physicist and Program Director for the Office of Science at Sandia National Laboratories. **email:** sarrao@slac.stanford.edu

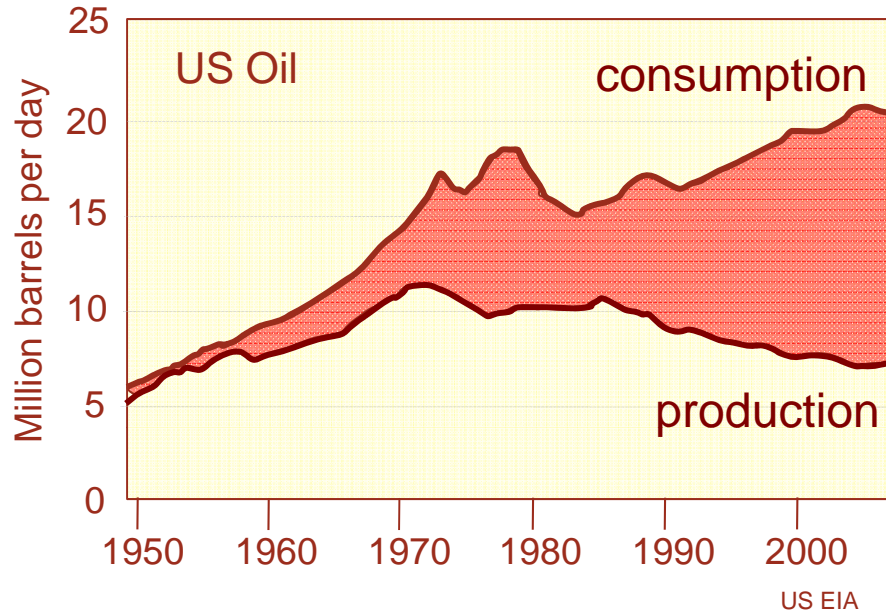
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higher than they were before the Industrial Revolution, and they are rising at an accelerating pace, driven by the human combustion of fossil fuels. The potential implications for global warming and climate change are sobering. Left unchecked, climate change could produce distortions in the agricultural, trade and demographic patterns that define global economic and social structures. A particularly worrying feature of global warming is the atmospheric feedback. It takes 100,000 years for carbon dioxide in the atmosphere to equilibrate in the deep ocean. Hence, the carbon dioxide that we have already added – and continue to add – to the atmosphere will affect not only our grandchildren but also



Basic Energy Sciences

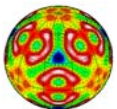
The Problem: Dependence on Imported Oil



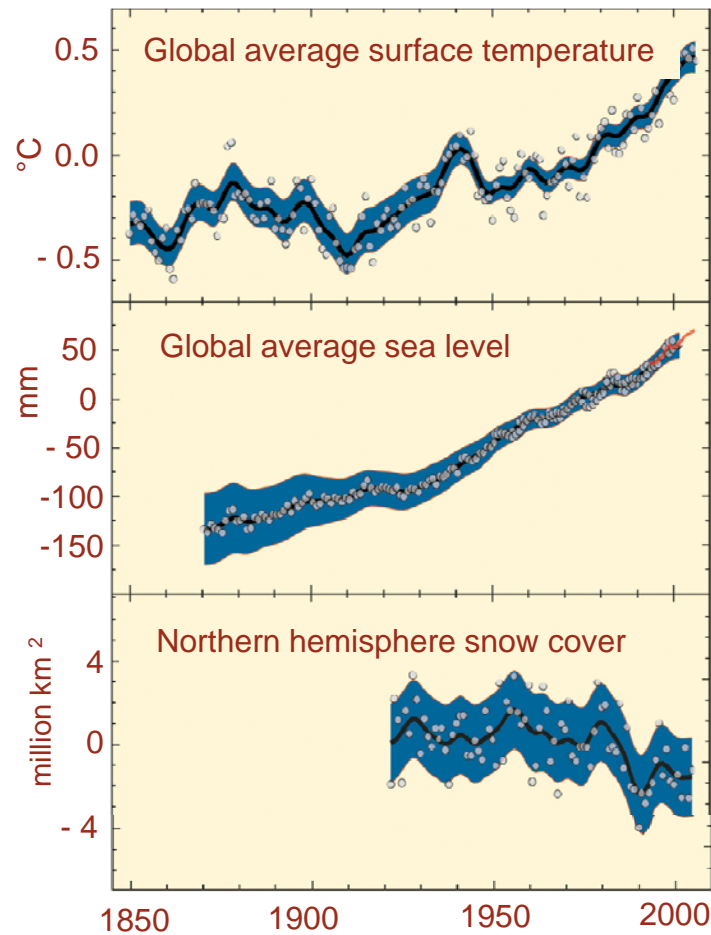
Unpredictable supply
threatens
economy, lifestyle, national security

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



The Problem: Greenhouse Gases and Climate Change



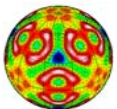
IPCC Fourth Assessment 2007
<http://www.ipcc.ch/graphics/gr-ar4-syr.htm> SPM1



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

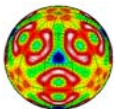
Driving our cars on imported oil

Unfettered emission of CO₂

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

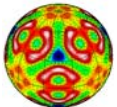
Nuclear electricity: no CO_2

Ethanol: reduced CO_2

Leaves no change

Closed chemical cycle

Electricity, hydrogen



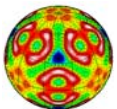
Roadblocks to Sustainable Energy Technologies

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 ☺

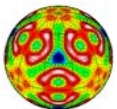
does no harm ☺

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



Basic

Carbon Sequestration

Sustainability Profile

lasts a long time

does no harm

leaves no change



emissions



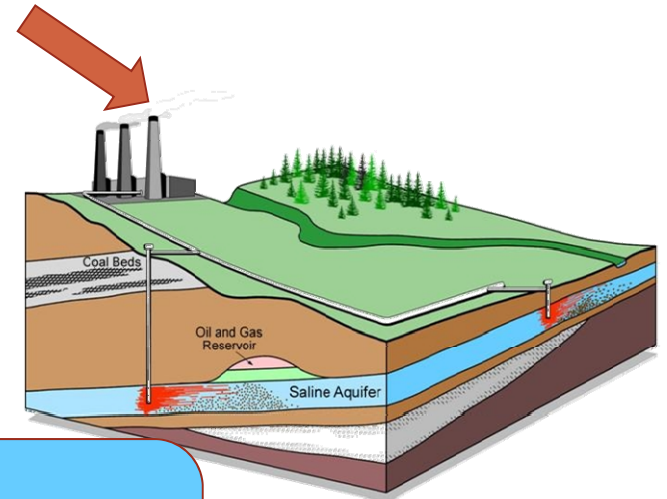
sequestration



depletes coal resource
100s of years

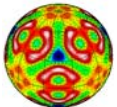


carbon dioxide



~ 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

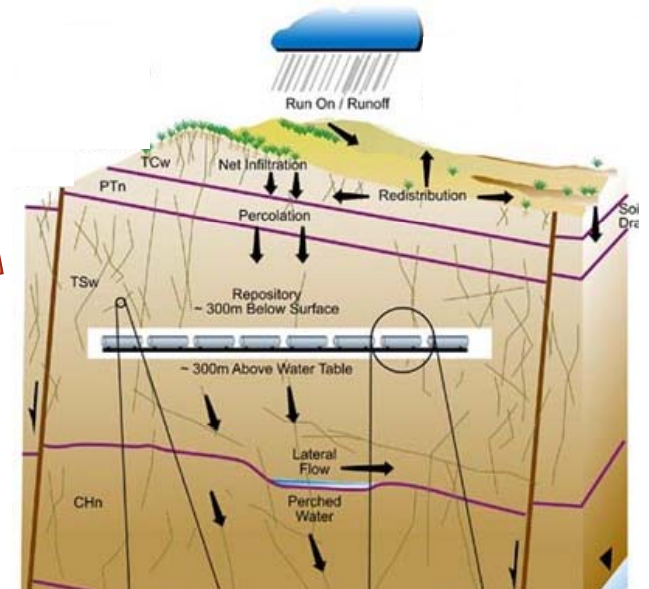
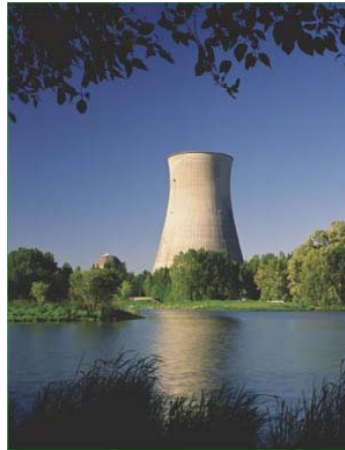
Sustainability Profile

lasts a long time
 does no harm
 leaves no change

☹️ emissions
 😊 ☹️ nuclear waste



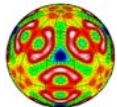
depletes uranium resource
 100s of yrs



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 😊



switchgrass

oil sands and shale
coal to liquid

lasts a long time 😞

does no harm 😞

leaves no change 😞



ethanol plant



recycles CO₂ ↗



cellulosic biofuel: recycles carbon dioxide

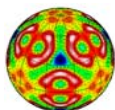
solar fuel without biology: thermo- or photo-chemistry

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 ☺

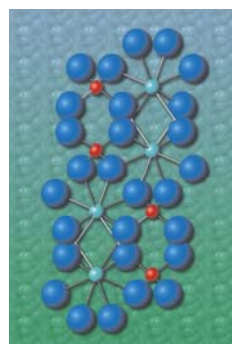
does no harm ☺

leaves no change ☺

renewable
electricity
production



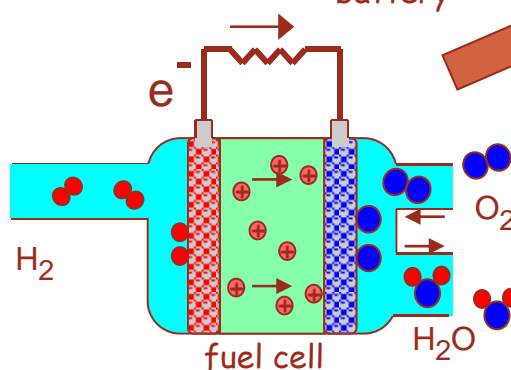
renewable
hydrogen
production



hydrogen
storage



battery



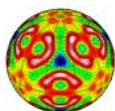
fuel cell

electric motor
replaces
gasoline engine

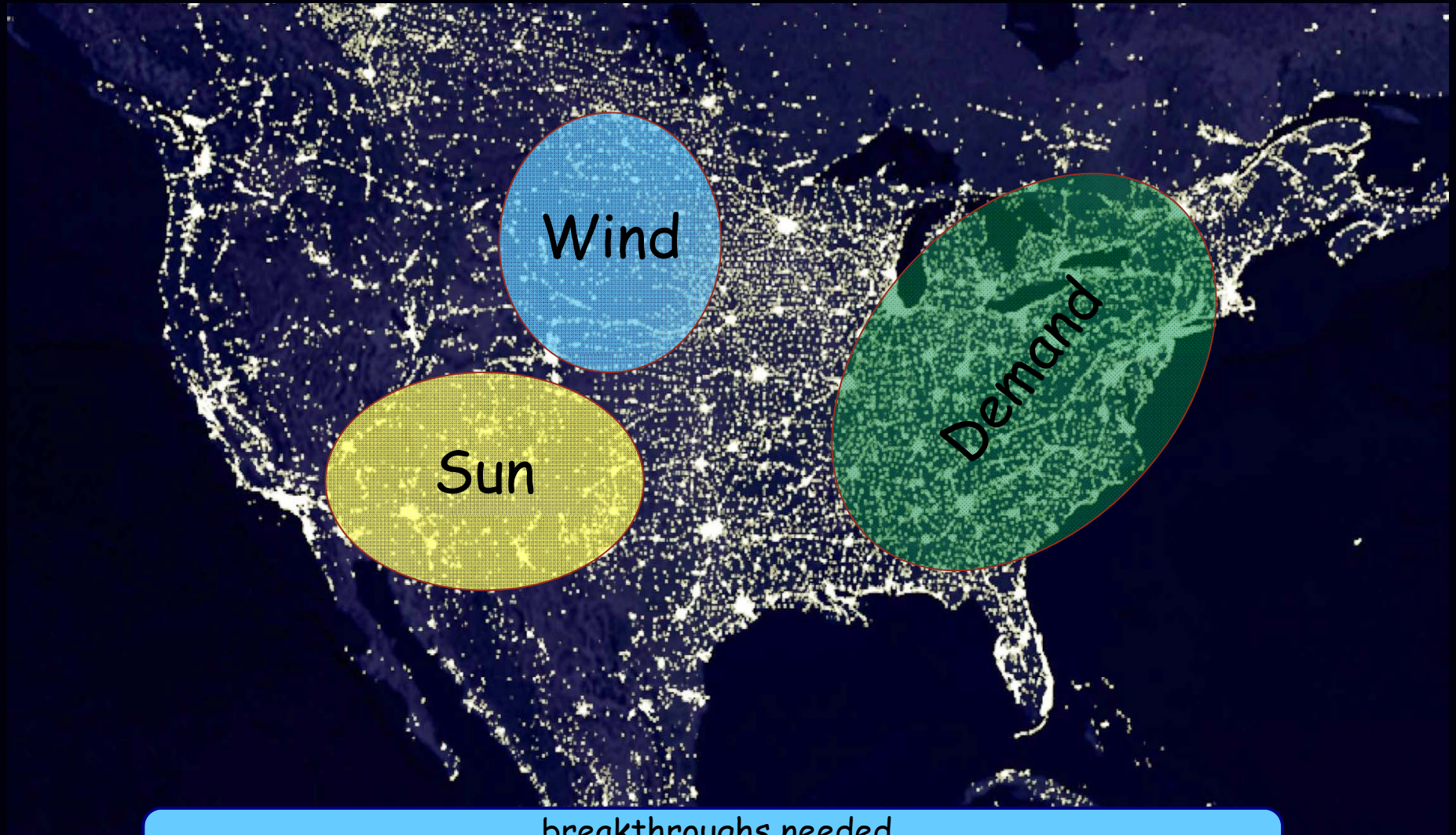


tesla motors

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

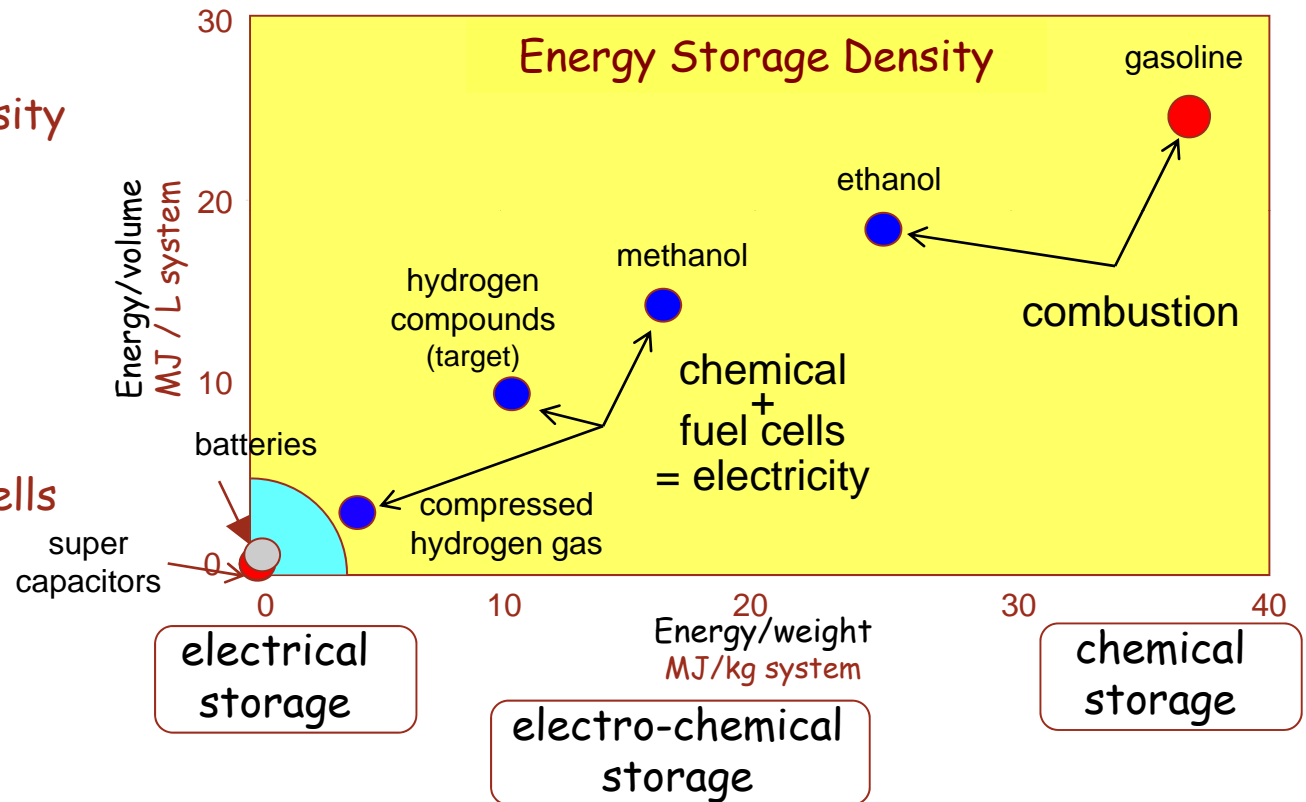
Enabling Technologies: Storing Energy

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

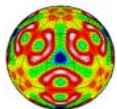
batteries:
30-50x less energy density
than gasoline

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



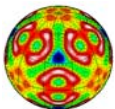
Which More Sustainable Technologies to Develop?

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

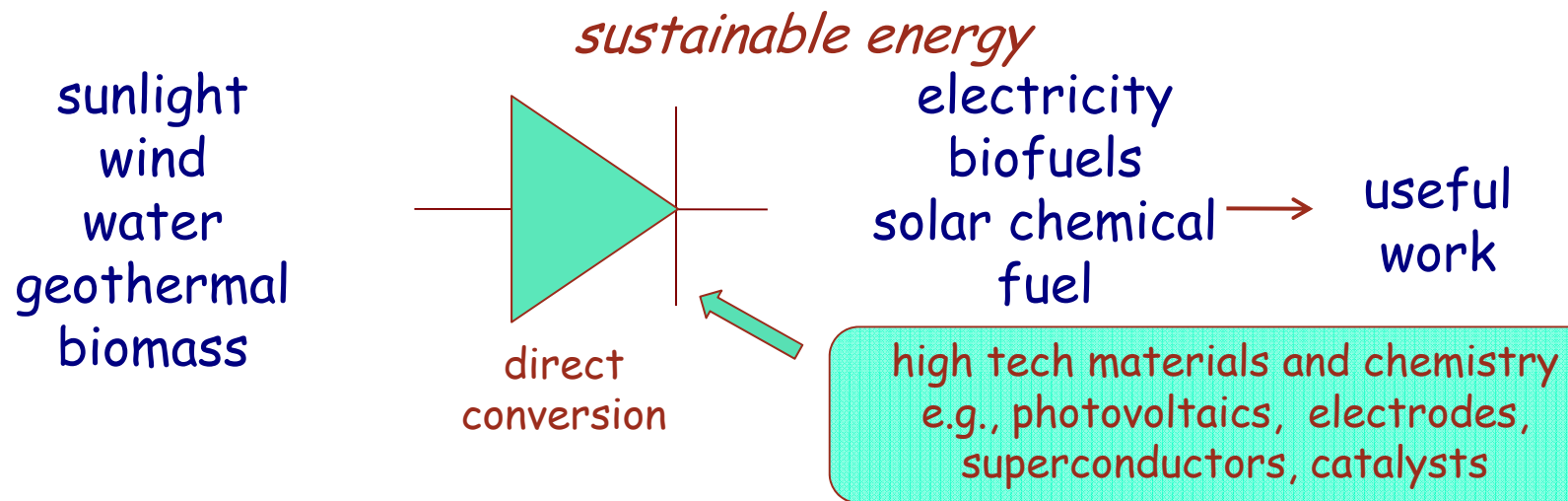
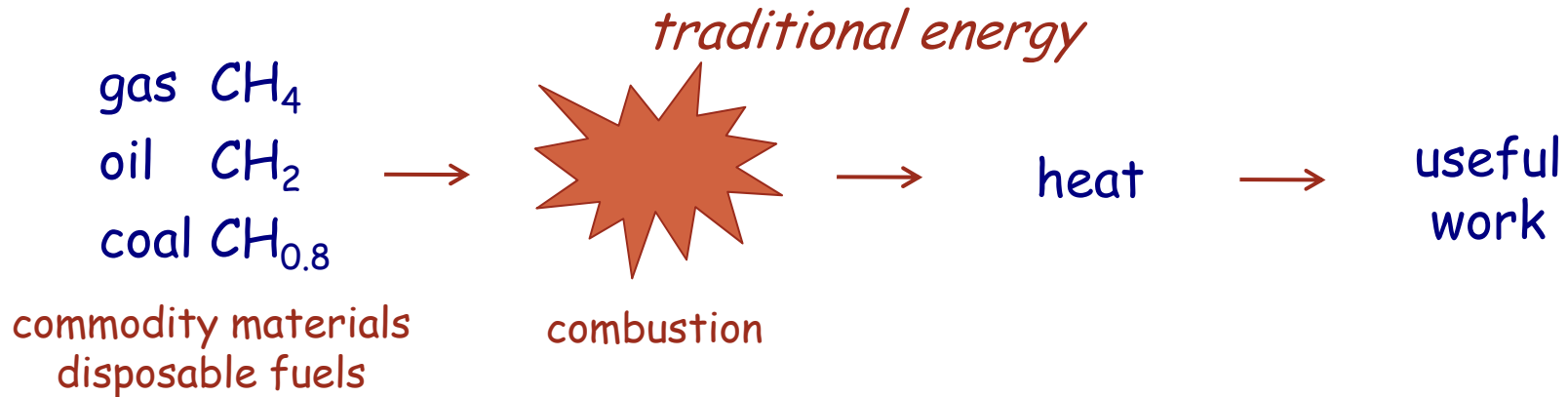
We don't know which will emerge as most effective

None can be implemented quickly - economics and
market inertia

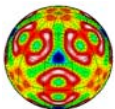
Successful sustainable energy requires controlling
materials and chemical change in ultrasmall and ultrafast
regimes



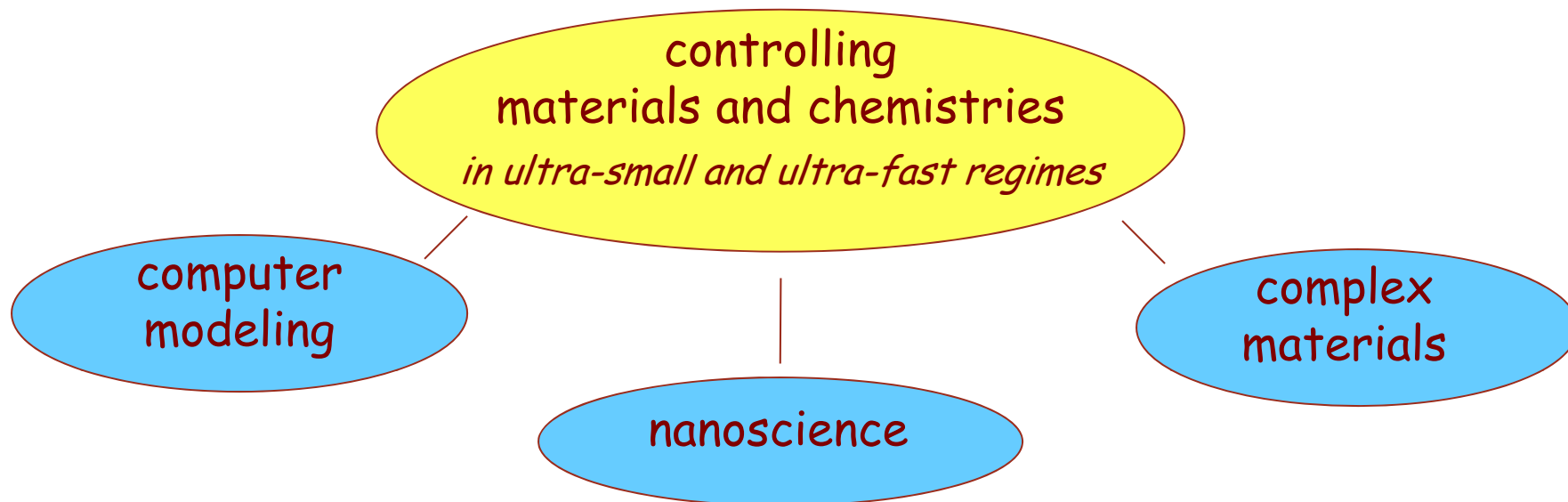
The Transition to Sustainable Energy: High Tech Materials and Chemistry



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



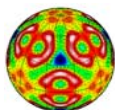
New Science: Controlling Complexity



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*

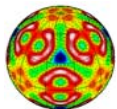


The Energy and Science Grand Challenges

BESAC and BES Reports

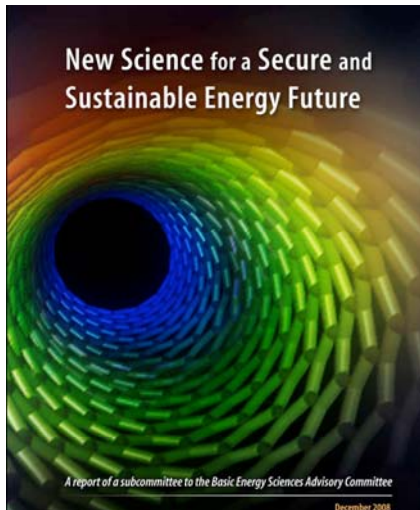
- Secure Energy Future, 2002
- Hydrogen Economy, 2003
- Solar Energy Utilization, 2005
- Superconductivity, 2006
- Solid-state Lighting, 2006
- Advanced Nuclear Energy Systems, 2006
- Clean and Efficient Combustion of Fuels, 2006
- Electrical Energy Storage, 2007
- Catalysis for Energy, 2007
- Geosciences: 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>



Basic Energy Sciences

How Do We Get There?



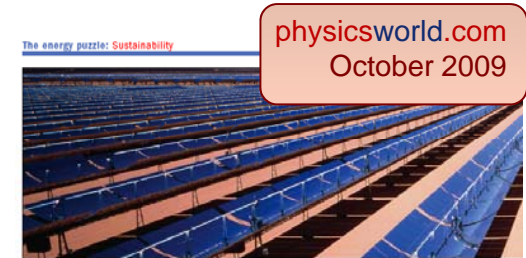
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Dream Teams of the best scientists working with the best tools and focused on the most important problems are needed to achieve breakthroughs and transformational change.

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.



The road to sustainability

George Crabtree and John Sarrao

George Crabtree is a Distinguished Fellow in the Materials Science Division of the Argonne National Laboratory, and **John Sarrao** is a Physical and Program Director for the Office of Science Programs at the Los Alamos National Laboratory. sarrao@llnl.gov

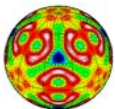
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The problem of oil dependency is compounded by cost. Before the current recession, the price of oil peaked at \$140 a barrel – five times its price in 2002 and 10 times its price in 1970 – rewriting the economics of transportation, food, manufacturing and trade that underlie the operation of society. In addition to dependency and

higher than they were before the Industrial Revolution, and they are rising at an accelerating pace, driven by the human combustion of fossil fuels. The potential implications for global warming and climate change are sobering. Left unchecked, climate change could produce disruptions in the agricultural, trade and demographic patterns that define global economic and social structures.

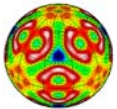
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<http://physicsworld.com/cws/article/indepth/40527>

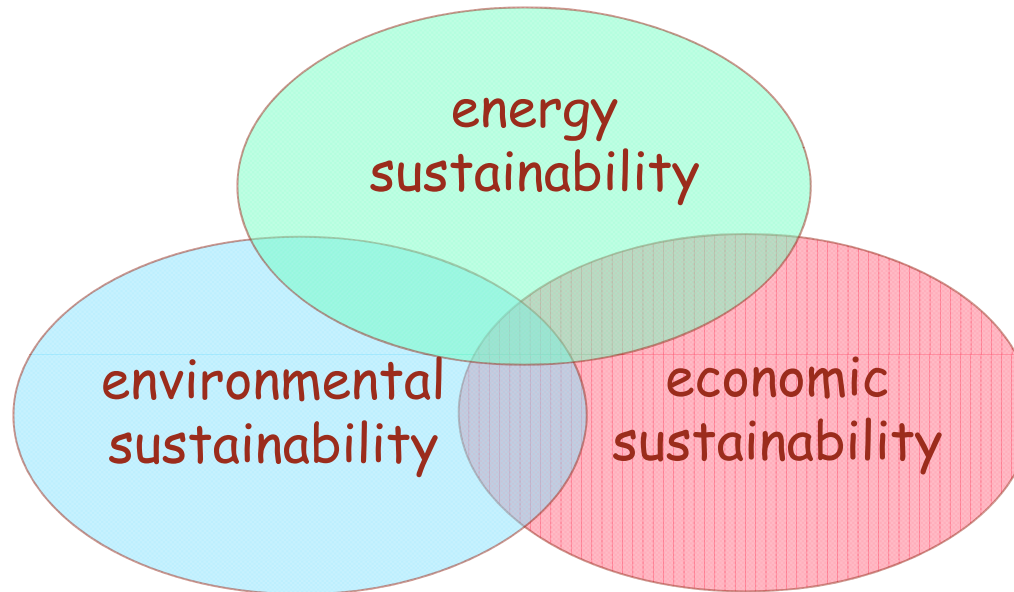


Basic Energy Sciences

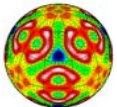
Back up Slides



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

