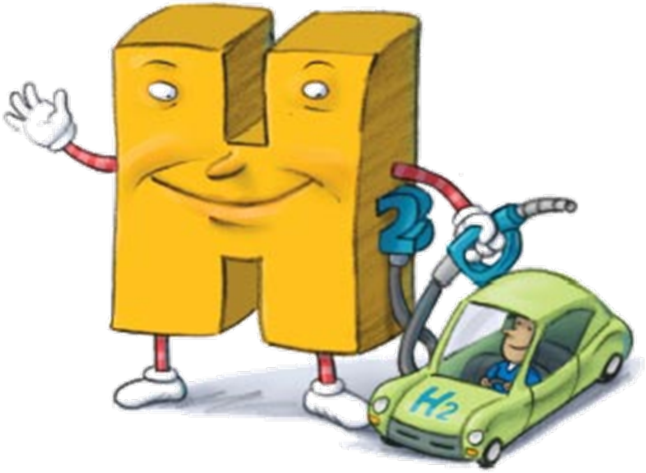
Energy Long Island, 2007 Conference
Farmingdale State College, New York
October 25, 2007

Energy Research: Forefront and Challenges

Mildred Dresselhaus
Massachusetts Institute of Technology
Cambridge, MA



Collaborator

George Crabtree, ANL

Energy Research:
Forefront and Challenges

Outline

- Introduction – the energy challenge
- Energy alternatives and the materials challenge
- Think big, go small
- Science and Policy Perspectives

Energy: A National Initiative
The hydrogen project

“Tonight I'm proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles… With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and pollution-free.”

President Bush, State-of the-Union Address,
January 28, 2003

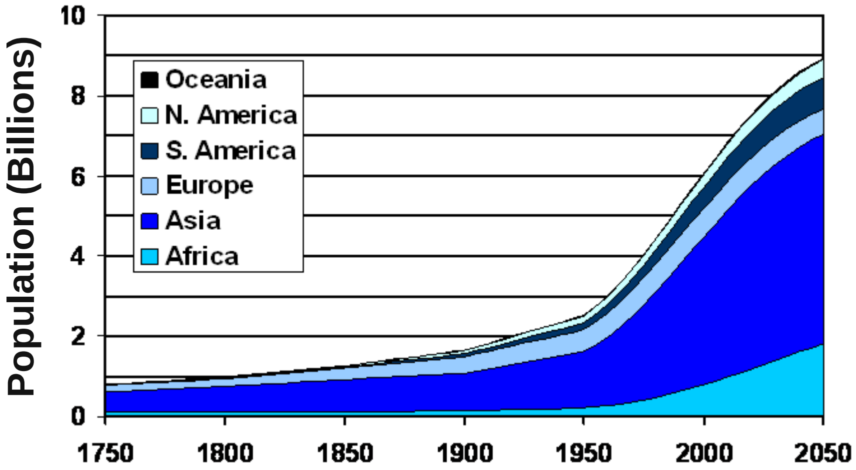
"America is addicted to oil, which is often imported from unstable parts of the world,“

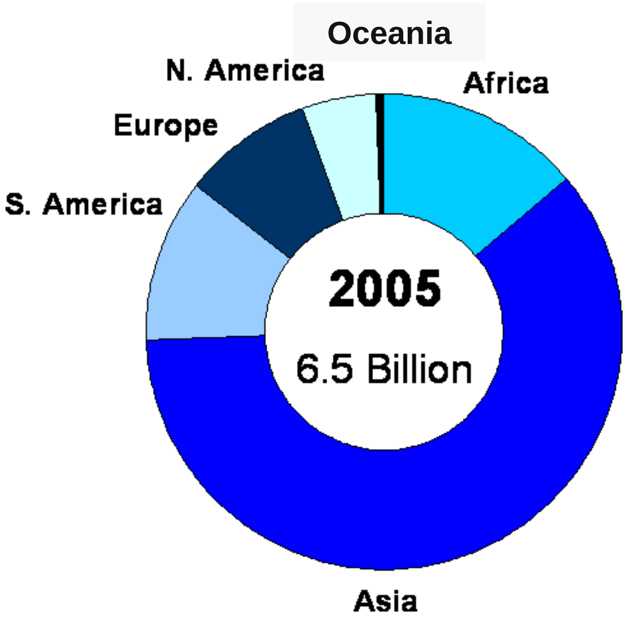
“The best way to break this addiction is through technology..”

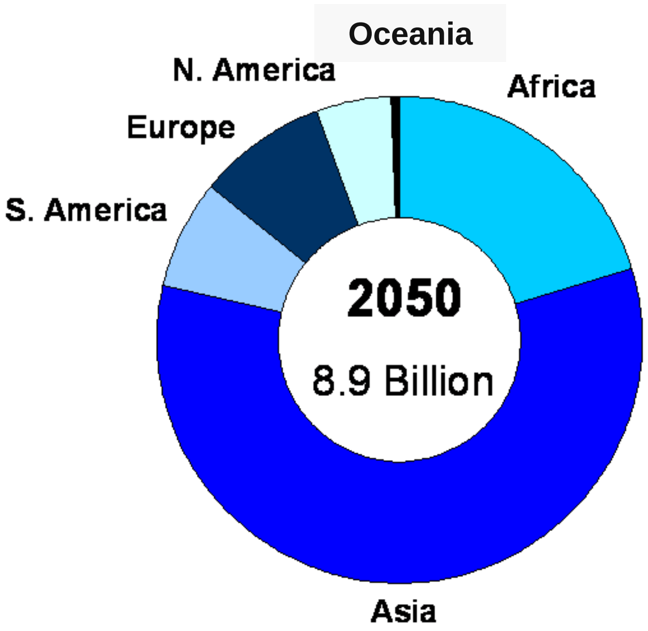
“..better batteries for hybrid and electric cars, and in pollution-free cars that run on hydrogen’

President Bush, State-of-the-Union Address,
January 31, 2006

Demographic Expansion

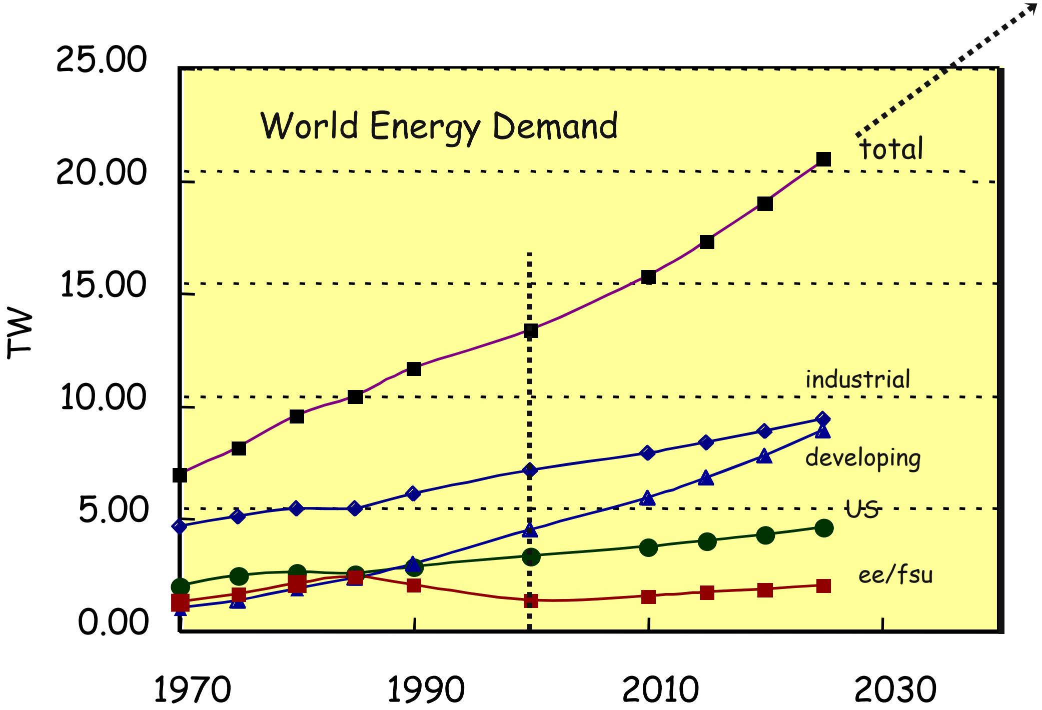






The World Energy Demand Challenge

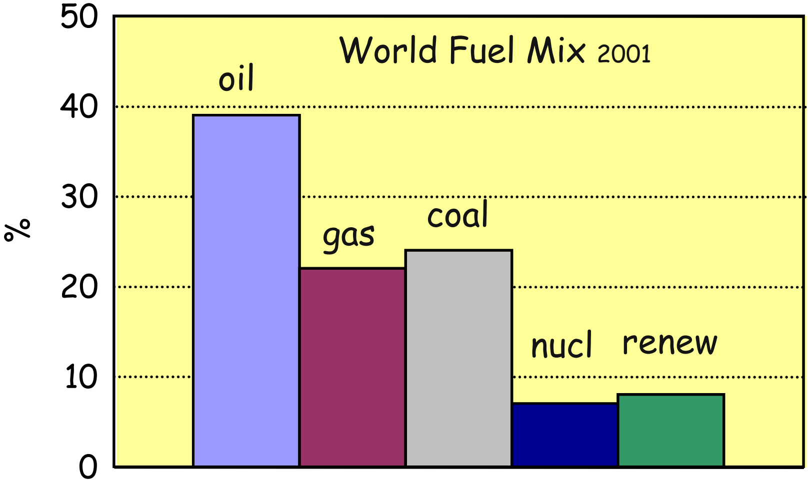
2100: 40-50 TW
2050: 25-30 TW
2000: 13 TW



EIA Intl Energy Outlook 2004
http://www.eia.doe.gov/oiaf/ieo/index.html

Hoffert et al Nature 395, 883,1998

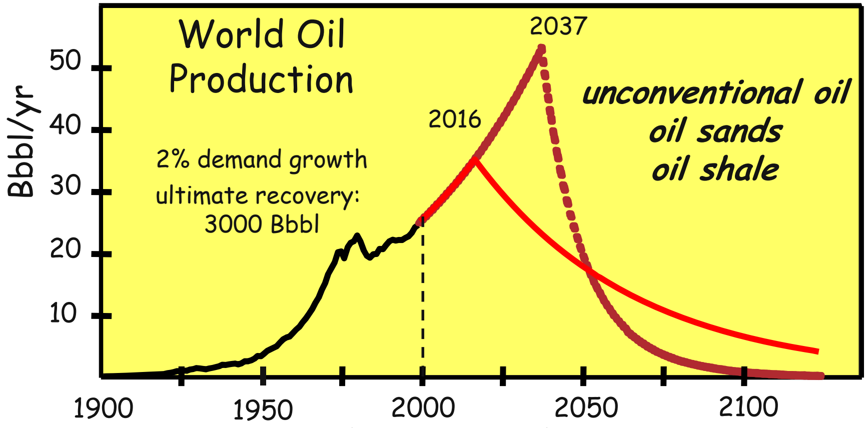
energy gap
~ 14 TW by 2050
~ 33 TW by 2100



85% fossil

The Challenge of Fossil Fuel Supply and Security

When Will Production Peak?



EIA: http://tonto.eia.doe.gov/FTPROOT/presentations/long_term_supply/index.htm

R. Kerr, Science **310**, 1106 (2005)

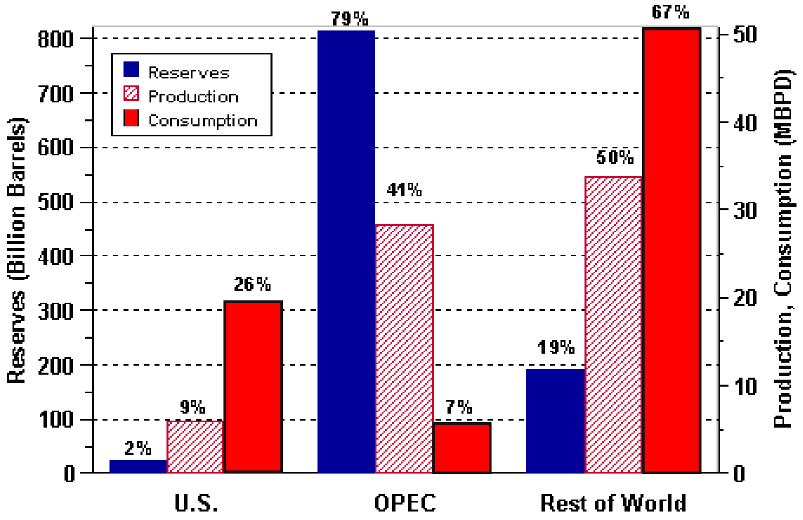
gas: beyond oil
coal: > 200 yrs

beyond the peak
new geopolitical relationships
alternative fuels
unconventional oil
break even ~ $30-40 / bbl
50% more CO_2/gallon gasoline

World Oil Reserves/Consumption
2001

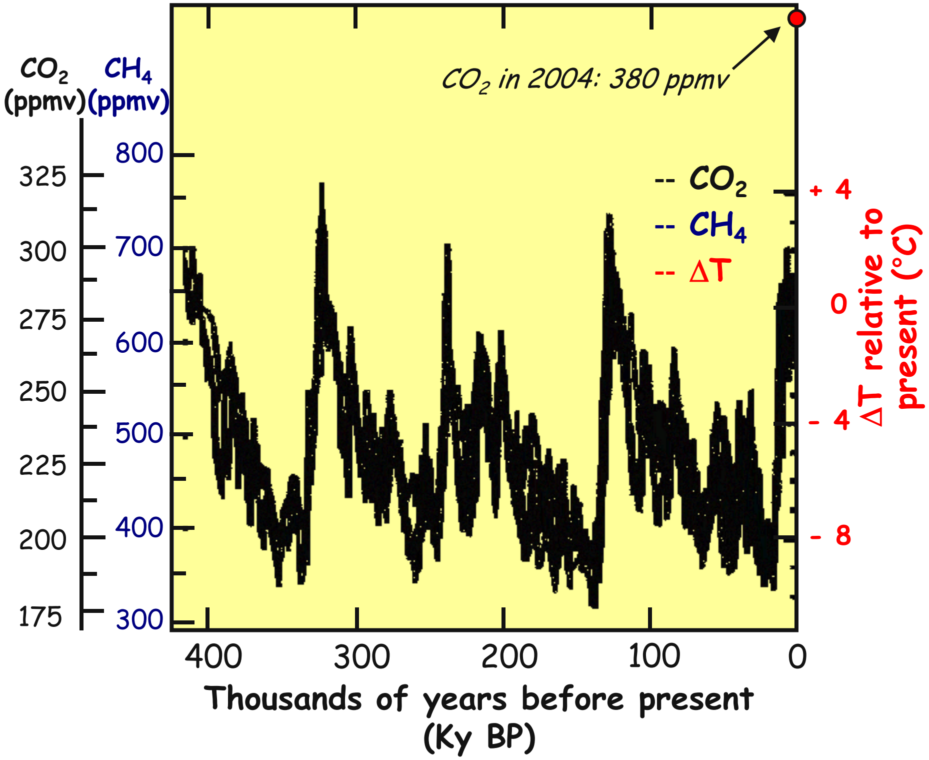
uneven distribution
⇒ insecure access

http://www.eere.energy.gov/vehiclesandfuels/facts/2004/fcvt_fotw336.shtml



OPEC: Venezuela, Iran, Iraq, Kuwait, Qatar, Saudi Arabia, United Arab Emirates, Algeria, Libya, Nigeria, and Indonesia

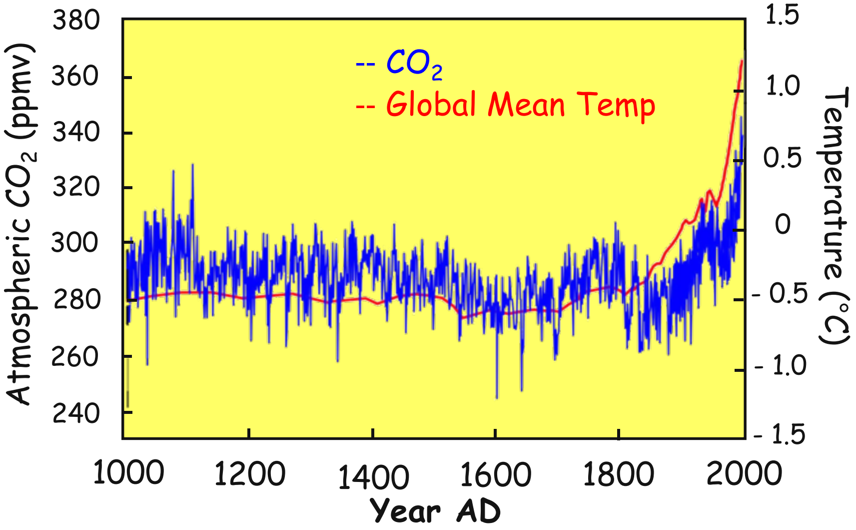
The Challenge of Fossil Fuel Related Climate Change



Climate Change 2001: The Scientific Basis, Fig 2.22

Relaxation time

transport of CO_2 or heat to deep ocean: 400 - 1000 years



J. R. Petit et al, Nature ***399****, 429, 1999*
Intergovernmental Panel on Climate Change, 2001
http://www.ipcc.ch
N. Oreskes, Science ***306****, 1686, 2004*
D. A. Stainforth et al, Nature ***433****, 403, 2005*

The Energy Alternatives

Fossil

Nuclear

Renewable

solar, wind, hydroelectric
ocean tides and currents
biomass, geothermal

Fusion

energy gap
~ 14 TW by 2050
~ 33 TW by 2100

→

10 TW = 10,000 1 GW power plants

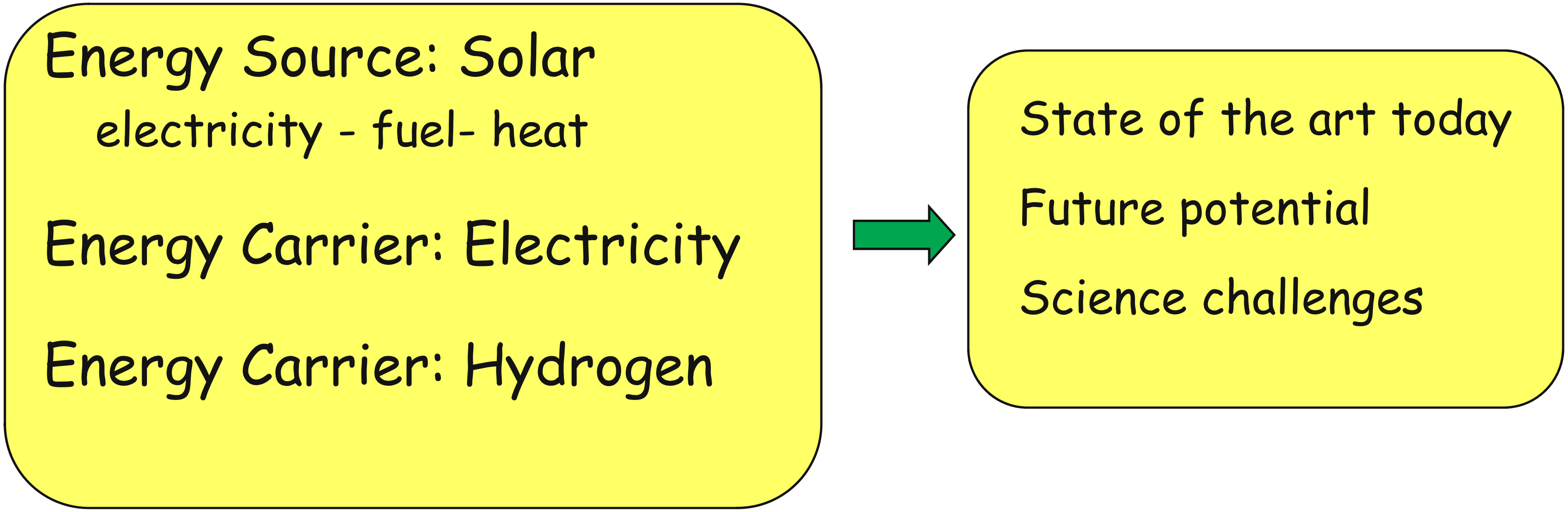
1 new power plant/day for 27 years

China: 1 GW / week

no single solution

diversity of energy sources required

Assessing Energy Futures



Energy Source: Solar

electricity - fuel- heat

Energy Carrier: Electricity

Energy Carrier: Hydrogen

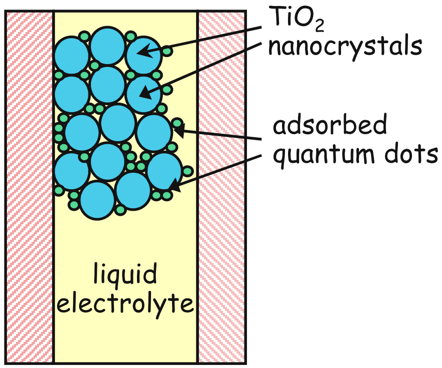
State of the art today

Future potential

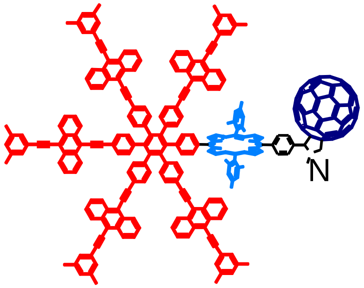
Science challenges

New Materials and Nanoscience will play a role

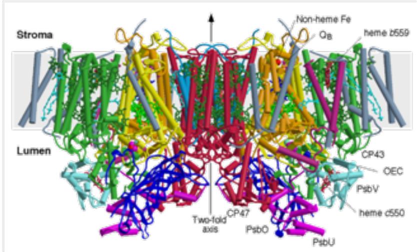
manipulation of photons, electrons, and molecules



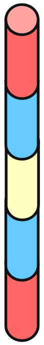
quantum dot solar cells



artificial photosynthesis



natural photosynthesis



nanostructured thermoelectrics

nanoscale architectures
top-down lithography
bottom-up self-assembly
multi-scale integration

characterization
scanning probes
electrons, neutrons, x-rays
smaller length and time scales

theory and modeling
multi-node computer clusters
density functional theory
10 000 atom assemblies

Solar energy requires interdisciplinary nanoscience research

Why Nanostructural materials are important for energy-based applications

- New desirable properties are available at the nanoscale but not found in conventional 3D materials e.g., higher diffusion coefficient to promote hydrogen release
- Higher surface area to promote catalytic interactions
- Independent control of nanomaterials parameters which depend on each other for 3D materials.

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The Energy in Sunlight

1.2×10^{5} TW delivered to Earth
36,000 TW on land (world)
2,200 TW on land (US)

San Francisco Earthquake
(1906)

magnitude 7.8

10^{17} Joules

1 second of sunlight

Earth's
Ultimate Recoverable Resource
of oil

3 Trillion (=Tera) Barrels

1.7×10^{22} Joules

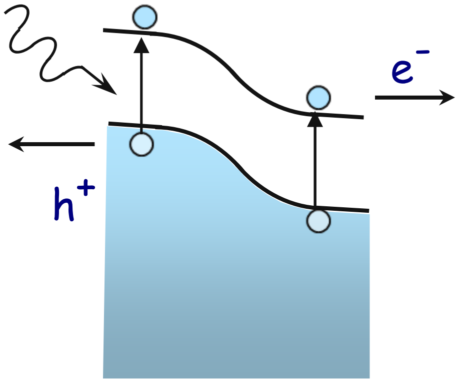
1.5 days of sunlight

Annual Human Production of Energy

4.6×10^{20} Joules

1 hour of sunlight

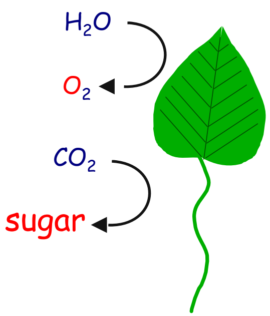
Solar Energy Utilization



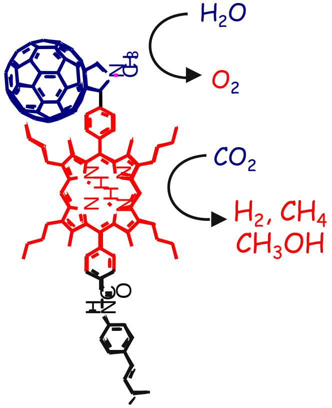
Solar Electric

.0002 TW PV (world)
.00003 TW PV (US)
$0.30/kWh w/o storage

1.5 TW electricity (world)
$0.03-$0.06/kWh (fossil)



natural
photosynthesis



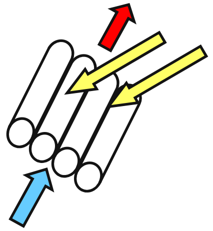
artificial
photosynthesis

Solar Fuel

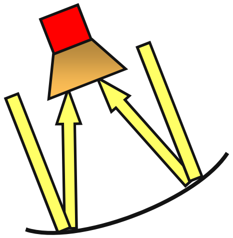
1.4 TW biomass (world)
0.2 TW biomass sustainable (world)

11 TW fossil fuel
(present use)

~ 14 TW additional energy by 2050



50 - 200 °C
space, water
heating



500 - 3000 °C
heat engines
electricity generation
process heat

Solar Thermal

0.006 TW (world)

2 TW
space and water
heating (world)

Basic Research Needs for Solar Energy

- ***The Sun is a singular solution to our future energy needs***
  - capacity dwarfs fossil, nuclear, wind . . .
  - sunlight delivers more energy in one hour than earth inhabitants use in one year
  - free of greenhouse gases and pollutants
  - secure from geo-political constraints

- ***Enormous gap between our tiny use of solar energy and its immense potential***
  - Incremental advances in today's technology will not bridge the gap
  - Conceptual breakthroughs are needed that come only from high risk-high payoff basic research

- ***Interdisciplinary research is required***

  physics, chemistry, biology, materials, nanoscience

- ***Basic and applied science should couple seamlessly***

Basic Research Needs for Solar Energy Utilization

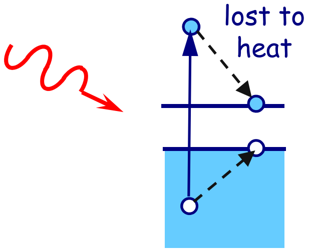
Report of the Basic Energy Sciences Workshop on Solar Energy Utilization April 18-21, 2005

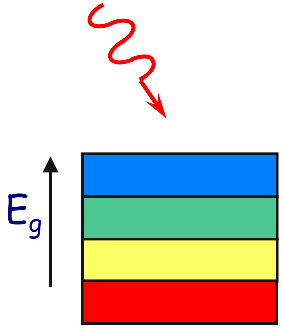
Office of Science

http://www.sc.doe.gov/bes/reports/abstracts.html#SEU

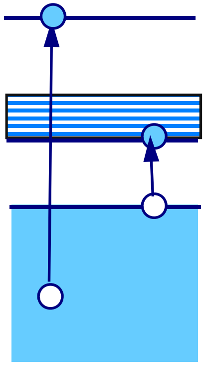
Revolutionary Photovoltaics: 50% Efficient Solar Cells

present technology: 32% limit for
- single junction
- one exciton per photon
- relaxation to band edge

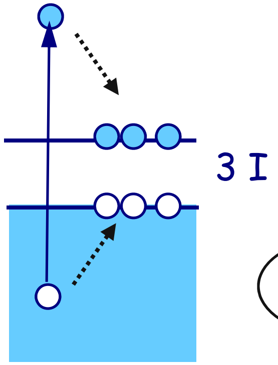




multiple junctions

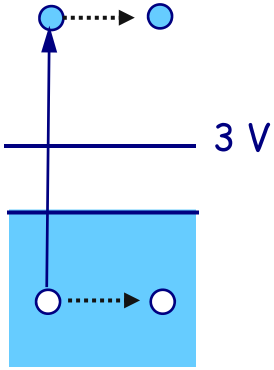


multiple gaps



multiple excitons per photon

nanoscale formats



hot carriers

rich variety of new physical phenomena
challenge: understand and implement

Solar Electric

- Despite 30-40% growth rate in installation, photovoltaics generate
  - *less* than 0.02% of world electricity (2001)
  - *less* than 0.002% of world total energy (2001)
- Decrease *cost*/watt by a factor 10 - 25 to be competitive with fossil electricity (without storage)
- Find effective method for *storage* of photovoltaic-generated electricity

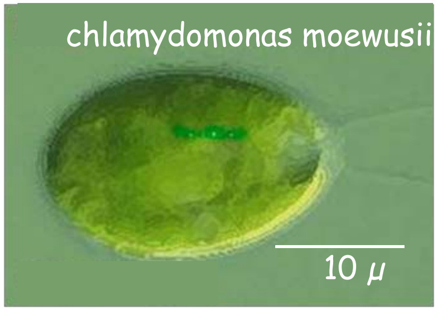
Leveraging Photosynthesis for Efficient Energy Production

- photosynthesis converts ~ 100 TW of sunlight to sugars: nature's fuel
- low efficiency (< 0.3%) requires too much land area

switchgrass

Modify the biochemistry of plants and bacteria

- improve efficiency by a factor of 5–10
- produce a convenient fuel methanol, ethanol, H_2, CH_4

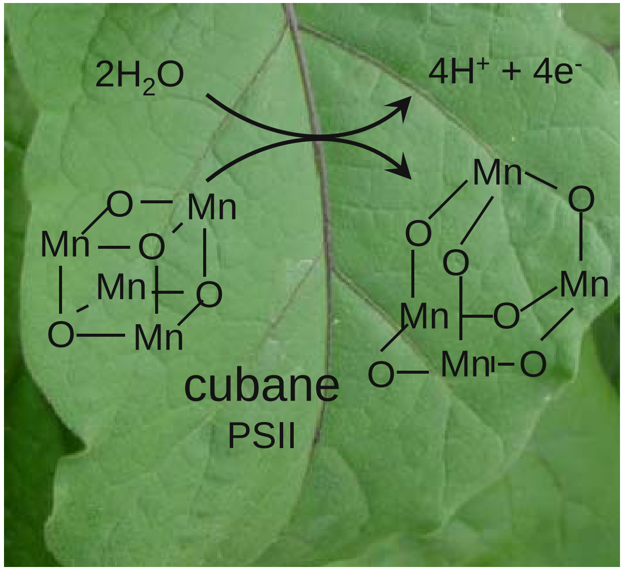


hydrogenase
$2H^+ + 2e^- \Leftrightarrow H_2$

Scientific Challenges

- understand and modify genetically controlled biochemistry that limits growth
- elucidate plant cell wall structure and its efficient conversion to ethanol or other fuels
- capture high efficiency early steps of photosynthesis to produce fuels like ethanol and H_2
- modify bacteria to more efficiently produce fuels
- improved catalysts for biofuels production

Solar-Powered Catalysts for Fuel Formation



Wu, Dismukes et al, *Inorg, Chem* 43, 5795 (2004)
Ferreira, et al, *Science* 303: 1831 (2004).

plants - photosynthesis

$2H_2O + h\nu \rightarrow 4H^+ + 4e^- + O_2$

$CO_2 + H^+ + e^- \rightarrow$ carbohydrates (~ $H_6C_{12}O_6$)

bio inspired artificial water splitting
fuel production:

artificial photosynthesis

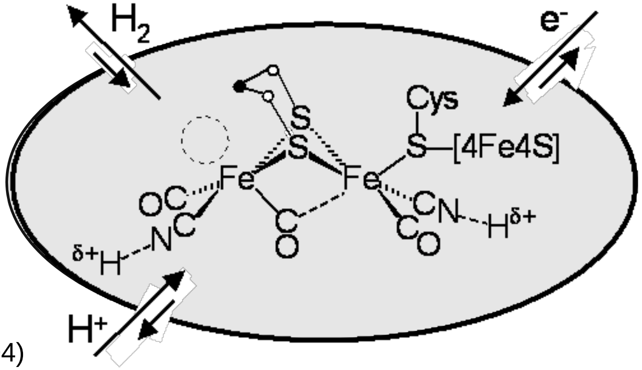
fuel from sunlight, H_2O, CO_2

H_2, CH_4, CH_3OH, C_2H_5OH

bacteria - hydrogenase
catalyst for

$$2\ H^+ + 2e^- \Leftrightarrow H_2$$

Tard et al, *Nature* 433, 610 (2005)
Justice, Rauchfuss et al, *J. Am. Chem. Soc.*126, 13214 (2004)
Alper, *Science* 299, 1686 (2003)



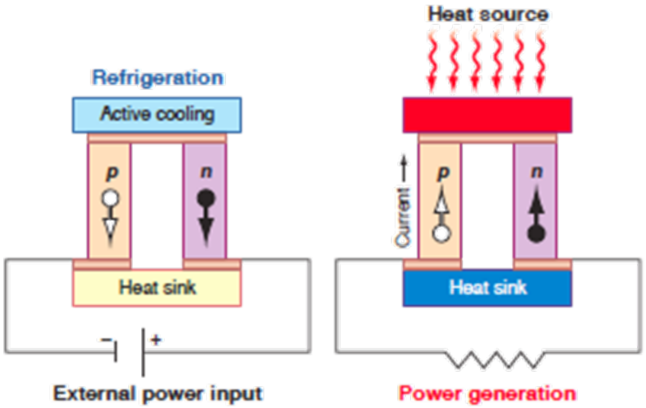
Solar Fuels: Solving the Storage Problem

- Biomass $< 0.3\%$ efficient: too much land area
  Increase efficiency 5 - 10 times
- Designer plants and bacteria for designer fuels: H_2, CH_4, methanol and ethanol
- Develop artificial photosynthesis

Energy Conversion Efficiency

conversion	*efficiency*	*practical target*
chemical bonds ⇒ electrons	30% (fossil electricity)	> 60%
chemical bonds ⇒ motion	28% (gasoline engine)	> 60%
photovoltaics photons ⇒ electrons	18% (market) / 28% (lab)	> 60%
photosynthesis photons ⇒ chemical bonds	0.3% (biomass)	> 20%
solid state lighting electrons ⇒ photons	5-25%	> 50%

Thermoelectric Conversion



No moving parts

thermal gradient ⇔ electricity

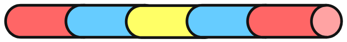
figure of merit: $ZT \sim (S^2\sigma/\kappa)\,T$

ZT ~ 1 (today)

Challenge: use nanostructures to achieve ZT~ 2-3

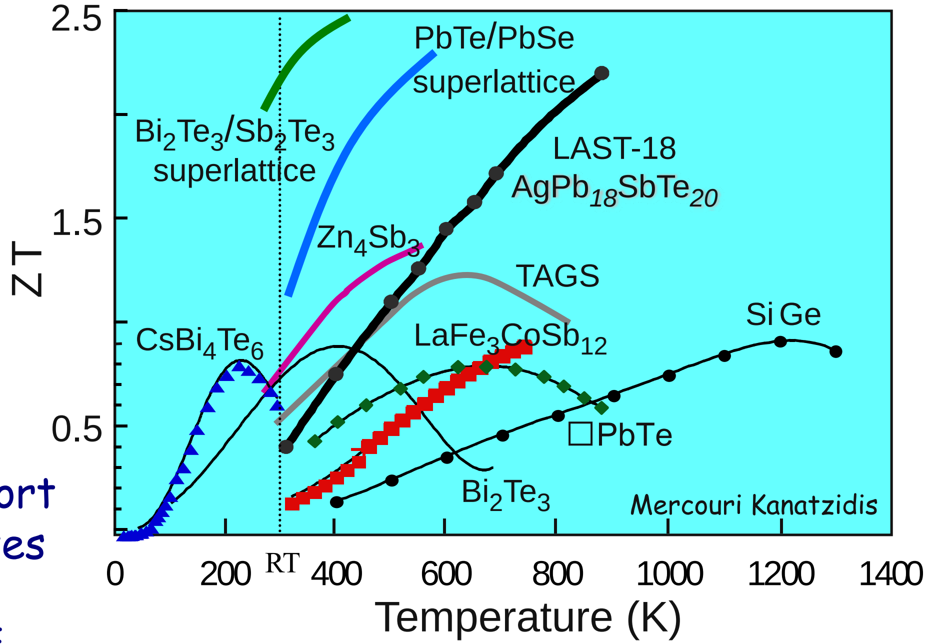
Scientific Challenges

increase electrical conductivity
decrease thermal conductivity



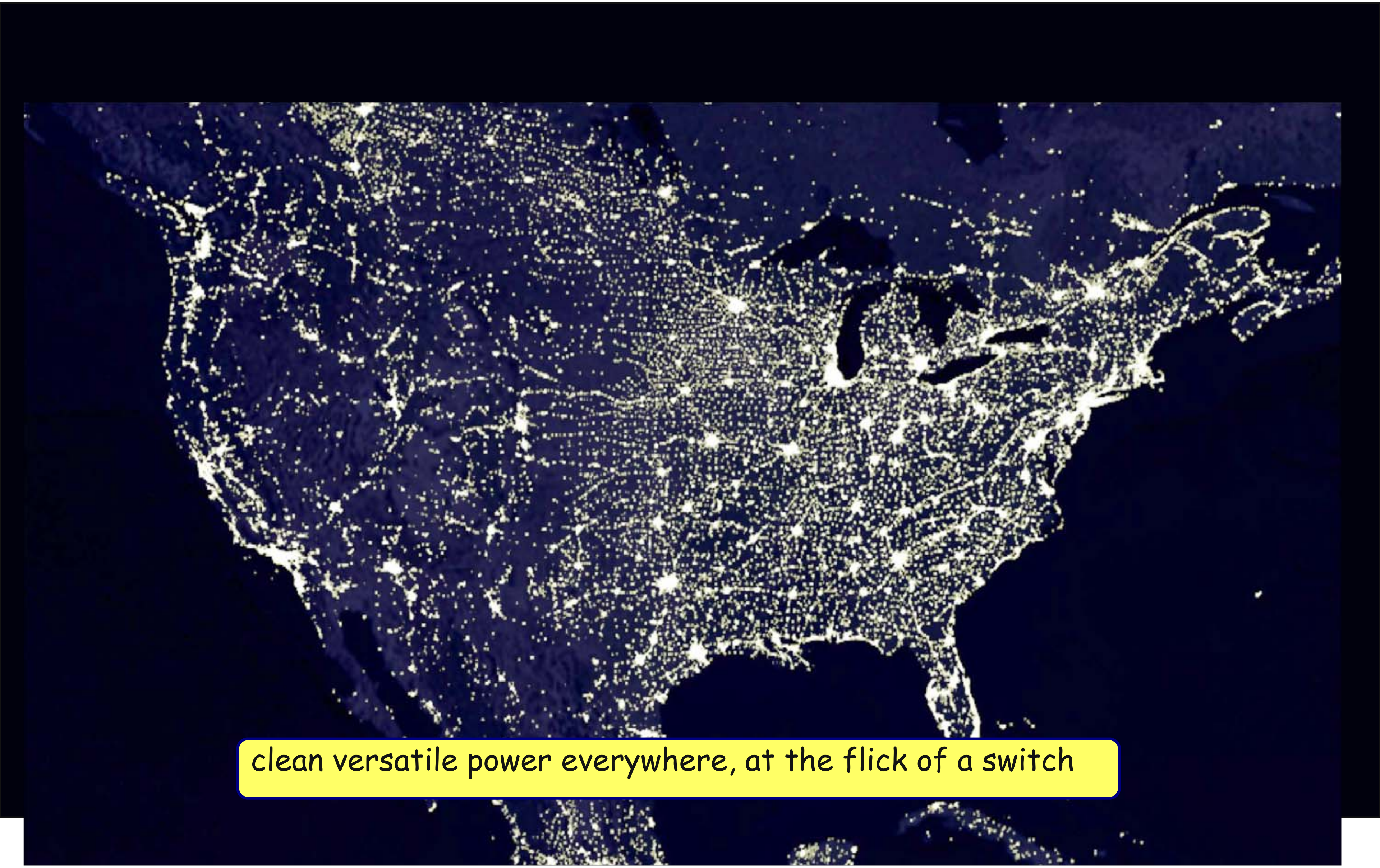
nanowire superlattice

nanoscale architectures
Interfaces preferentially block heat transport
Quantum confinement tunes density of states
doping adjusts Fermi level
Thermoelectrics industry is now taking off.
One million cooling/heating devices based on waste heat conversion in autos were sold in 2007



The Grid - the Triumph of 20th Century Engineering

electricity is our dominant energy carrier



clean versatile power everywhere, at the flick of a switch

The 21st Century: A Different Set of Challenges

capacity

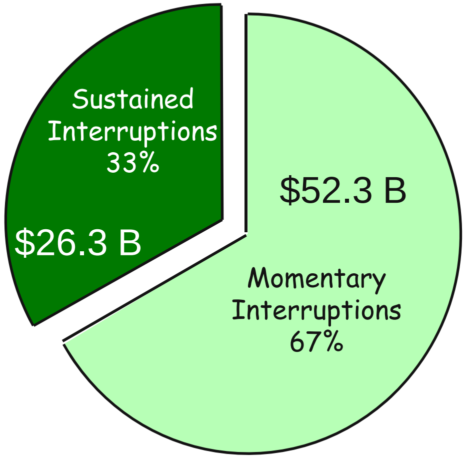
growing use ofelectricity
growing cities and suburbs
high people / power density
urban power bottleneck

2030
50% demand growth (US)
100% demand growth (world)

reliability power quality

average
power loss/customer
(min/yr)

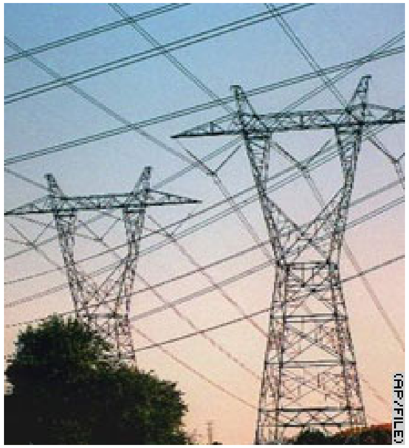
US	214
France	53
Japan	6



$79 B economic loss (US)

LaCommare & Eto, Energy 31, 1845 (2006)

efficiency lost energy



(AP/FILE)

62% energy lost in production / delivery

8-10% lost in grid

40 GW lost (US)
~ 40 power plants

2030: 60 GW lost (US)
340 Mtons CO_2

Superconductivity for the 21st Century Grid

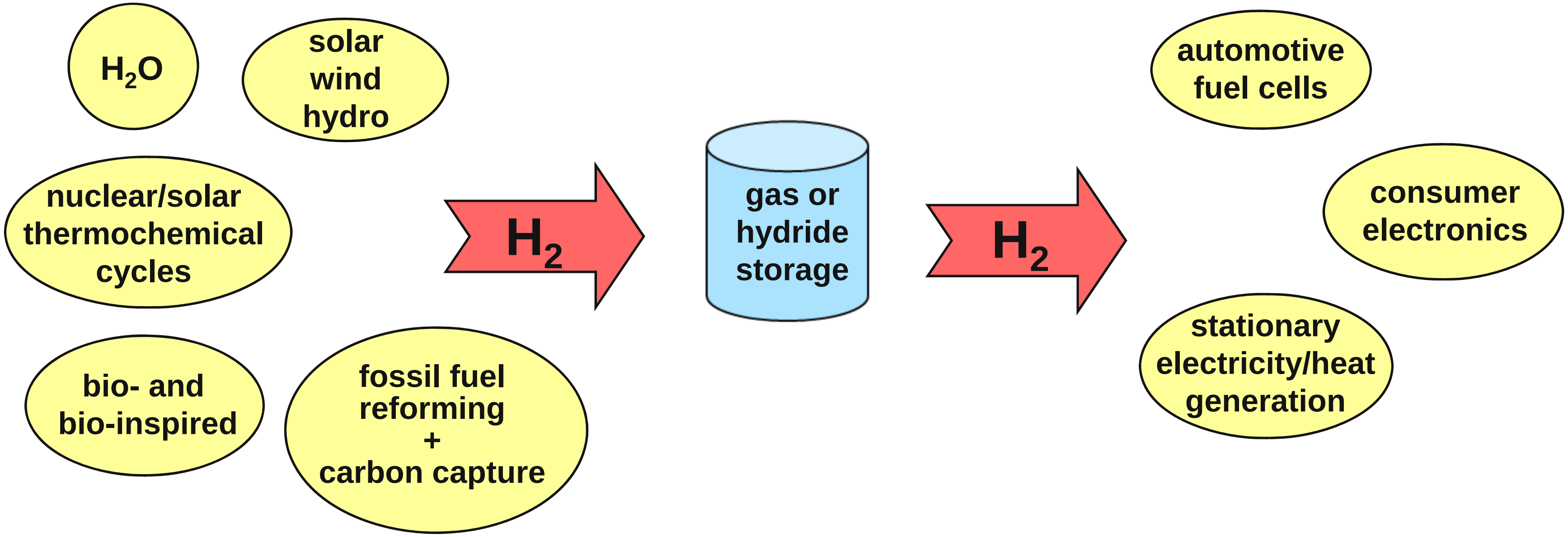
Superconductors carry electrical current
without resistance or energy loss

capacity ⇒ high current / low voltage

reliability / quality ⇒ smart, self-healing power control

efficiency ⇒ zero resistance (DC)
100 times lower than copper (AC)

Hydrogen as an Energy Carrier



H_2O

solar
wind
hydro

nuclear/solar
thermochemical
cycles

bio- and
bio-inspired

fossil fuel
reforming
+
carbon capture

H_2

gas or
hydride
storage

H_2

automotive
fuel cells

consumer
electronics

stationary
electricity/heat
generation

production

9M tons/yr

↓

150 M tons/yr
(light trucks and cars in 2040)

storage

4.4 MJ/L (Gas, 10,000 psi)
8.4 MJ/L (LH2)

↓

9.72 MJ/L
(2015 FreedomCAR Target)

use in fuel cells

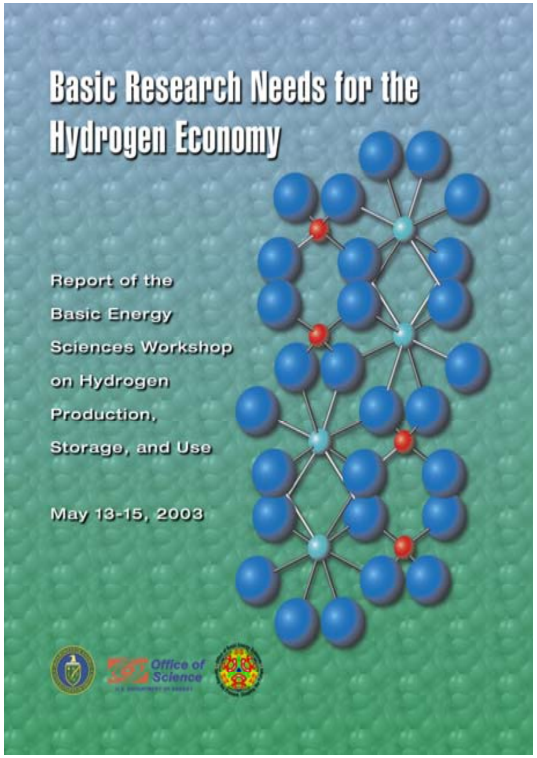
$3000/kW

↓

$300/kW
mass production

$30/kW
(Internal Combustion Engine)

Hydrogen Studies



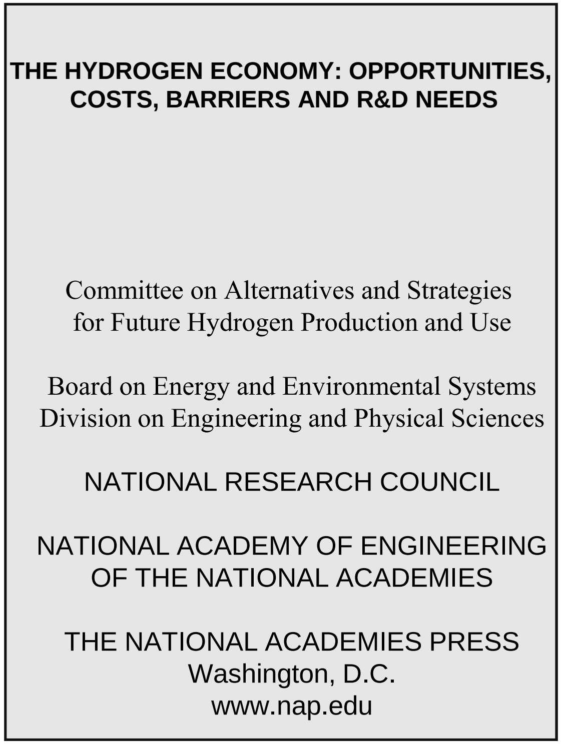
Basic Research Needs for the Hydrogen Economy

Report of the
Basic Energy
Sciences Workshop
on Hydrogen
Production,
Storage, and Use

May 13-15, 2003

Basic Energy Sciences
Department of Energy
July 2003/February 2004

http://www.sc.doe.gov/bes/hydrogen.pdf



THE HYDROGEN ECONOMY: OPPORTUNITIES,
COSTS, BARRIERS AND R&D NEEDS

Committee on Alternatives and Strategies
for Future Hydrogen Production and Use

Board on Energy and Environmental Systems
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

National Research Council
National Academy of Sciences
February 2004

http://www.nap.edu/catalog/10922.html

December
2004
PHYSICS TODAY

The Hydrogen Economy

If the fuel cell is to become the modern steam engine, basic research must provide breakthroughs in understanding, materials, and design to make a hydrogen-based energy system a vibrant and competitive force.

George W. Crabtree, Mildred S. Dresselhaus, and Michelle V. Buchanan

Since the industrial revolution began in the 18th century, fossil fuels in the form of coal, oil, and natural gas have powered the technology and transportation networks that drive society. But continuing to power the world from fossil fuels threatens our energy supply and puts enormous strains on the environment. The world's demand for energy is projected to double by 2050 in response to population growth and the industrialization of developing countries.[1] The supply of fossil fuels is limited, with restrictive shortages of oil and gas projected to occur within our lifetimes (see the article by Paul Weisz in PHYSICS TODAY, July 2004, page 47). Global oil and gas reserves are concentrated in a few regions of the world, while demand is growing everywhere; as a result, a secure supply is increasingly difficult to assure. Moreover, the use of fossil fuels puts our own health at risk through the chemical and particulate pollution it creates. Carbon dioxide and other greenhouse gas emissions that are associated with global warming threaten the stability of Earth's climate.

A replacement for fossil fuels will not appear overnight. Extensive R&D is required before alternative sources can supply energy in quantities and at costs competitive with fossil fuels, and making those alternative sources available commercially will itself require developing the proper economic infrastructure. Each of those steps takes time, but greater global investment in R&D will most likely hasten the pace of economic change. Although it is impossible to predict when the fossil fuel supply will fall short of demand or when global warming will become acute, the present trend of yearly increases in fossil fuel use shortens our window of opportunity for a managed transition to alternative energy sources.

Hydrogen as energy carrier

One promising alternative to fossil fuels is hydrogen[2,3] (see the article by Joan Ogden, PHYSICS TODAY, April 2002, page 69). Through its reaction with oxygen, hydrogen releases energy explosively in heat engines or quietly in fuel cells to produce water as its only byproduct. Hydrogen is abundant and generously distributed throughout the world without regard for national boundaries; using it to create a hydrogen economy—a future energy system based on hydrogen and electricity—only requires technology, not political access.

Although in many ways hydrogen is an attractive replacement for fossil fuels, it does not occur in nature as the fuel H_2. Rather, it occurs in chemical compounds like water or hydrocarbons that must be chemically transformed to yield H_2. Hydrogen, like electricity, is a carrier of energy, and like electricity, it must be produced from a natural resource. At present, most of the world's hydrogen is produced from natural gas by a process called steam reforming. However, producing hydrogen from fossil fuels would rob the hydrogen economy of much of its raison d'être: Steam reforming does not reduce the use of fossil fuels but rather shifts them from end use to an earlier production step; and it still releases carbon to the environment in the form of CO_2. Thus, to achieve the benefits of the hydrogen economy, we must ultimately produce hydrogen from non-fossil resources, such as water, using a renewable energy source.

Figure 1 depicts the hydrogen economy as a network composed of three functional steps: production, storage, and use. There are basic technical means to achieve each of these steps, but none of them can yet compete with fossil fuels in cost, performance, or reliability. Even when using the cheapest production method—steam reforming of methane—hydrogen is still four times the cost of gasoline for the equivalent amount of energy. And production from methane does not reduce fossil fuel use or CO_2 emission. Hydrogen can be stored in pressurized gas containers or as a liquid in cryogenic containers, but not in densities that would allow for practical applications—driving a car up to 500 kilometers on a single tank, for example. Hydrogen can be converted to electricity in fuel cells, but the production cost of prototype fuel cells remains high: \$3000 per kilowatt of power produced for prototype fuel cells (mass production could reduce this cost by a factor of 10 or more), compared with \$30 per kilowatt for gasoline engines.

The gap between the present state of the art in hydrogen production, storage, and use and that needed for a competitive hydrogen economy is too wide to bridge in incremental advances. It will take fundamental breakthroughs of the kind that come only from basic research.

Beyond reforming

The US Department of Energy estimates that by 2040 cars and light trucks powered by fuel cells will require about 150 megatons per year of hydrogen.[3] The US currently produces about 9 megatons per year, almost all of it by reforming natural gas. The challenge is to find inexpensive

George Crabtree *is a physicist in the materials science division at Argonne National Laboratory in Illinois.* **Mildred Dresselhaus** *is a professor in the department of physics and the department of electrical engineering and computer science at the Massachusetts Institute of Technology in Cambridge.* **Michelle Buchanan** *is a chemist in the chemical sciences division at Oak Ridge National Laboratory in Tennessee.*

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December 2004 Physics Today 39

G. W. Crabtree, M. S. Dresselhaus,
M. V. Buchanan

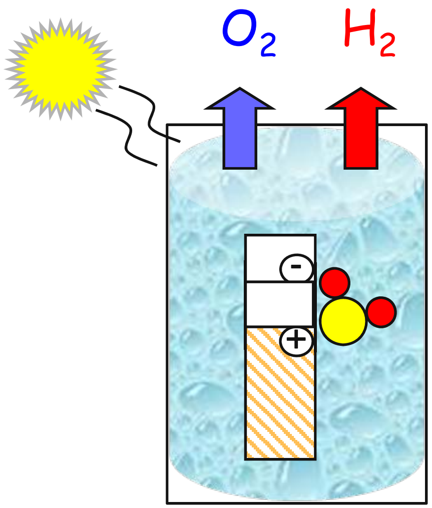
Physics Today **57**(12), 39-44, 2004

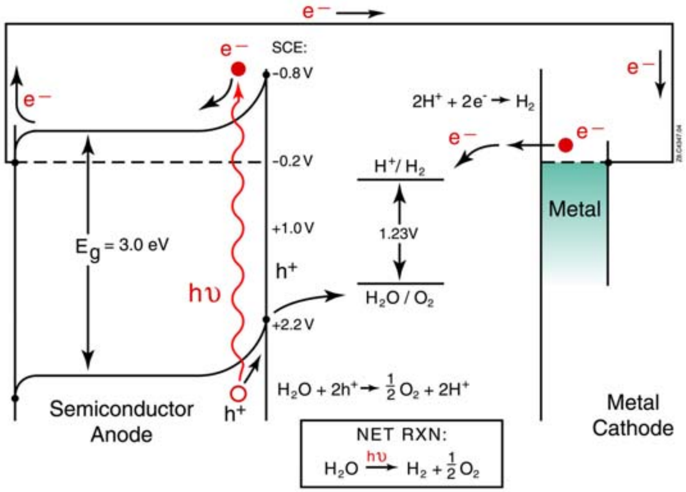
http://www.physicstoday.org/vol-57/iss-12/p39.html

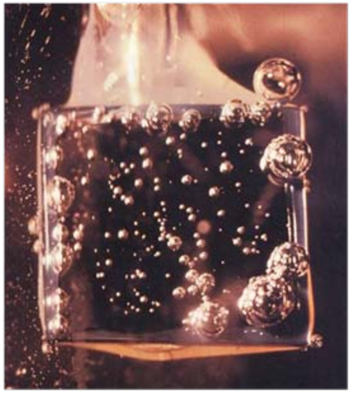
All emphasize:

- Necessity for basic research
- Collaborations between basic and applied research, multidisciplinarity

Efficient Solar Water Splitting







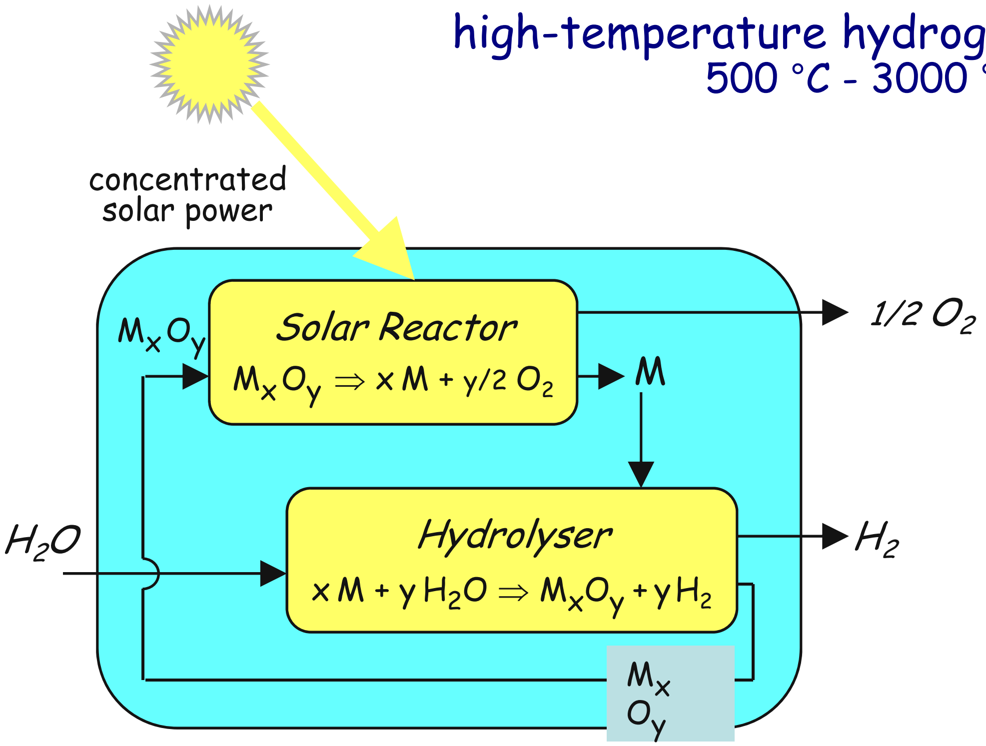
demonstrated efficiencies 10% in laboratory

Scientific Challenges

- cheap electrode materials that are robust in water
- catalysts for the redox reactions at each electrode
- nanoscale architecture for electron excitation ⇒ transfer ⇒ reaction

Solar Thermochemical Fuel Production

high-temperature hydrogen generation
500 °C - 3000 °C



concentrated solar power

Solar Reactor

$M_xO_y \Rightarrow x\,M + y/2\ O_2$

M_xO_y

1/2 O_2

M

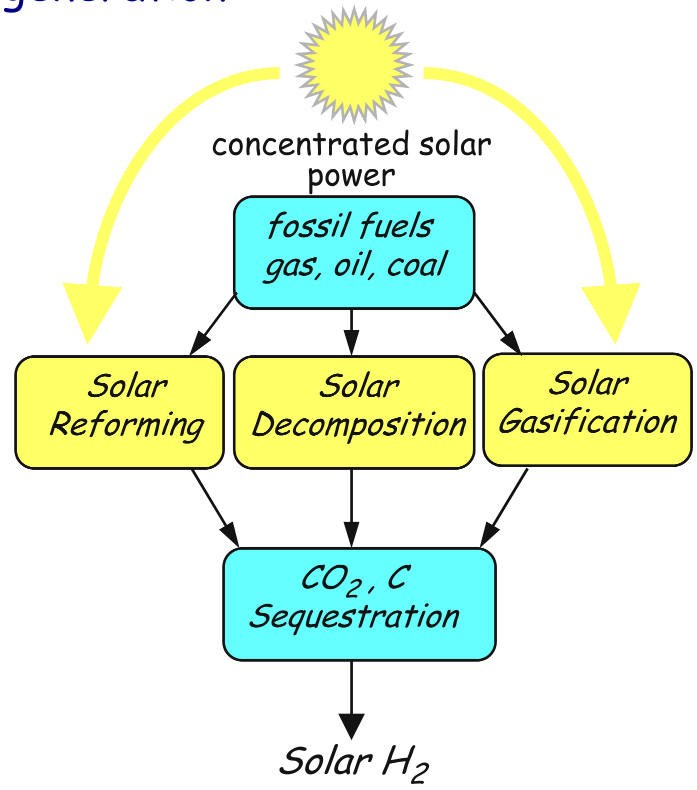
Hydrolyser

$x\,M + y\,H_2O \Rightarrow M_xO_y + y\,H_2$

H_2O

H_2

M_xO_y



concentrated solar power

fossil fuels
gas, oil, coal

Solar Reforming

Solar Decomposition

Solar Gasification

CO_2, C Sequestration

Solar H_2

Scientific Challenges

high temperature reaction kinetics of
- metal oxide decomposition
- fossil fuel chemistry

robust chemical reactor designs and materials

A. Streinfeld, Solar Energy, 78,603 (2005)

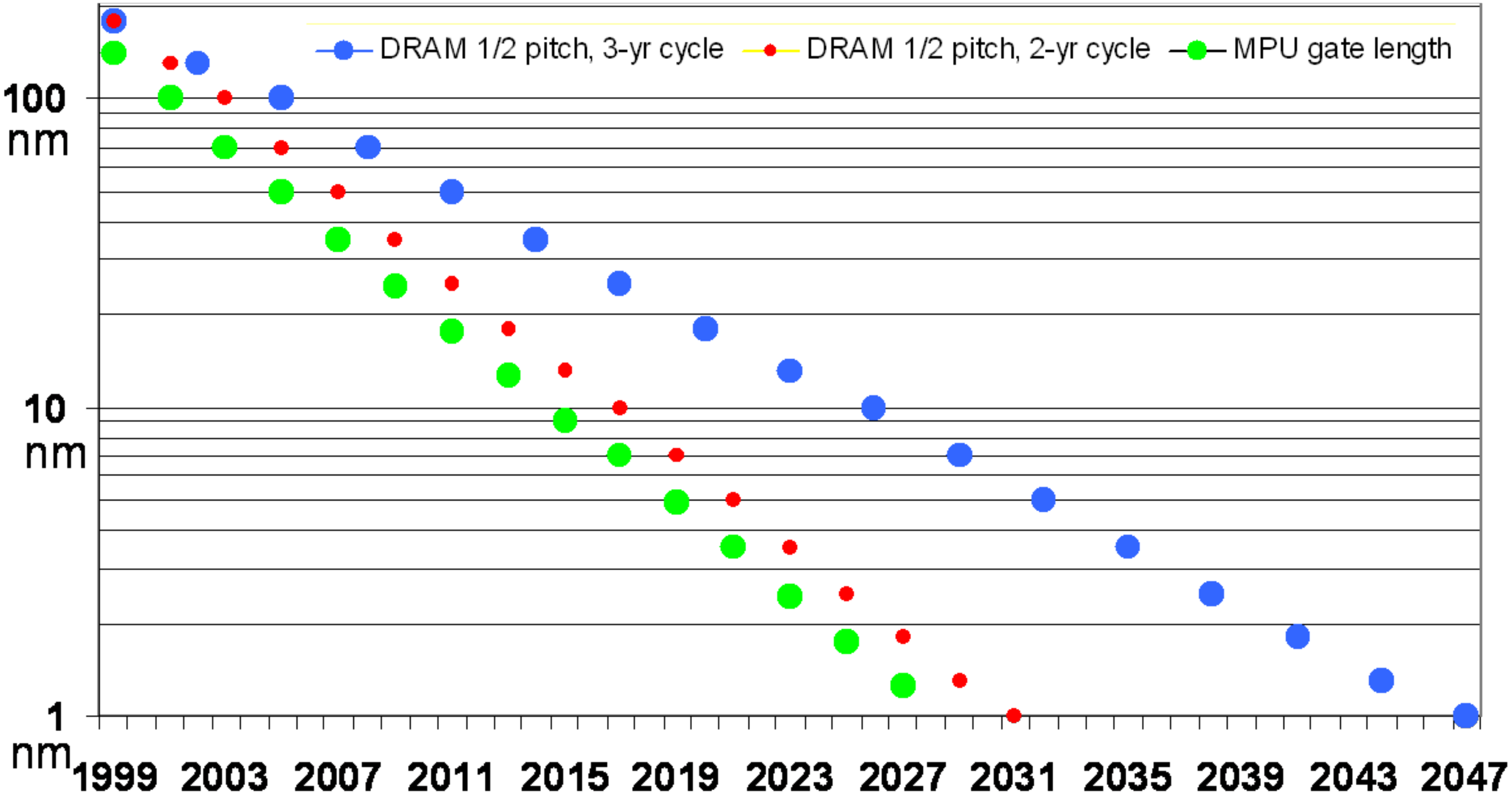
Energy Research: Forefront and Challenges

Outline

- Introduction – the energy challenge
- Energy alternatives and the materials challenge
- Think big, go small
- Science and Policy Perspectives

Moore’s Law for semiconductor electronics

soon, all microchips will be nanoscale devices



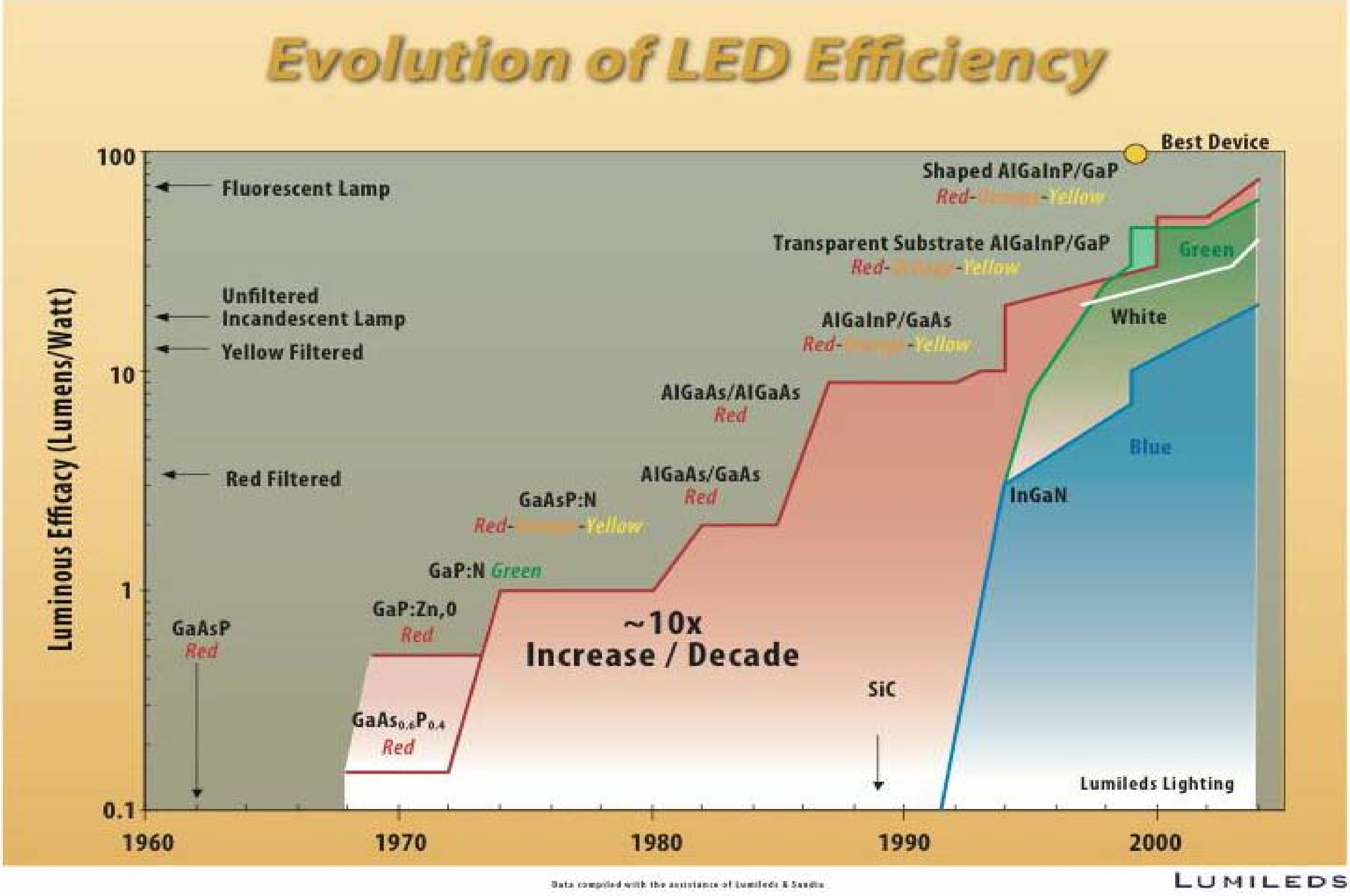
CONCLUSION: *Moore’s law continues for this decade regarding future size, device performance and cost for semiconductor electronics industry.*

Semiconductor Research Corporation

Extension of Moore's Law to the Energy Industry

- Moore's law has for many years been working to set goals for the electronics, opto-electronics, and magnetics industries.
- We now need to apply Moore's law to set goals for the energy industry.

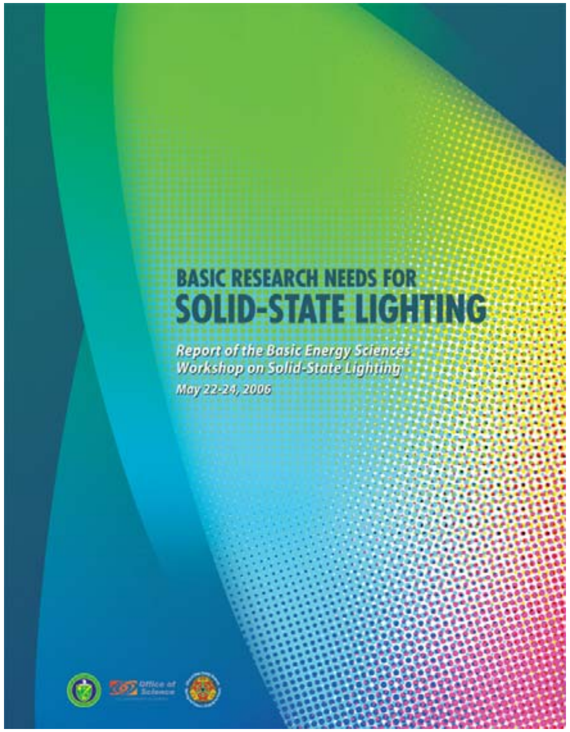
Moore’s law for Solid-State Lighting at Half the Energy Consumption as for Conventional Lighting



Evolution of LED Efficiency

Data compiled with the assistance of Lumileds & Sandia

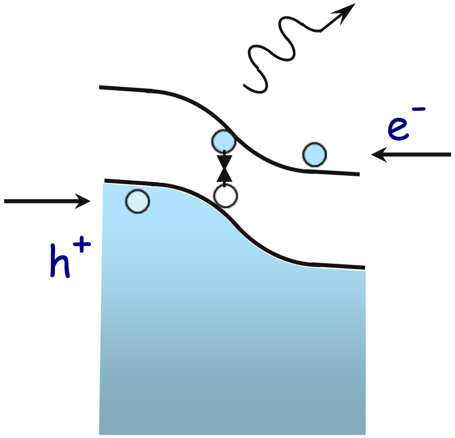
Electricity Use: Solid State Lighting



BASIC RESEARCH NEEDS FOR
SOLID-STATE LIGHTING

Report of the Basic Energy Sciences Workshop on Solid-State Lighting
May 22-24, 2006

http://www.sc.doe.gov/bes/reports/abstracts.html#SSL

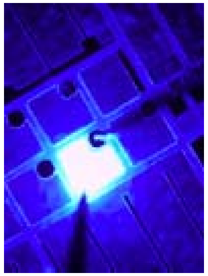


wide bandgap
compound semicondutors
GaN InGaN AlGaN
color: control bandgap
efficiency: control defects
white light: mix 3 or 4 colors

Research Challenges
new materials
doping and defect control
white light at 50% efficiency
cut cost

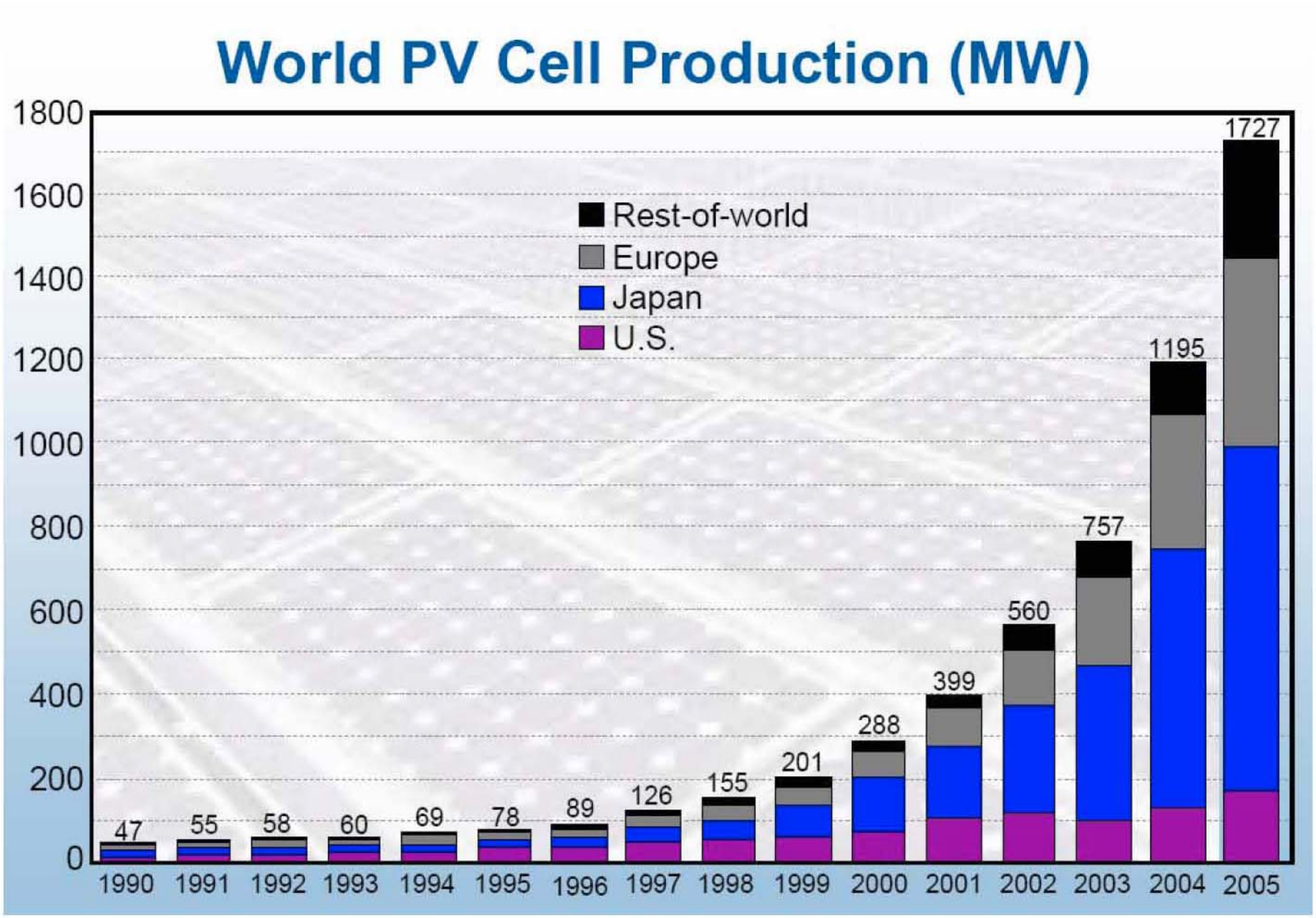
Lighting ~ 22%
of electricity use

incandescent
~ 5% efficient



Solid state
> 50% efficient

Example of Moore's law



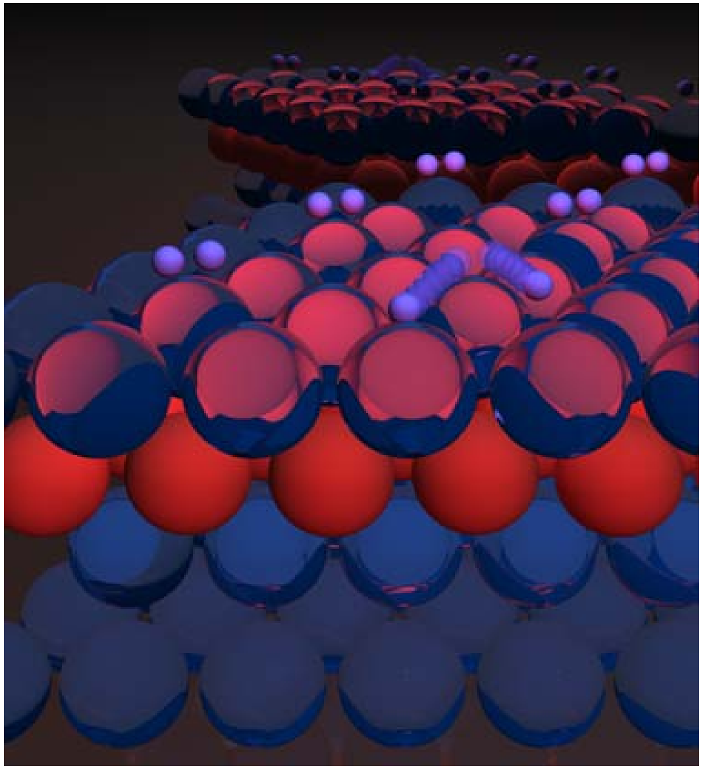
Source: Paul Maycock, PV News, March 2006

Annual Growth Rate > 30% For The Last Decade

Technological Advances in Solar Photovoltaics

- Multiple gap solar cell (e.g., GaInP/GaInAs/Ge) to capture solar spectrum efficiently (40.7% efficiency achieved): R.R. King et al., Appl. Phys. Lett. 90, 183516 (2007)
- Tune compositions and strain for superlattices to optimize response to solar spectrum
- Use solar concentrator (e.g., 240 suns) to drastically reduce size of active area of solar cell by factor of 1000
- Allows reduction of overall cost despite added costs for MOCVD fabrication, solar tracking and cooling
- Spectrolab is in high volume production of a system with 40% average efficiency and cost of < 0.15 $/kw hr by 2010. This company has a roadmap for year by year increase in efficiency

Predicting Catalysts for Hydrogen Production, Storage or Fuel-Cell Utilization



Theoretical calculation of molecular hydrogen undergoing dissociation over near-surface alloys.

- Small purple spheres: hydrogen
- Blue spheres: platinum atoms
- Red spheres: nickel atoms
- Bicolor blue and red spheres: platinum atoms whose electronic properties have been dramatically altered by the underlying nickel.

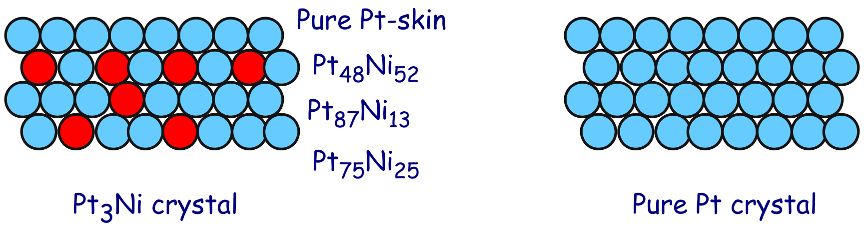
- There is a need for low-temperature, highly efficient and durable catalysts for large scale hydrogen production.
- New catalyst structures and compositions are now being predicted *a priori* using quantum chemistry and molecular dynamics.
- Single metallic layers of one metal embedded within a matrix of another metal produce low-energy hydrogen scission and recombination.
- Nickel within platinum can attach atomic hydrogen weakly like copper and gold, while dissociating molecular hydrogen rapidly like platinum and rhodium.
- This study may lead to breakthroughs in hydrogen production, storage and combustion in fuel cells.

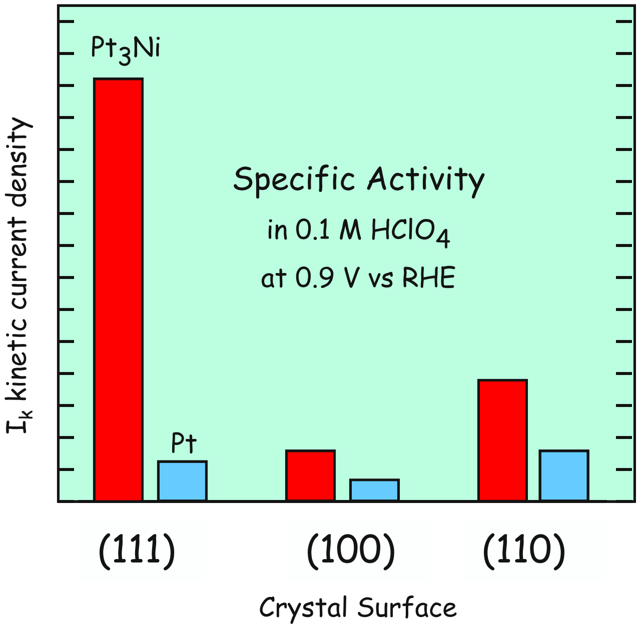
J. Zhang, et al, Angew. Chem. Int Ed. **44**, 2132 (2005)

Pt Catalysis: 10x Increase for Oxygen Reduction Reaction

Oxygen Reduction Reaction

$$1/2\ O_2 + 2\ H^+ + 2\ e^- \Rightarrow H_2O$$





10x greater catalytic activity in Pt_3Ni with a (111) surface means

10x less Pt

10x higher reaction rate

Surface catalysis controlled by subsurface structure

Continuous tuning by subsurface composition

Tune surface electronic structure and bond strength

Predictable by density functional theory of the effect of d-band impurities

Other substitutions:

25	26	27	28	29
Mn	Fe	Co	Ni	Cu

V. Stamenkovic et al, Science **315**, 493 (2007)

V. Stamenkovic et al, Nature Materials **6**, 241 (2007)

Energy Research:
Forefront and Challenges

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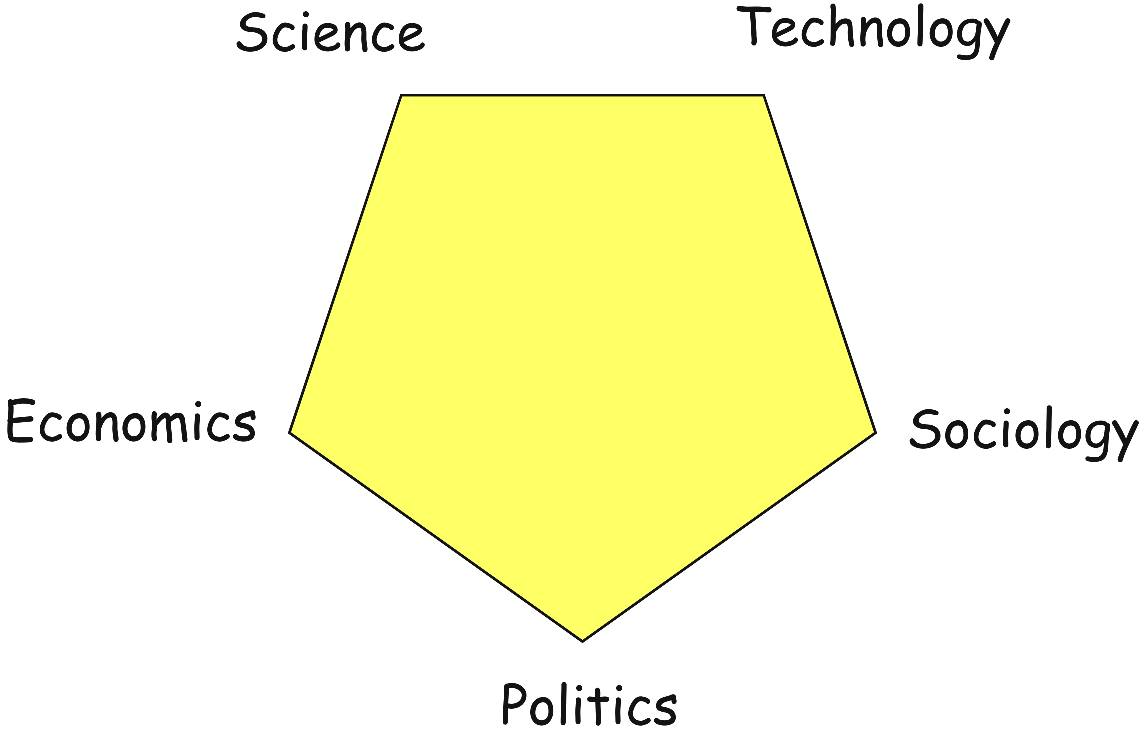
Energy: a BIG Complex System



Science

Technology

Economics

Sociology

Politics

- no one dimensional solutions will work
- transition to renewable energy requires confluence of all elements

Perspective

- Grand energy challenge
  - Double by 2050, triple by 2100
  - Supply, security, pollution, climate
  - Complex emergent system- cannot predict distant outcomes
- Efficient energy conversion is key for production, storage and use
- Materials and nanoscience are key to energy conversion
- Discovery science is needed, incremental advances not sufficient
- Basic research investments today create energy alternatives tomorrow

Summary and Policy Issues

- A mix of future sustainable energy conversion technologies will be needed
- New materials and nanoscience discoveries are necessary to its development
- Strong interplay between basic and applied sciences is a key to success
- Interdisciplinary approaches, and coupling theory/experiment are vital
- Working with <u>industry</u> at all stages is a key factor
- The challenges and constraints are global and complementary among different countries
- International collaboration and networking must be encouraged and supported

European Commission

European Materials Forum

Lisbon 2007 Declaration

On

International Cooperation in Materials Research: Key to Meeting Energy Needs and Addressing Climate Change

Conclusions of the

First World Materials Summit

Held under the auspices of:

Portuguese European Presidency

Lisbon

5th October 2007

PORTUGAL 2007

Presidência Portuguesa da União Europeia 2007 - Evento de interesse cientifico - Ciência 2007UE

Materials Scientists Meet in Lisbon and Unite to Battle Climate Change

(1) To produce internationally agreed strategic plans (“road maps”) for the development of new and improved materials and the products for future energy technologies.

(2) To bring together leading academic, public sector and industrial scientists in a series of focused workshop meetings, to discuss important technical issues, to ensure that key problems are tackled in a swift and effective manner. Several topics have already been selected and the agenda has been prepared:

- Transformation and recycling of CO_2 into a new raw material,
- Hydrogen generation and storage,
- Clean Coal Technology,
- Nuclear energy: Fusion and Fission, in particular for hydrogen production
- Fuel Cells Technologies (Sydney 2008)

(3) To identify and train a new generation of young international leaders for leveraging materials science and technology for clean energy research and development.

(4) To promote major new international collaborative materials research programs relevant to future energy technologies.

(5) To provide information to global, regional and national policy makers, and to investment analysts in the energy sector.

(6) To ensure that manufacturers in the energy sector, especially small and medium enterprises, have the best possible access to information related to innovative materials developments.

(7) To interface with other key international organizations relevant to the energy sector or involved in energy-related materials research.

(8) To stimulate public interest in, and awareness of, energy-related issues.

(9) To attract and nurture the young generation of scientists and engineers to meet the mega challenge of clean energy sustainability and growth through providing a clear picture of the challenges, opportunities and career paths.