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U.S. Department
of Energy

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The future of the human race is in the hands of undergraduates: what physics can do for sustainable energy

*Presented at the SPIN-UP
Central Regional Workshop,
Marquette Univ., Wisconsin
06/19/2009*



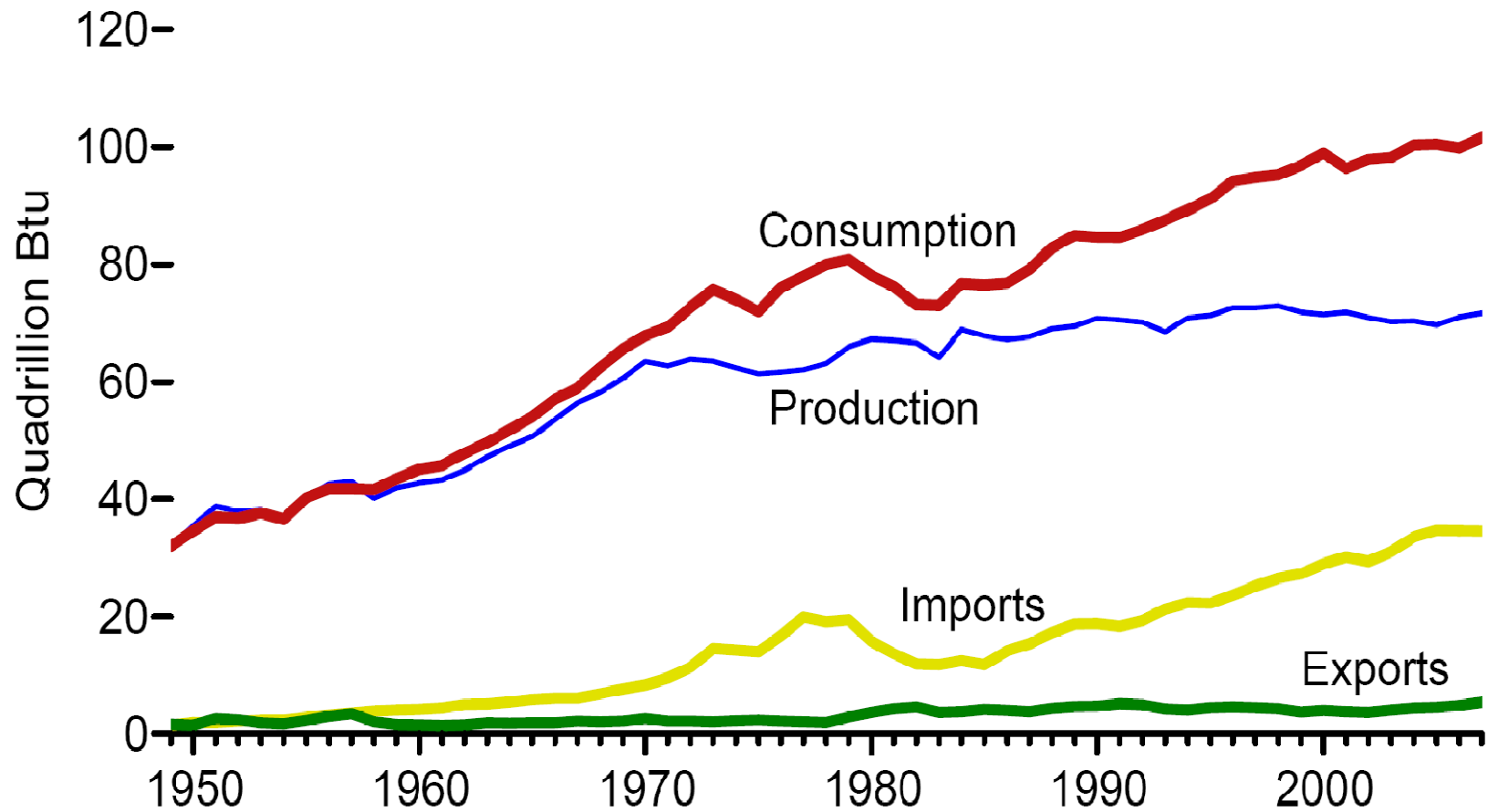
*J. Murray Gibson
Associate Laboratory Director for Photon Sciences, ANL
Director, Advanced Photon Source*

*Thanks to Pat Dehmer Deputy Director DOE Office of Science and
the DOE BESAC committee for much of the material used here
(www.science.doe.gov)*

The US thirst for energy

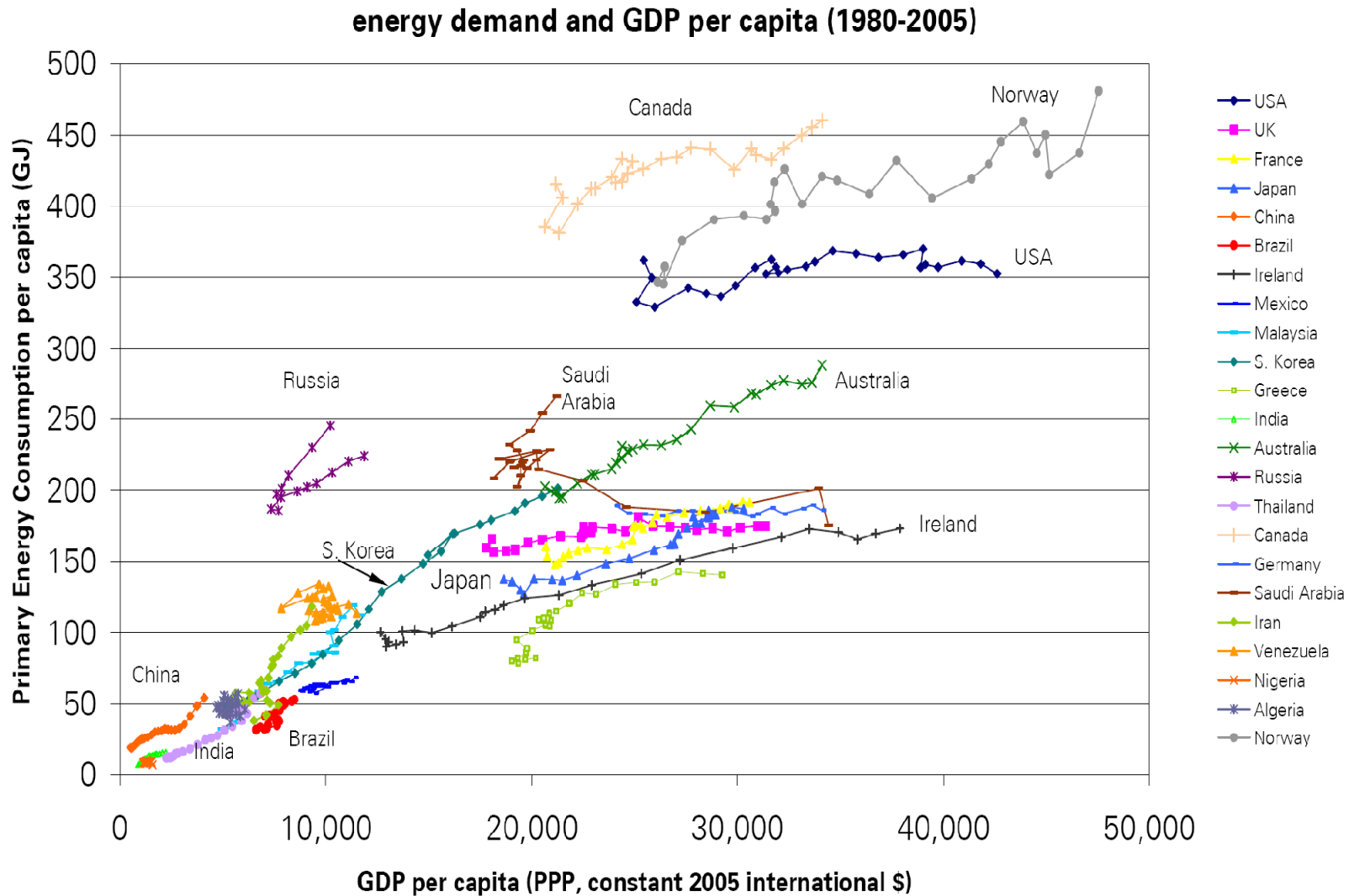
- Today the US consumes about 100 Quads of energy per year
 - 100 Quadrillion(10^{15}) btu's – 10^{18} Joules
 - *This energy would raise the temperature of Lake Tahoe by 1 °C*
- The power needs of the US are 3.3 Terawatts
 - *Equivalent of a 1 megaton nuclear bomb every day and a half*
- US share is 22% of the world's total consumption of 463 Quads (2005)
 - *Yet we represent less than 5% of the world's population*

The US has been a net importer of energy since the 1950's

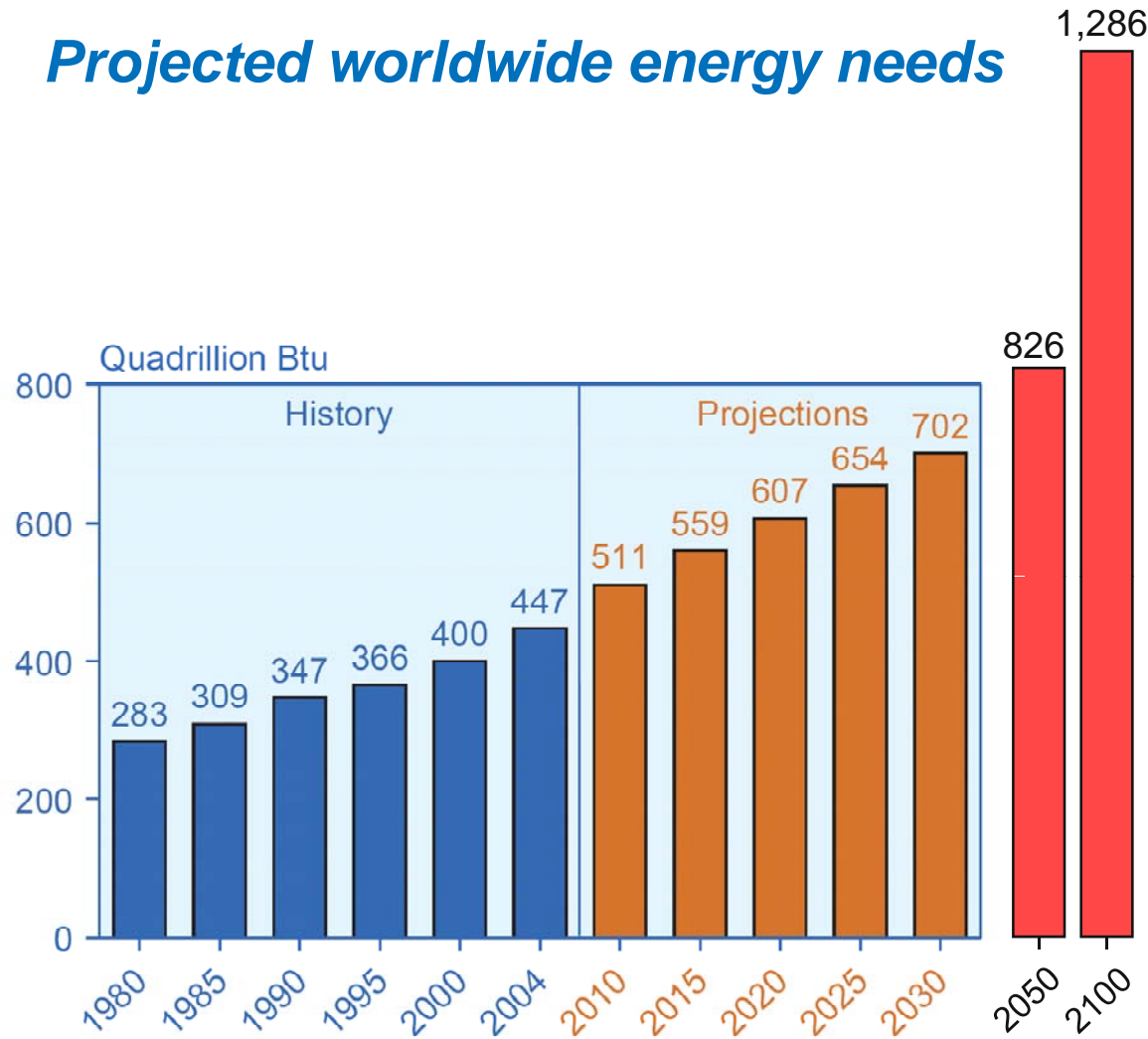


In 2007 we imported one third of our energy needs

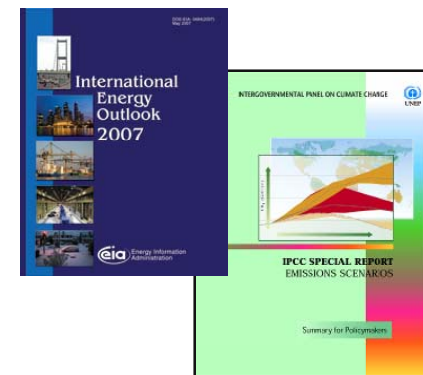
Demand grows with GDP (we take more than our share)



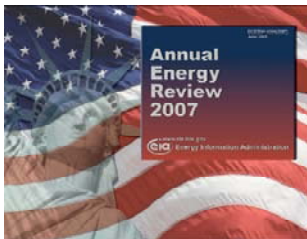
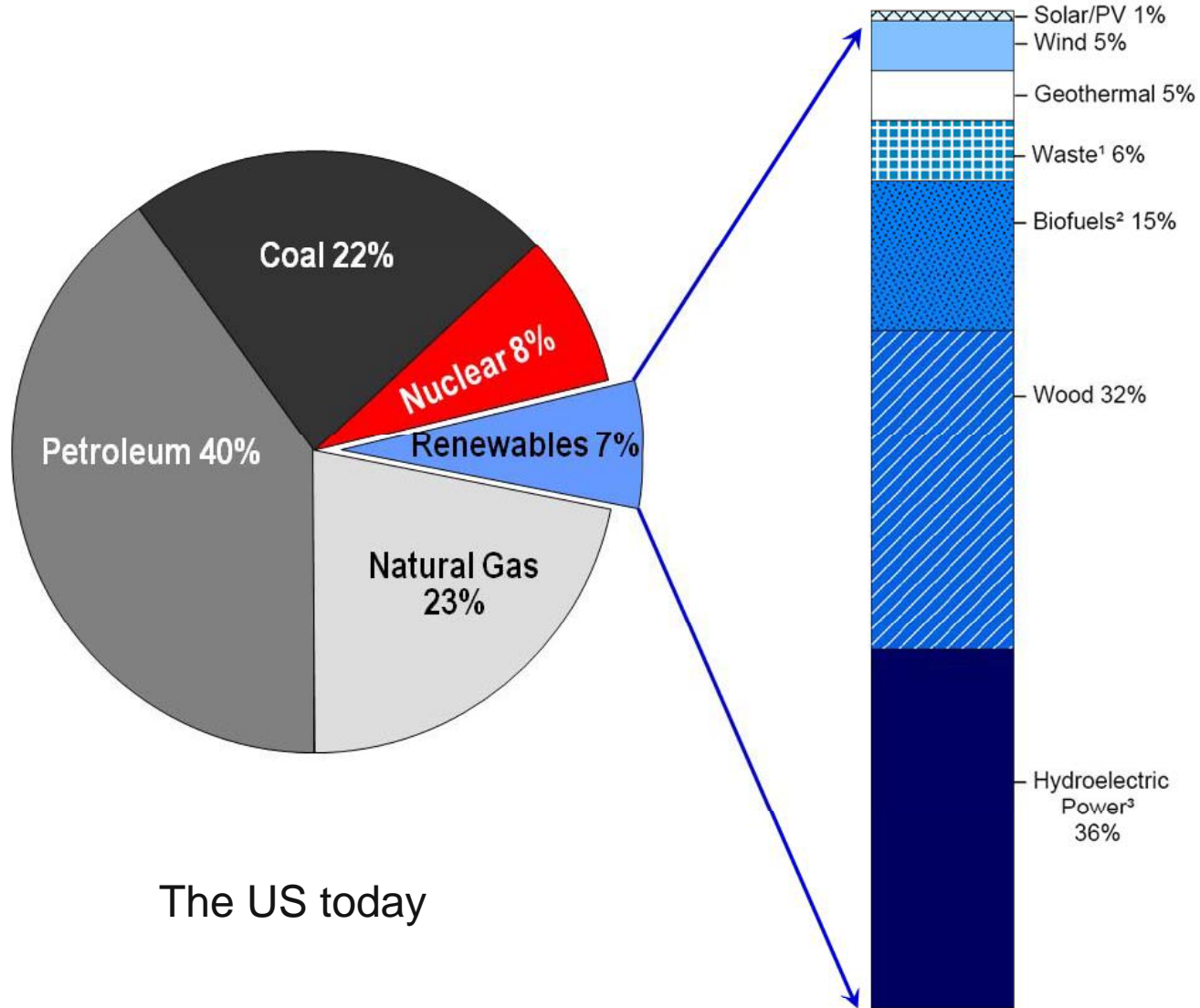
Projected worldwide energy needs



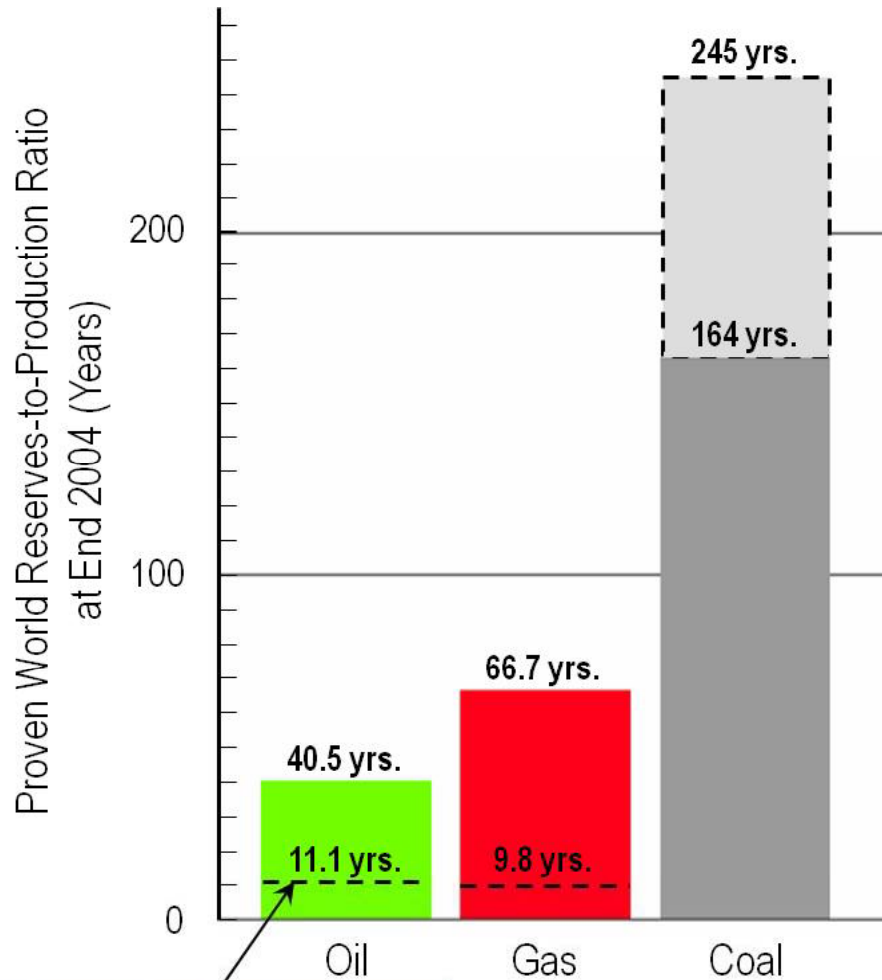
Projections till 2030 from Energy Information Administration. Beyond 2030 projections from Intergovernmental Panel on Climate Change (IPCC) – “moderate” scenarios



Where does the energy come from?



Worldwide fossil fuel reserves are finite



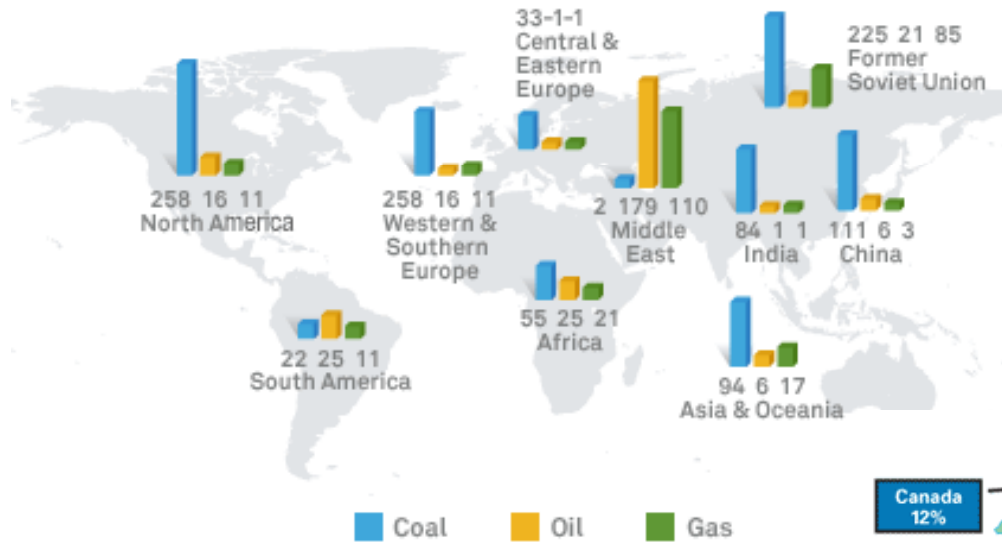
U.S. R/P ratios shown by dotted lines.



BP Statistical Review of World Energy 2005

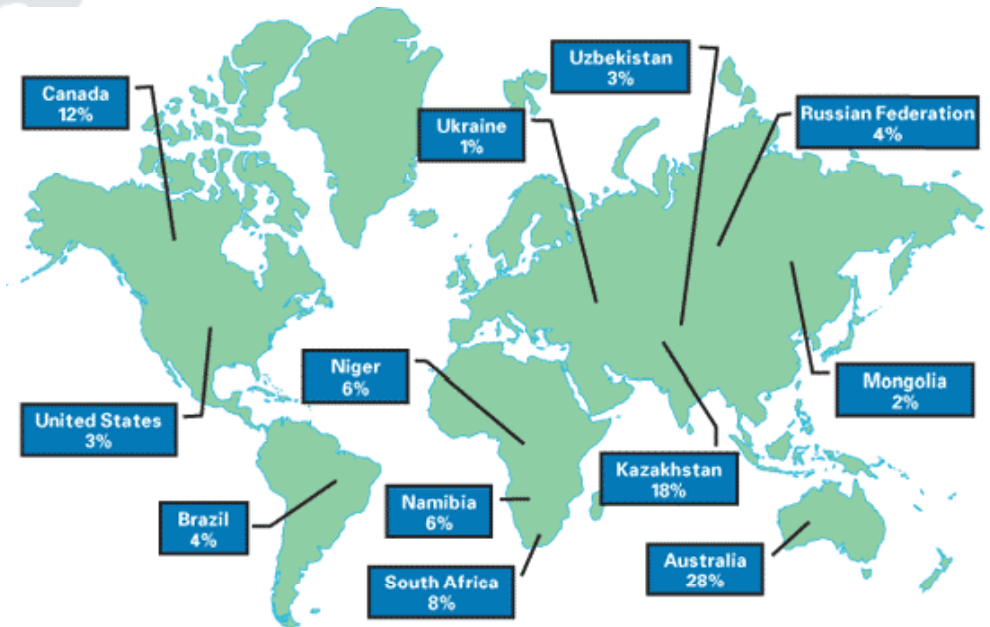
Data based on reserve to production ratios (R/P). Problem is, coal won't run out soon enough from the climate impact point-of-view.

Strategic factors will ensure that coal is utilized

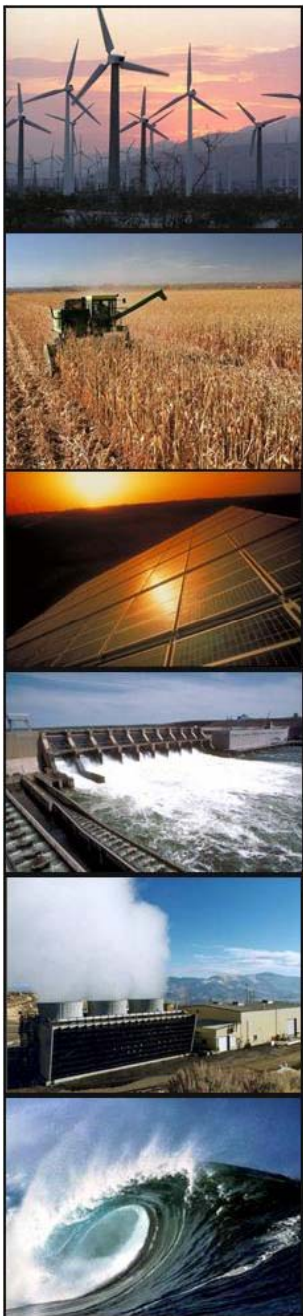


Gigatons coal equivalent (courtesy World Coal Institute 2005)

World Uranium reserves (courtesy Coolschool, Canada)



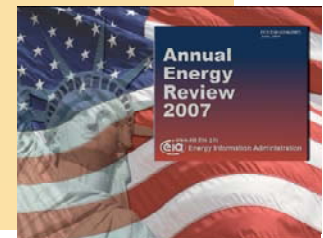
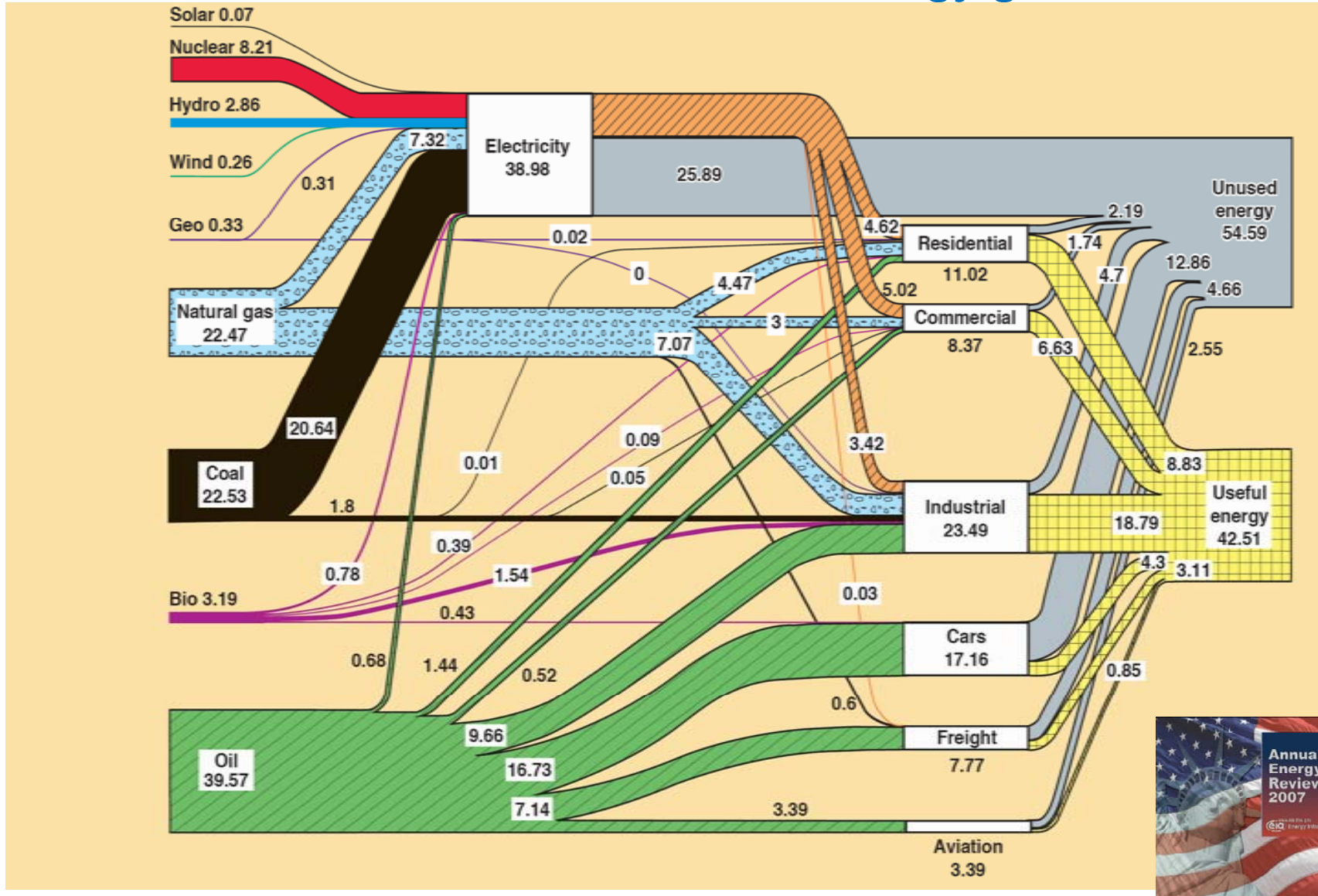
Estimated potential for US renewables



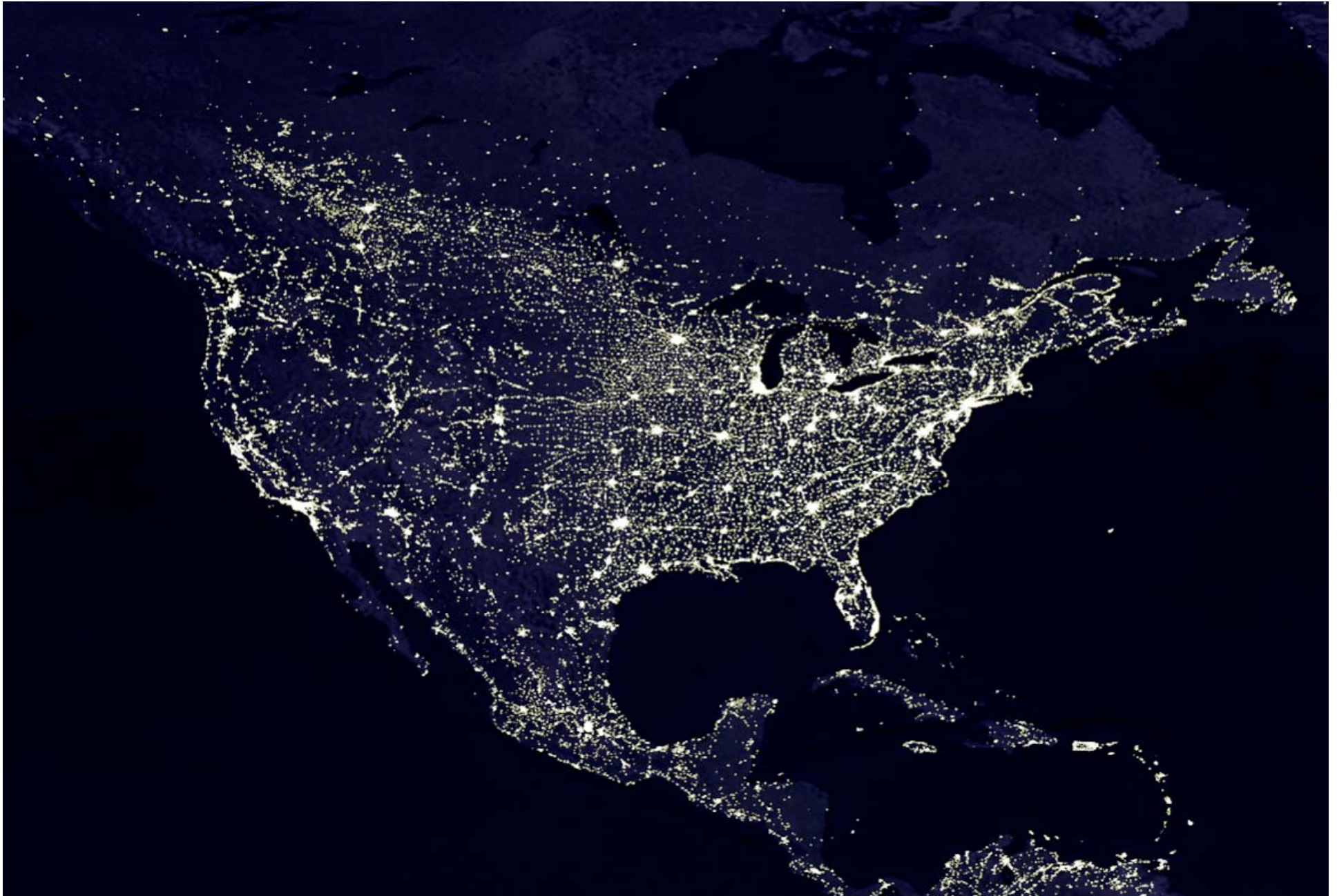
United States Renewable Energy (Quads/Year)	
Wind	
<u>2003 Consumption</u>	<u>Potential Capacity</u>
0.11	15
Biomass	
<u>2003 Consumption</u>	<u>Potential Capacity</u>
2.88	24
Solar	
<u>2003 Consumption</u>	<u>Potential Capacity</u>
0.06	1,255
Hydroelectric	
<u>2003 Consumption</u>	<u>Potential Capacity</u>
2.78	4
Geothermal	
<u>2003 Consumption</u>	<u>Potential Capacity</u>
0.31	8

Pat Dehmer

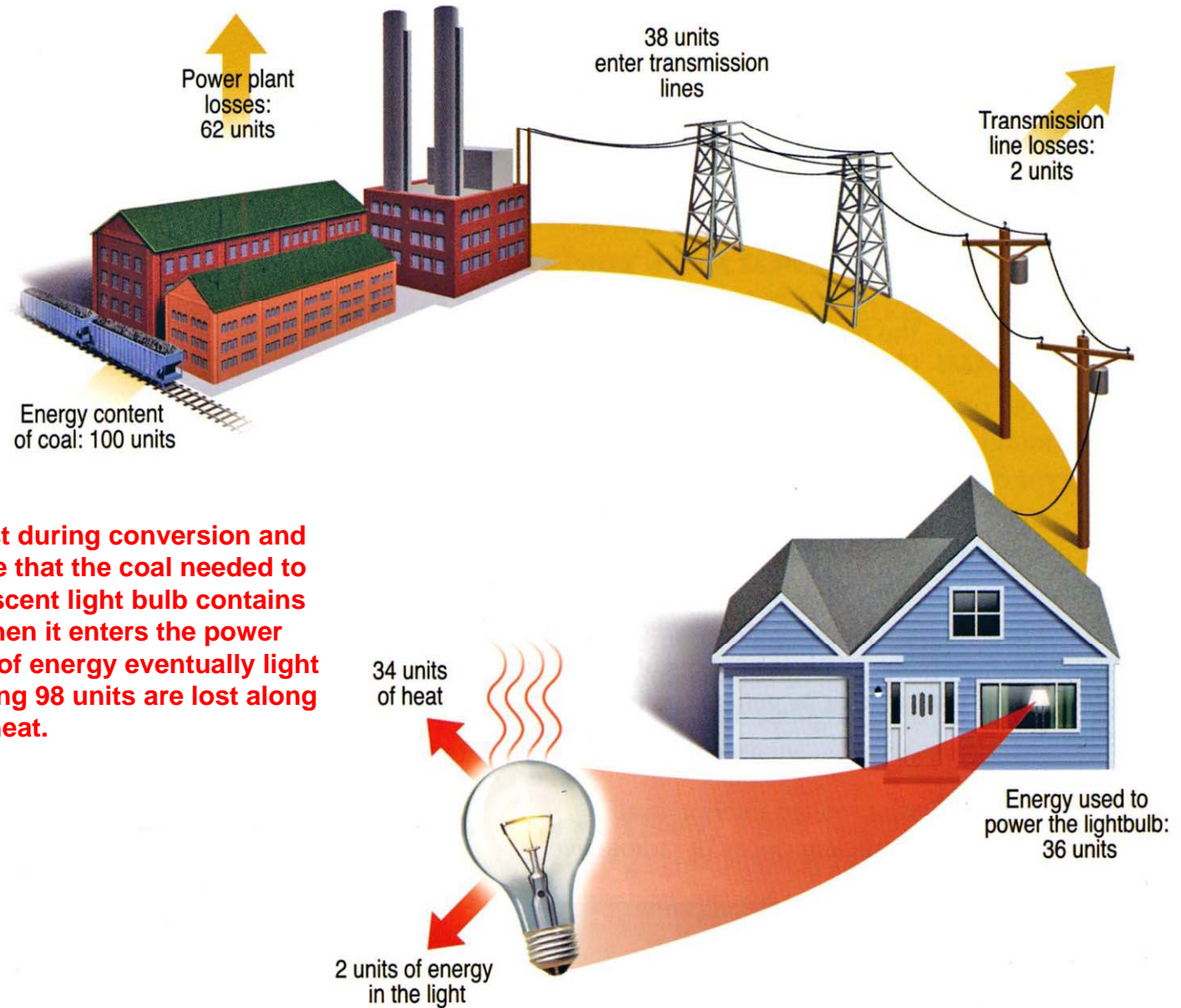
The mother of all charts – where does energy go?



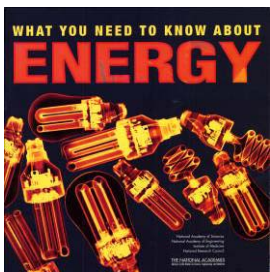
Light pollution reveals energy needs in the USA



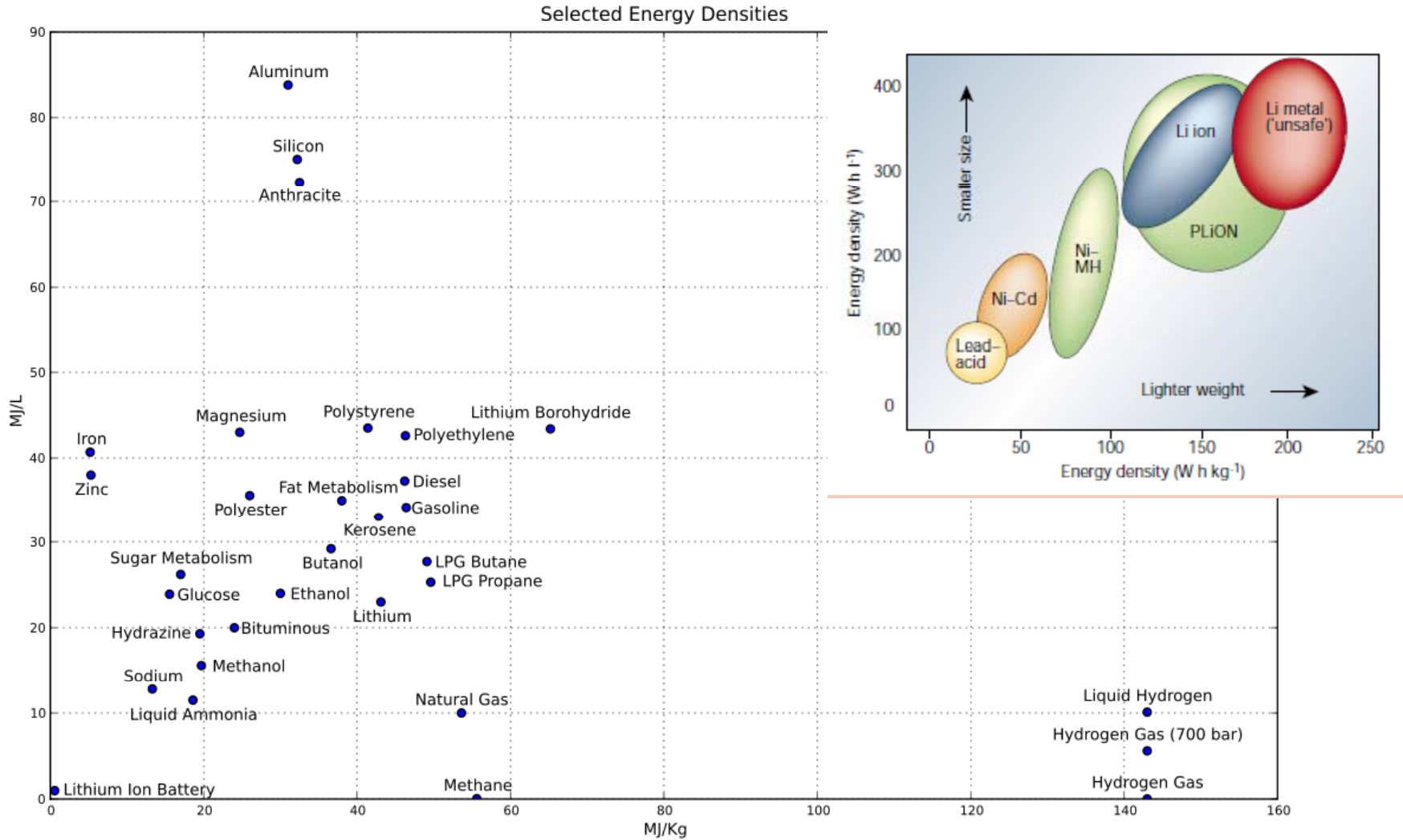
Energy Efficiency



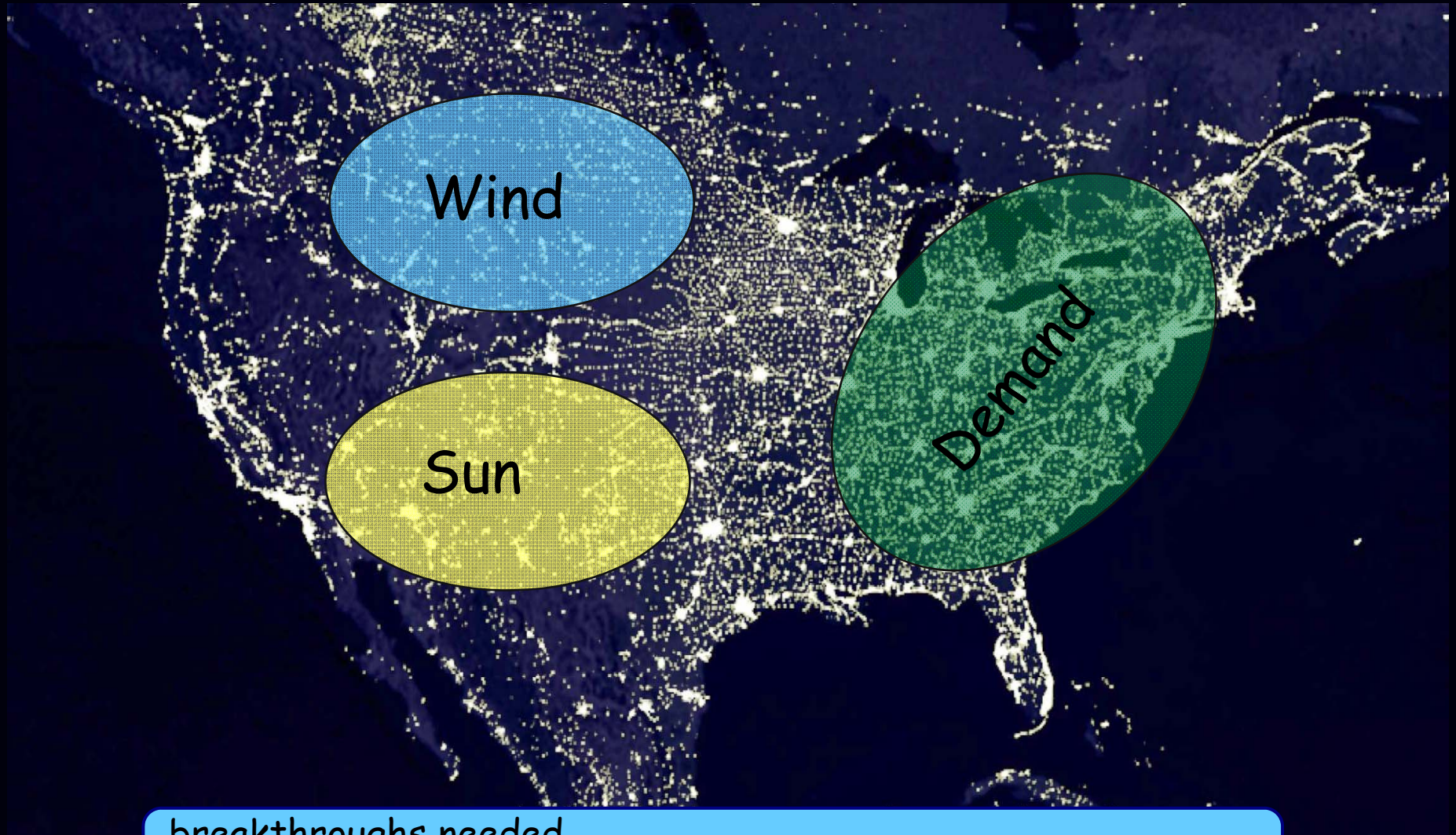
Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent light bulb contains 100 units of energy when it enters the power plant. Only two units of energy eventually light the bulb. The remaining 98 units are lost along the way, primarily as heat.



Battery technology has a long way to go



Sustainable Energy Enabling Technologies: The Grid

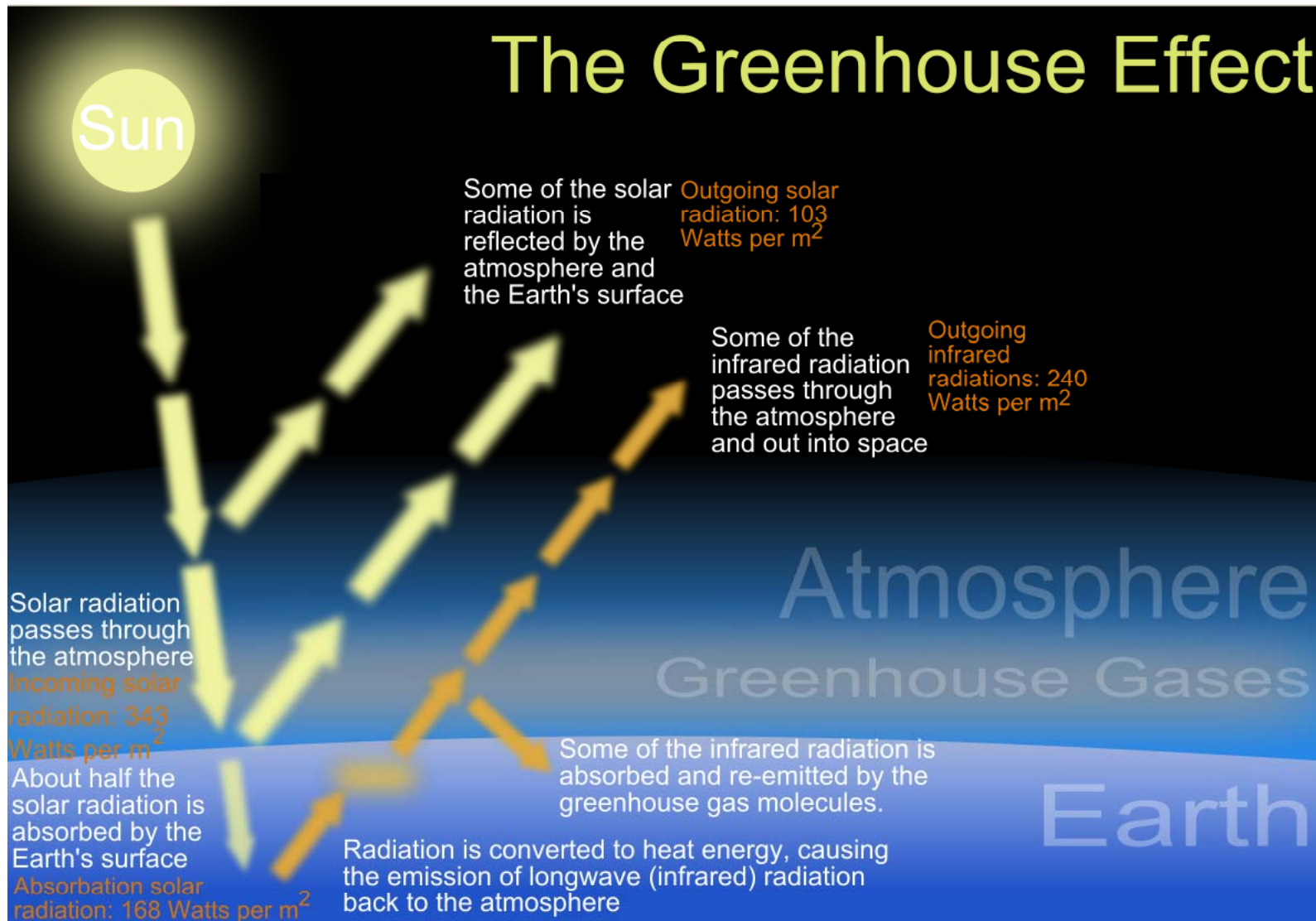


breakthroughs needed
long distance reliable, efficient delivery of electricity

Sustaining the climate

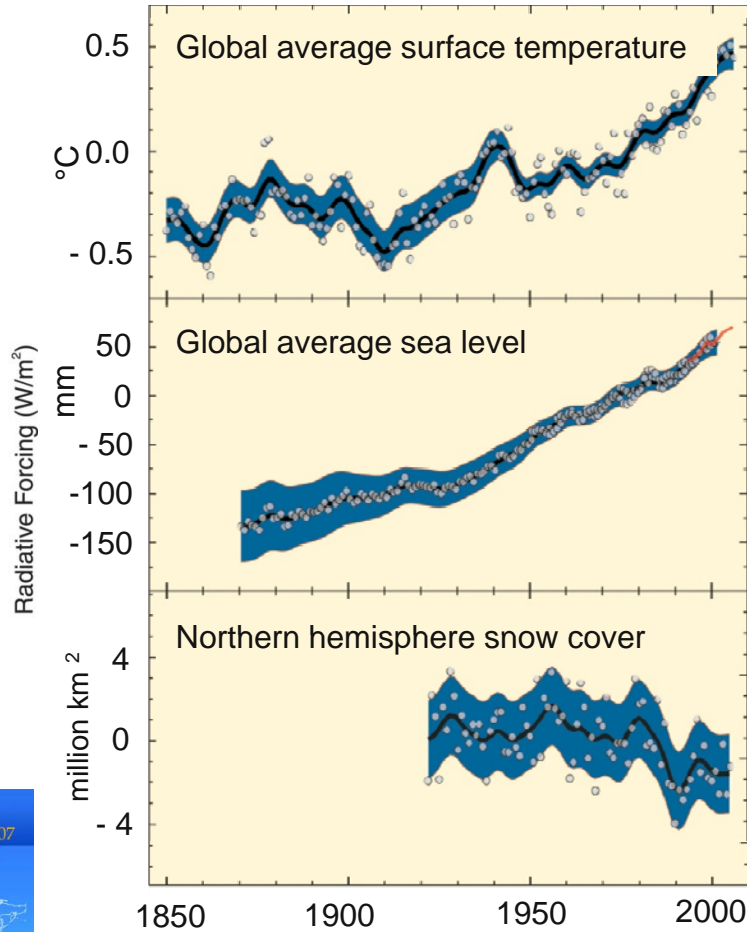
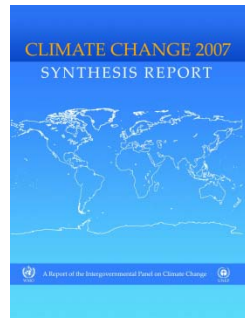
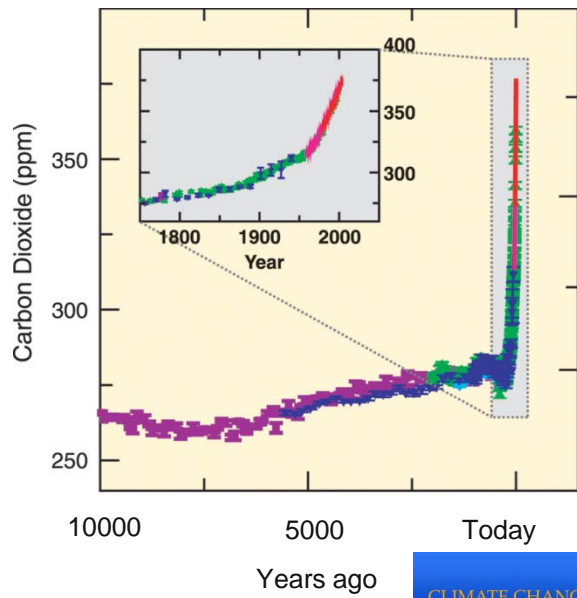


CO₂ is the second most important greenhouse gas, after H₂O



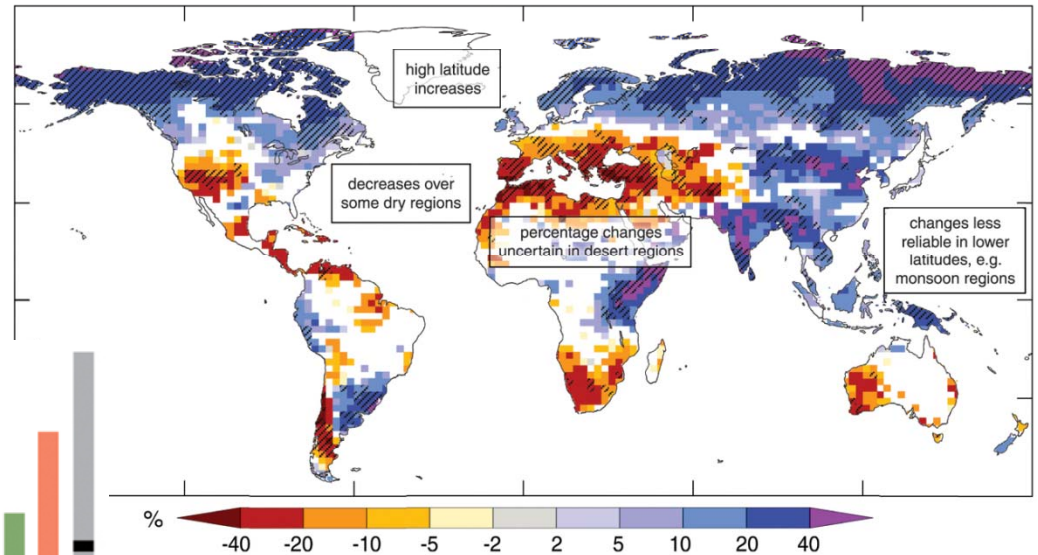
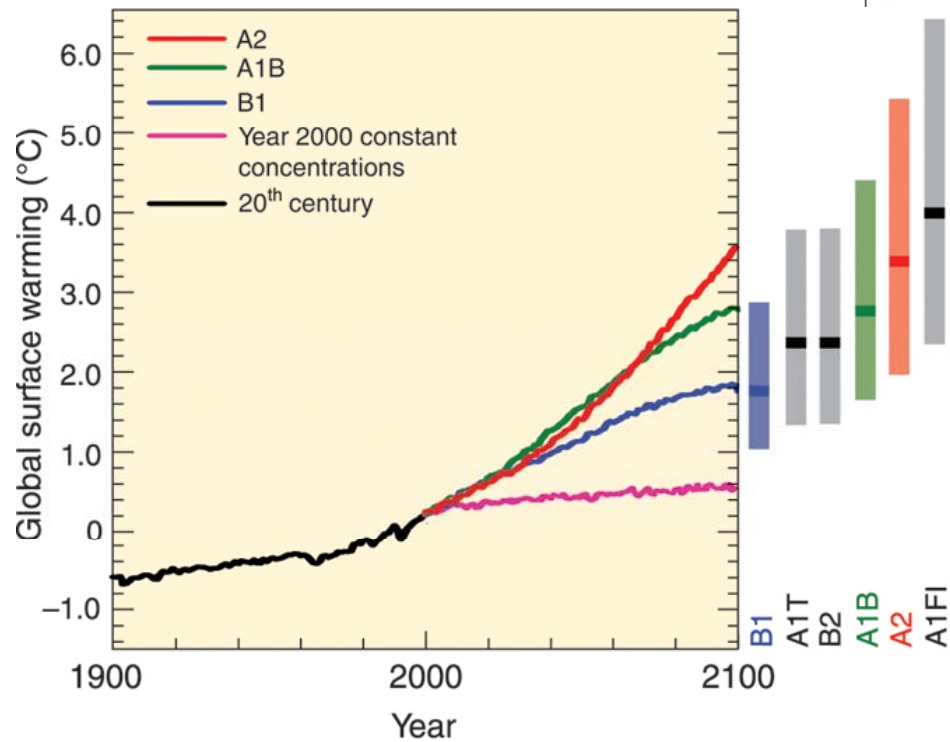
Courtesy ZooFari, Wikimedia Commons

CO₂ and global temperature



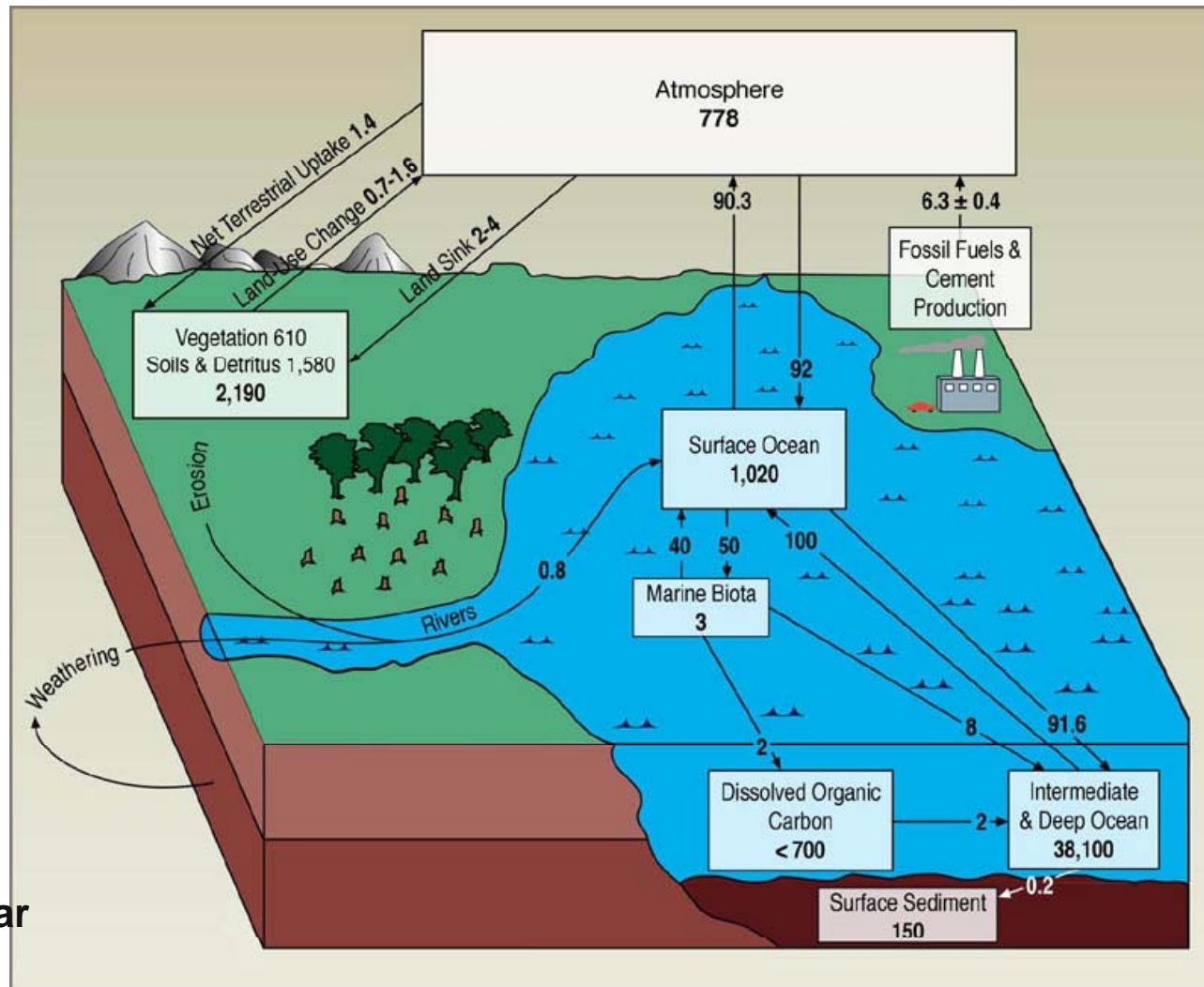
Projections and consequences

Models (IPCC)



Change in water run-off by 2100

Natural carbon cycle between the land and oceans

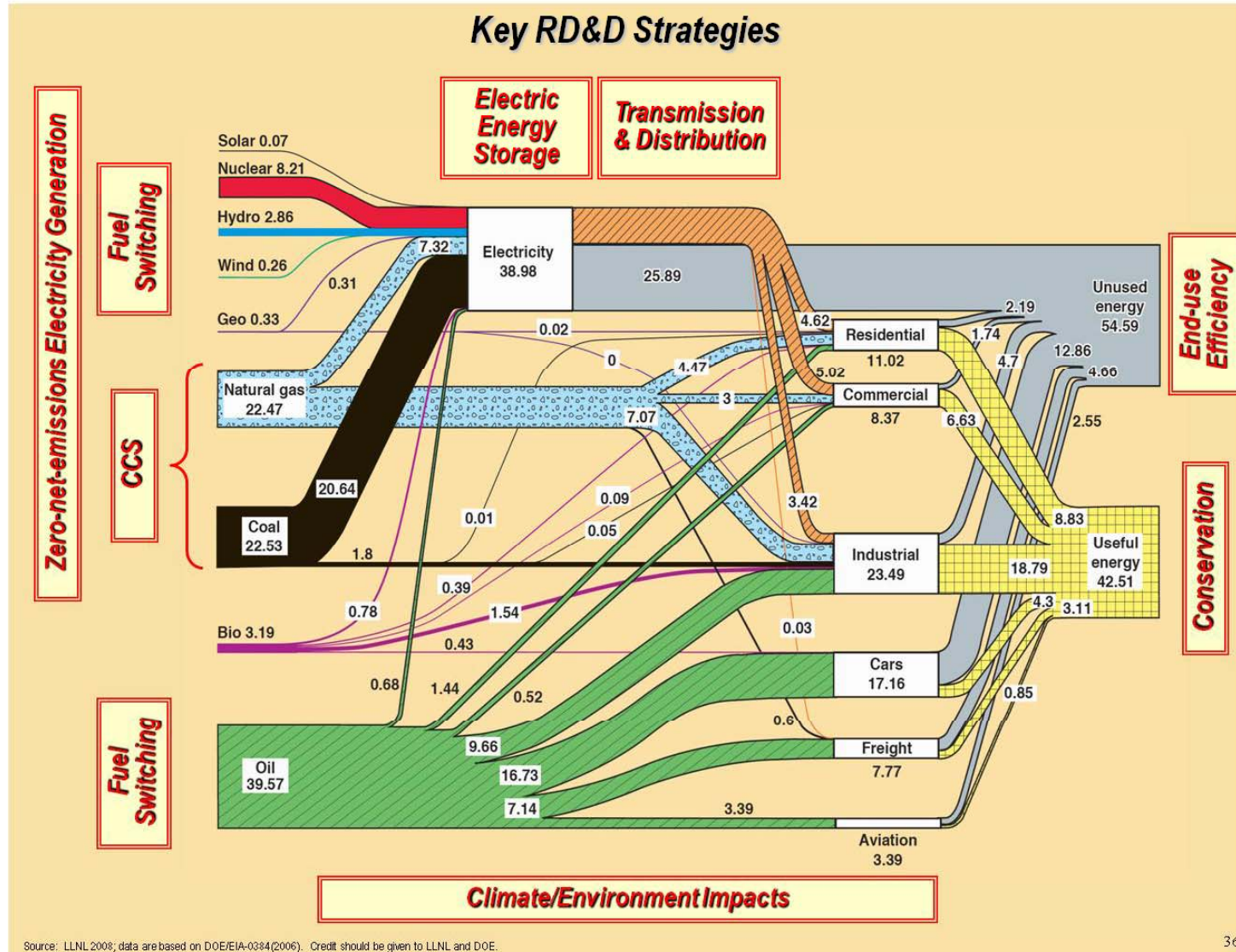


Storage in Gt C
 Fluxes in Gt C/year
 1 Gton = 10⁹ tons

A plausible technology vision – but we don't yet know how

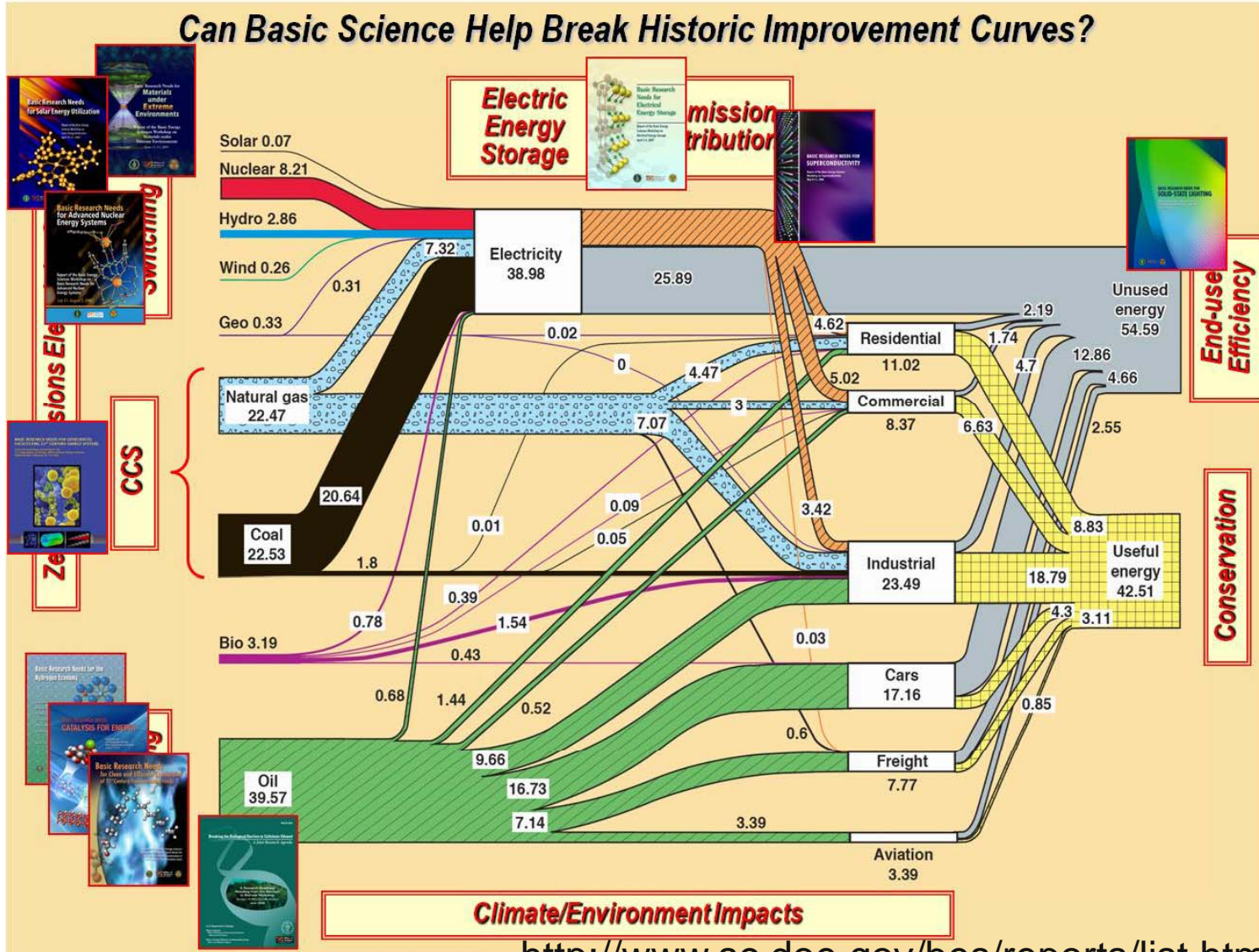
- Electric vehicles with adequate energy storage
 - fuel cells as a more efficient way of using biofuels in plug-in hybrids
- Efficient lighting
- More efficient industrial processes (calatysts with the specificity of enzymes)
- Renewable sources of electricity
 - Cheap solar
- New grid technologies
 - Especially for distribution and temporary storage of renewables
- Understanding of carbon cycle in climate, including oceans and land
- Carbon sequestration

Key R&D Strategies (DOE Science)



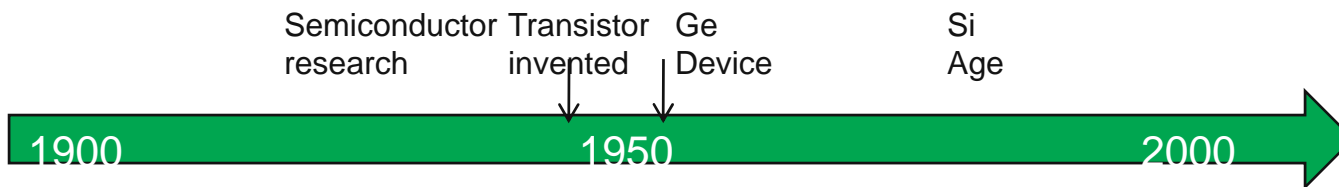
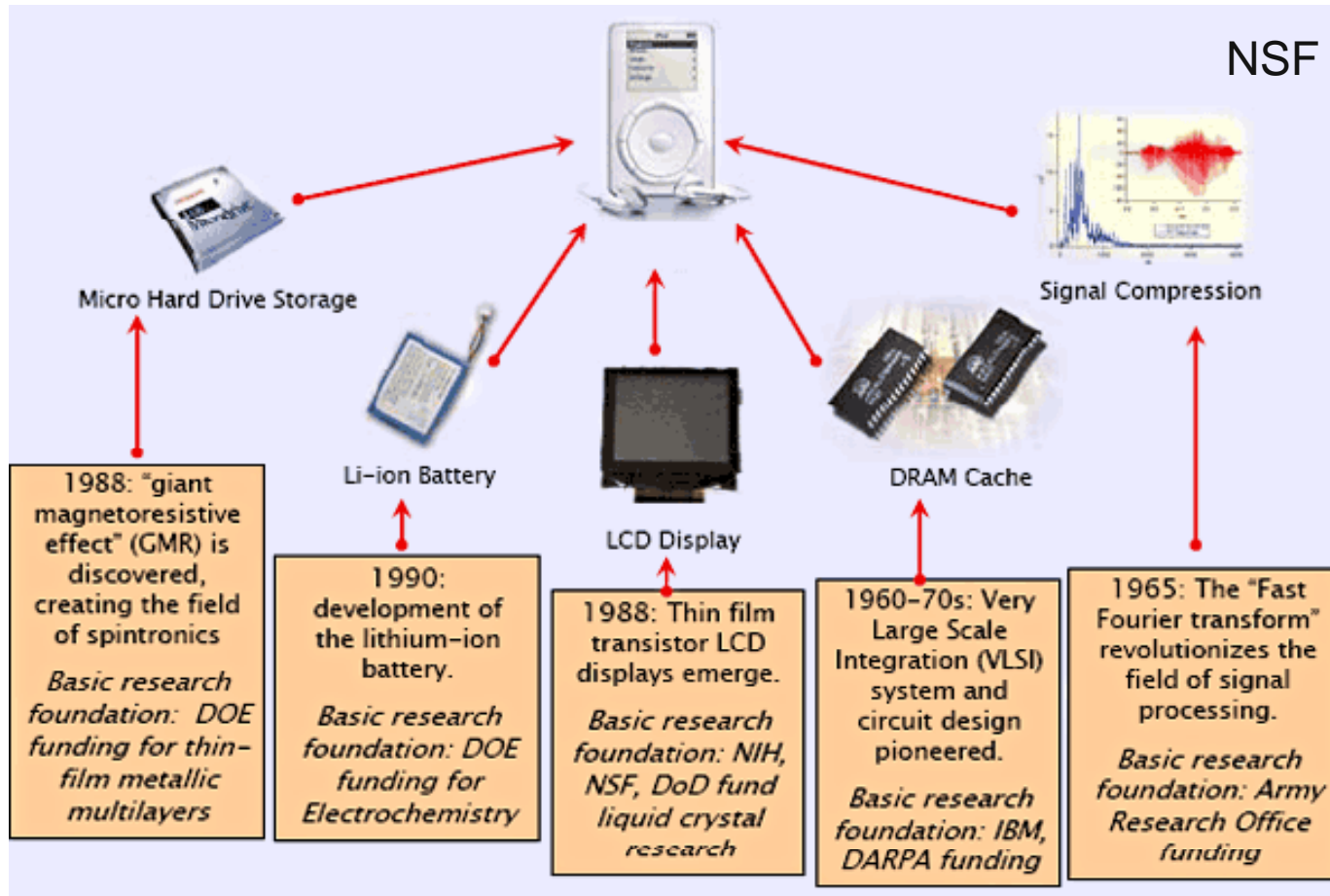
Basic science enabling revolutionary technology

Can Basic Science Help Break Historic Improvement Curves?

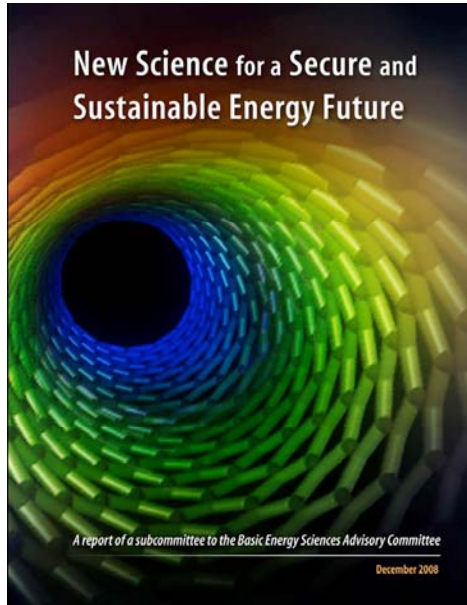


Source: LLNL 2008; data are based on DOE/EIA-0384(2006). Credit should be given to LLNL and DOE. <http://www.sc.doe.gov/bes/reports/list.html>

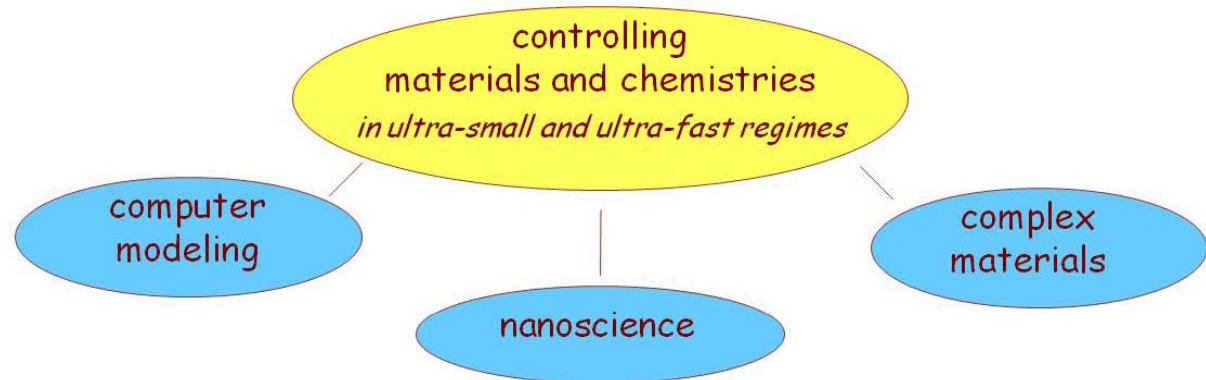
We must be conscious of research timescales



A “New Era”?



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

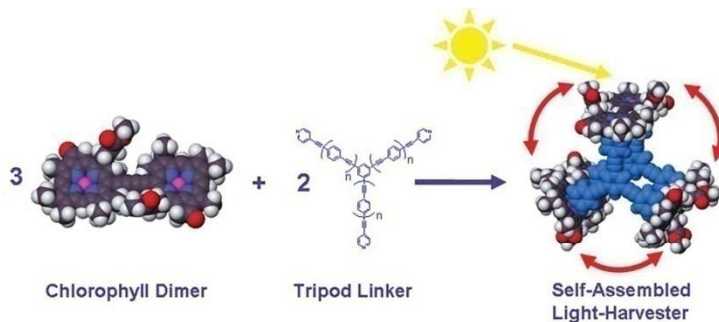
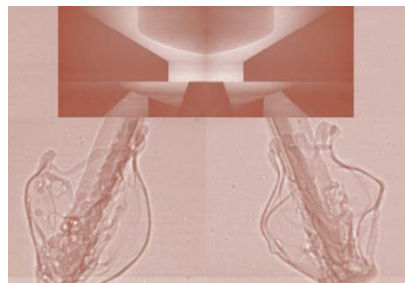
breakthroughs to next-generation sustainable energy technologies are within reach

The Advanced Photon Source – a tool to solve these problems

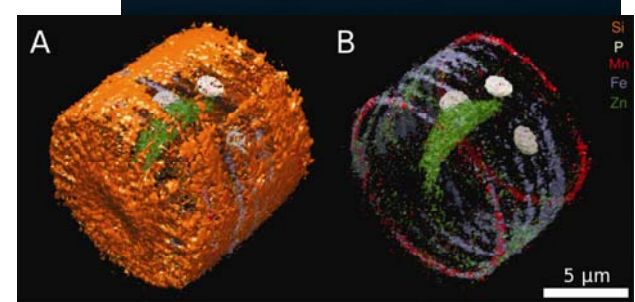
- Synchrotron x-ray radiation can penetrate into complex environments and provide information on atomic, electronic and spin arrangements which control materials properties



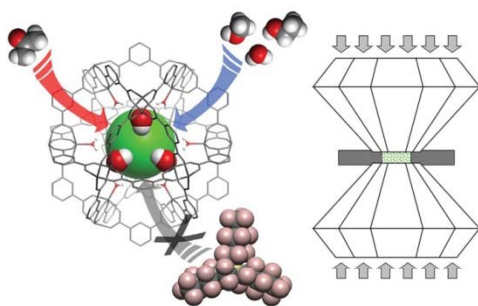
Examples of APS research for societal problems



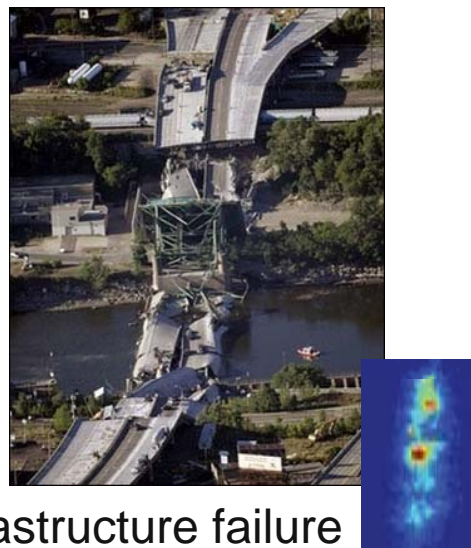
How sea animals capture carbon



Better burning

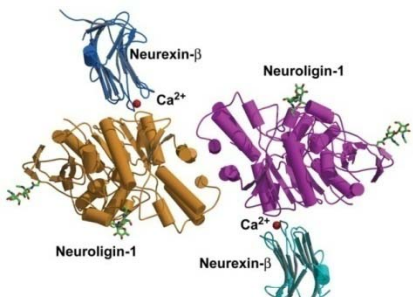


Natural solar cells



Infrastructure failure

Storing hydrogen



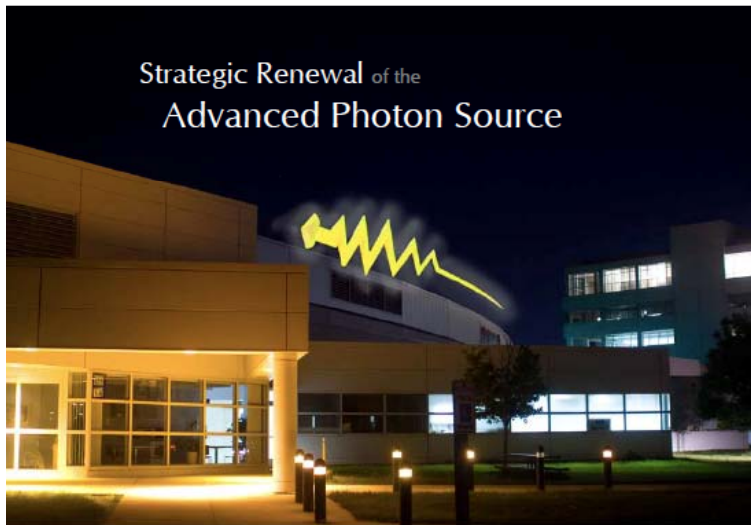
Understanding autism

Argonne's Major Initiatives

- Energy Storage ■ Alternative Energy ■ Nuclear Energy
- Materials & Molecular Design & Discovery ■ National Security
- Hard X-ray Sciences ■ Leadership Computing



APS plans future upgrade to develop better capabilities



Strategic Renewal of the
Advanced Photon Source

Proposal for approval
of Conceptual Design (CD-0)

Submitted to the US Department of Energy
Office of Basic Energy Sciences
May 31, 2009

Message from Murray Gibson:
Renewing and upgrading the Advanced Photon Source: a real opportunity for user engagement
May 22, 2008

Now in its twelfth year of operation, the Advanced Photon Source (APS) annually provides almost 3500 users with brilliant x-rays that lead to more than 1000 refereed publications each year covering many areas of science and engineering. Nevertheless, the facility, like any scientific instrument, is showing its age, and we have been working for several years on renewal and upgrade plans. These plans have recently received a boost because our sponsor - the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences - has asked us for a detailed, science-driven plan for the renewal of APS to cover the next five years. This renewal plan will encompass innovations in the beamlines and the x-ray source that are needed for major improvements in important areas of user science. We are engaging our users and staff advisors in building this APS renewal plan, and we will use our **Scientific Advisory Committee (SAC)** and other outside experts to help us craft a plan with maximum scientific impact. A planning milestone will be a workshop to be held October 20-21, 2009 near the APS, at which the SAC will take a first complete look at the plan and give their advice. At present we continue to solicit proposals from our beamline staff, users, and accelerator and other APS staff. These proposals will be filtered by science-focused user groups, and they will also be analyzed in a matrix fashion by technique coordinators. More information, as well as details about how you can take part in the planning and communicate your perspective, can be found on this Web site.

The renewal of APS is the first component of a strategic plan for the APS that aims to provide our users with the best hard x-ray source in the nation, and beyond, by the year 2020. During the renewal period, we will be evaluating, with

SAC-approved Letters of Intent (LOIs) or Proposals for New and Redeveloped Beamlines:

- Advanced X-ray Imaging Collaborative Development Team (AXI-CDT)
- BioRadProbe
- Sector 5-BM Redevelopment
- X-ray High Field Collaborative Development Team (XHFC-CDT)
- X-ray Interfacial Science Collaborative Development Team (XIS-CDT)

Medium-Term Proposals:

- Beamlines | Call for Proposals (pdf)
- Accelerator Systems | Call for Proposals (pdf)

APS 2020 Upgrade Plan:

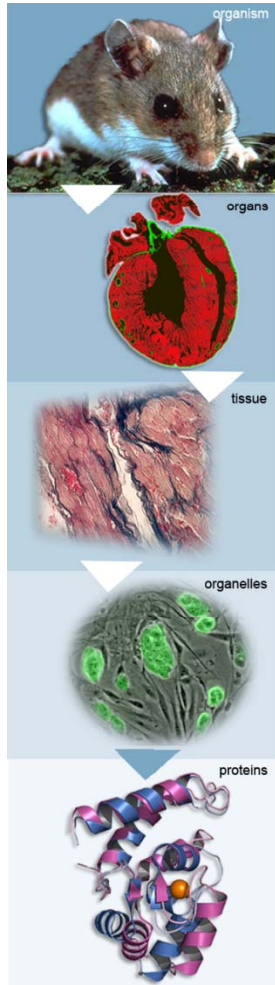
- APS Upgrade Options

Steering Committee Members:

- Denny Mills
- Rod Gerig
- George Srager
- John Maclean
- Denis Keane (APS PUC Chair)
- Paul Fuoss (APS/USO Rep)
- Bob Fitchett (Life Sciences Council Chair)
- Dan Neumann (SAC Member)



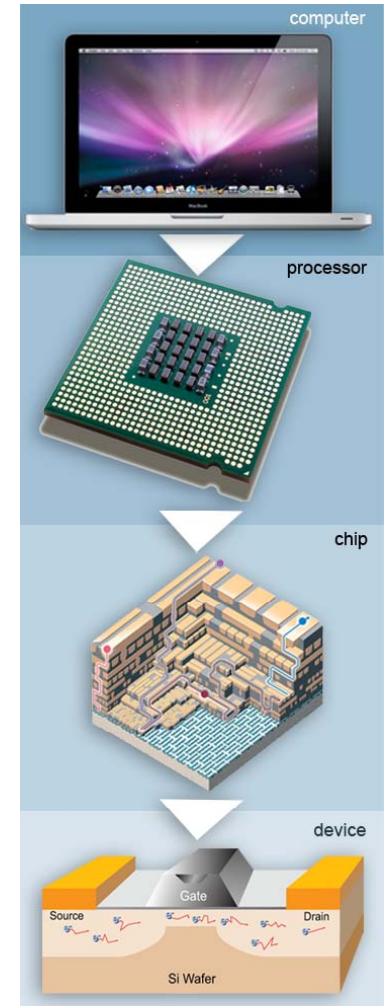
Mastering hierarchical structures through imaging



“Imaging specific molecules and their interactions in space and time will be essential to understand how genomes create cells, how cells constitute organisms and how errant cells cause disease. Molecular imaging must be extended and applied from nanometre to metre scales...”, Roger Tsien

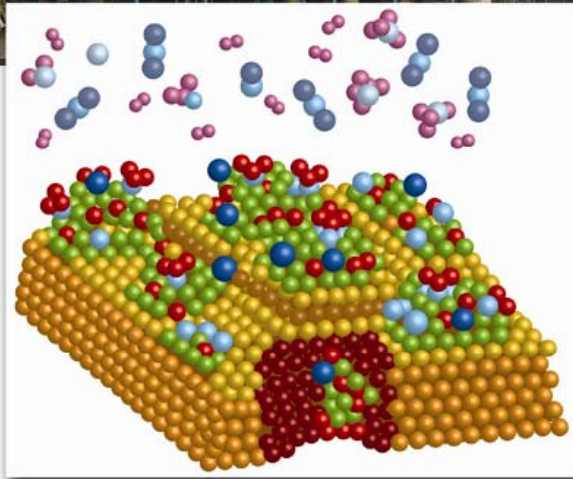
- Hierarchical structures are key to life, machines and complex nanostructured materials

- High-energy x-rays offer a unique tool to probe all relevant length scales and understand their interconnection

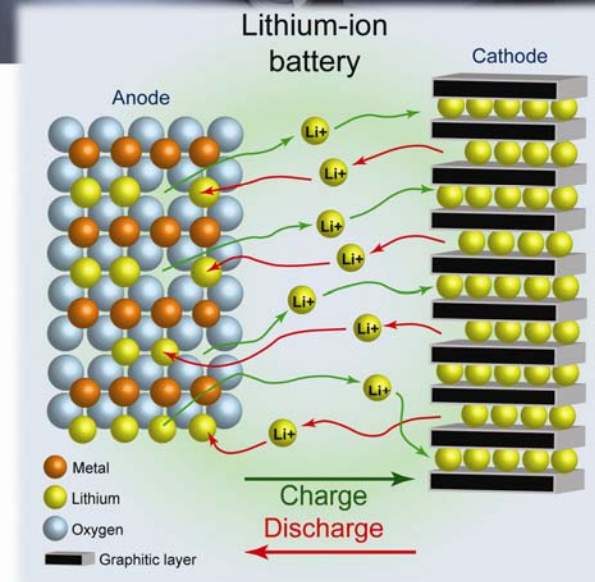


Real materials under real conditions in real time

Catalysis



Batteries



Conclusion

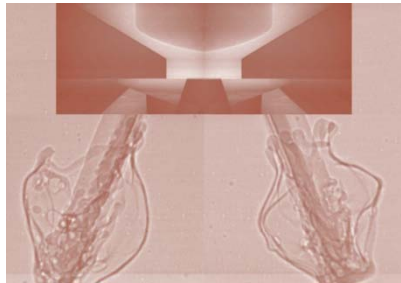
Milwaukee

- ~~Houston~~, we have a problem....
- Science and technology offers the (only) hope for life as we know it...
- We have time for basic research to provide new paradigms to capture solar energy, store and transmit it efficiently
- Current technology and aggressive implementation could keep us going for ~50 years?
- Sustainable energy is the biggest challenge facing the planet, and physics will play a key role – a great challenge to galvanize the young

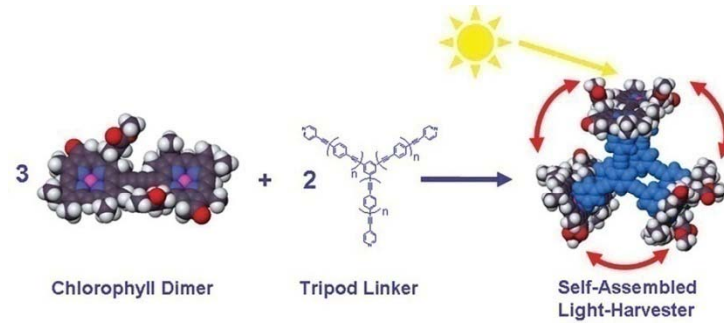


Extras (on APS applications)

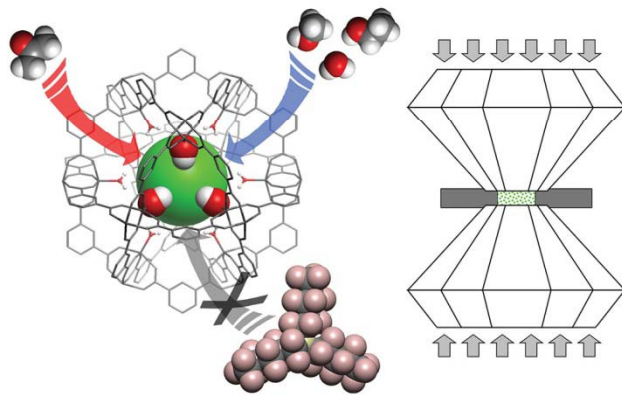
APS research addresses key challenges in energy...



Better burning



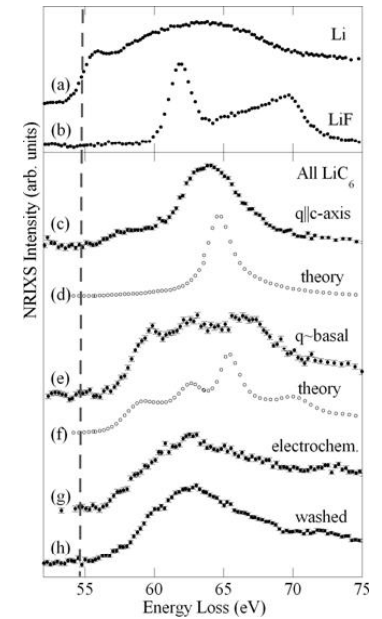
Natural solar cells



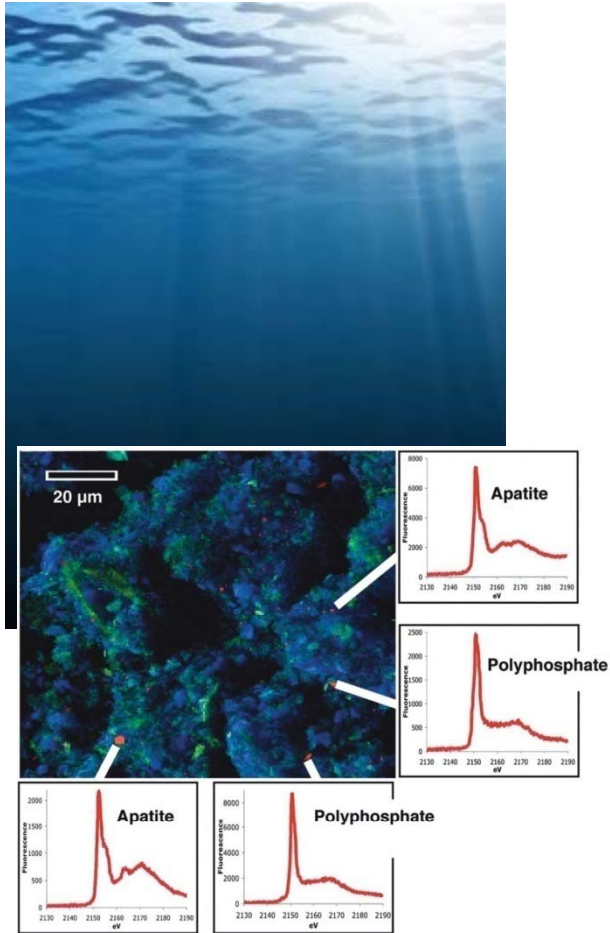
Storing hydrogen



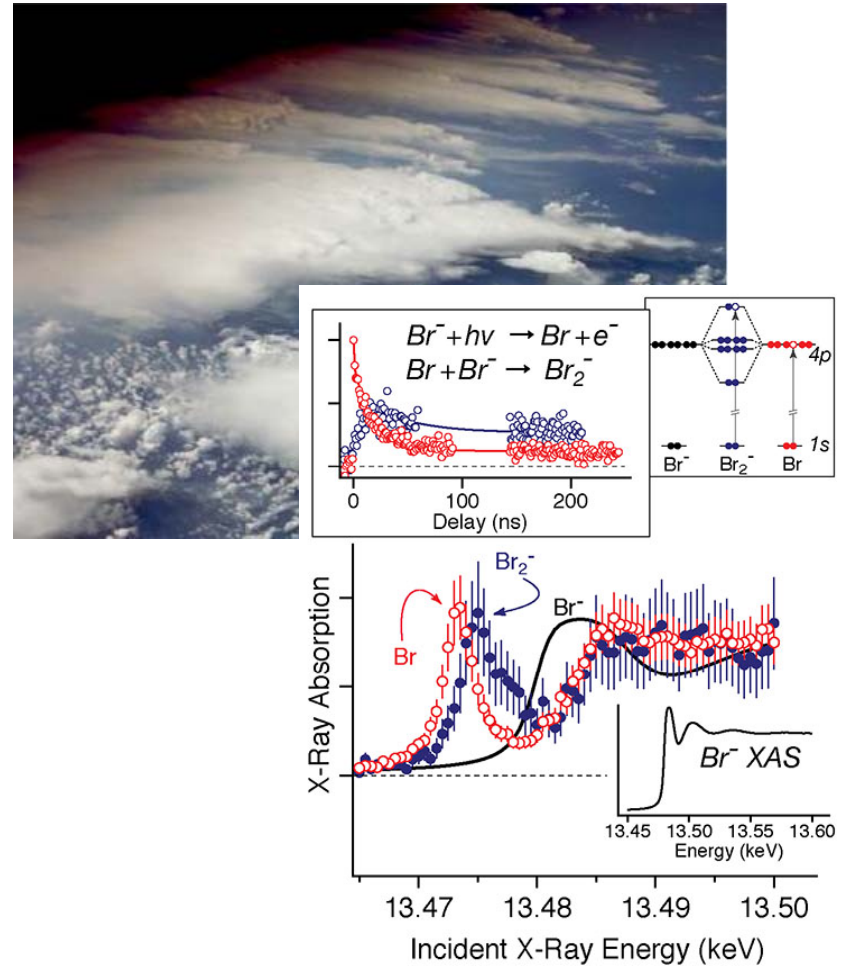
Better batteries



and climate change...

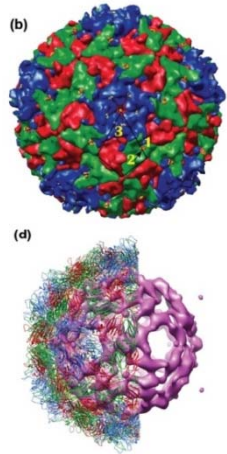


how sea animals capture carbon

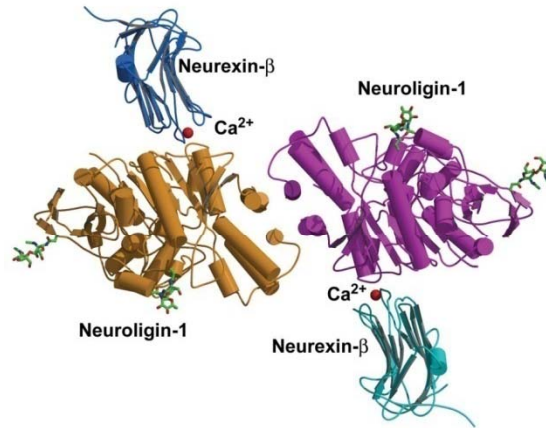


understanding free radicals in the atmosphere

human health...



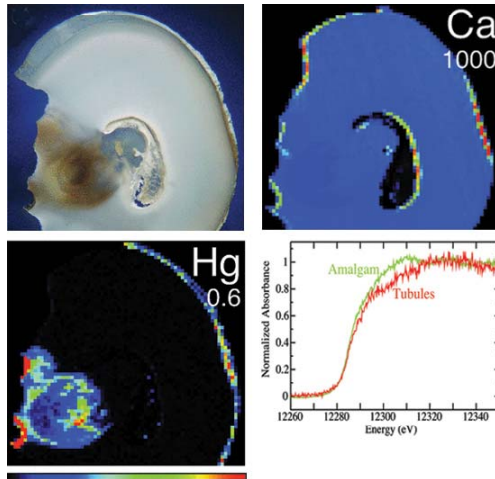
viruses that attack cancer



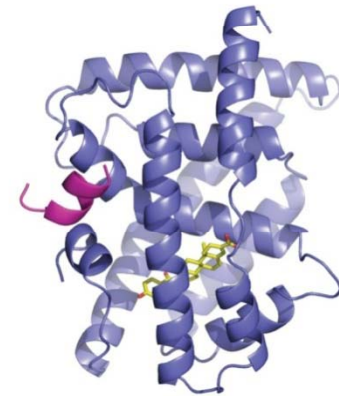
understanding autism



taming a killer



safer dentistry

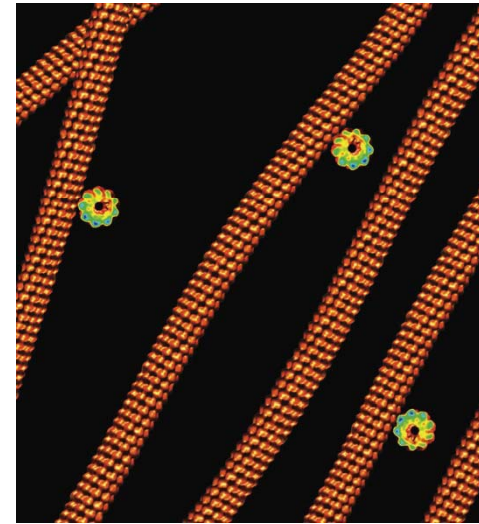
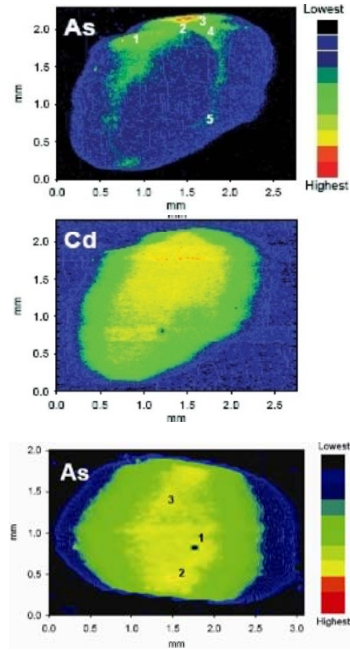


living with obesity

food and water...



is brown rice good for you?

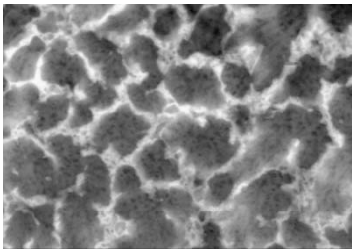
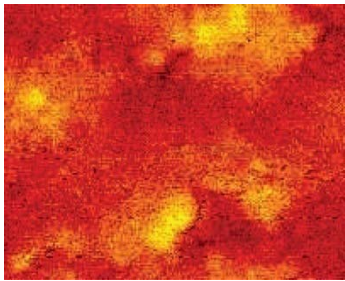


understanding plant viruses



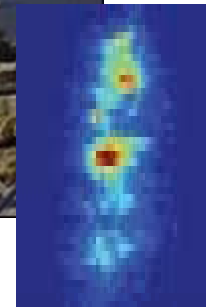
jets and aerosols

better infrastructure...

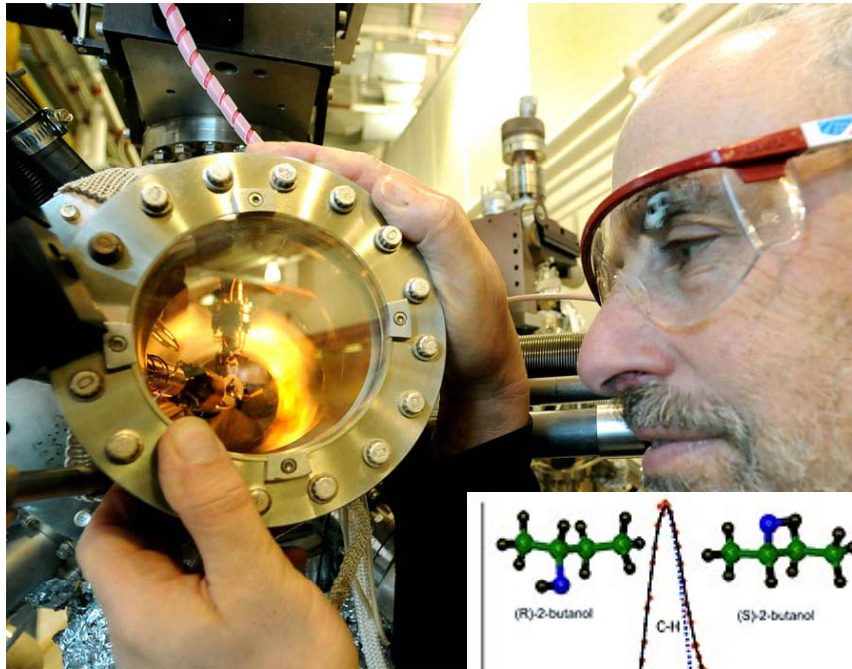


oxide scales
could save \$1B for
US hydrogen industry

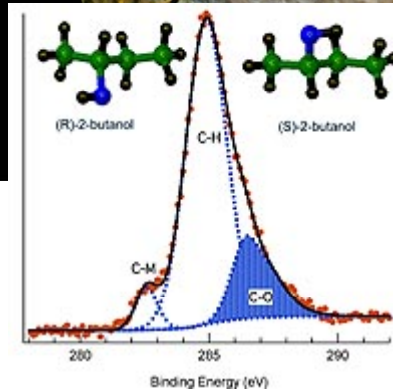
understanding metal fatigue
could save lives and money



ancient history...

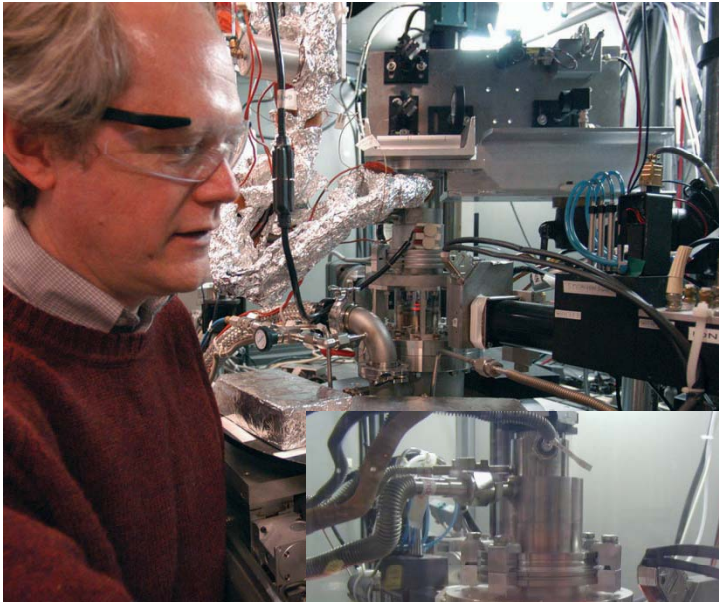


life began with a twist

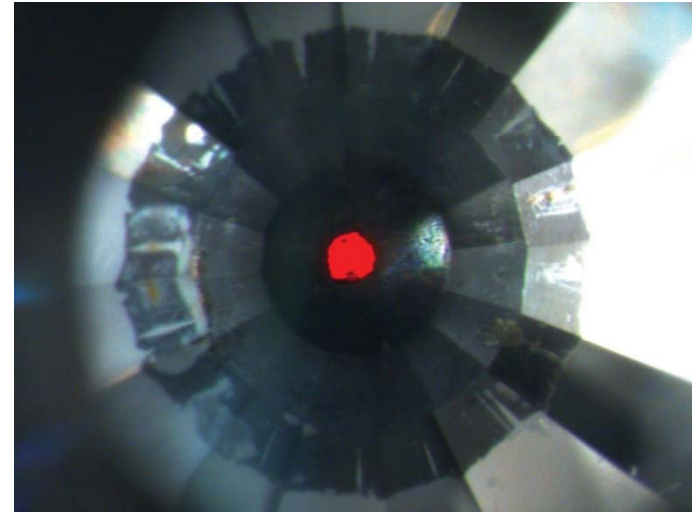


trading with the enemy in 1000BC

basic science that could enable new technology...

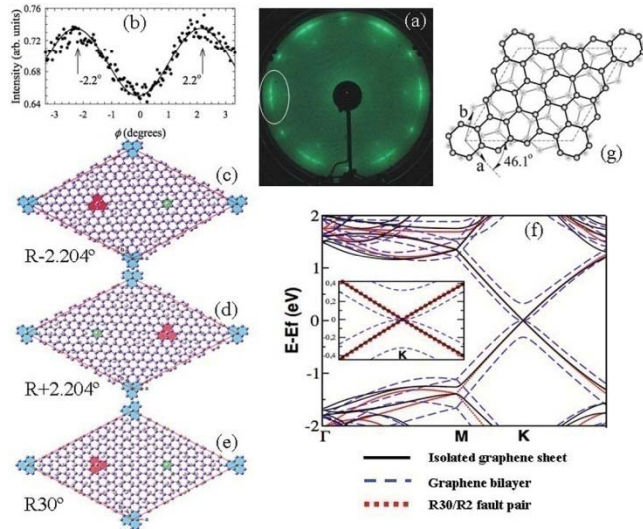


making waves for efficient lighting

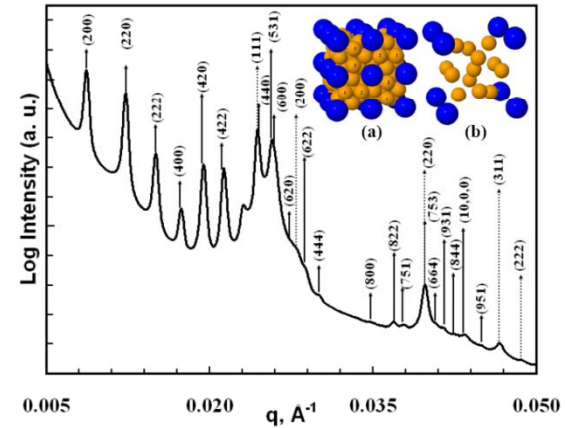


solid oxygen holds surprise
at HP

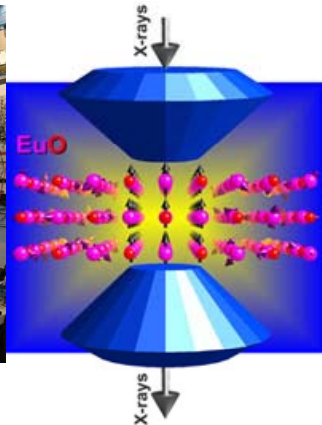
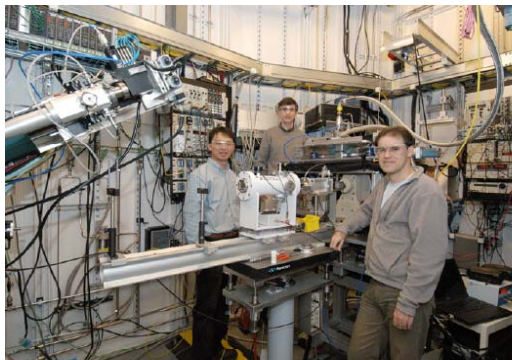
and enhance economic competitiveness



the road to “graphene” electronics



self-assembly of polymers



better magnetic materials