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… for a brighter future

U.S. Department of Energy

UChicago ▶ Argonne LLC

Office of Science 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

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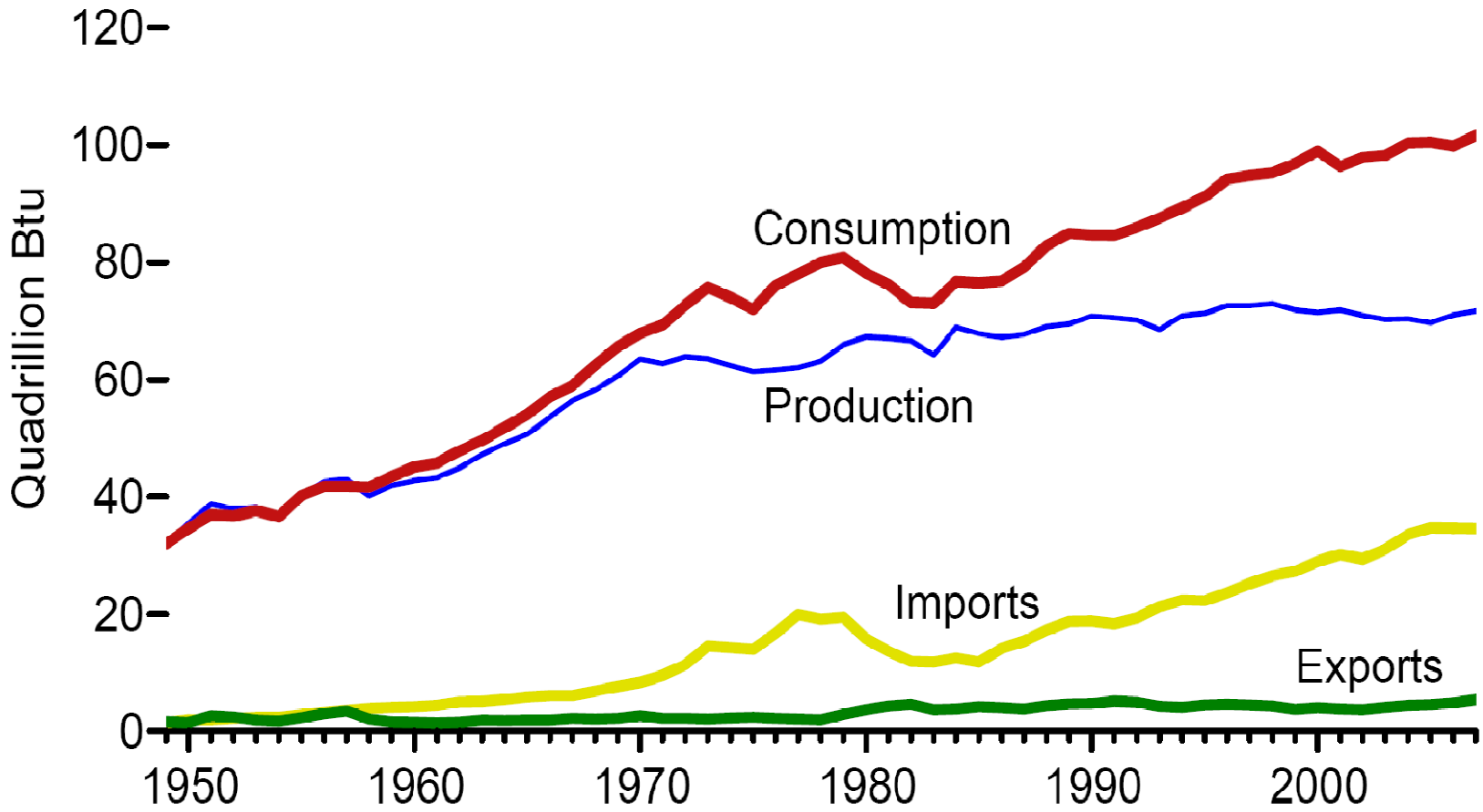
Director, Advanced Photon Source

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

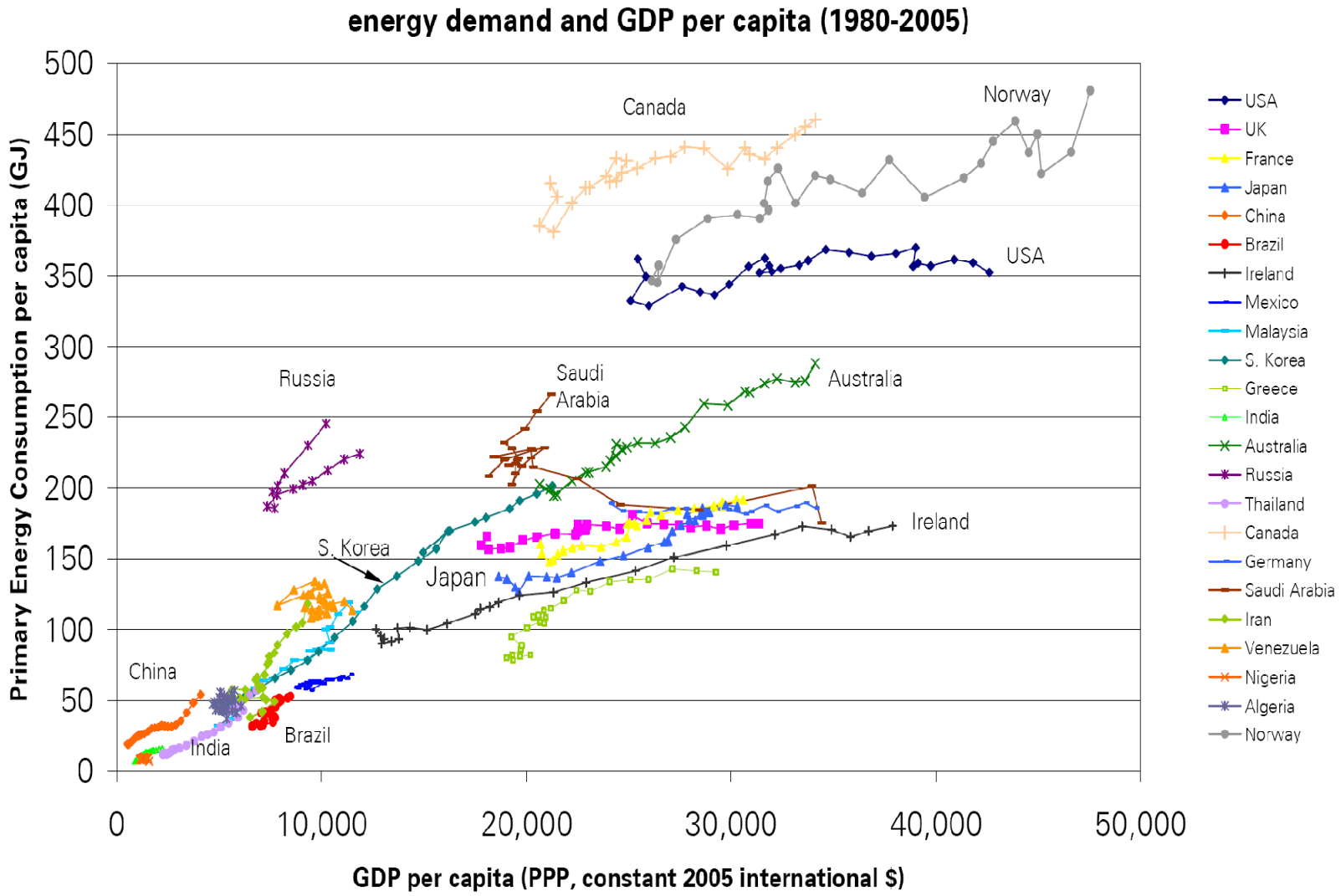
- Today the US consumes about 100 Quads of energy per year
  - 100 Quadrillion(10^{15}) btu's = 10^{18} Joules
    - *This energy would raise the temperature of Lake Tahoe by 1 ^{o}C*
- The power needs of the US are 3.3 Terawatts
    - *Equivalent of a 1 megaton nuclear bomb every day and a half*
- US 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

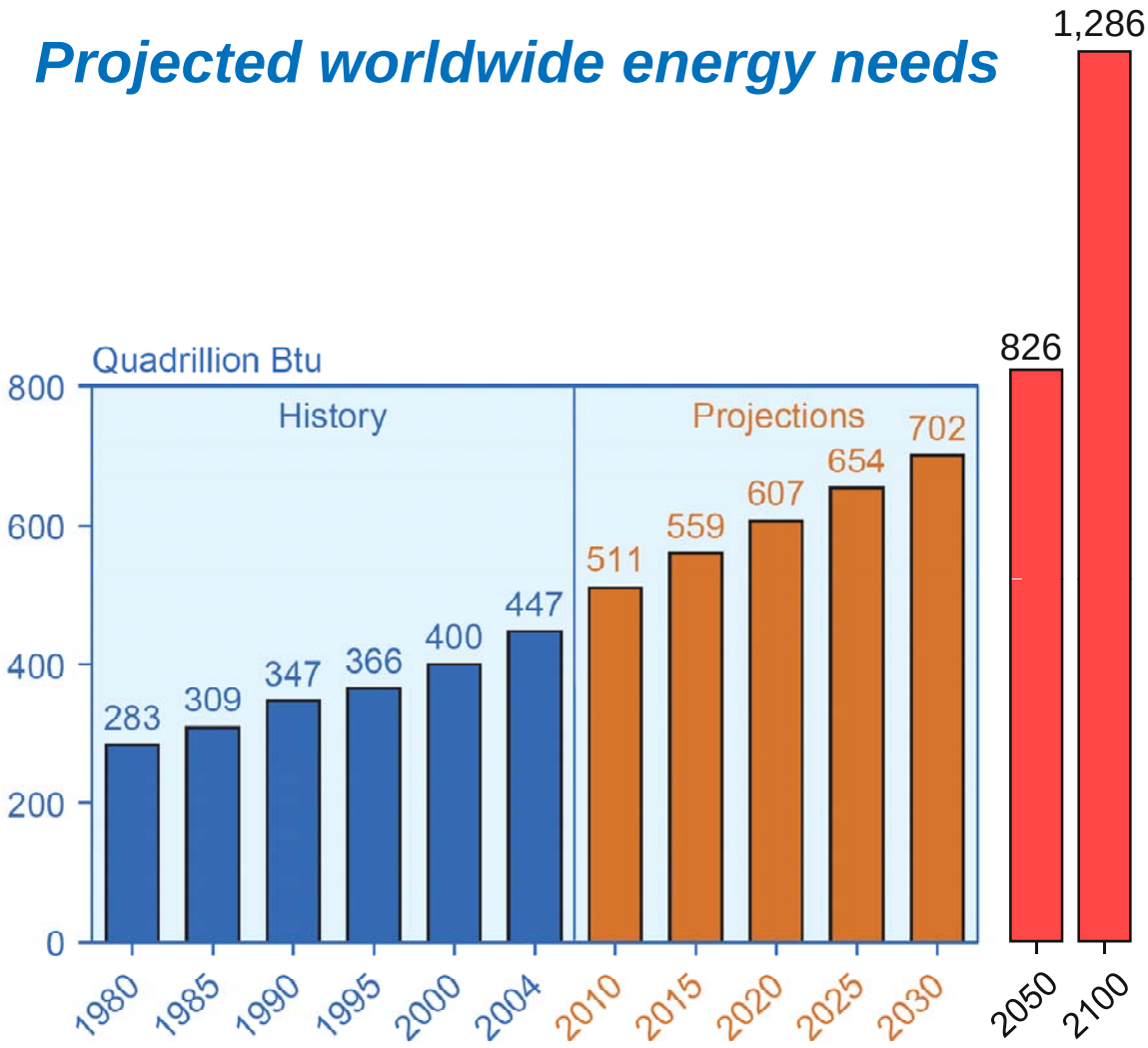


In 2007 we imported one third of our energy needs

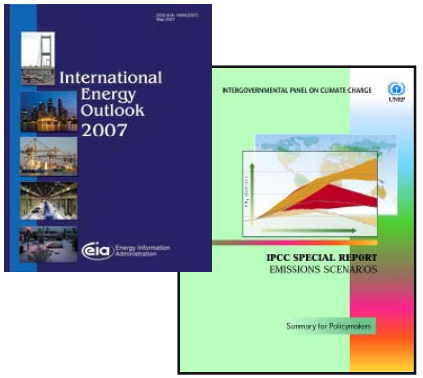
Demand grows with GDP (we take more than our share)



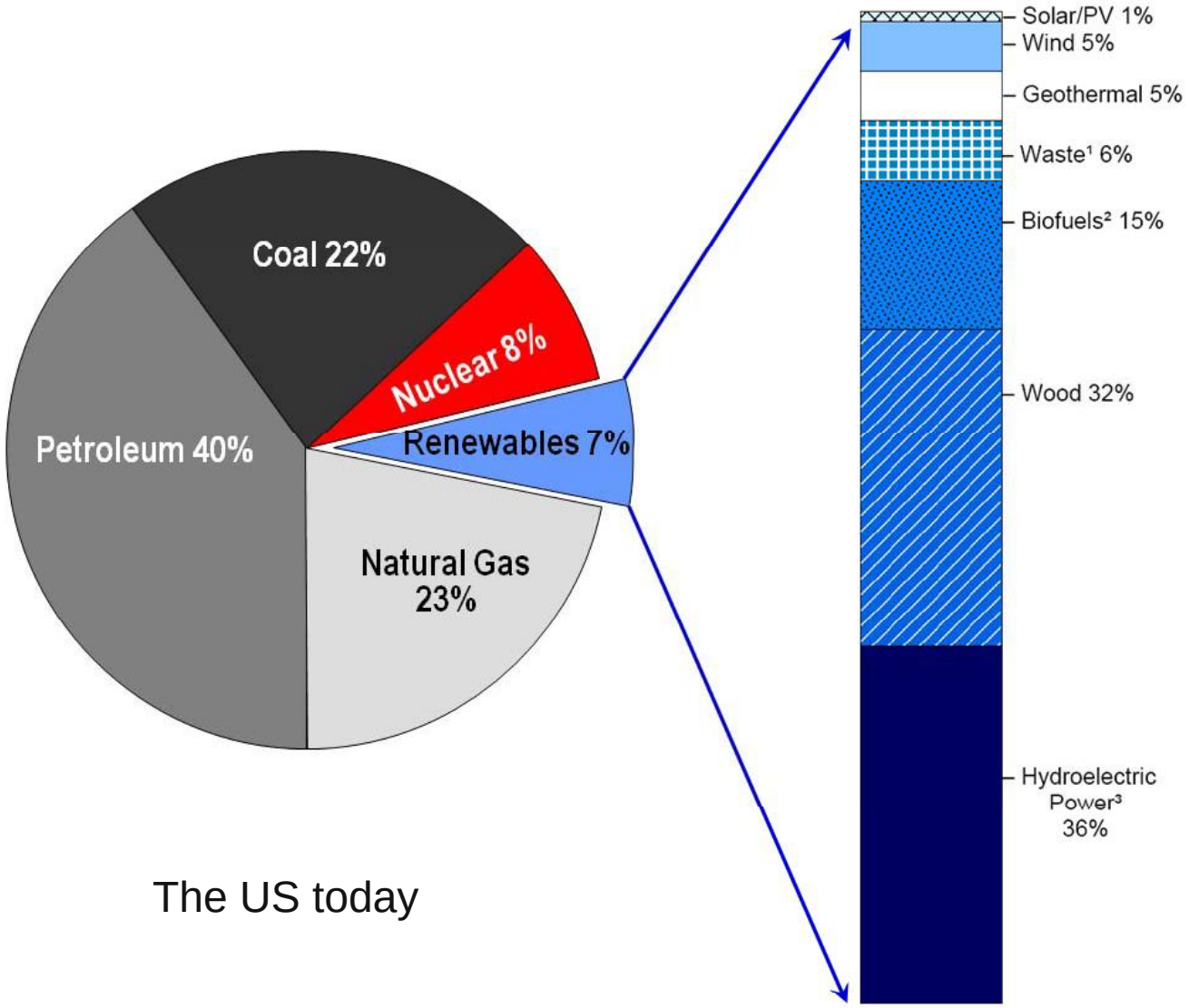
Projected worldwide energy needs

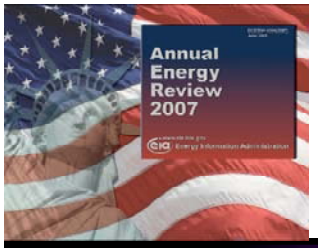


Projections till 2030 from Energy Information Administration. Beyond 2030 projections from Intergovernmental Panel on Climate Change (IPCC) – "moderate" scenarios



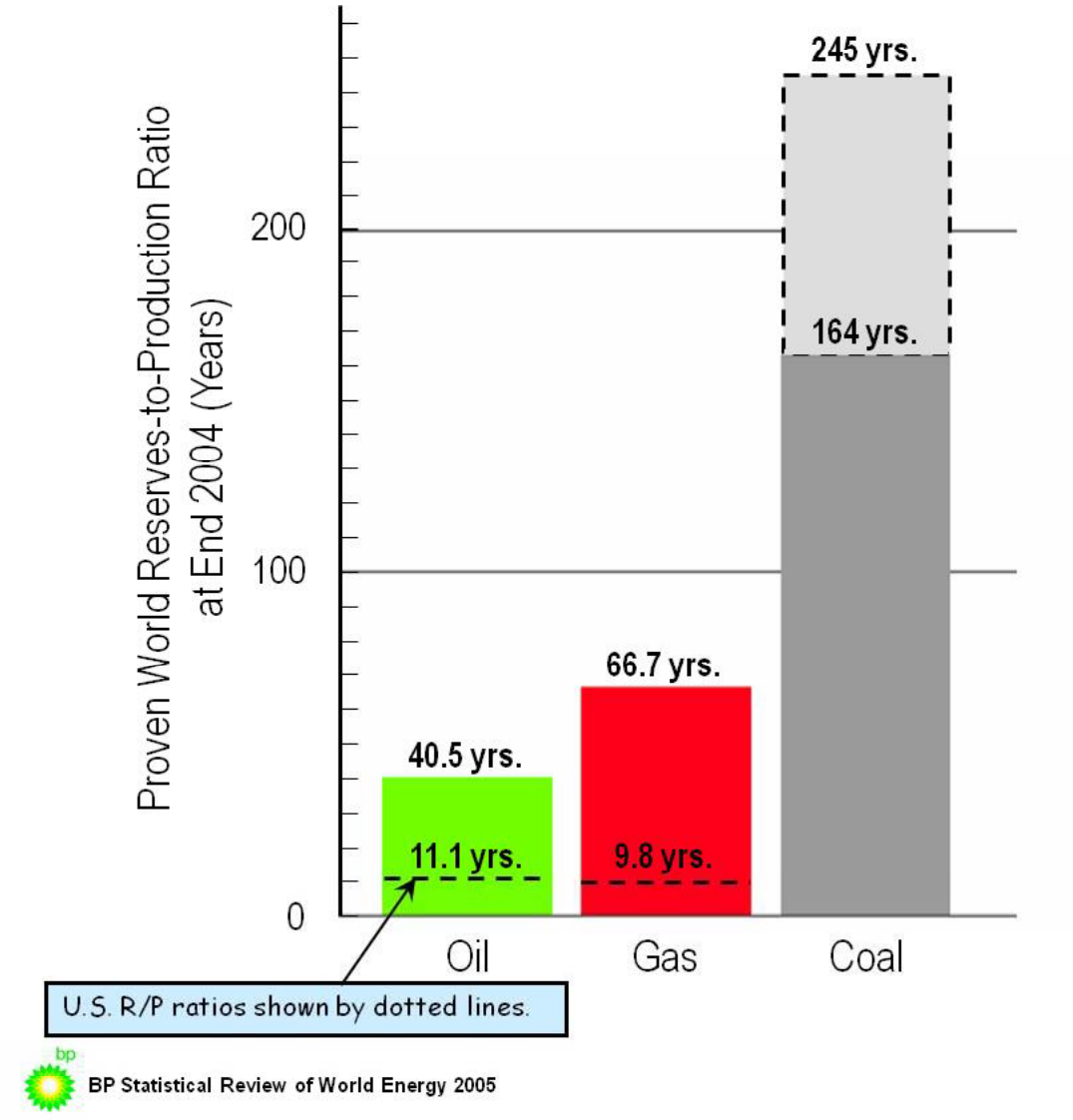
Where does the energy come from?





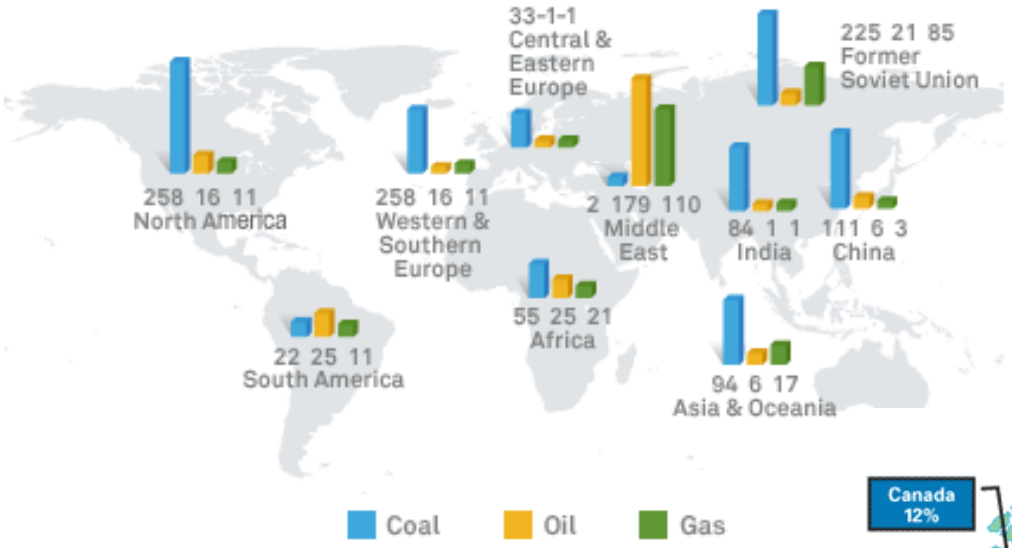
The US today

Worldwide fossil fuel reserves are finite



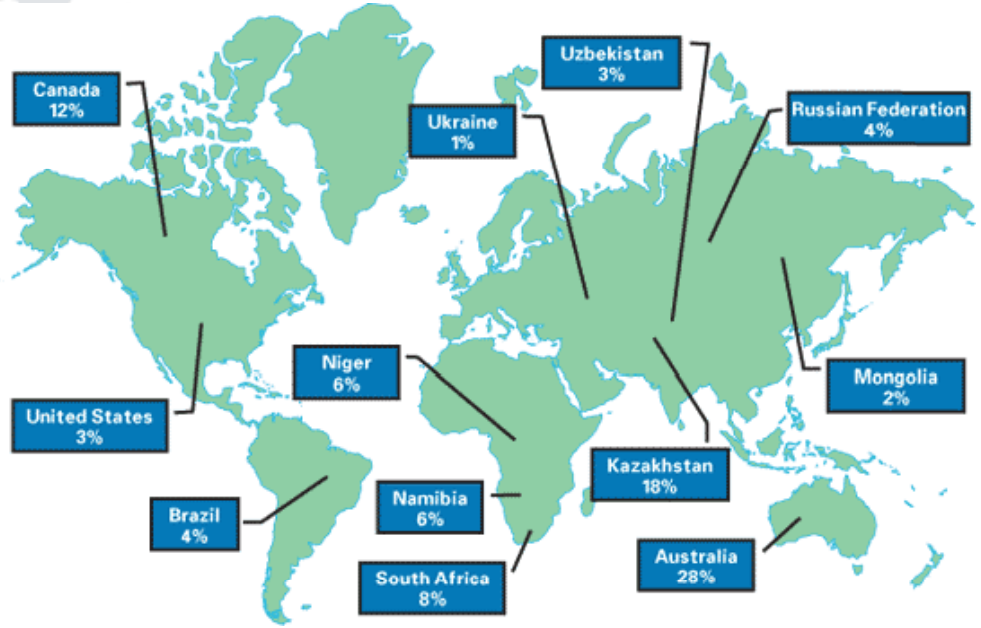
Data based on reserve to production ratios (R/P). Problem is, coal won't run out soon enough from the climate impact point-of-view.

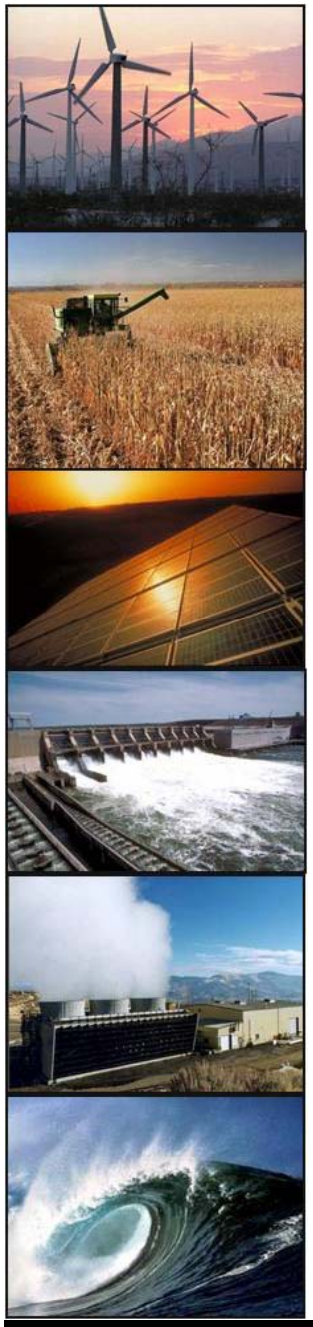
Strategic factors will ensure that coal is utilized



Gigatons coal equivalent (courtesy World Coal Institute 2005)

World Uranium reserves (courtesy Coolschool, Canada)





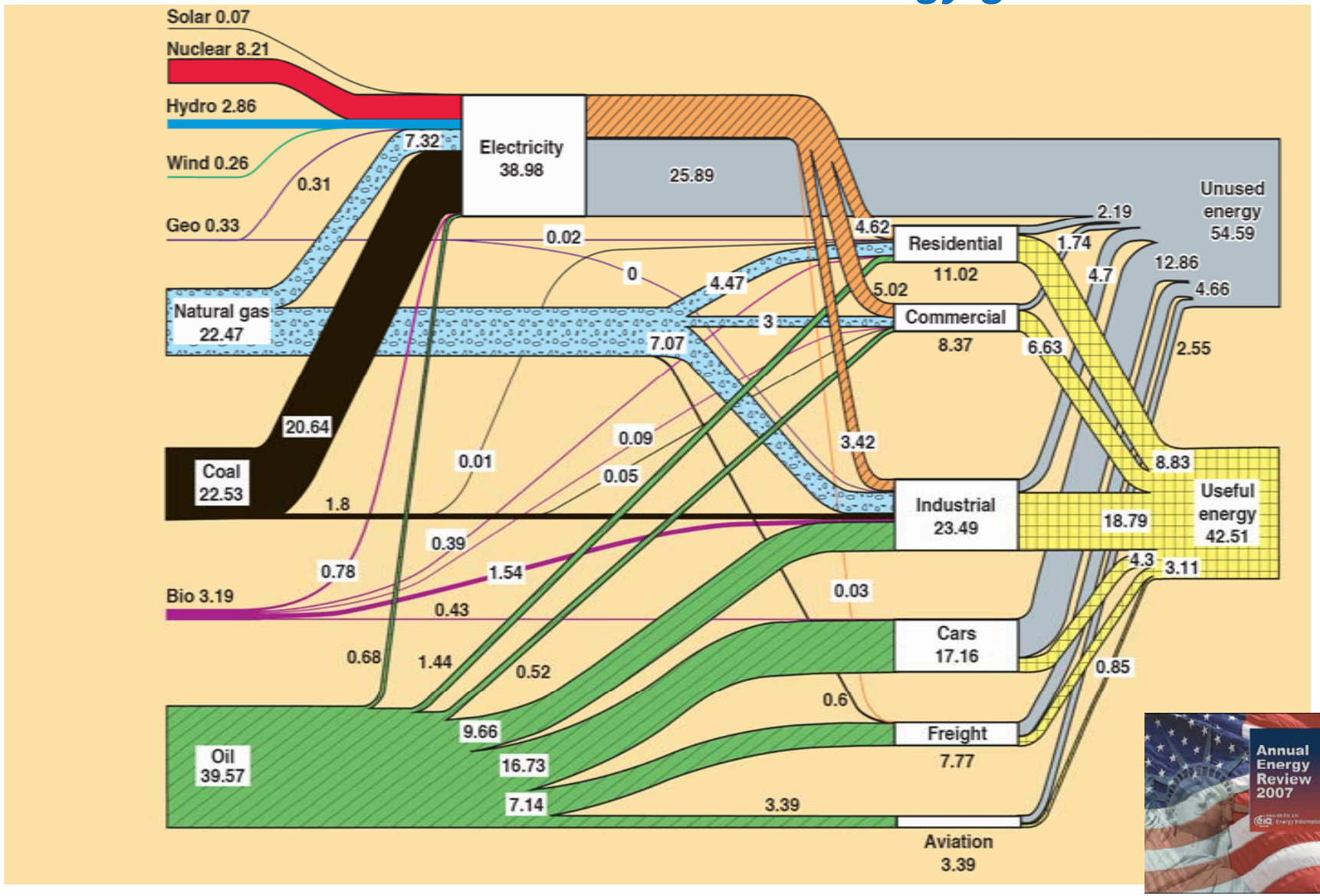
Estimated potential for US renewables

United States
Renewable Energy
(Quads/Year)

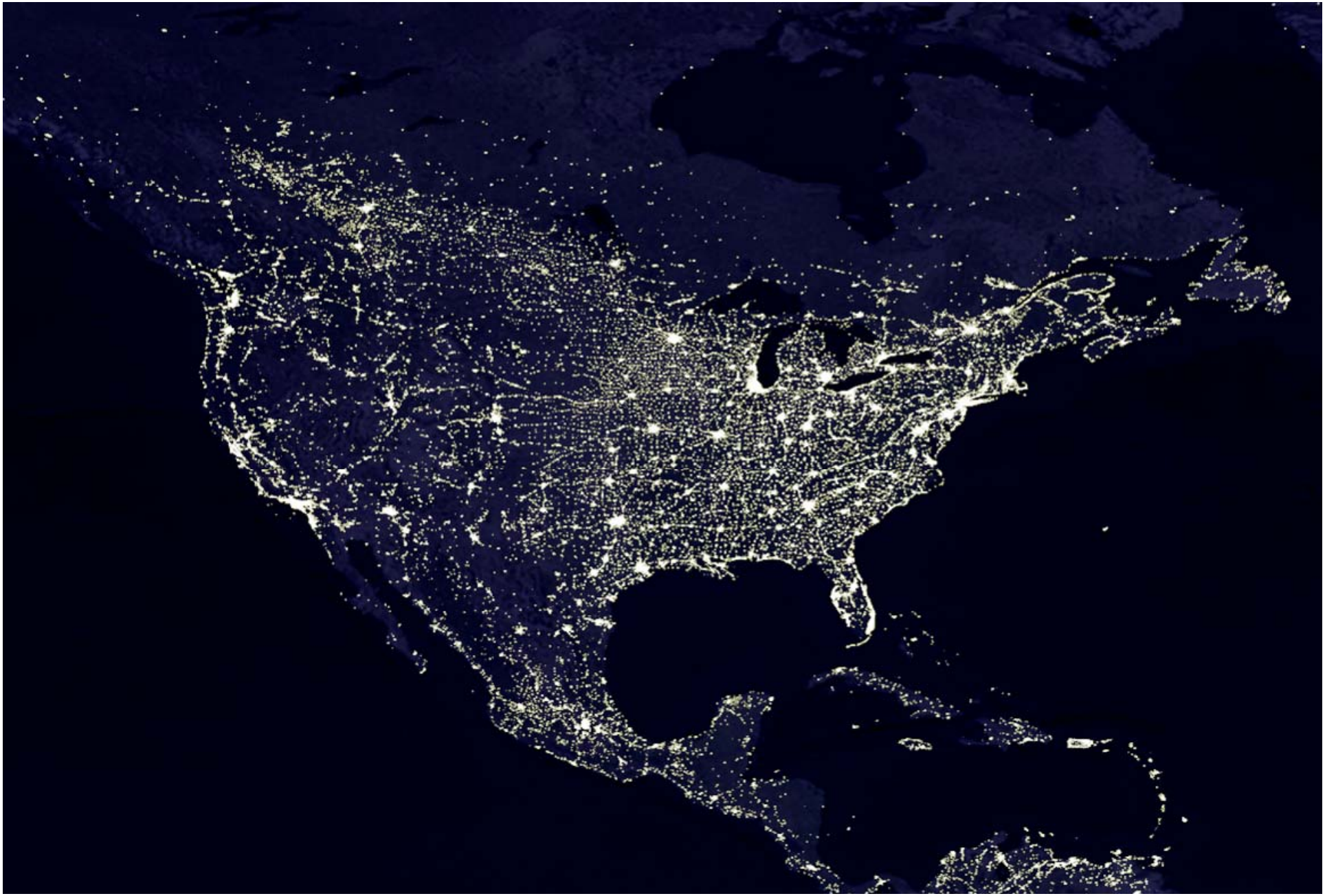
	2003 Consumption	Potential Capacity
Wind	**0.11**	**15**
Biomass	**2.88**	**24**
Solar	**0.06**	**1,255**
Hydroelectric	**2.78**	**4**
Geothermal	**0.31**	**8**

Pat Dehmer

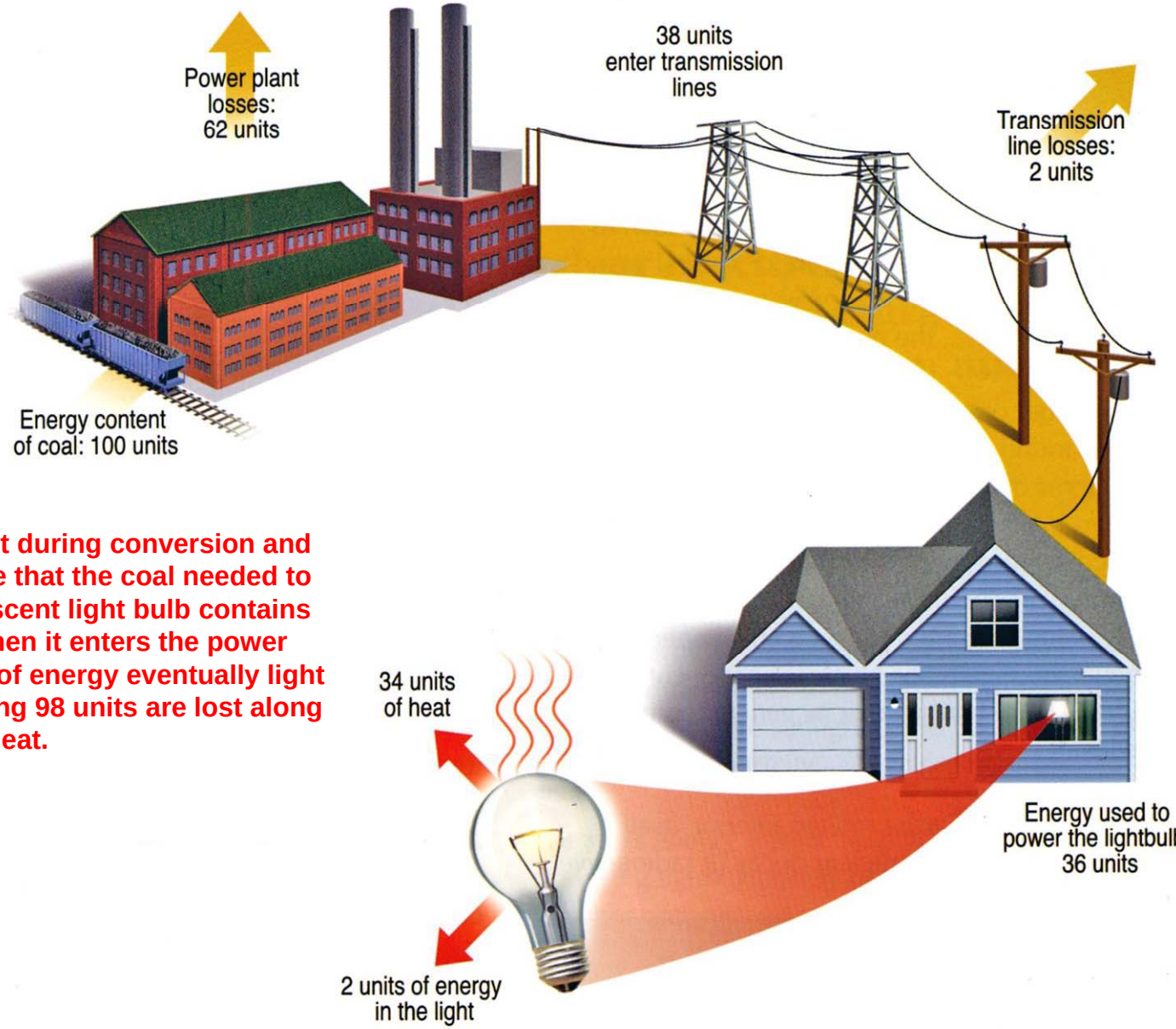
The mother of all charts – where does energy go?



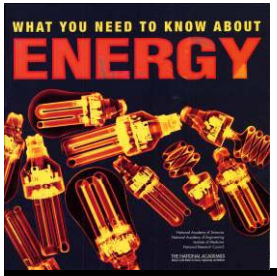
Light pollution reveals energy needs in the USA



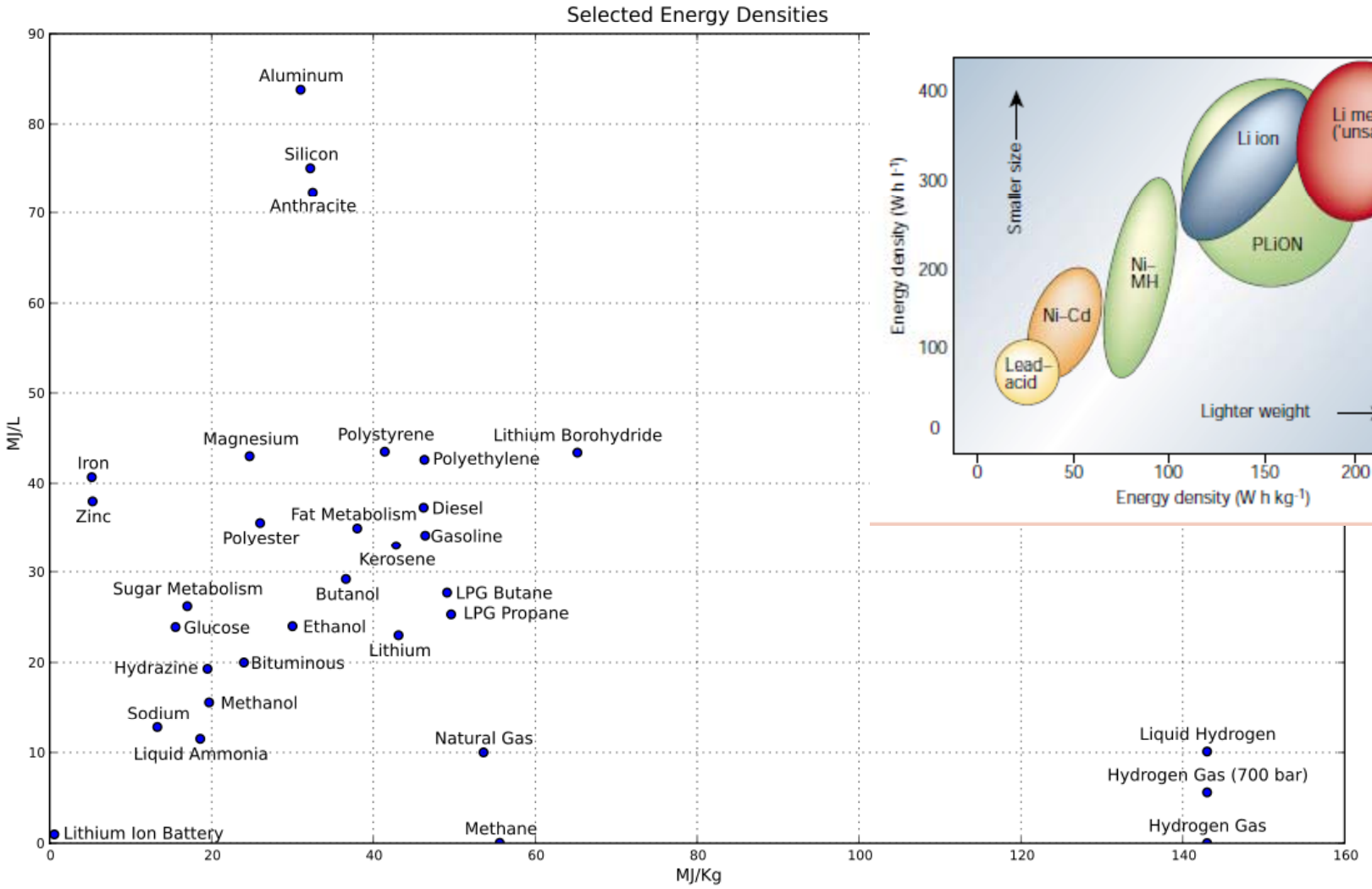
Energy Efficiency



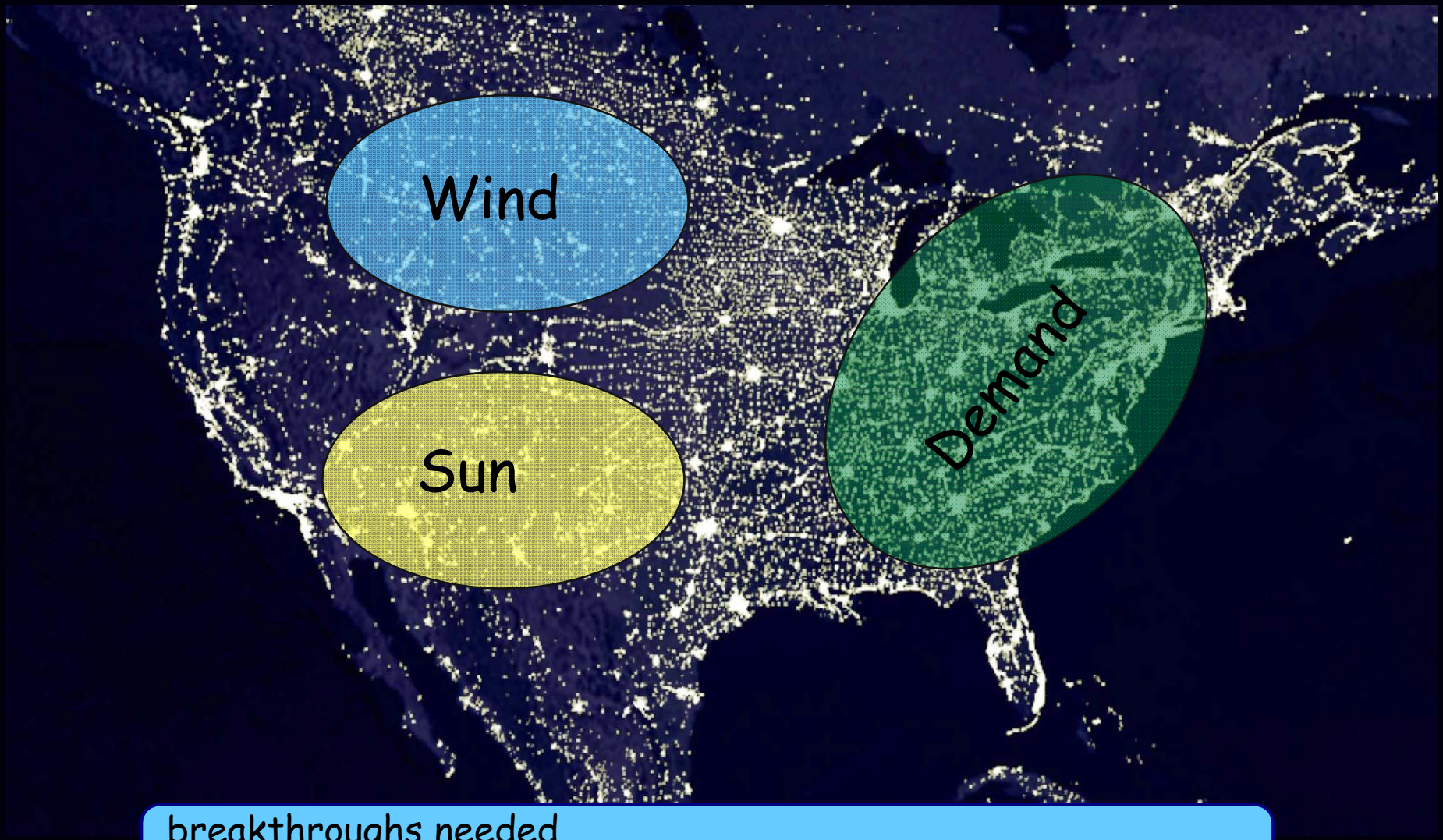
Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent light bulb contains 100 units of energy when it enters the power plant. Only two units of energy eventually light the bulb. The remaining 98 units are lost along the way, primarily as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



Battery technology has a long way to go



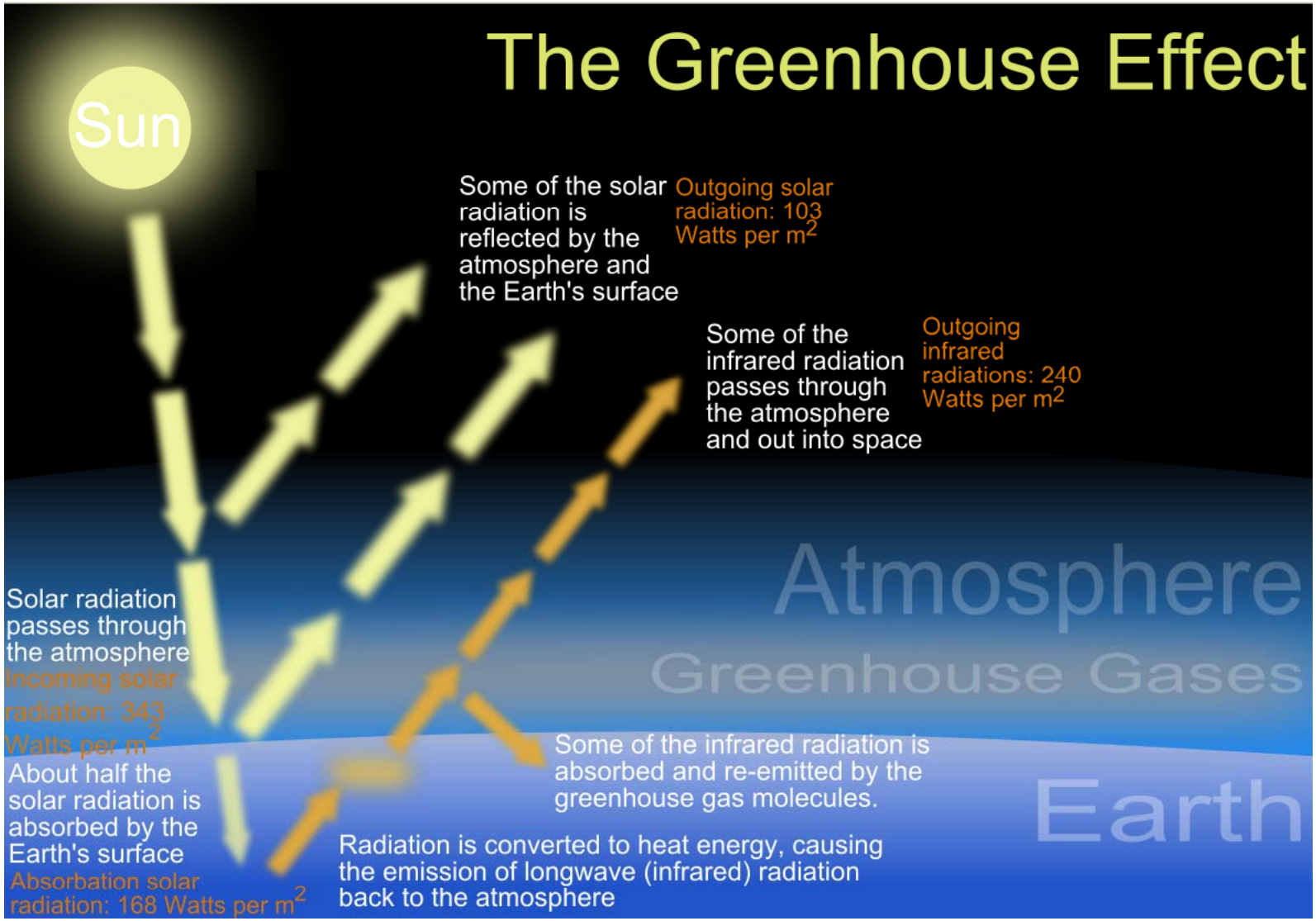
Sustainable Energy Enabling Technologies: The Grid



breakthroughs needed
long distance reliable, efficient delivery of electricity

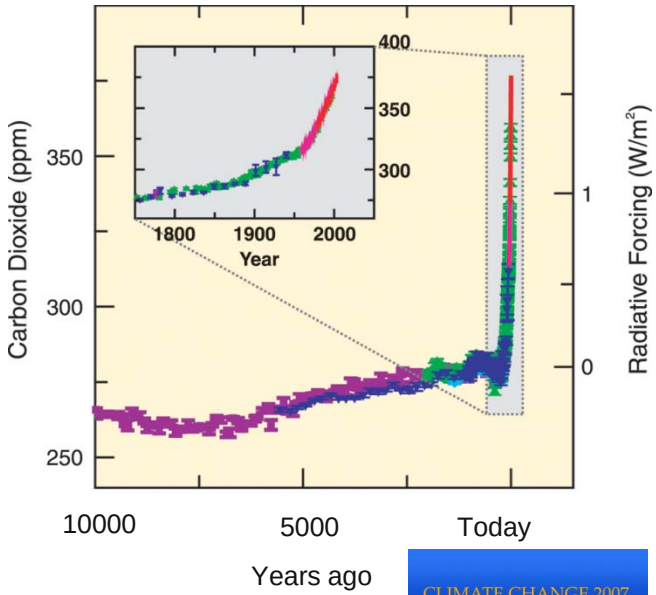
Sustaining the climate

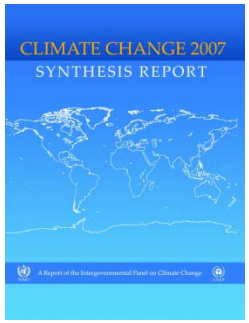
CO_2 is the second most important greenhouse gas, after H_20

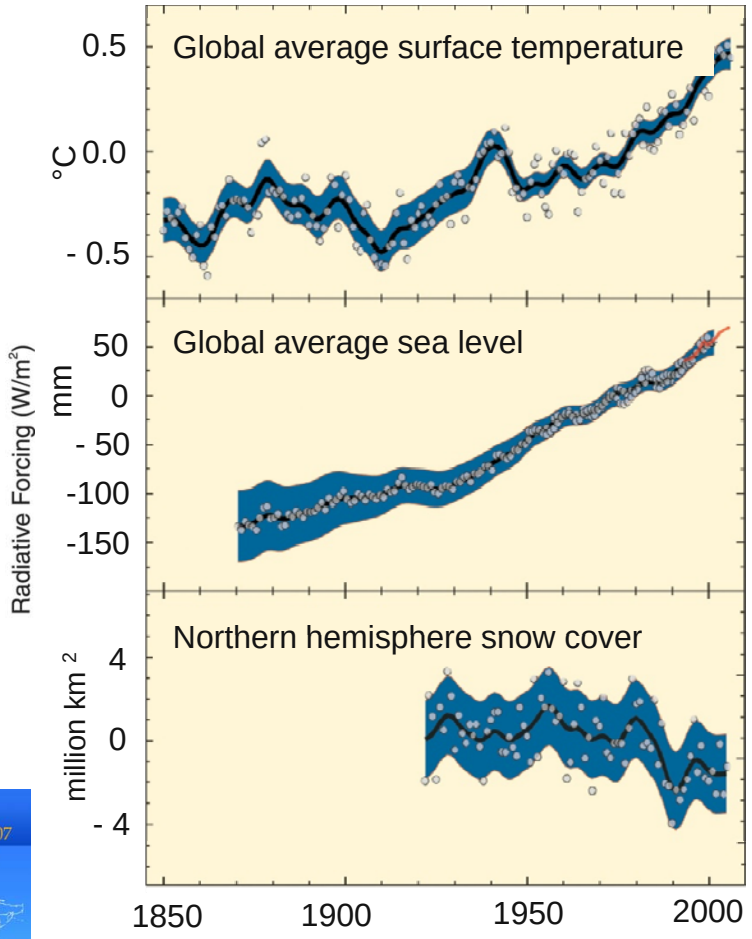


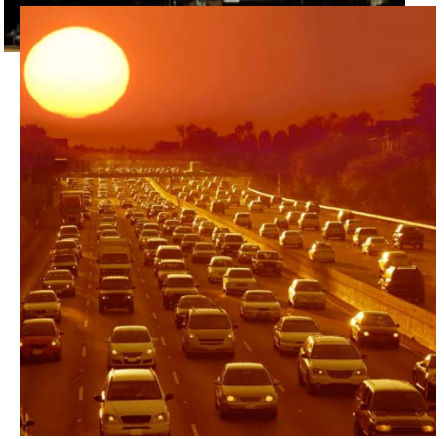
Courtesy ZooFari, Wikimedia Commons

CO_2 and global temperature



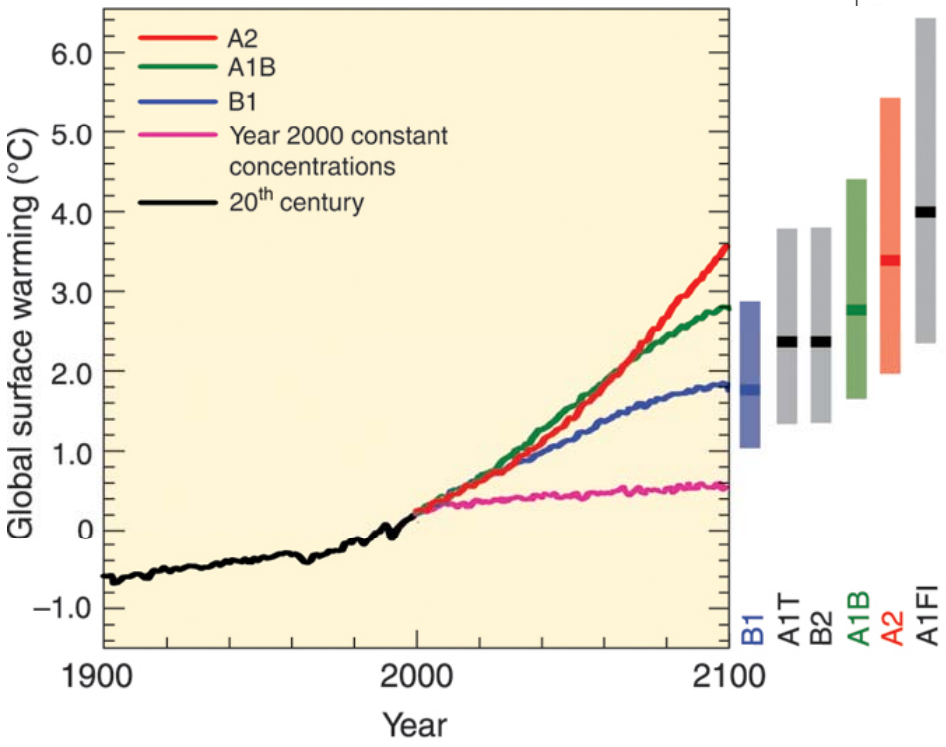


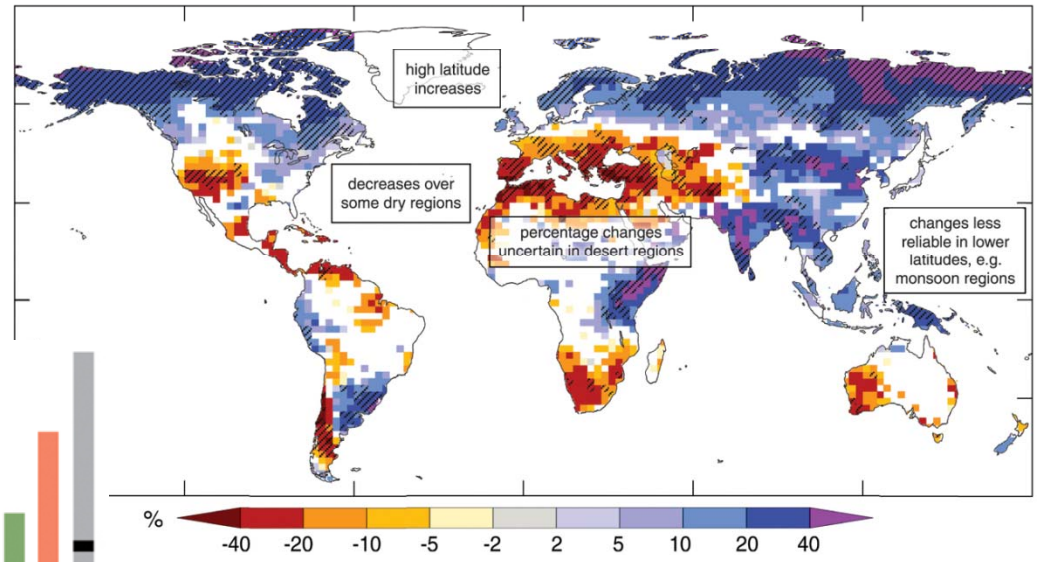




Projections and consequences

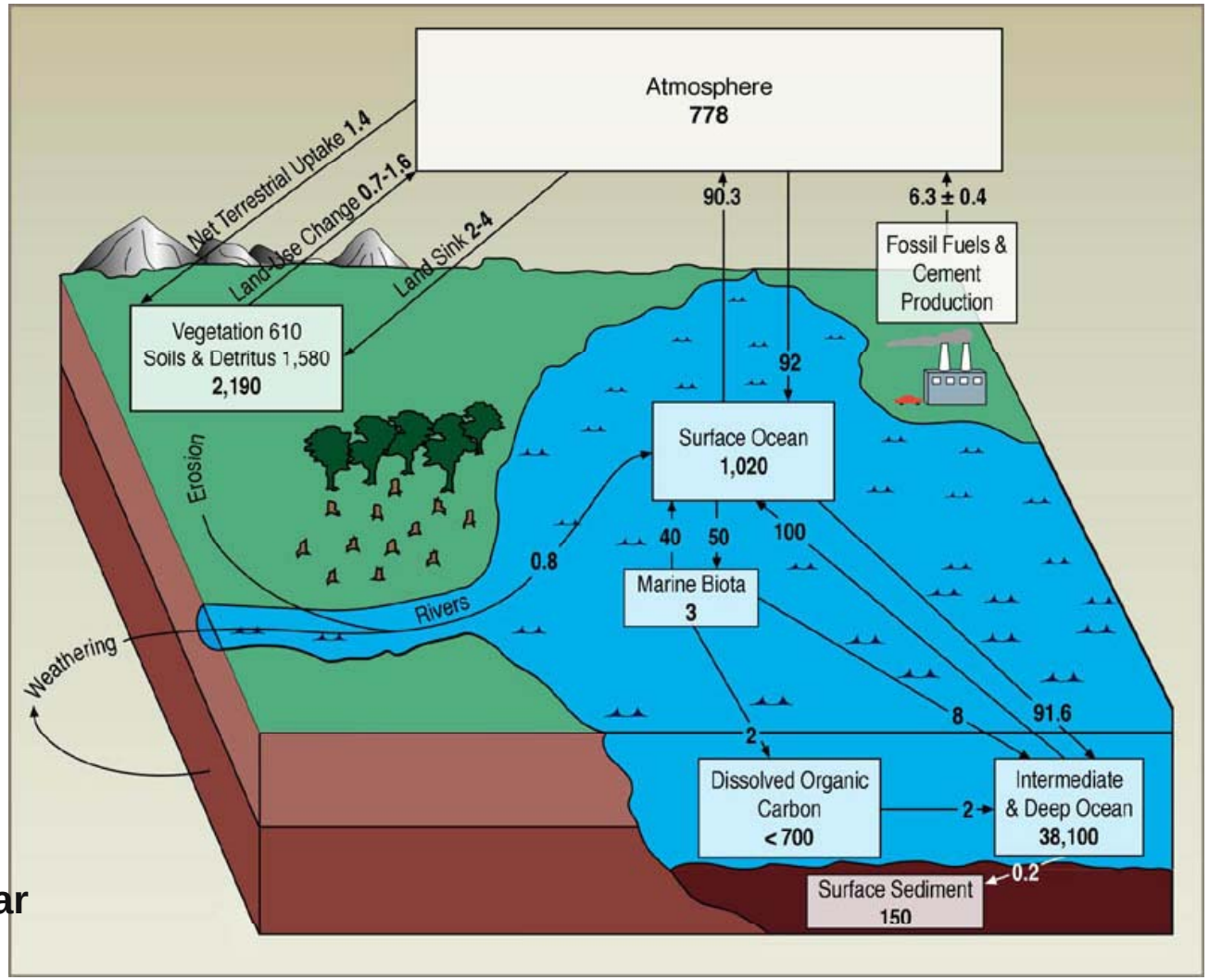
Models (IPCC)





Change in water run-off by 2100

Natural carbon cycle between the land and oceans

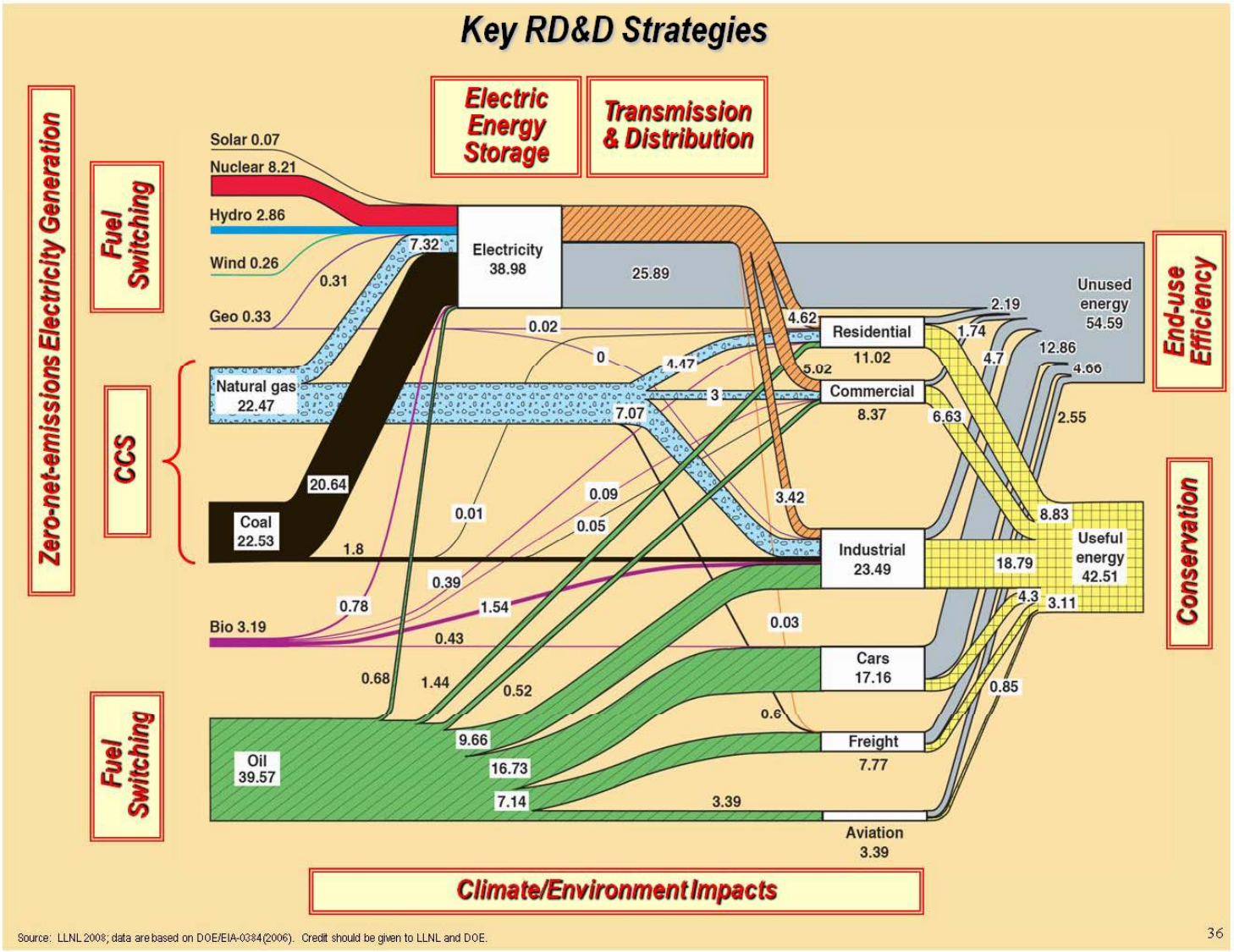


Storage in Gt C
Fluxes in Gt C/year
1 Gton = 10^9 tons

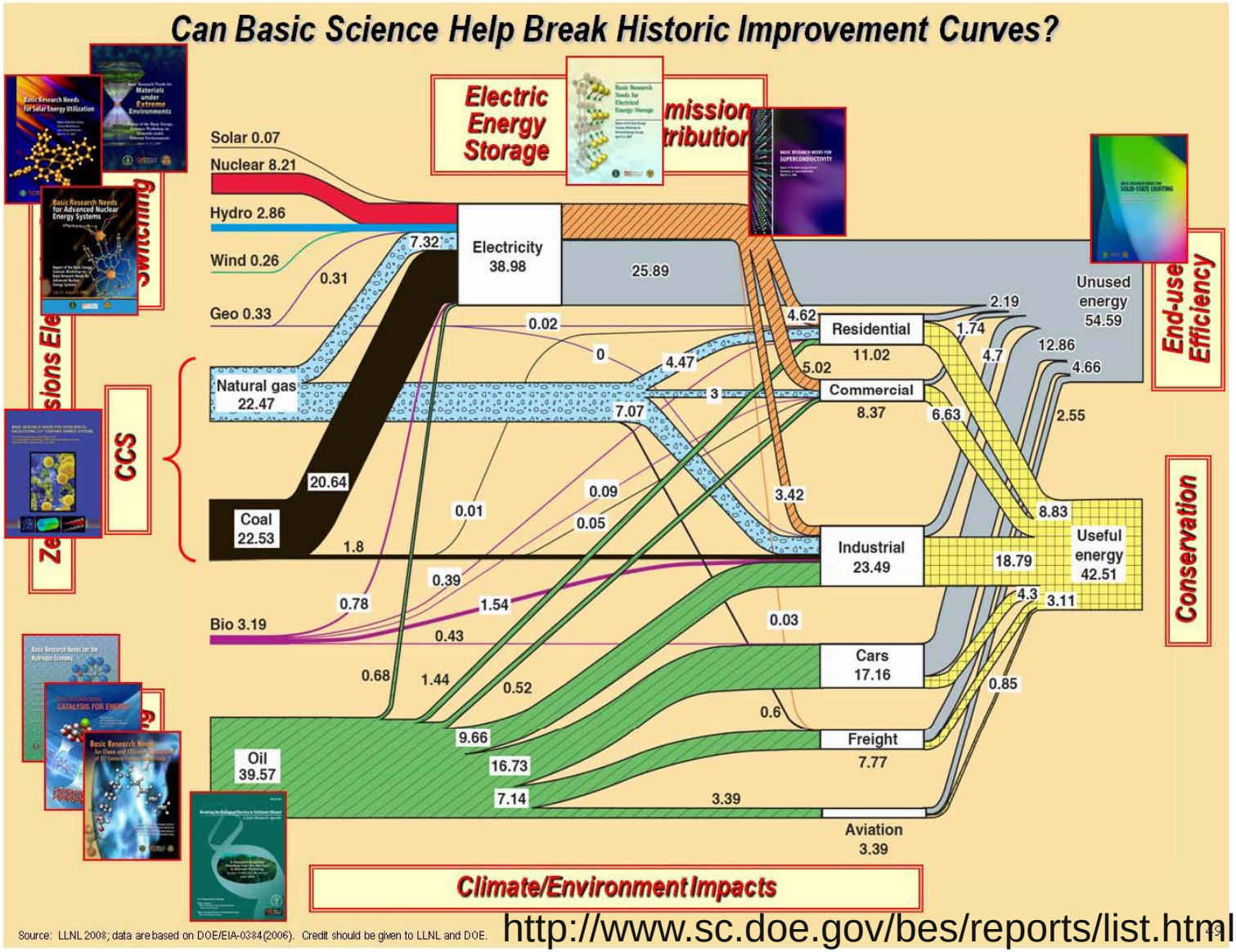
A plausible technology vision – but we don't yet know how

- 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)

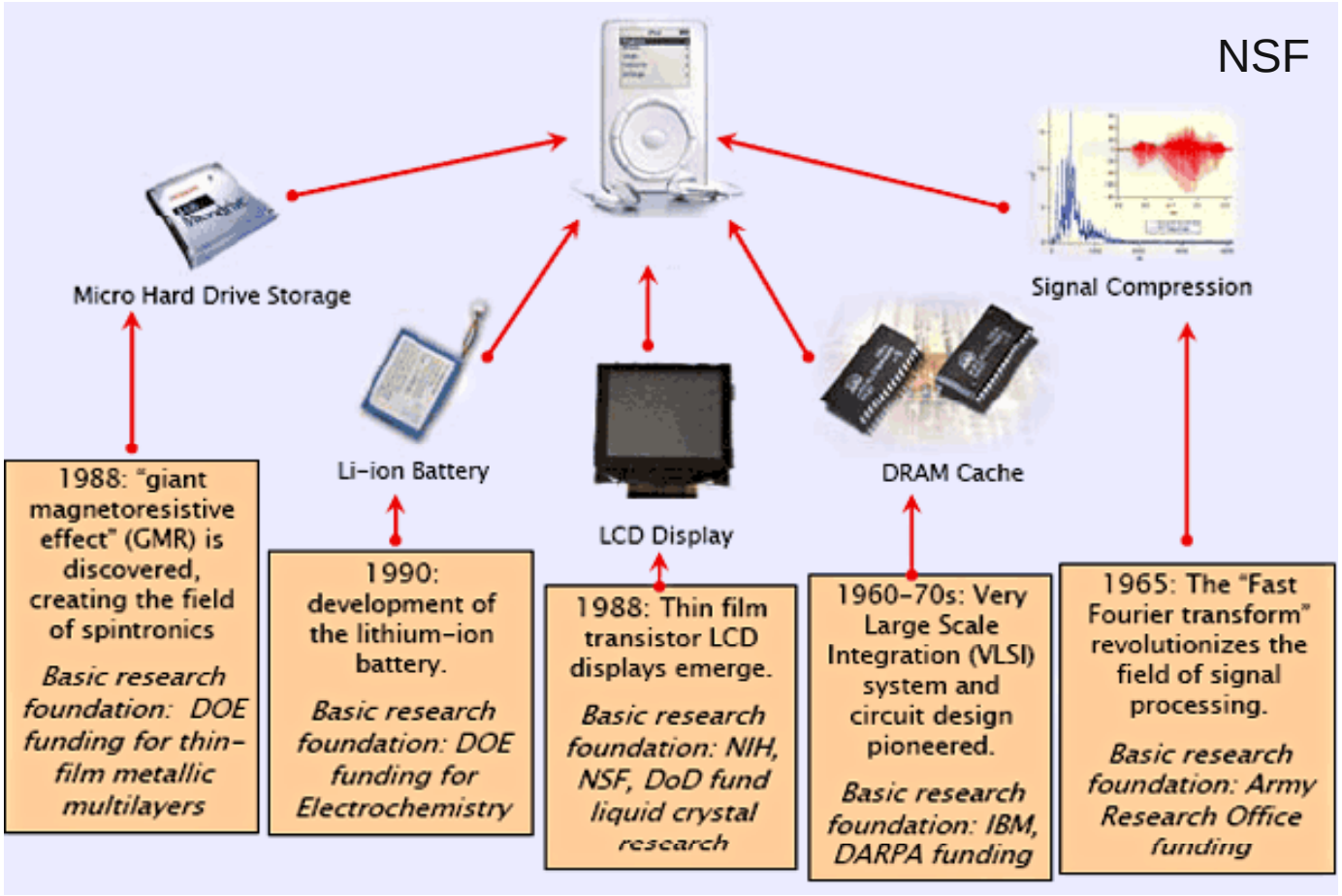


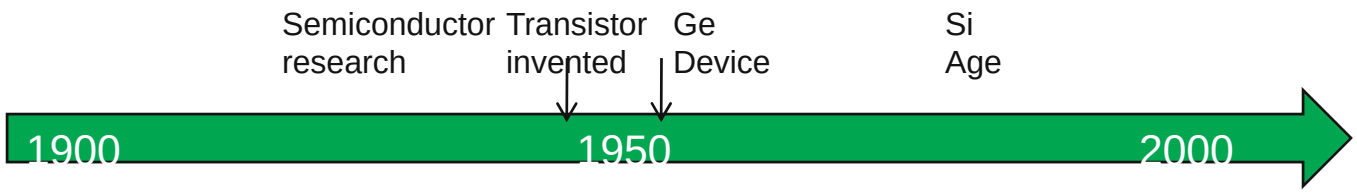
Basic science enabling revolutionary technology



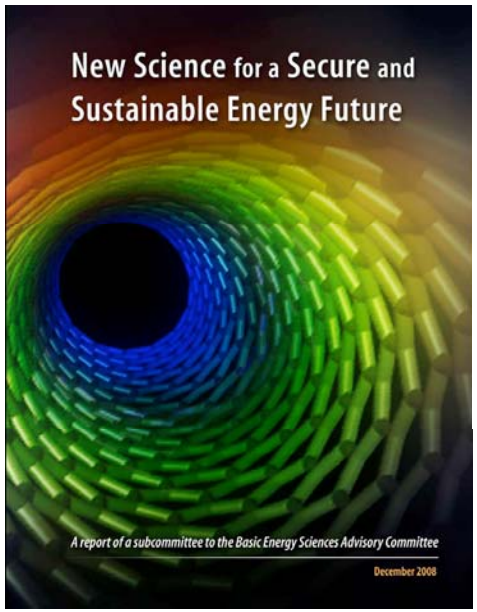
http://www.sc.doe.gov/bes/reports/list.html

We must be conscious of research timescales

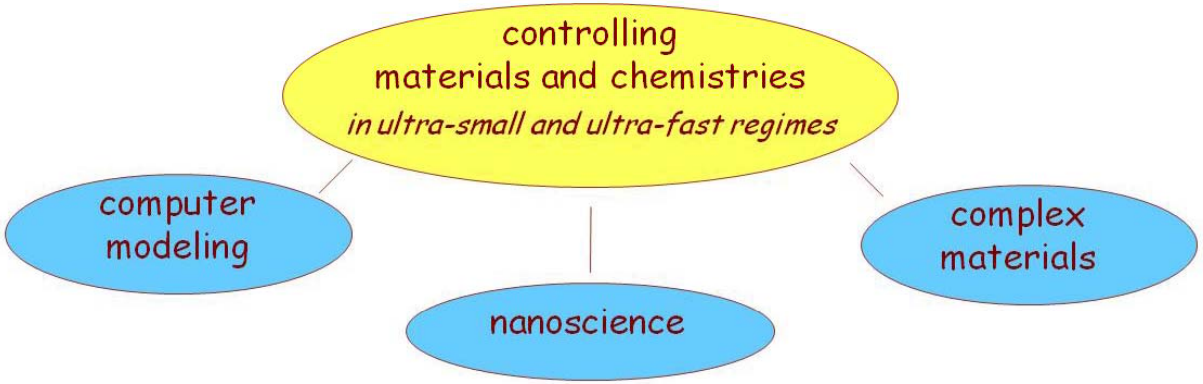




A "New Era"?



New Science: Controlling Complexity



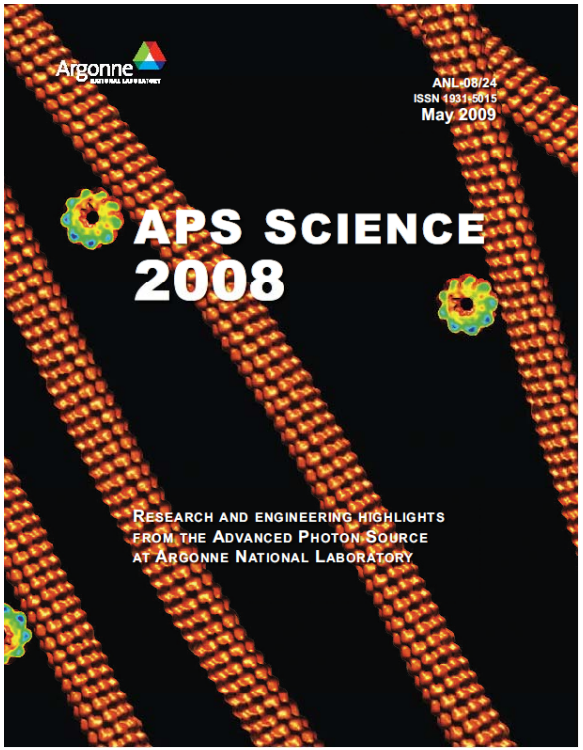
We are at the dawn of a new era

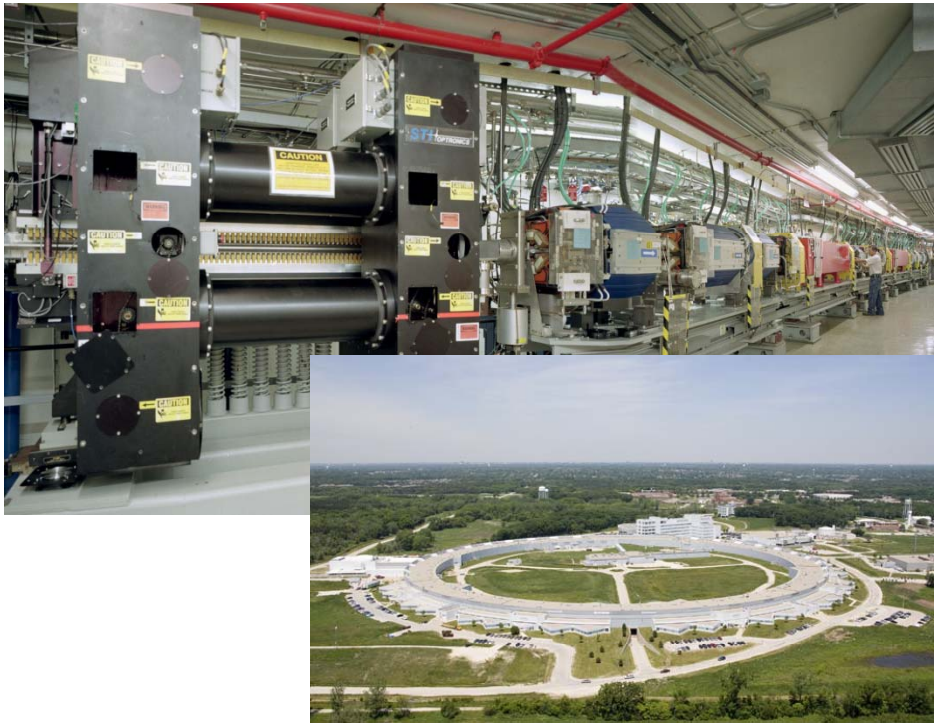
- build materials with atom-by-atom chemical precision
- predict behavior of materials that have not been made
- design new materials and chemistries for specific tasks

breakthroughs to next-generation sustainable energy technologies are within reach

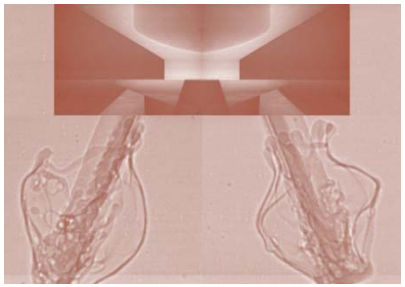
The Advanced Photon Source – a tool to solve these problems

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

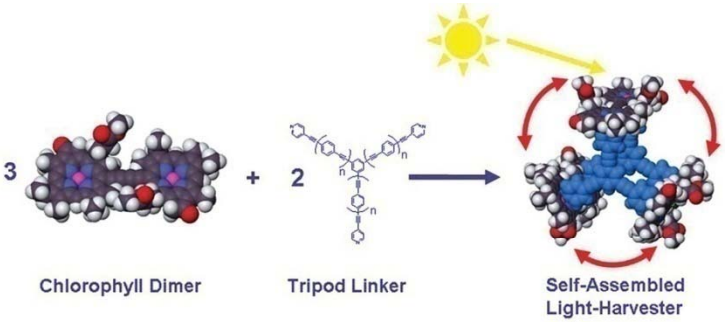




Examples of APS research for societal problems

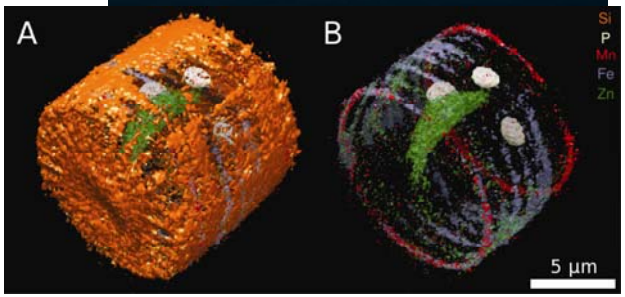


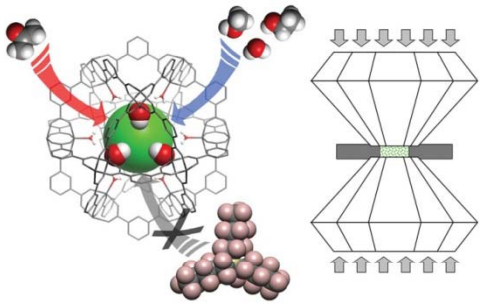
Better burning



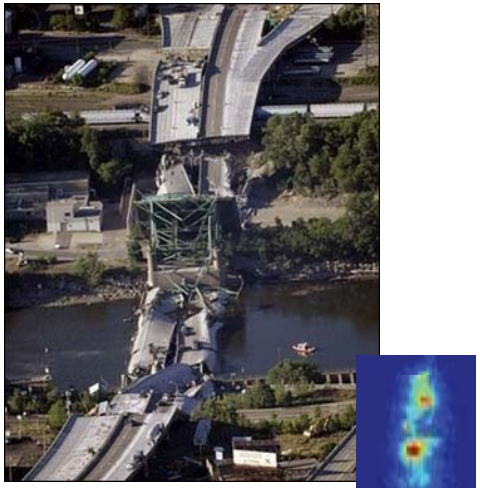
Natural solar cells

How sea animals capture carbon

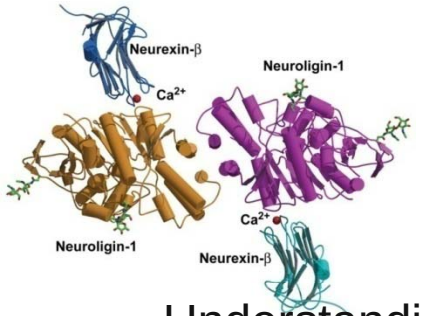




Storing hydrogen



Infrastructure failure



Understanding autism

Argonne's Major Initiatives

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

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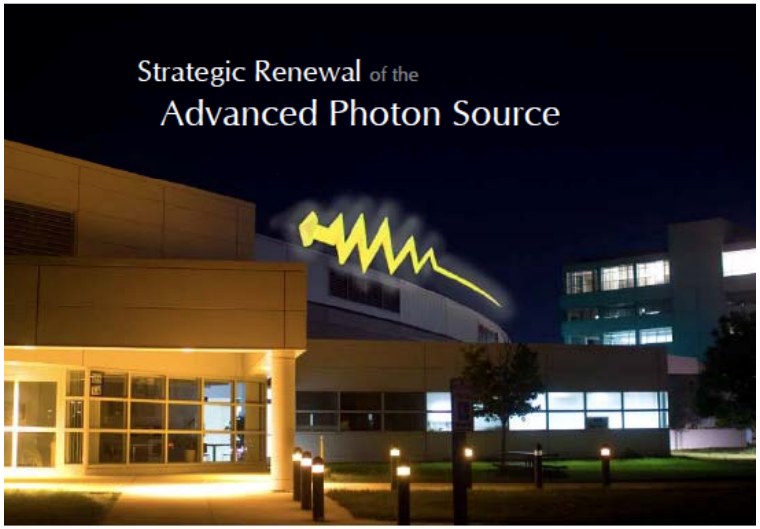
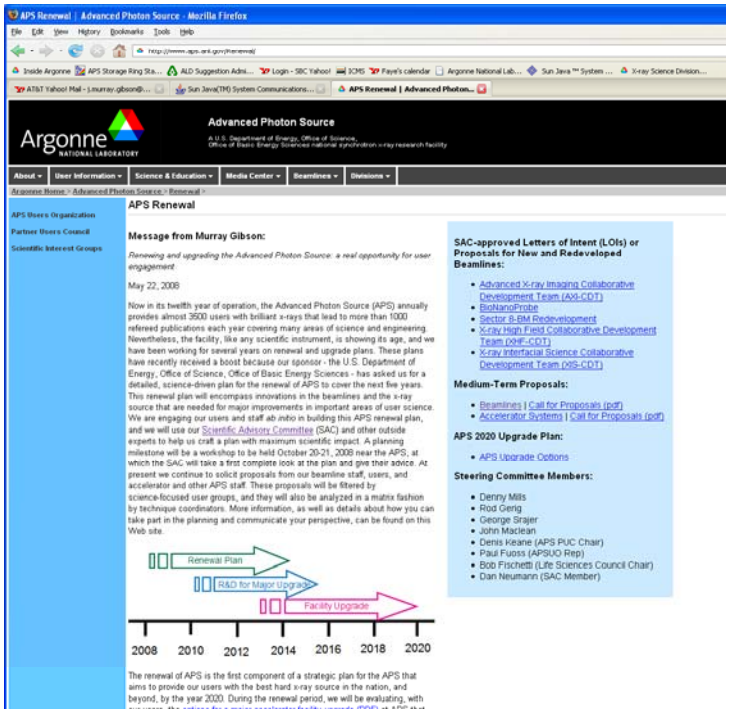
APS plans future upgrade to develop better capabilities

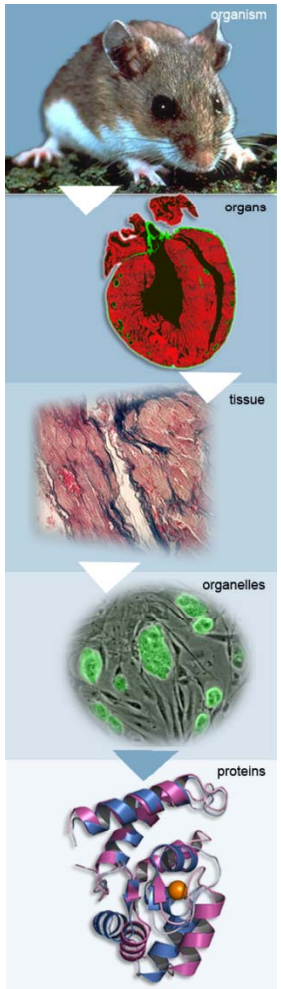


Proposal for approval
of Conceptual Design (CD-0)

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



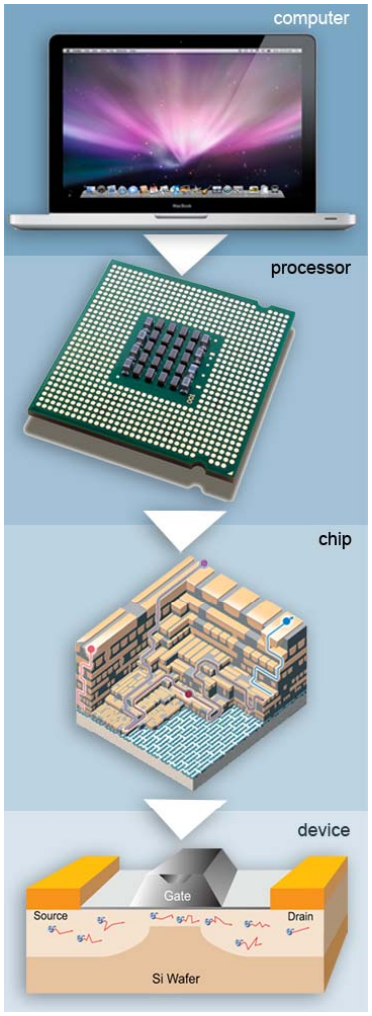
Mastering hierarchical structures through imaging



"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

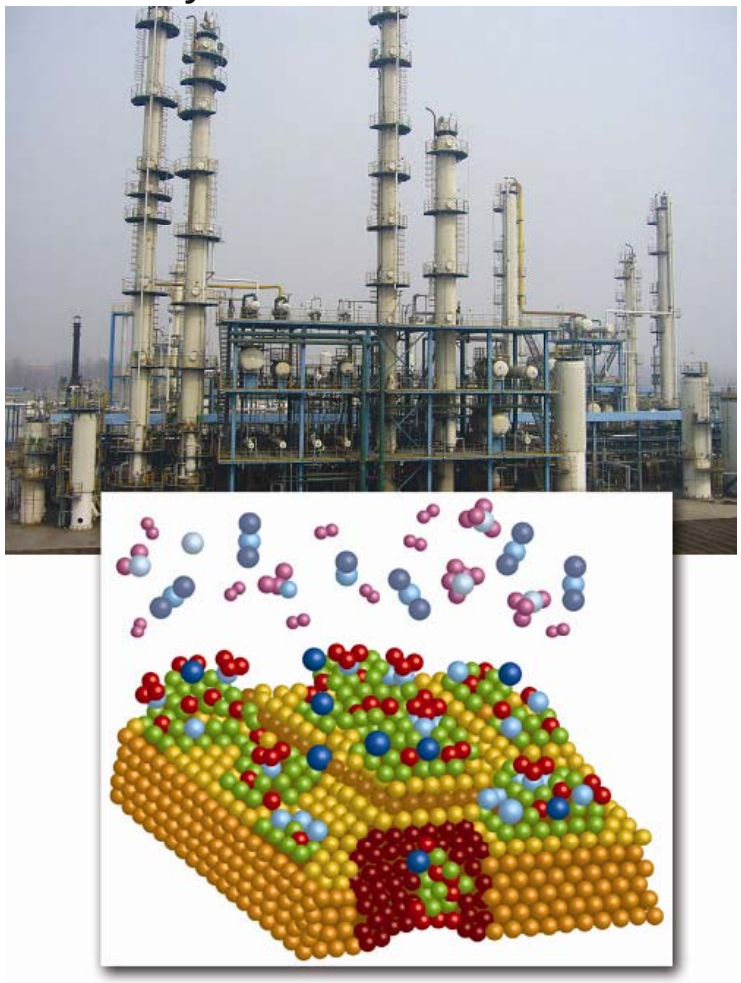
- Hierarchical structures are key to life, machines and complex nanostructured materials

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

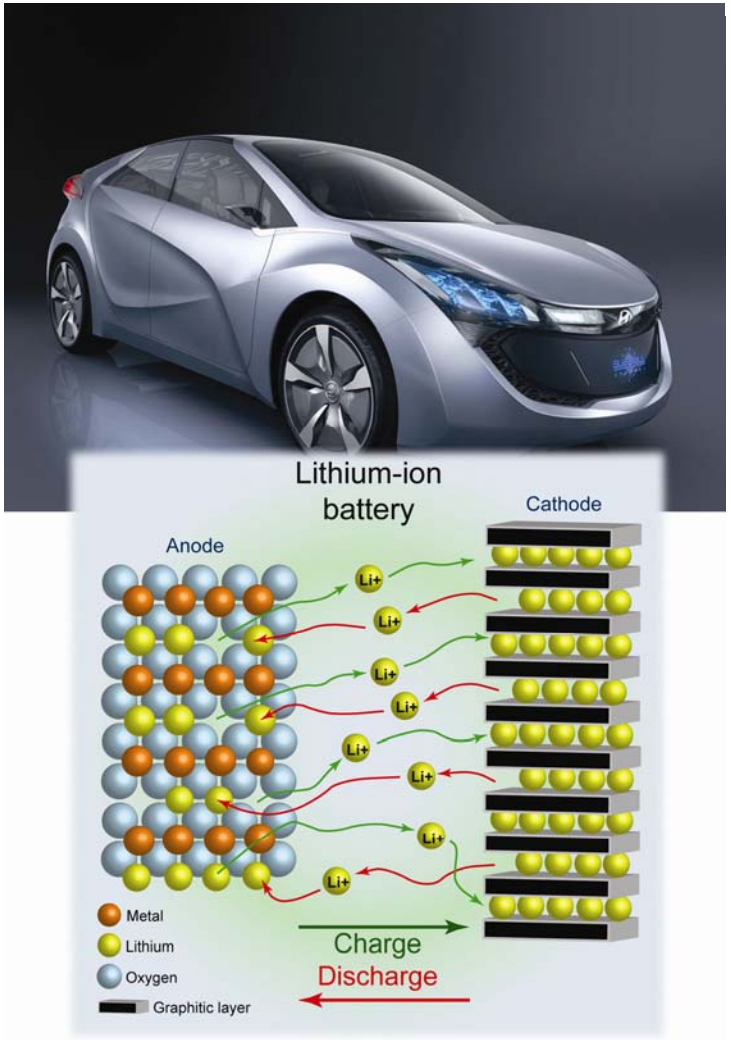


Real materials under real conditions in real time

Catalysis



Batteries



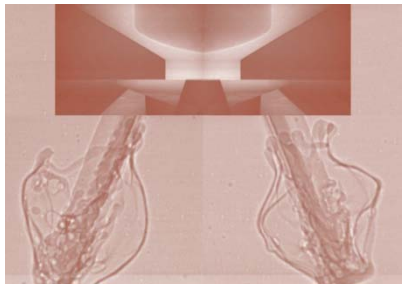
Conclusion

Milwaukee

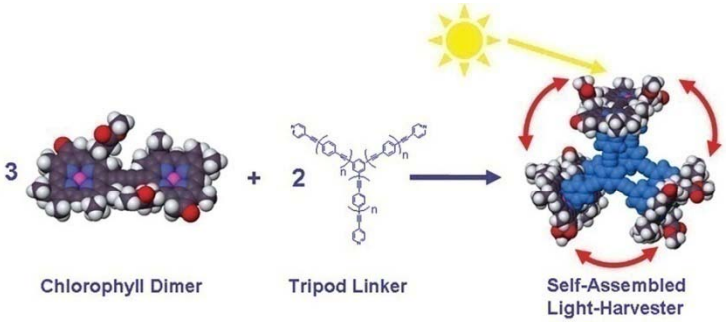
- ~~Houston~~, we have a problem….
- Science and technology offers the (only) hope for life as we know it…
- We have time for basic research to provide new paradigms to capture solar energy, store and transmit it efficiently
- Current technology and aggressive implementation could keep us going for ~50 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…

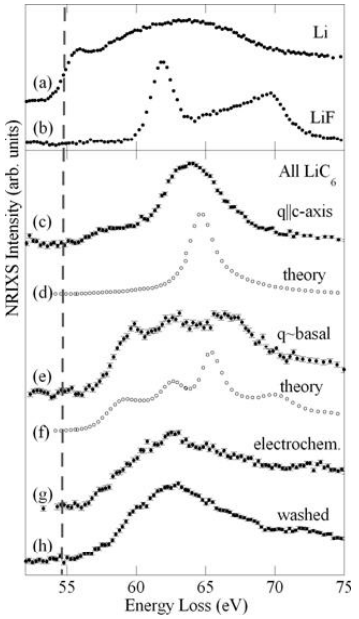


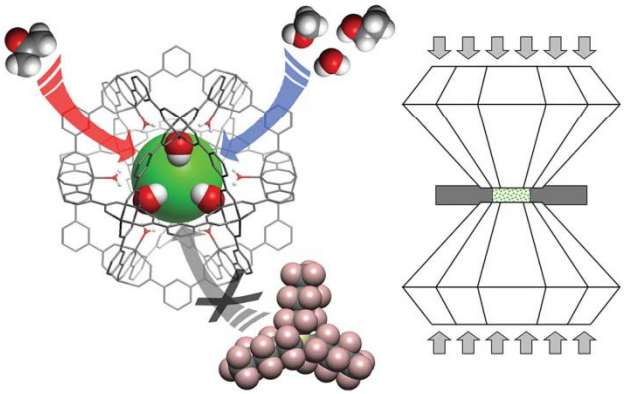
Better burning



Natural solar cells

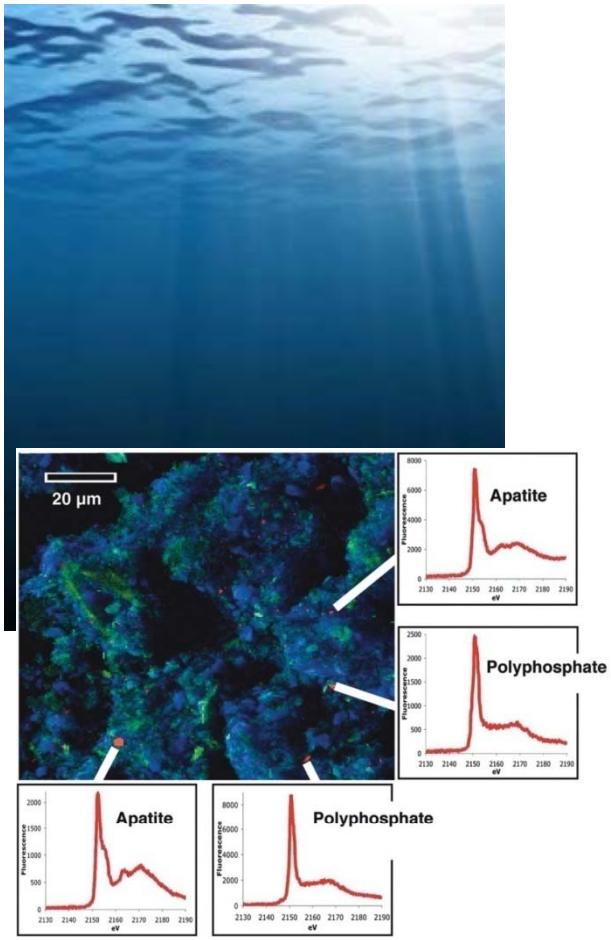
Better batteries



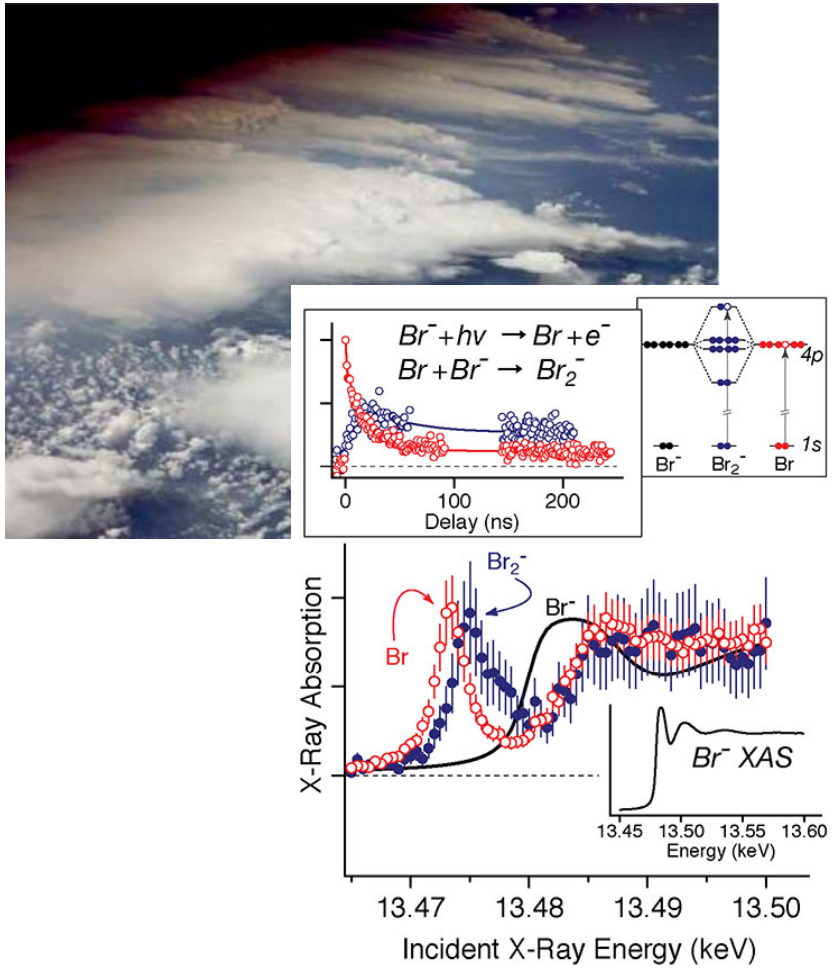


Storing hydrogen

and climate change…

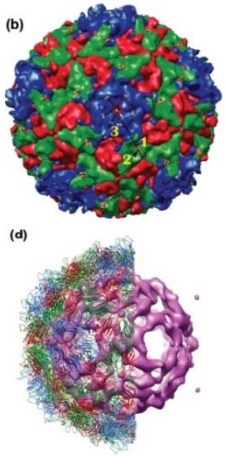


how sea animals capture carbon

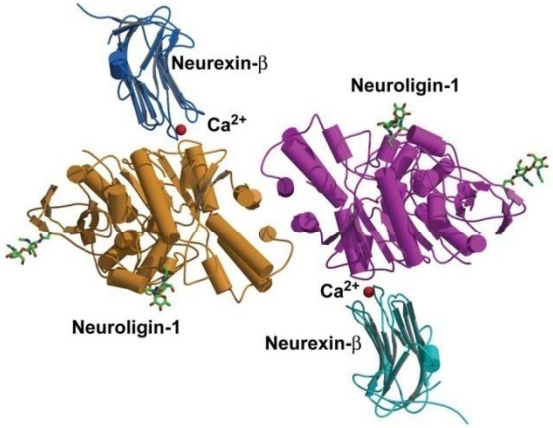


understanding free radicals in the atmosphere

human health…

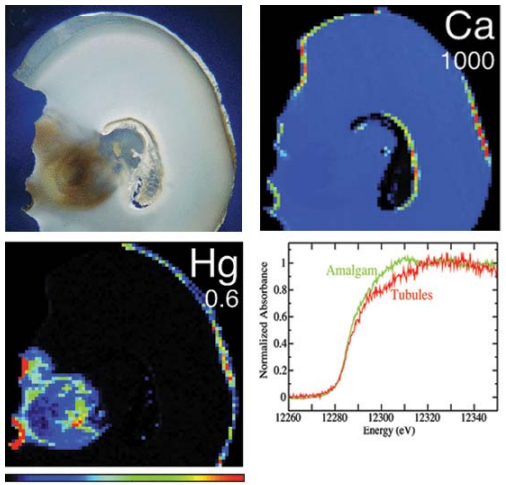


viruses that attack cancer

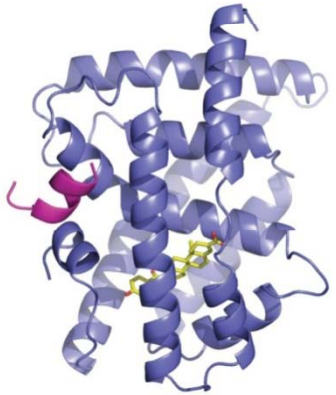


understanding autism

taming a killer

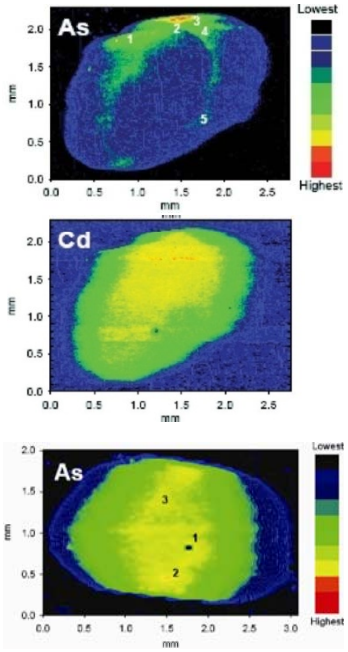


safer dentistry

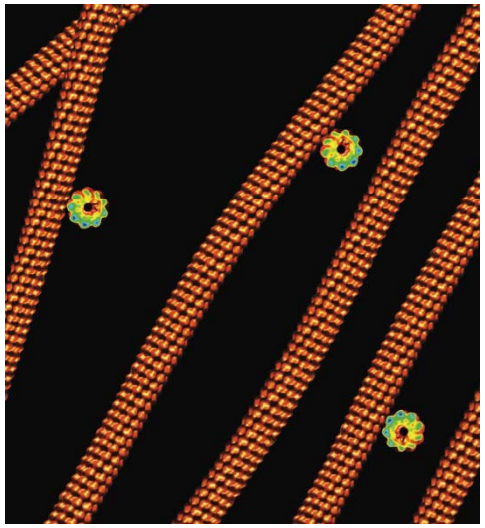


living with obesity

food and water…



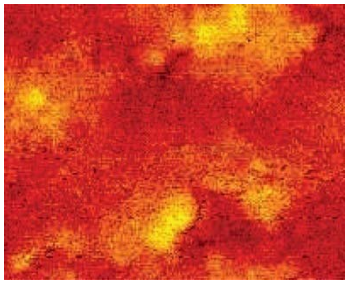
is brown rice good for you?

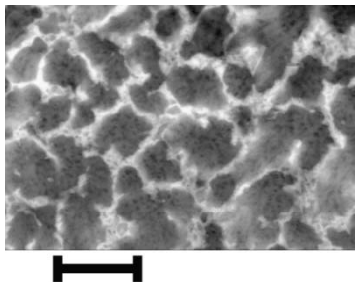


understanding plant viruses

jets and aerosols

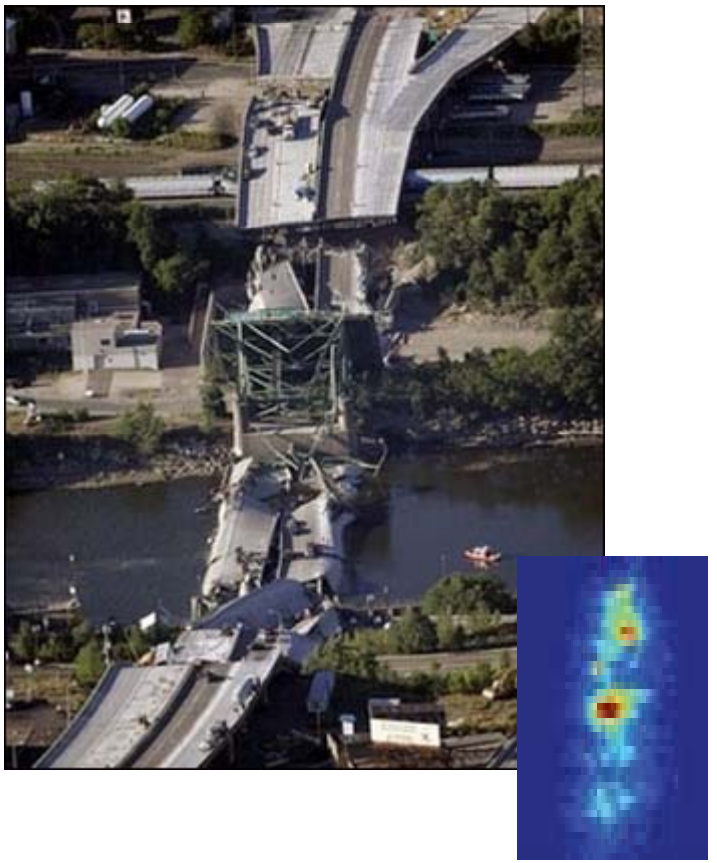
better infrastructure…



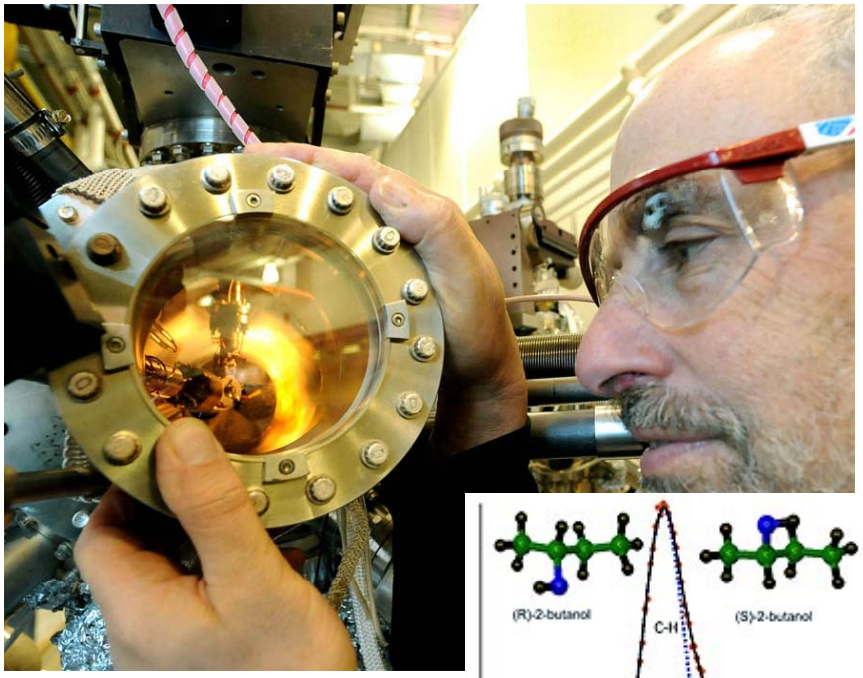


oxide scales
could save $1B for
US hydrogen industry

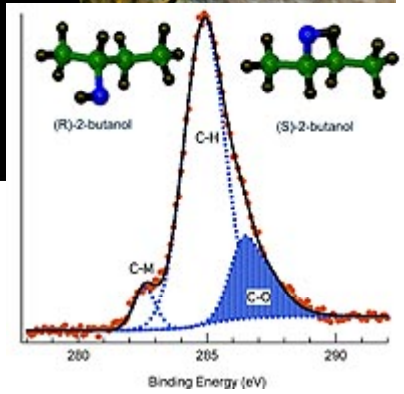
understanding metal fatigue
could save lives and money



ancient history...

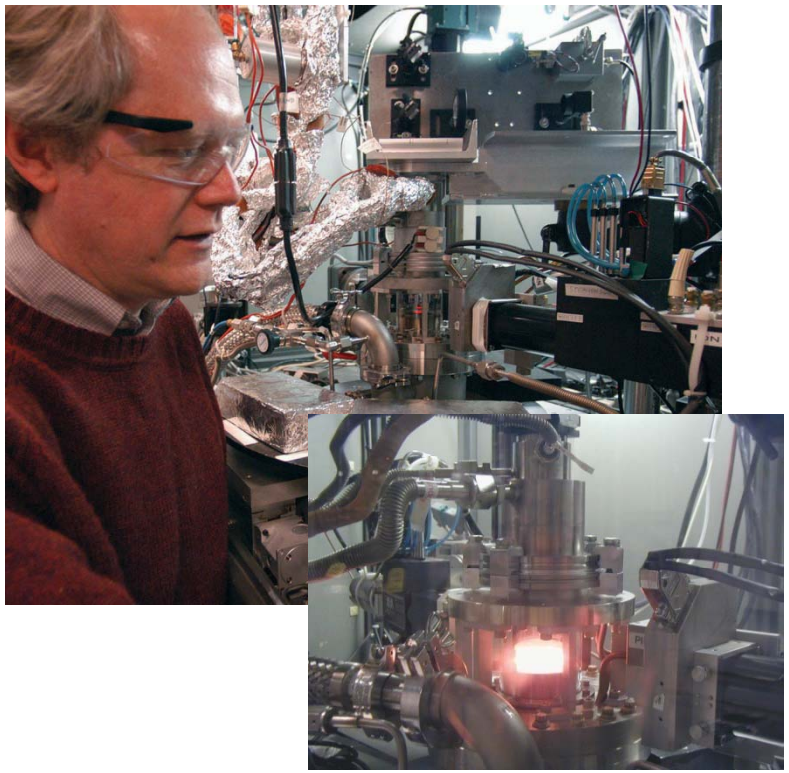


life began with
a twist

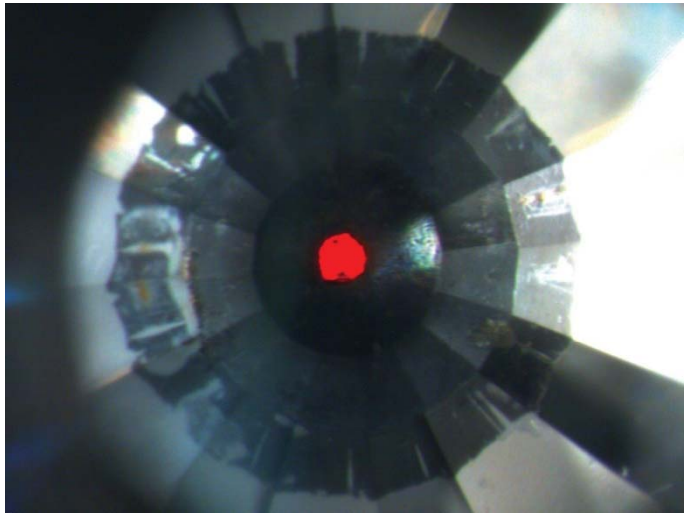


trading with the
enemy in 1000BC

basic science that could enable new technology…

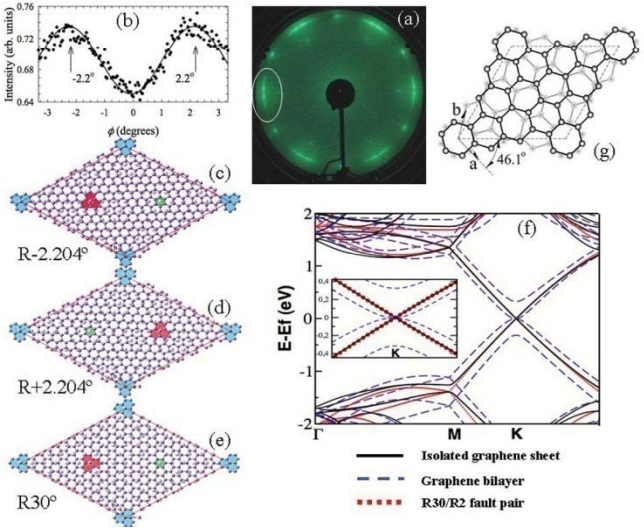


making waves for efficient lighting

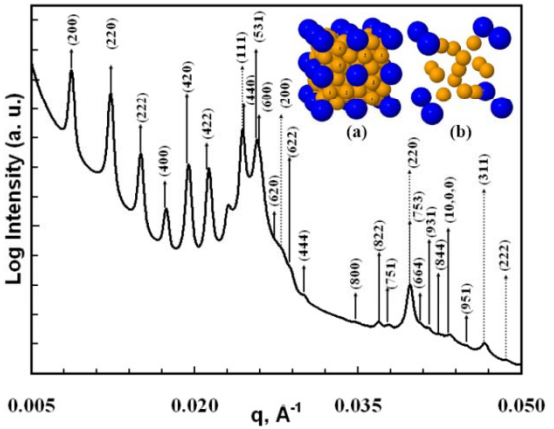


solid oxygen holds surprise at HP

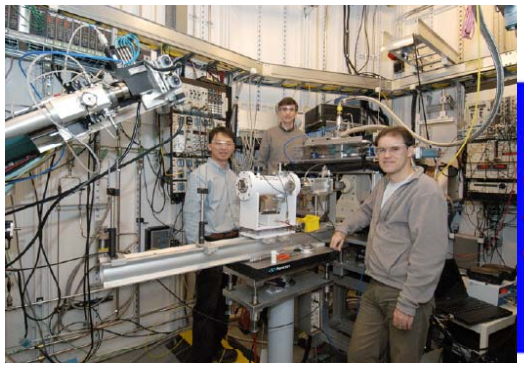
and enhance economic competitiveness

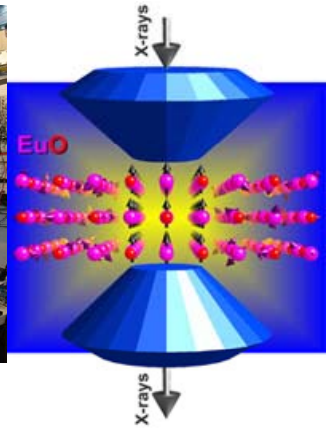


the road to "graphene" electronics



self-assembly of polymers





better magnetic materials