U.S. DEPARTMENT OF ENERGY | Office of Science

# Science for Energy

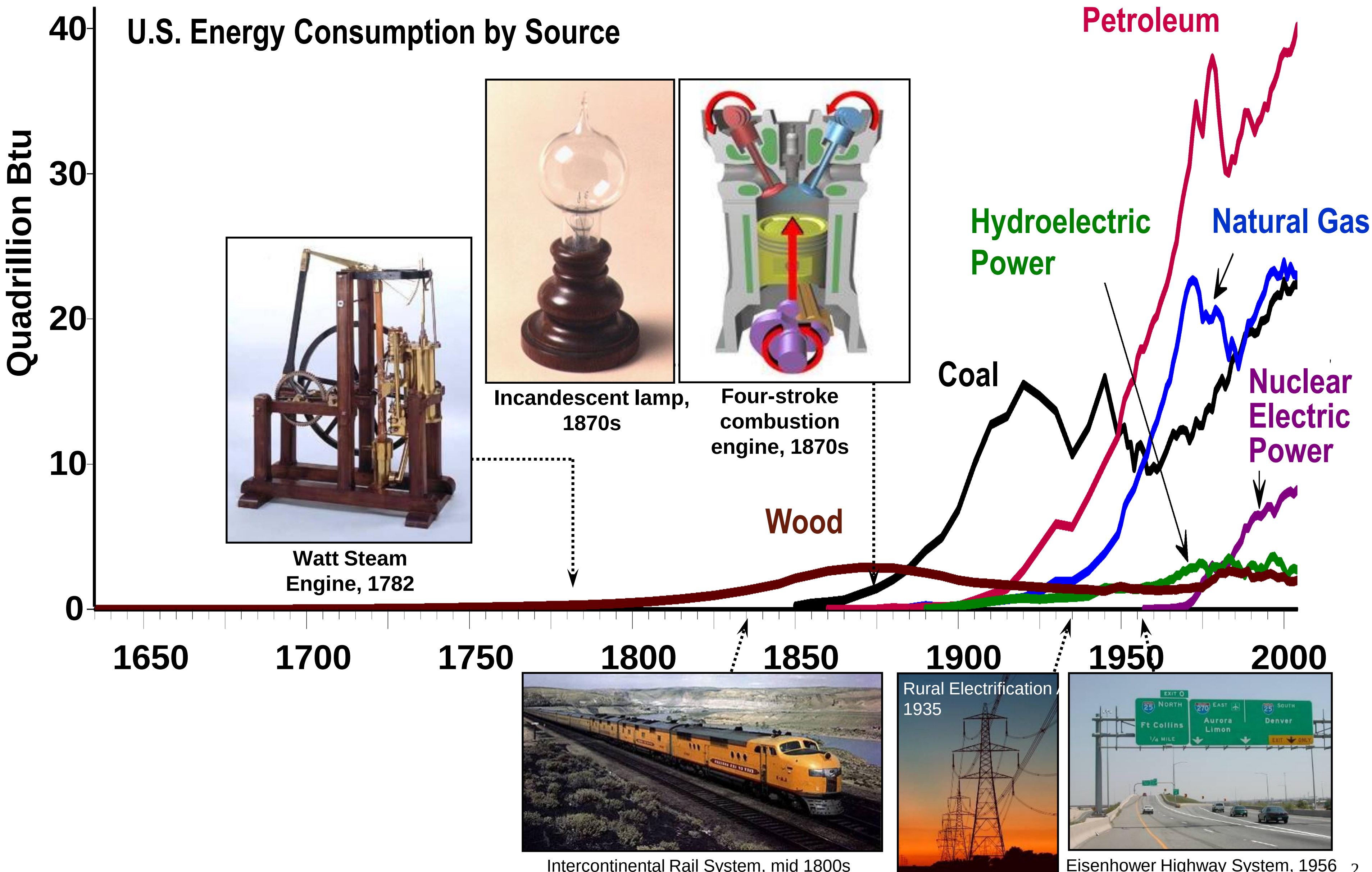
## Energy: Socio-Economical Stakes and Technological Challenges

**6 June 2011**

Dr. Harriet Kung
Director, Office of Basic Energy Sciences
Office of Science, U.S. Department of Energy

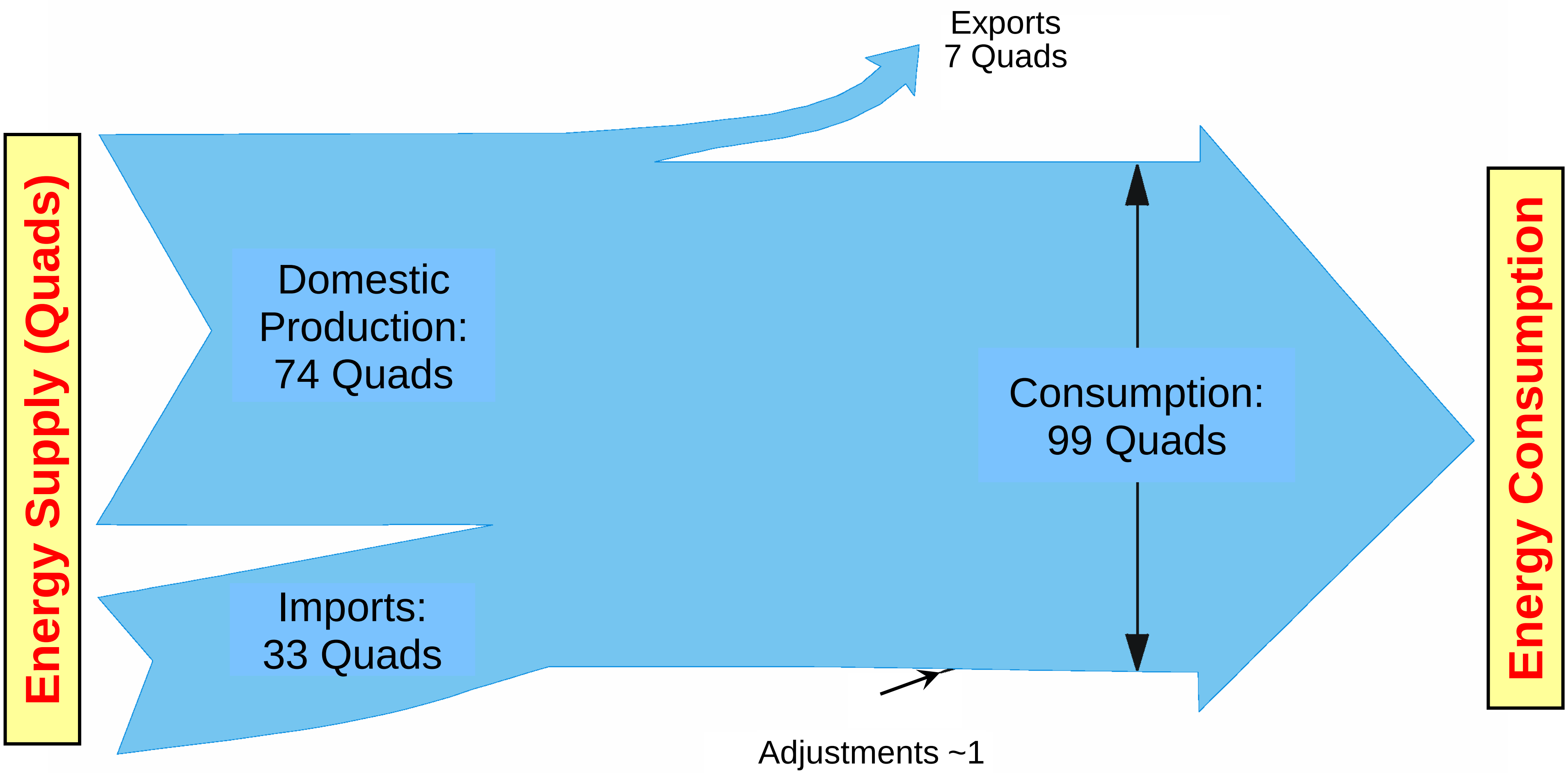
# 400 Years of Energy Use in the U.S.

## 19th C discoveries and 20th C technologies are very much part of today's infrastructure



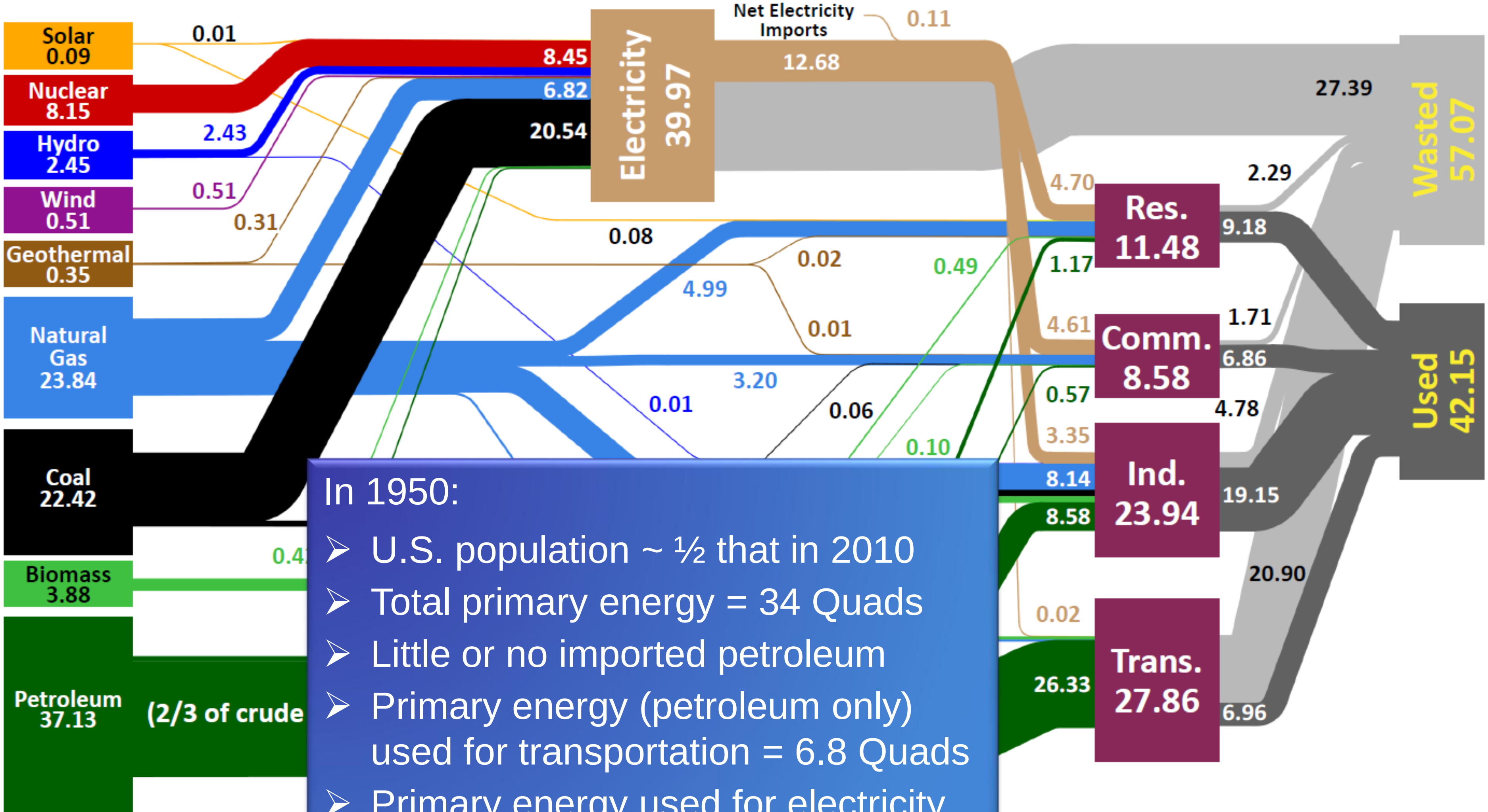
# U.S. Energy Flow, 2008

*About 1/3 of U.S. primary energy is imported*



# U.S. Energy Production and Usage in 2008

*Units in Quadrillion BTUs (Quads)*



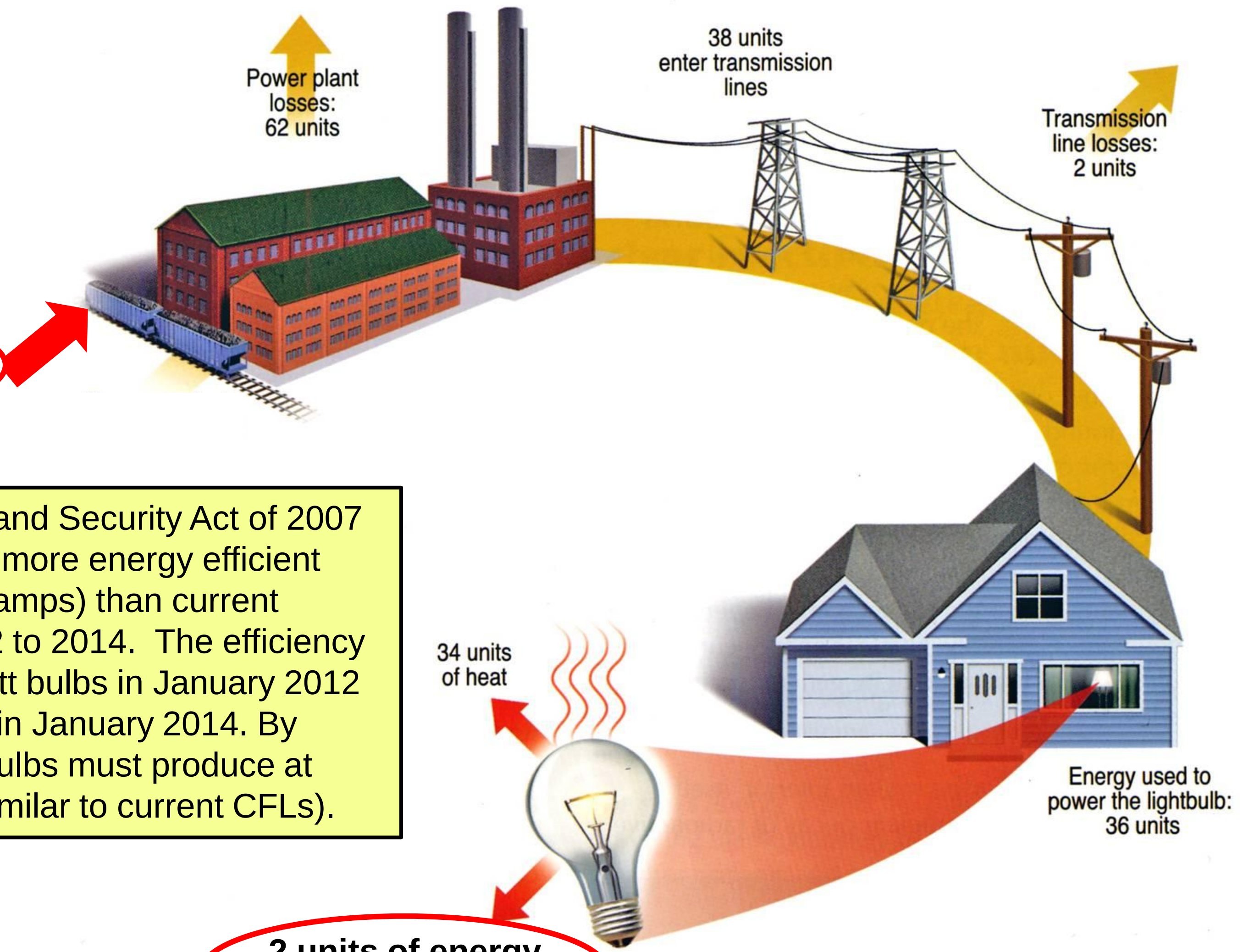

In 1950:

- U.S. population ~ ½ that in 2010
- Total primary energy = 34 Quads
- Little or no imported petroleum
- Primary energy (petroleum only) used for transportation = 6.8 Quads
- Primary energy used for electricity generation = 4 Quads
- “Used” and “Wasted” about equal

*Source: Lawrence Livermo... ...ation Administration, 2009 (based on data from DOE/EIA-0384(2008),*

# Overall Efficiency of an Incandescent Bulb ≅ 2%

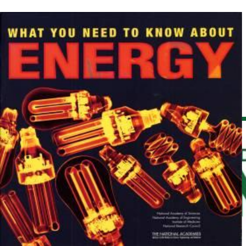
*Lighting accounts for 22% of all electricity usage in the U.S.*




**Energy content of coal: 100 units**

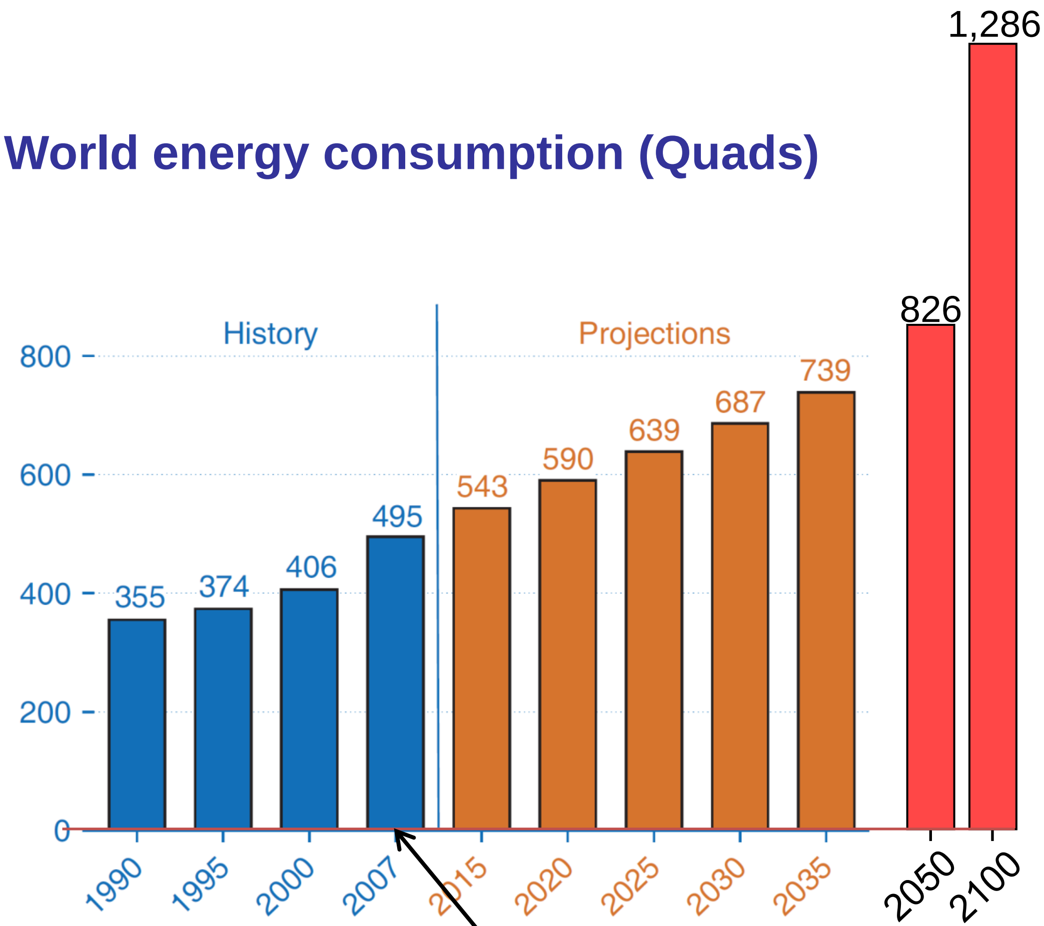
**2 units of energy in light output**

The Energy Independence and Security Act of 2007 requires light bulbs be 30% more energy efficient (similar to current halogen lamps) than current incandescent bulbs by 2012 to 2014. The efficiency standards start with 100-watt bulbs in January 2012 and end with 40-watt bulbs in January 2014. By 2020, all general-purpose bulbs must produce at least 45 lumens per watt (similar to current CFLs).



# World Energy Needs will Grow in the 21st Century

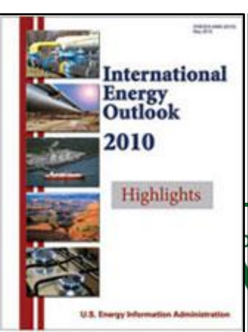
## World energy consumption (Quads)

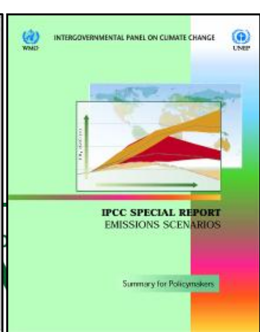



Projections to 2035 are from the Energy Information Administration, International Energy Outlook, 2010.

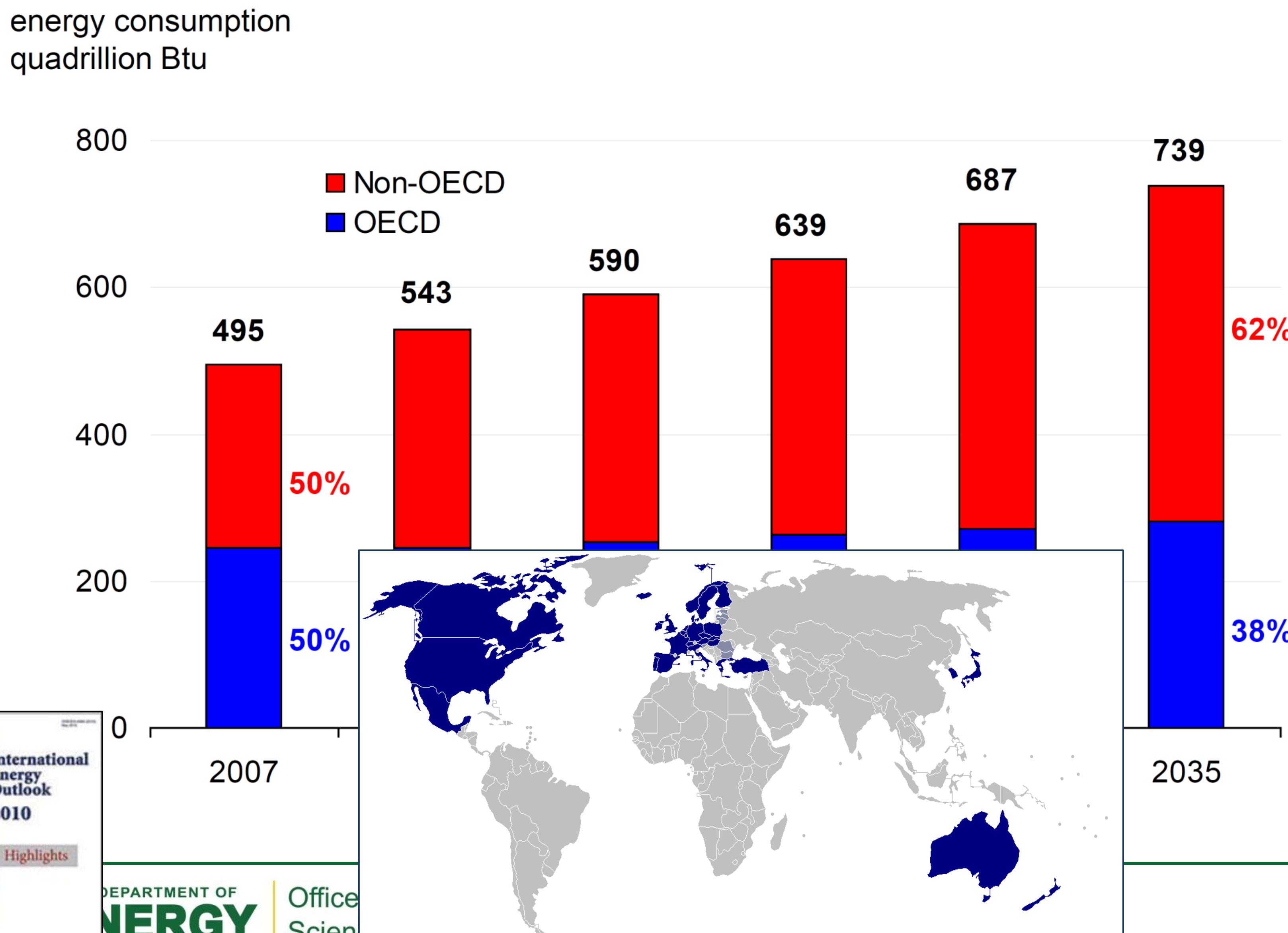
Projections for 2050 and 2100 are based on a scenario from the Intergovernmental Panel on Climate Change (IPCC). The IPCC provides comprehensive assessments of information relevant to human-induced climate change. The scenario chosen is based on "moderate" assumptions (Scenario B2) for population and economic growth.

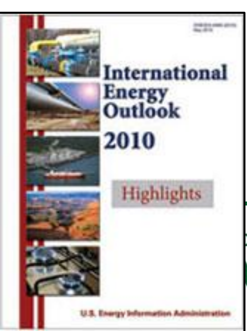
**U.S. consumption ~100 Quads**



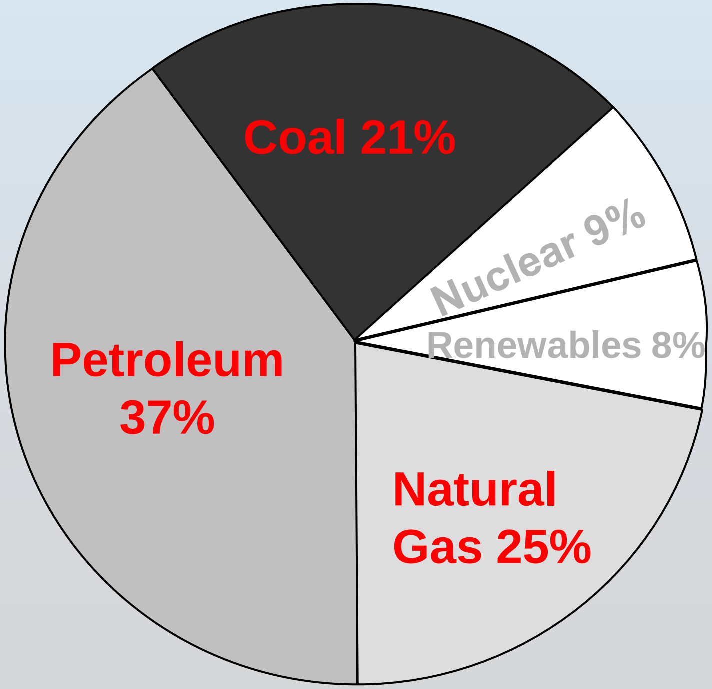



# Non-OECD Countries Account for 86% of the Increase in Global Energy use

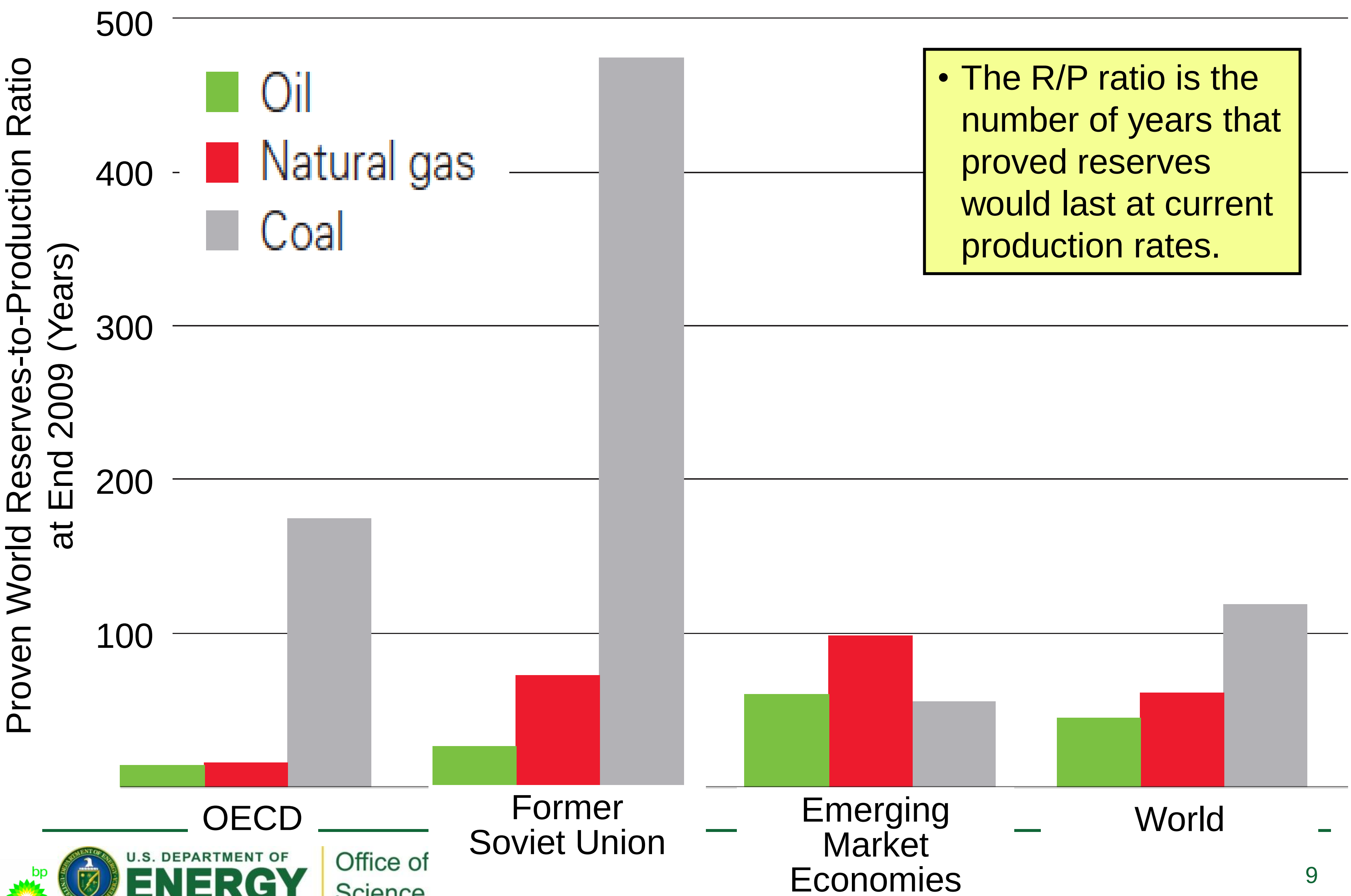


# Energy Supply: Fossil Fuels



# Fossil Fuel Supplies are Estimated using Reserves-to-Production (R/P) Ratios




- The R/P ratio is the number of years that proved reserves would last at current production rates.

bp

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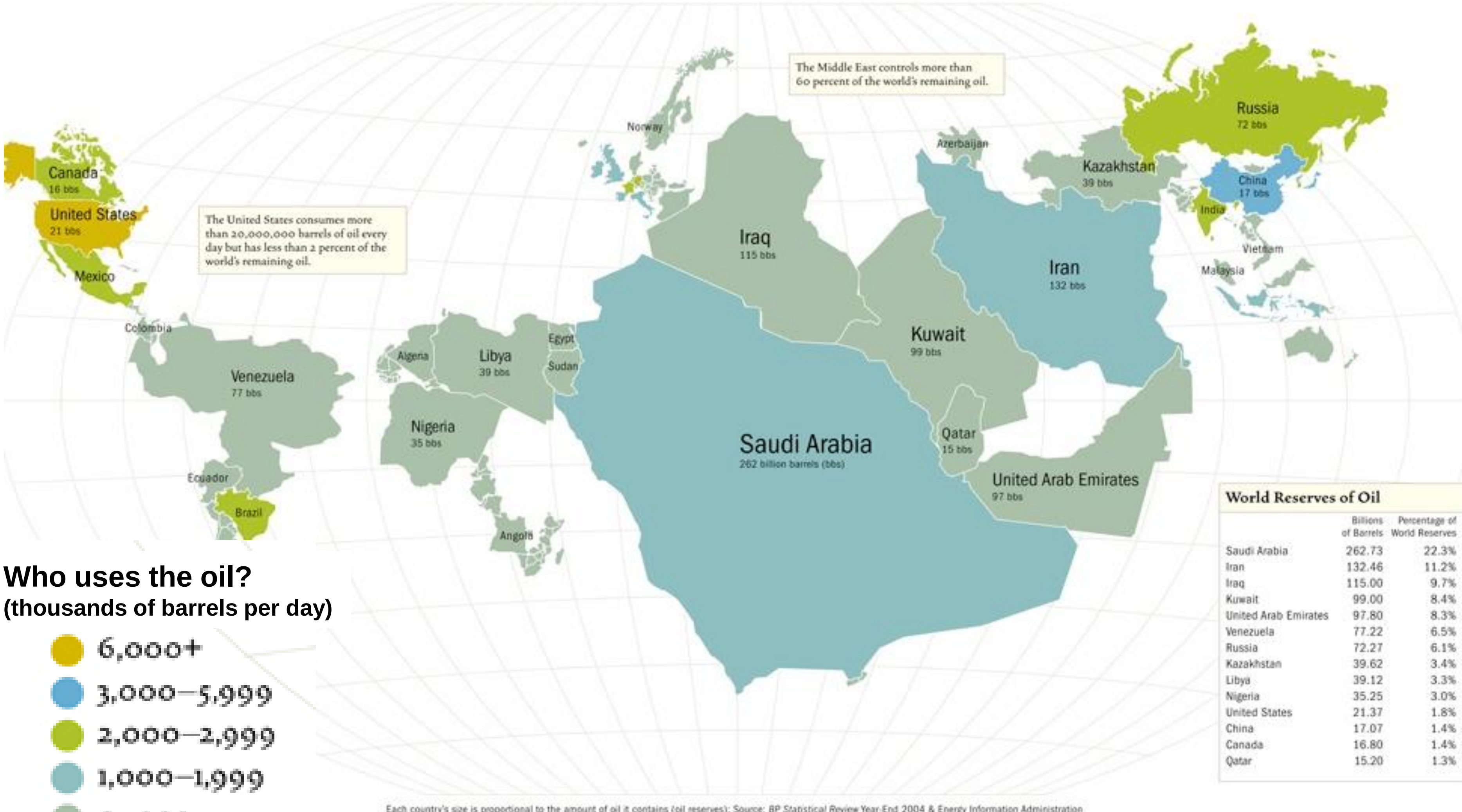
# World Reserves of Oil

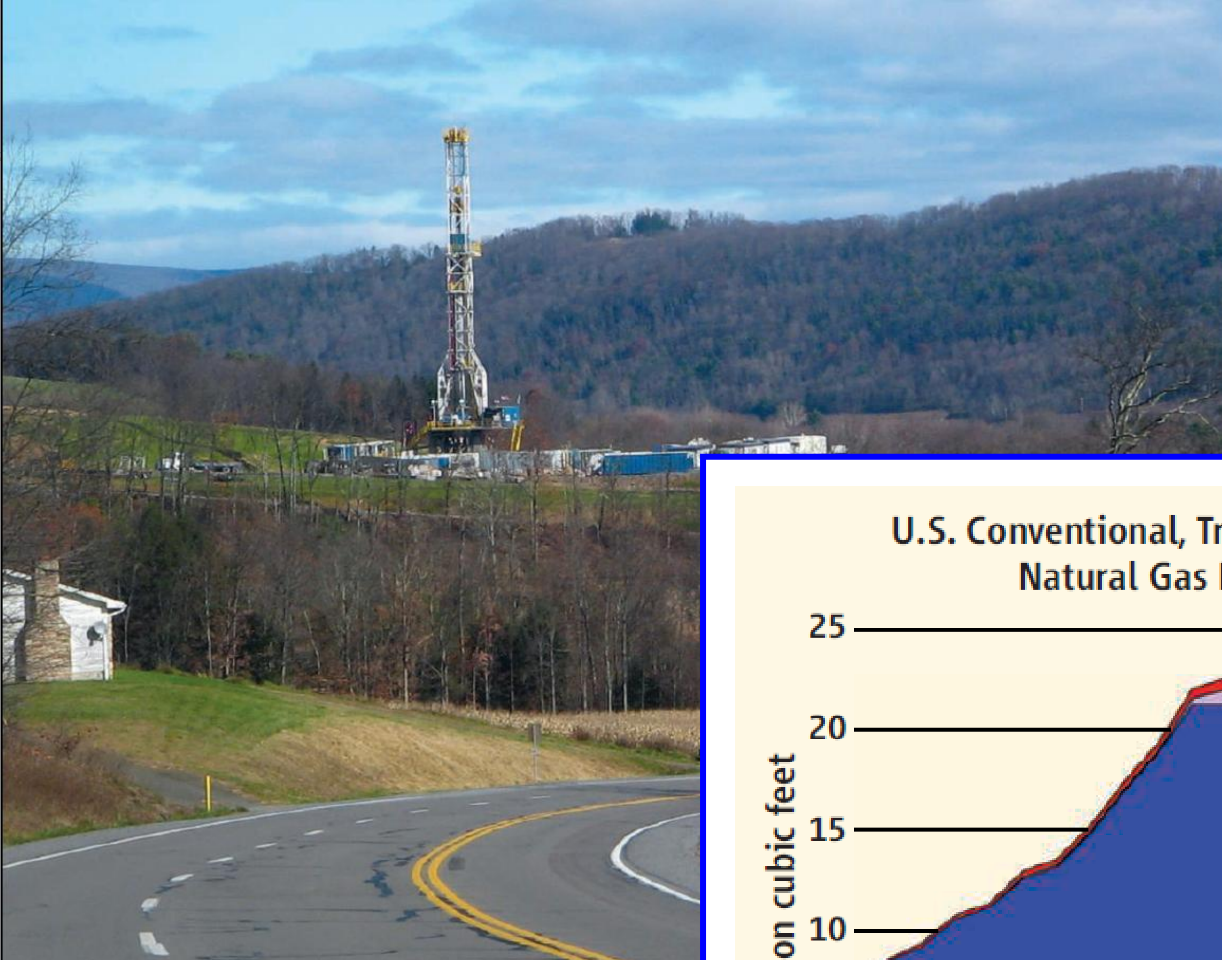
*There is a significant dislocation between fossil fuel supply and demand*




**World Reserves of Oil**

| | Billions of Barrels | Percentage of World Reserves |
|---|---|---|
| Saudi Arabia | 262.73 | 22.3% |
| Iran | 132.46 | 11.2% |
| Iraq | 115.00 | 9.7% |
| Kuwait | 99.00 | 8.4% |
| United Arab Emirates | 97.80 | 8.3% |
| Venezuela | 77.22 | 6.5% |
| Russia | 72.27 | 6.1% |
| Kazakhstan | 39.62 | 3.4% |
| Libya | 39.12 | 3.3% |
| Nigeria | 35.25 | 3.0% |
| United States | 21.37 | 1.8% |
| China | 17.07 | 1.4% |
| Canada | 16.80 | 1.4% |
| Qatar | 15.20 | 1.3% |

**(http://www.energybulletin.net/37329.html)**



**Different roads to gas.** Gas from deep shale can turn up beneath both rural and urban landscapes.

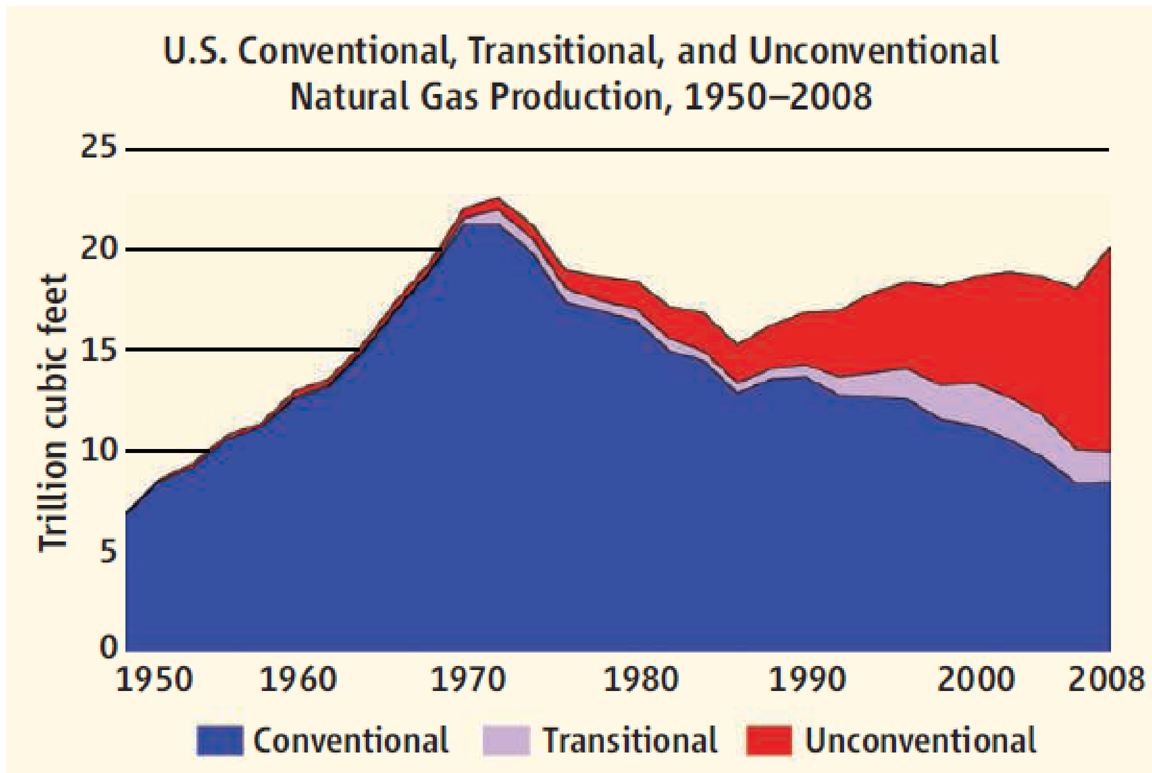
in the Northeast could hobble the revolution (see sidebar, p. 1625).

### How to unleash the gas

The newly applied technology of shale gas extraction is letting drillers go straight to the source. Conventional deposits of oil and gas are actually the final resting places of far-traveled hydrocarbons that were gener-

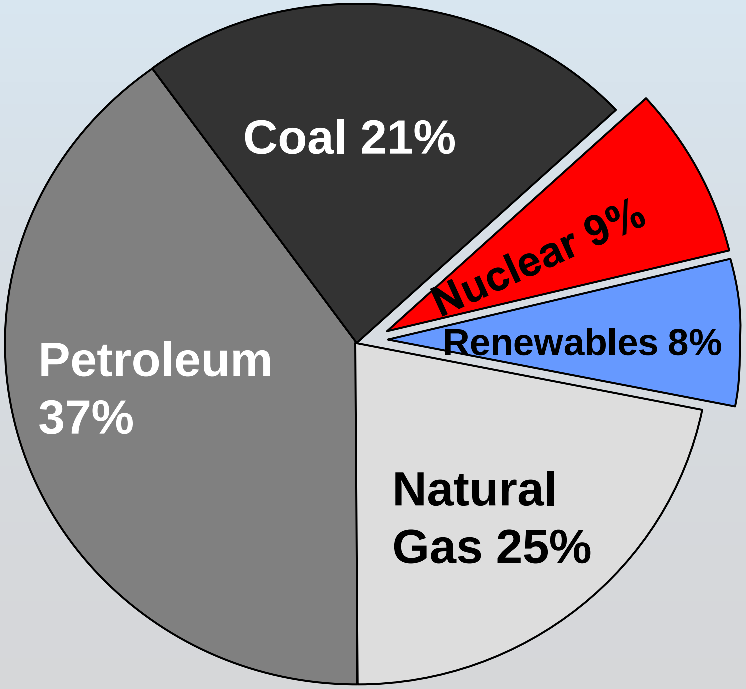
# Natural Gas
# Bursts Onto t

**New technologies have sparked a rus**
**but environmental concerns and eco**
**shale gas from becoming a bridge to**



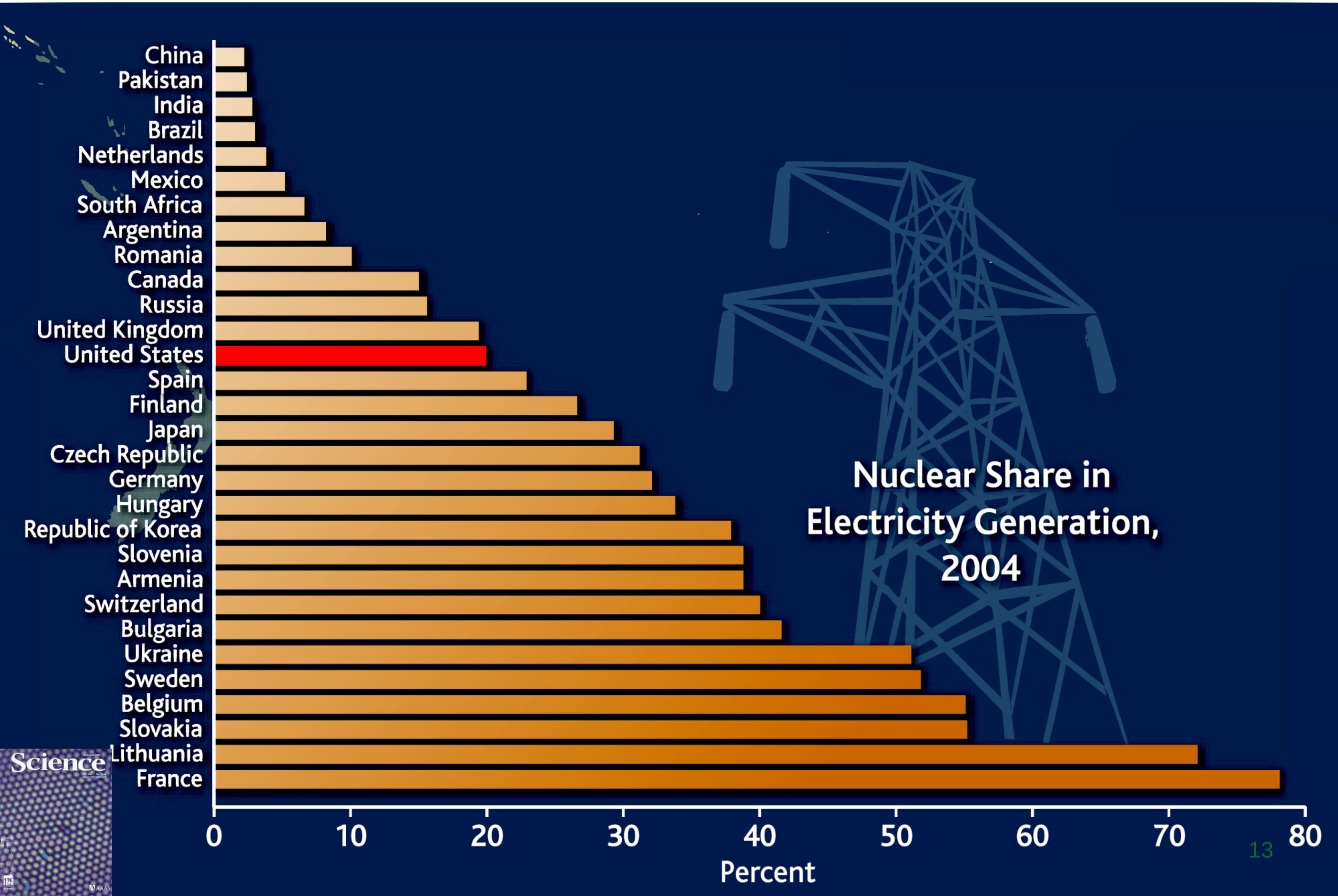

**Gas comeback.** Unconventional gas (red) has been more than replacing declining conventional gas (blue).

# Energy Supply: Nuclear and renewable



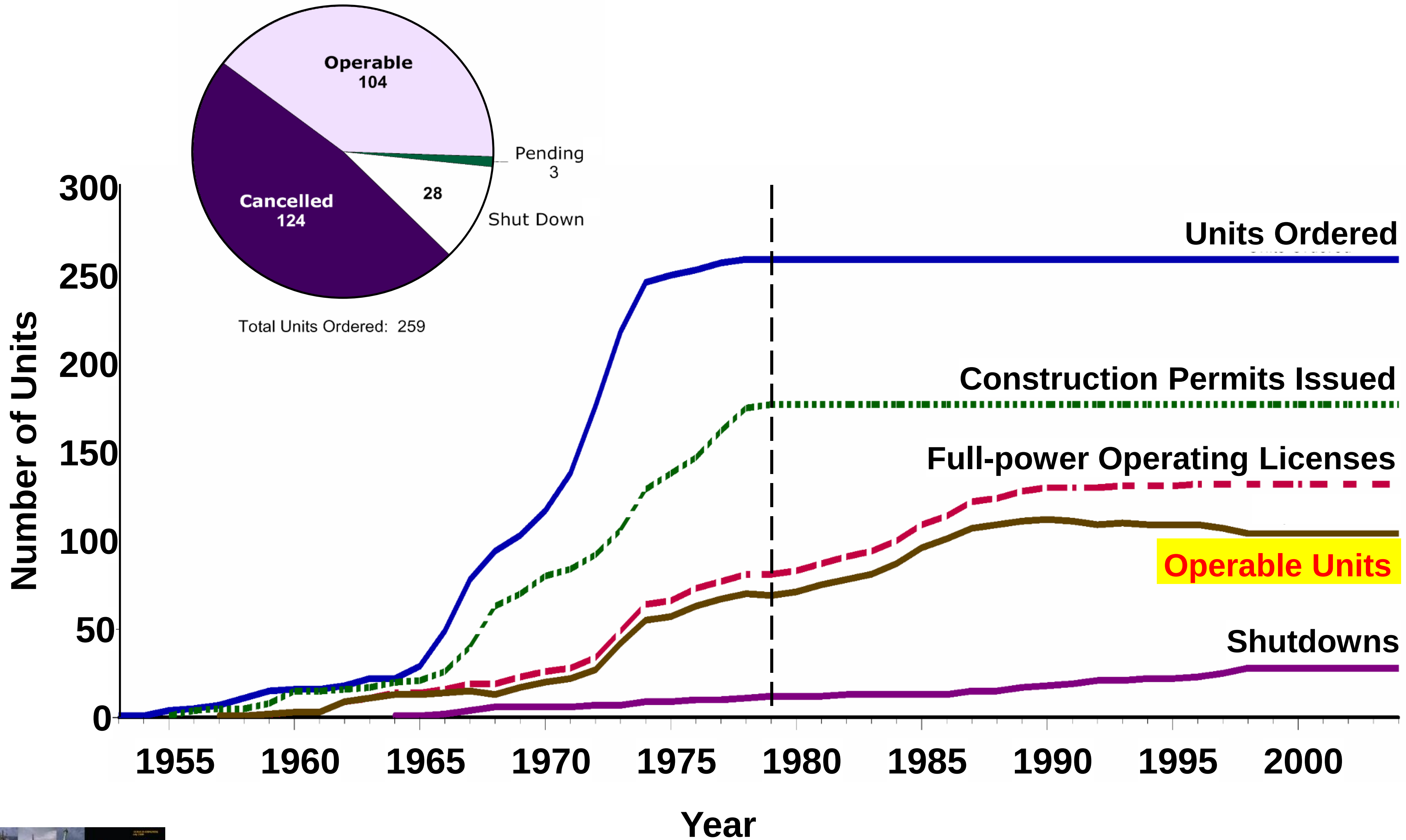
# Nuclear Energy Provides 20% of U.S. Electricity

*Europe and Japan rely much more heavily on nuclear energy for electricity generation*



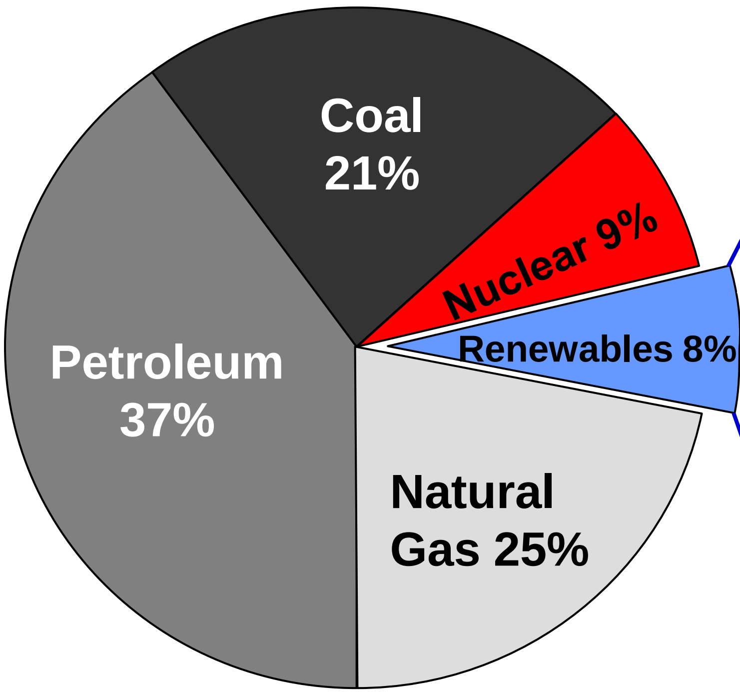
# Permits for U.S. Reactors Issued Only Until 1979

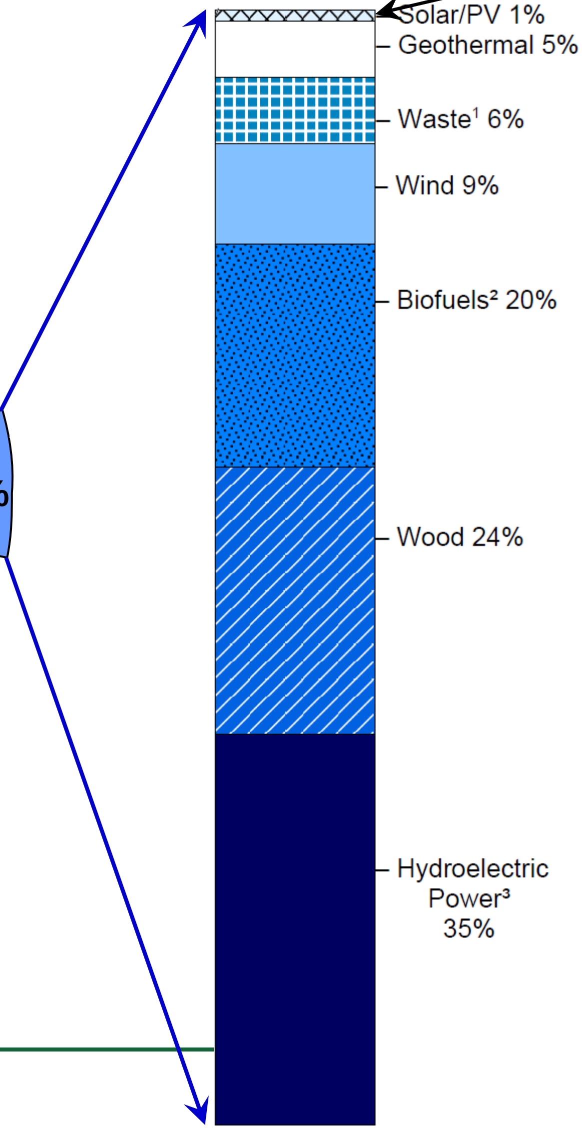
*8.4 quads of nuclear energy produced by 104 operable nuclear power plants*

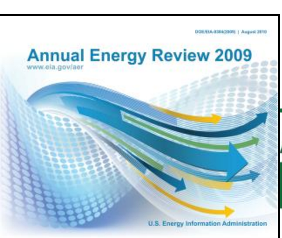


# Nuclear and Renewable are ~15% of Energy Supply

*Hydroelectric and wood still dominate the renewable energies*

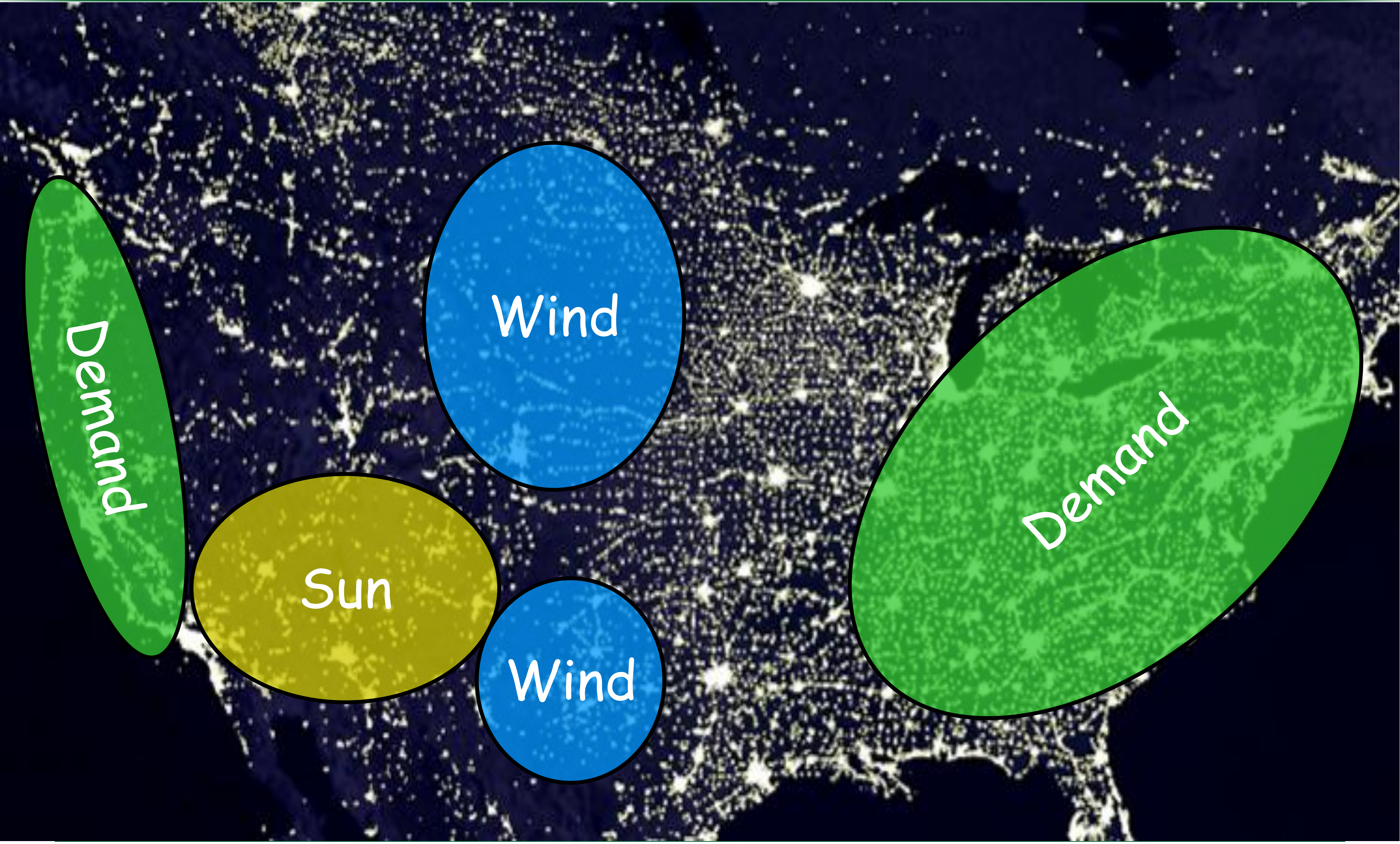


# Generation and Use of Wind and Solar Energy

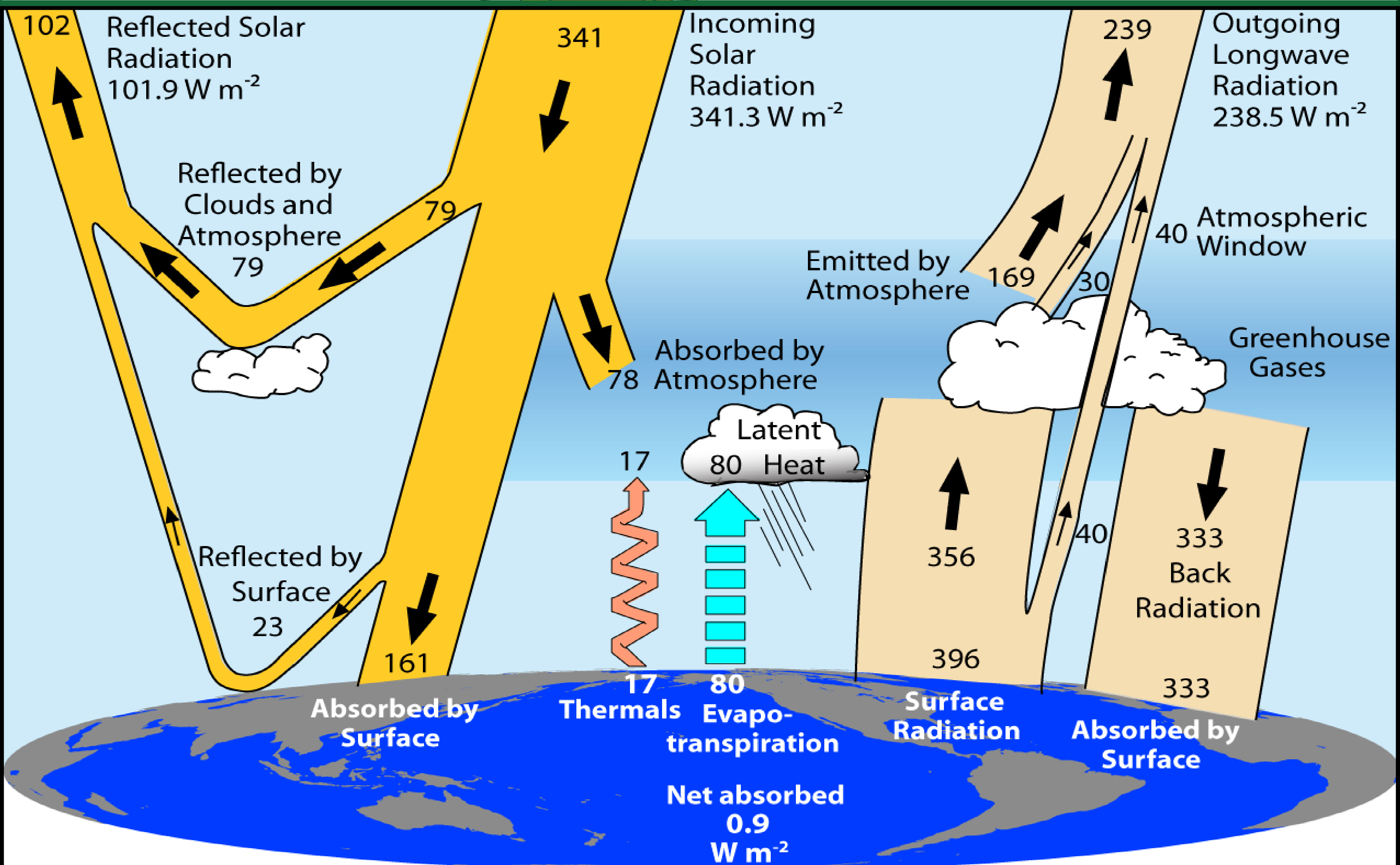
*The separation between renewable sources and demand centers requires new long distance transmission lines.*




http://visibleearth.nasa.gov/view_rec.php?id=1438l
Chart adapted from the American Physical Society report, Integrating Renewable Energy on the Grid

# Energy and the environment

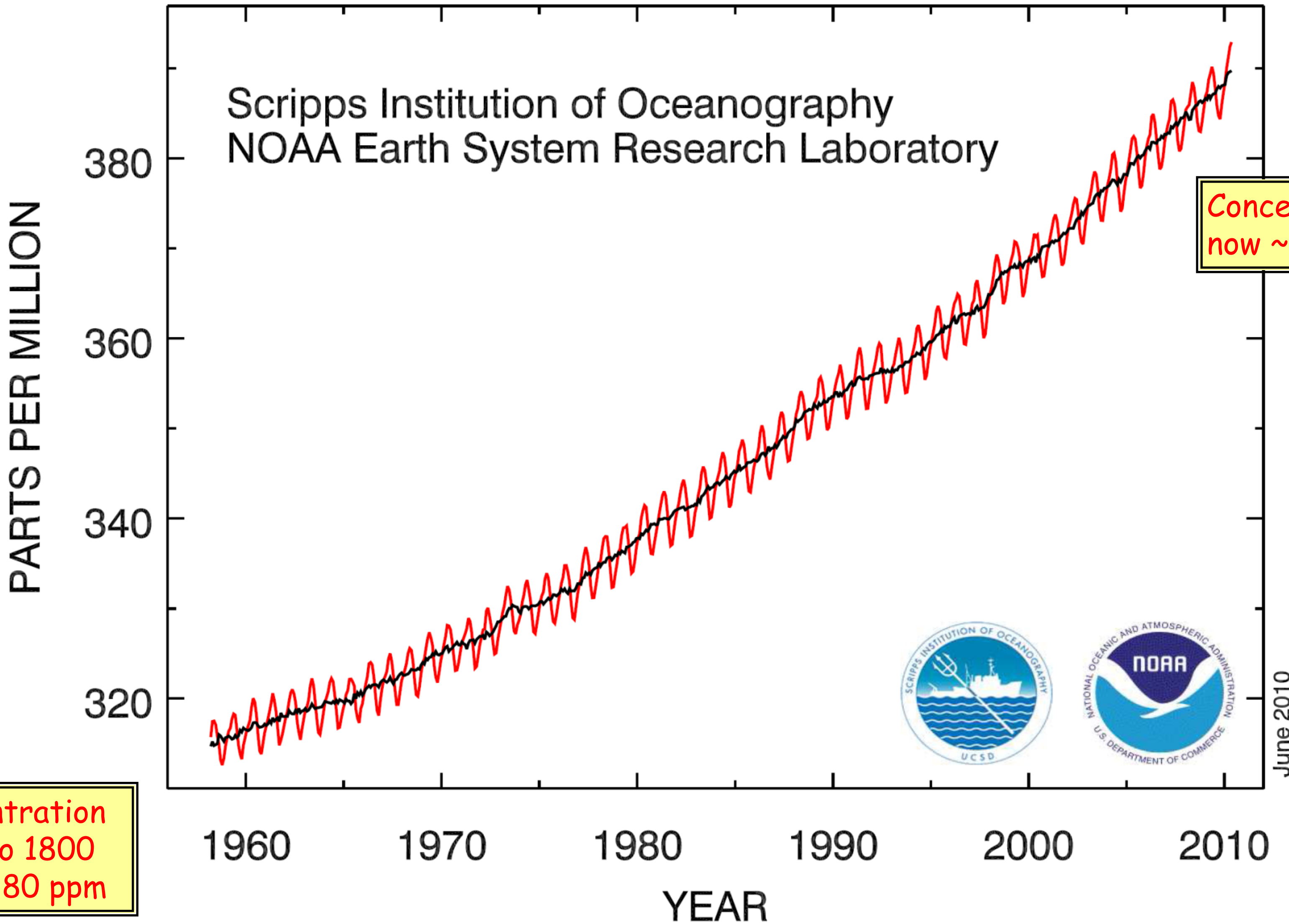
# Greenhouse Effect




Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse gases that are not naturally occurring include hydro-fluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$), which are generated in a variety of industrial processes.

# Modern $CO_2$ Concentrations are Increasing

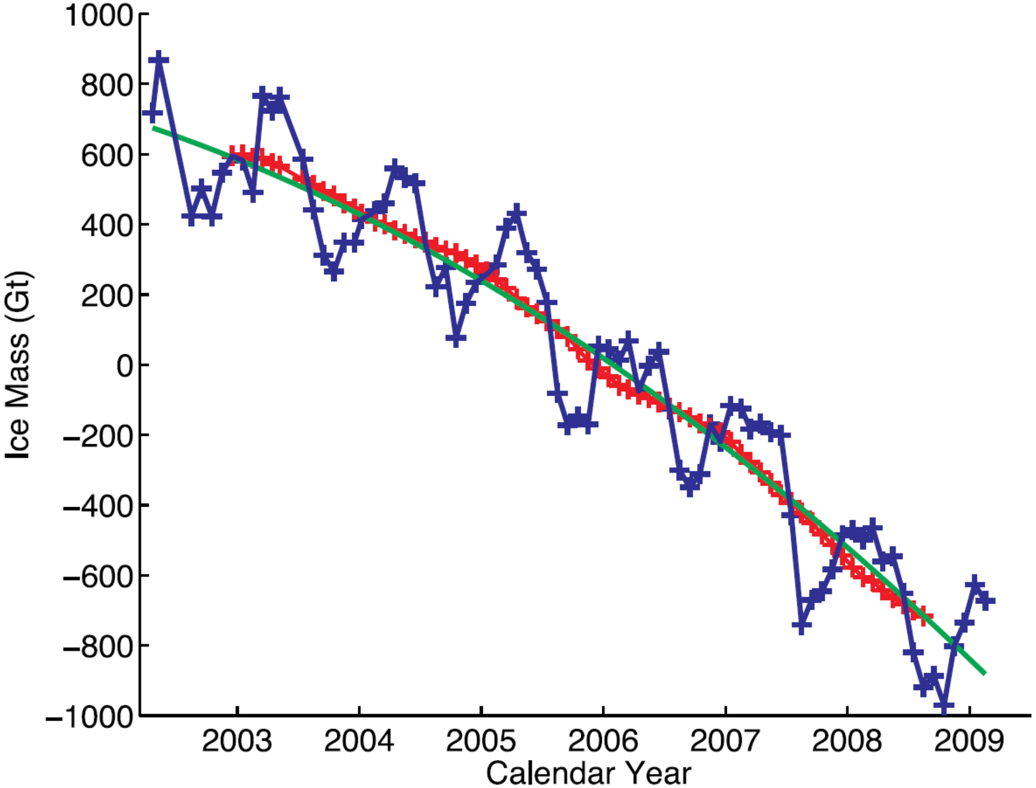
*The current concentration is the highest in 800,000 years, as determined by ice core data*




Concentration now ~390 ppm

Concentration prior to 1800 was ~280 ppm

# Greenland Ice Mass Loss – 2002 to 2009



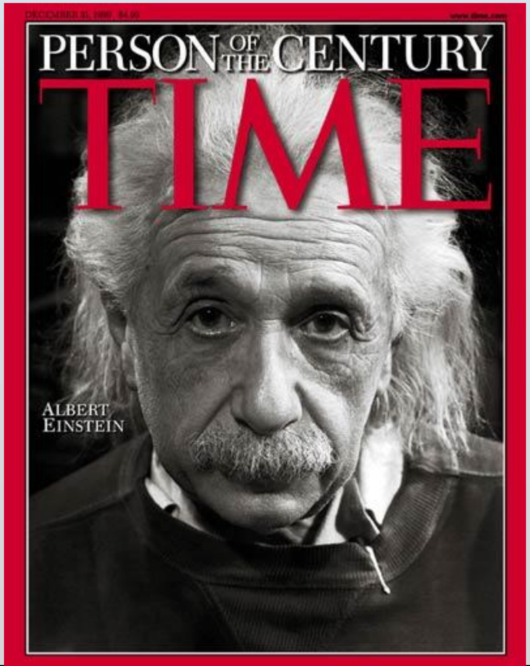

Time series of ice mass changes for the Greenland ice sheet estimated from GRACE monthly mass solutions for the period from April 2002 to February 2009. Unfiltered data are blue crosses. Data filtered for the seasonal dependence using a 13-month window are shown as red crosses. The best-fitting quadratic trend is shown (green line). The GRACE data have been corrected for leakage and GIA.

Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE (Gravity Recovery and Climate Experiment) satellite

- In Greenland, the mass loss increased from 137 Gt/yr in 2002–2003 to 286 Gt/yr in 2007–2009
- In Antarctica, the mass loss increased from 104 Gt/yr in 2002–2006 to 246 Gt/yr in 2006–2009

I. Velicogna, GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L19503, doi:10.1029/2009GL040222, 2009

# Transformational change – the role of basic research and innovation



U.S. DEPARTMENT OF **ENERGY**

~ $25.6 B

**Secretary**
Steven Chu

**Deputy Secretary**
Daniel B. Poneman

**Advanced Research Projects Agency – Energy**
Arun Majumdar
~ $180 M

**Under Secretary for Nuclear Security/Administrator for National Nuclear Security Administration**
Thomas P. D'Agostino

- Defense Nuclear Nonproliferation
- Defense Programs
- Naval Reactors
- Counter-terrorism
- Defense Nuclear Security
- Emergency Operations

**Under Secretary for Science**
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**Office of Science**
William Brinkman
Patricia Dehmer
~ $4.8 B

- Basic Energy Sciences – Harriet Kung
- High Energy Physics – Mike Procario (A)
- Advanced Scientific Computing Research – Dan Hitchcock (A)
- Nuclear Physics – Tim Hallman
- Biological & Environmental Research – Sharlene Weatherwax
- Fusion Energy Sciences – Ed Synakowski
- SBIR/STTR – Manny Oliver
- Workforce Develop. for Teachers & Scientists – Pat Dehmer (A)

**Under Secretary**
Arun Majumdar (A)

- Energy Efficiency & Renewable Energy – Henry Kelly (A) – ~ $1.8 B
- Fossil Energy – Vacant – ~ $445 M
- Nuclear Energy – Pete Lyons – ~ $730 M
- Electricity Delivery & Energy Reliability – Pat Hoffman – ~ $150 M

# DOE Leadership


LEARNING THE ROPES Secretary of Energy Steven Chu at his office in Washington, D.C. A Silicon Valley physicist, Chu is a newcomer to the capital.

## THE SECRETARY OF SAVING THE PLANET

Steven Chu has a Nobel Prize in physics and a mandate to stop global warming. But can Obama's energy visionary win the battle against Big Coal?

By Jeff Goodell

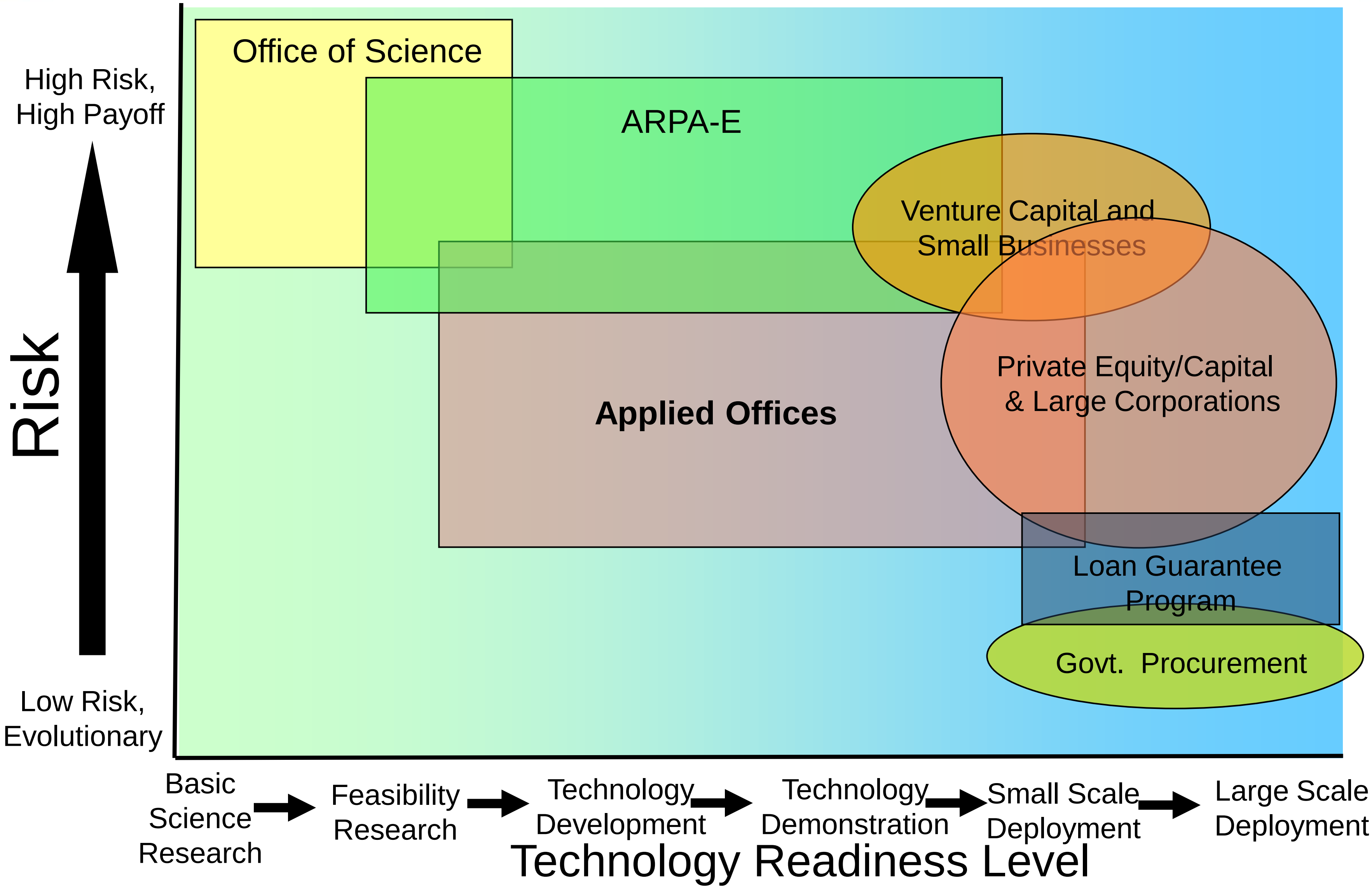
WHEN STEVEN CHU, PRESIDENT OBAMA'S PICK FOR SECretary of energy, was confirmed in January, the rap on him was that he's a brilliant scientist who doesn't know politics. "Washington is going to eat him alive," one congressional staffer told me. Chu is the first member of any presidential Cabinet to have won a Nobel Prize. But at this moment in history, should he prove less adept at the physics of congressional appropriations than he is at quantum mechanics, the entire planet could be in big trouble. Chu is not only one of the president's most trusted advisers on global warming – by far the most pressing issue facing human civilization – he is also responsible for doling out $38 billion from Obama's stimulus bill and creating a new economy founded on green energy. In the early days after his confirmation,

Photograph by Charles Ommanney

88 • Rolling Stone, June 25, 2009

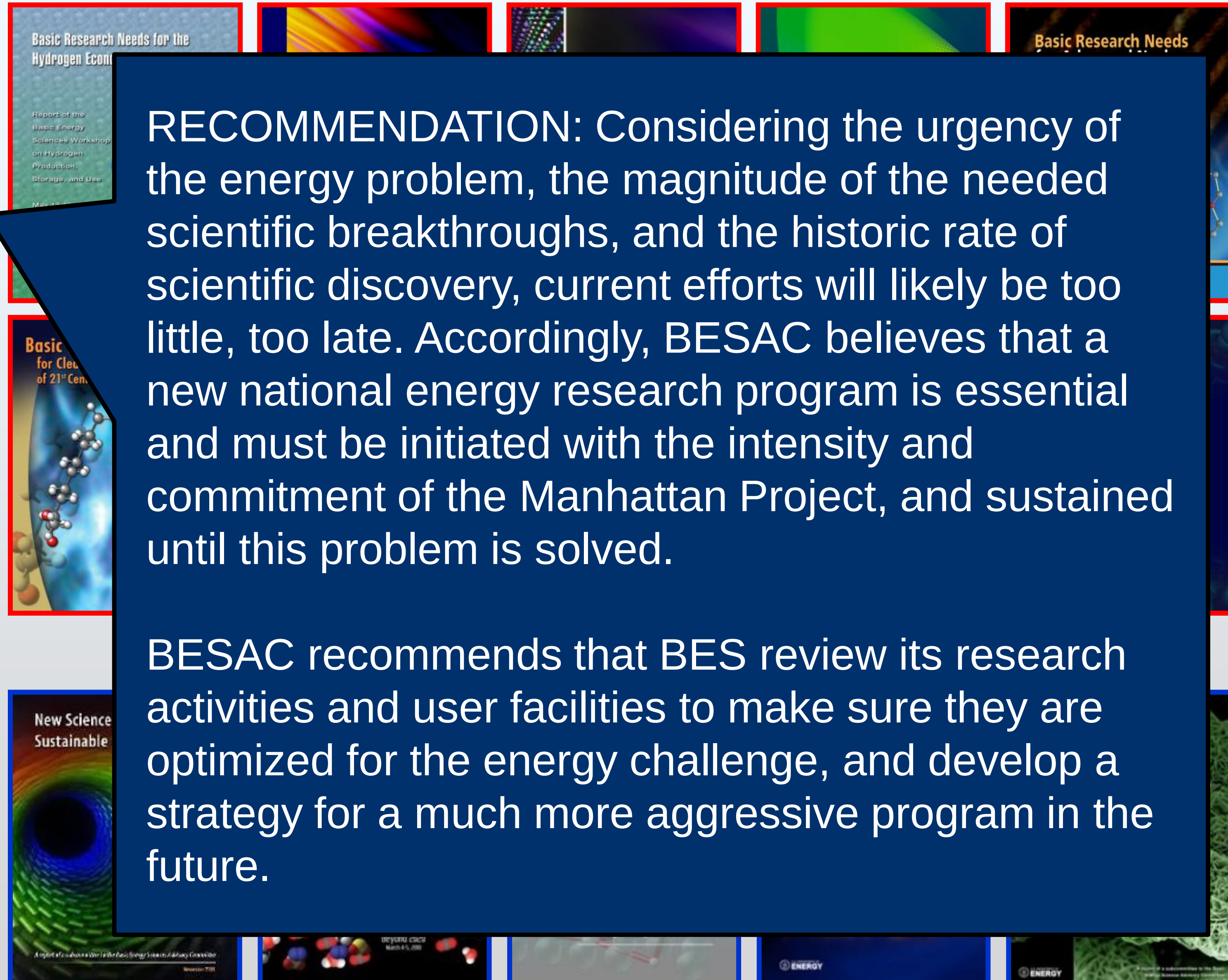
Rolling Stone, June 25, 2009 • 89

# Energy Innovation Profile



# "Basic Research Needs" and Beyond


**John Stringer**
**Linda Horton**



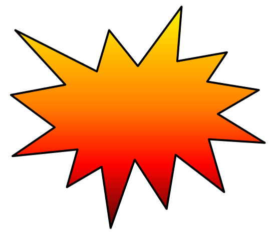

RECOMMENDATION: Considering the urgency of the energy problem, the magnitude of the needed scientific breakthroughs, and the historic rate of scientific discovery, current efforts will likely be too little, too late. Accordingly, BESAC believes that a new national energy research program is essential and must be initiated with the intensity and commitment of the Manhattan Project, and sustained until this problem is solved.

BESAC recommends that BES review its research activities and user facilities to make sure they are optimized for the energy challenge, and develop a strategy for a much more aggressive program in the future.

# Sustainable Energy = High Tech Materials and Chemistry

## Today

combustion

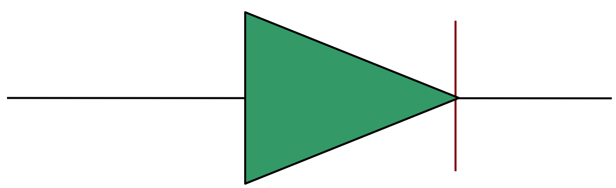
**Gas** $CH_4$
**Oil** $CH_2$
**Coal** $CH_{0.8}$ →  → **heat** → **useful work**

**commodity materials**
**disposable fuels**

## Future

direct conversion

**Sunlight**
**Wind**
**Water**
**Geothermal**
**Biomass**
**+**
**Storage**
**Transmission**
**CCS**
**Efficiency**



**electricity fuels** → **useful work**

**High-tech materials and chemistry, e.g., for photovoltaics, electrodes and electrolytes, smart membranes and separators, superconductors, catalysts, sensors and novel piezoelectrics and piezotronics**

# BES Research — Science for Discovery & National Needs

## Three Major Types of Funding Modality

increasing progression of scientific scope and level of effort

- **Core Research**

  Support single investigator and small group projects to pursue their specific research interests.

  - Enable seminal advances in the core disciplines of the basic energy sciences—materials sciences and engineering, chemistry, and aspects of geosciences and biosciences. Scientific discoveries at the frontiers of these disciplines establish the knowledge foundation to spur future innovations and inventions.

- **Energy Frontier Research Centers**

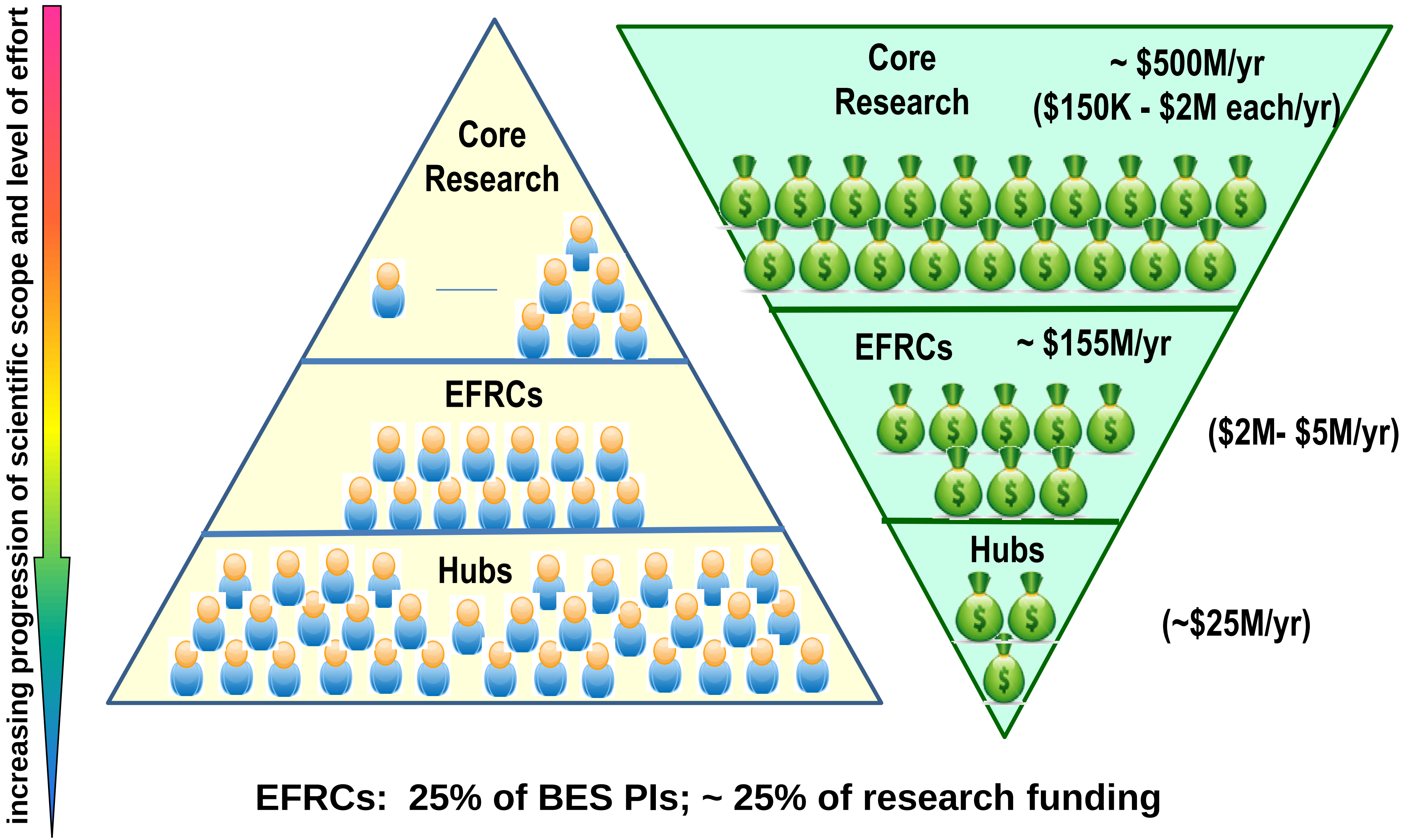
  $2-5 million-per-year research centers, established in 2009, focused on fundamental research related to energy

  - Multi-investigator and multi-disciplinary centers to harness the most basic and advanced discovery research in a concerted effort to accelerate the scientific breakthroughs needed to create advanced energy technologies. Bring together critical masses of researchers to conduct fundamental energy research in a new era of grand challenge science and use-inspired energy research.

- **Energy Innovation Hubs**

  $25 million-per-year research centers will focus on co-locating and integrating multi-components, multi-disciplinary research with technology development to enable transformational energy applications

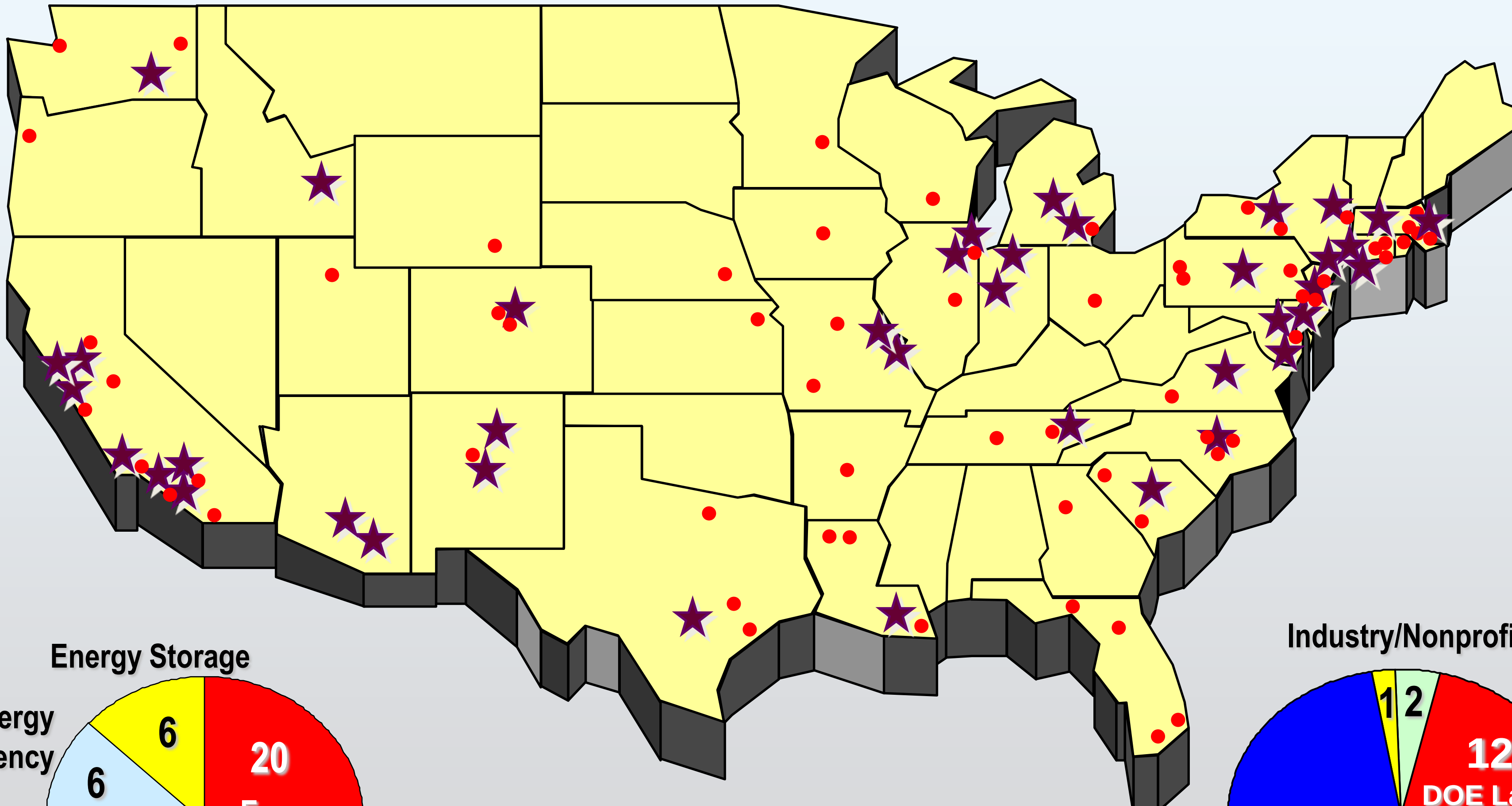
# BES Research — Science for Discovery & National Needs
## Follow the $$ and People

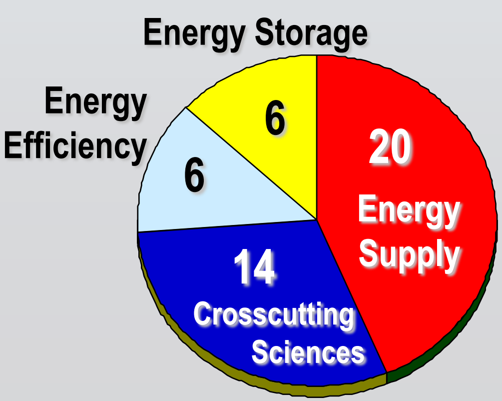



**EFRCs: 25% of BES PIs; ~ 25% of research funding**

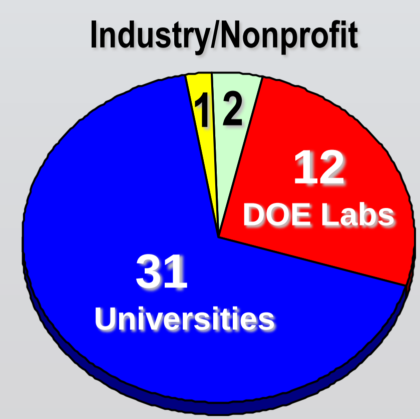
# 46 Energy Frontier Research Centers

**( ★ Leads; • Participants)**





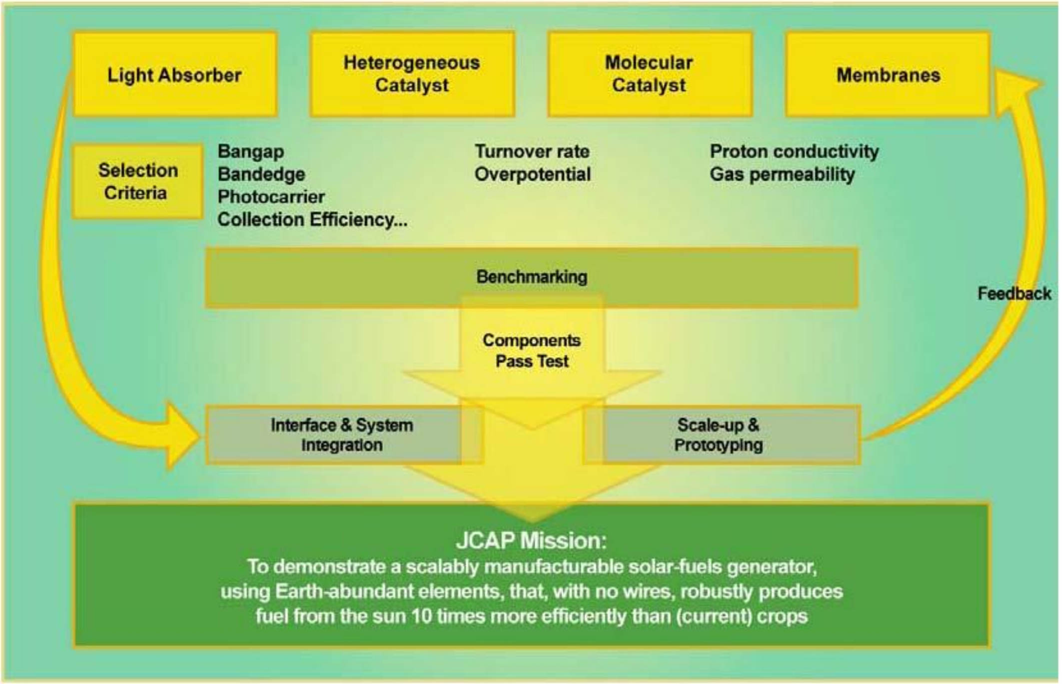

By Topical Category

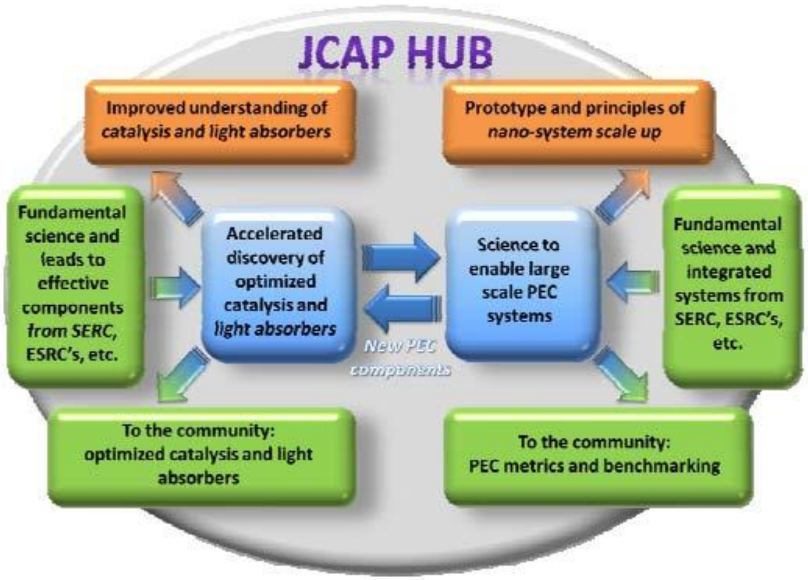



By Lead Institution

# Energy Innovation Hub:
## Fuels from Sunlight

JCAP
JOINT CENTER FOR ARTIFICIAL PHOTOSYNTHESIS




### JCAP R&D will focus on:

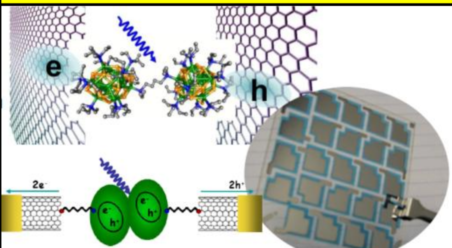
- ➢ Robustness of components
- ➢ Accelerating the rate of catalyst discovery for solar fuel reactions
- ➢ Discovering earth-abundant, robust, inorganic light absorbers with optimal band gap
- ➢ System integration, benchmarking, and scale-up

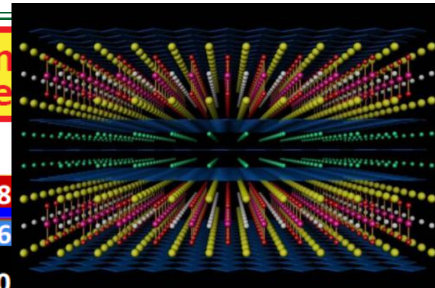
### JCAP's role as a solar fuels Hub:

- ➢ Incorporating the latest discoveries from the community (EFRCs, single-PI or small-group research)
- ➢ Providing metrics and benchmarking to the community

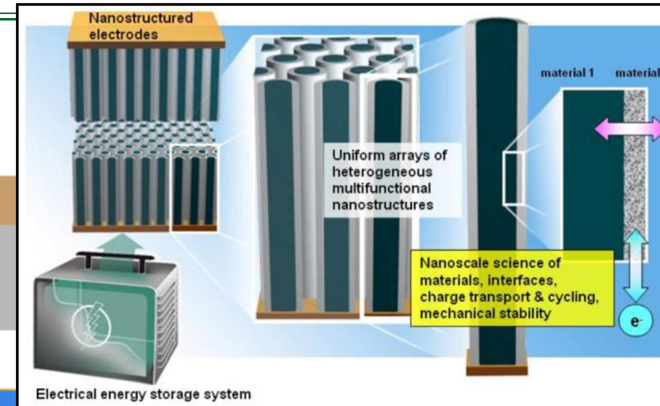
# A National Research Strategy for a New Energy Economy

**Nanostructured thin-film organic photovoltaic devices**

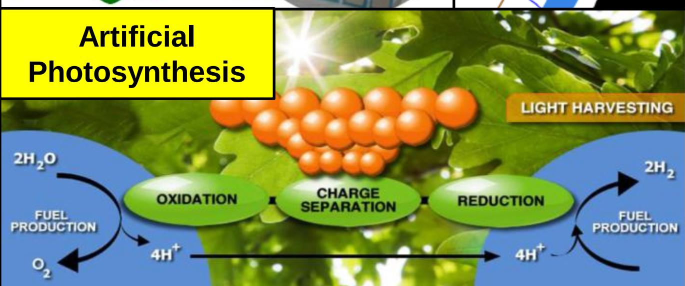


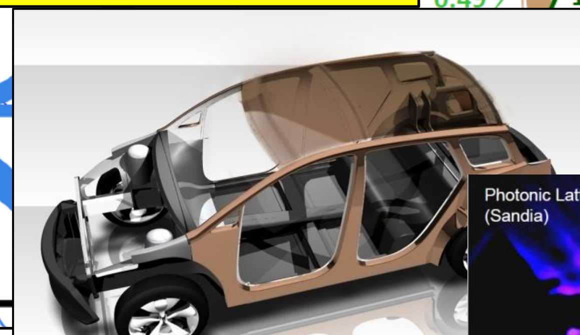



**High-Tc and high current superconductors for grid and other electrical applications**



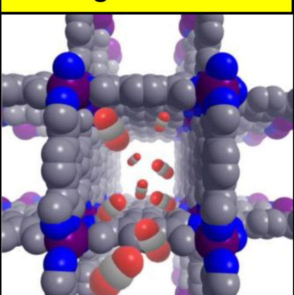

**Artificial Photosynthesis**

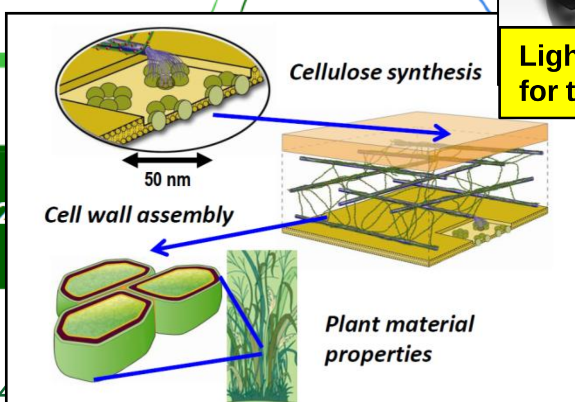


**Lightweight structural materials for transportation**

**Capture or separation of $CO_2$ from gas mixtures**






**Structure of lignocellulose at the nanoscale and the rules by which plants create this material**


**Conversion of electricity to light using new designs, such as luminescent nanowires, quantum dots, and hybrid architectures;**

*Source: Lawrence ... from DOE/EIA-038... ...tment of Energy, Energy Infor...*

U.S. DEPART... ENE...


END