Sustainability

- Definition: Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs - United Nations

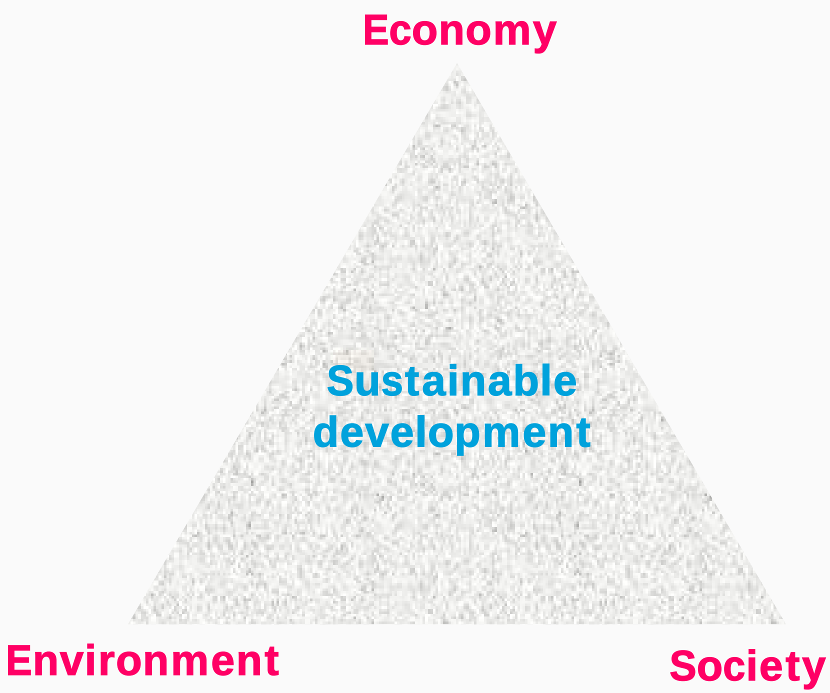
- Sustainable energy: a dynamic harmony between the equitable availability of energy-intensive goods and services to all people and preservation of the earth for future generation – It is the engine of the sustainable development (Tester, et. al.)

References

- "What You Need to Know About Energy," Board on Energy & Environmental Systems, National Research Council, 2008, http://www.nap.edu/catalog/12204.html
- "Lighting the Way: Toward a Sustainable Energy Future," by Dr. Steven Chu,
- "Basic Science for America's Energy Future," by Dr. Raumond Orbach,

  - Both presented at the National Academies Summit on America's Energy Future, March 2008 http://sites.nationalacademies.org/Energy/Energy_043332
- "Plan B 3.0, Mobilizing to Save Civilization" by Lester Brown, Earth Policy Institute, 2009, http://www.earth-policy.org/Books/PB3/index.htm
- Dr. Krothapalli's lecture notes

Energy and Sustainability



Energy has strong relationship with three pillars of sustainable development.

Sustainability requires secure, reliable and affordable supply of energy.

Sustainable energy future is not static - it must be continuously redefined and rebalanced with new technical solutions and technologies.

Sustainability demands that we seek to change present trends.

Change the structure of energy sector, behavior in our societies and economics

Challenge: *To fuel worldwide economic growth with secure and reliable energy supply without despoiling our environment*

Source: IEA statement on sustainable development at the world summit on sustainable development, Johannesburg, 2002

General Indicators of Sustainability

Chapter 6.4.1 from Tester et. al.

- Environmental
  - Government and institutional commitment; water resources (population accessible to clean water); biodiversity; energy use (GDP/energy use, CO_2 emission per capita, etc..)
- Economic
  - Total per capita GDP; Gross National Product (GNP); national debt, employment rates; investment rates; stock market indices, etc..
- Social
  - Poverty (income inequality); education (primary enrollment and graduation rate, literacy rate, etc..); health (infant mortality, life span, health care system, etc..)

$$S_I = \left[(P)\times(GDP/P)\times(E/GDP)\right]\sum_{i=1}^{N} W_i(t)\left[A_i(E)/E\right] \quad (1-25, Tester et.al.)$$

P: population, E: energy consumption, $A_i(E)$: i_{th} impact related to energy (pollution, water consumption, climate factor, etc..), $W_i(t)$ weighting factor to i_{th} impact

Lighting the Way: Toward a Sustainable Energy Future

The National Academies Summit on
America's Energy Future
Washington, DC
14 March, 2008

InterAcademy Council

About the IAC |

InterAcademy Council (IAC) was created to produce reports on global scientific, technological, and health challenges.

An 18-member Board includes presidents of 15 academies of science:

Brazil, Chile, China, France, Germany, Hungary, India, Iran, Japan, Malaysia, Turkey, the United Kingdom, the United States, the African Academy of Sciences, the Academy of Sciences for the Developing World (TWAS) and representatives of the InterAcademy Panel (IAP) of the world's scientific, engineering and medical academies.

“Lighting the Way: Toward a Sustainable Energy Future”

Co-Chairs:

Steven Chu (USA)

José Goldemberg (Brazil) *

Panel Members (13):

Shem Arungu Olende (Kenya)

Ged Davis (UK) *

David Keith (Canada)

Nebosja Nakicenovic (Austria)

Majid Shafie-Pour (Iran)

Robert Socolow (USA)

Yan Luguang (China)

Mohamed El-Ashry (Egypt)

Thomas Johansson (Sweden)

Li Jinghai (China)

Rajendra Pachauri (India)

Evald Shpilrain (Russia)

Kenji Yamaji (Japan)

Conclusions and Recommendations

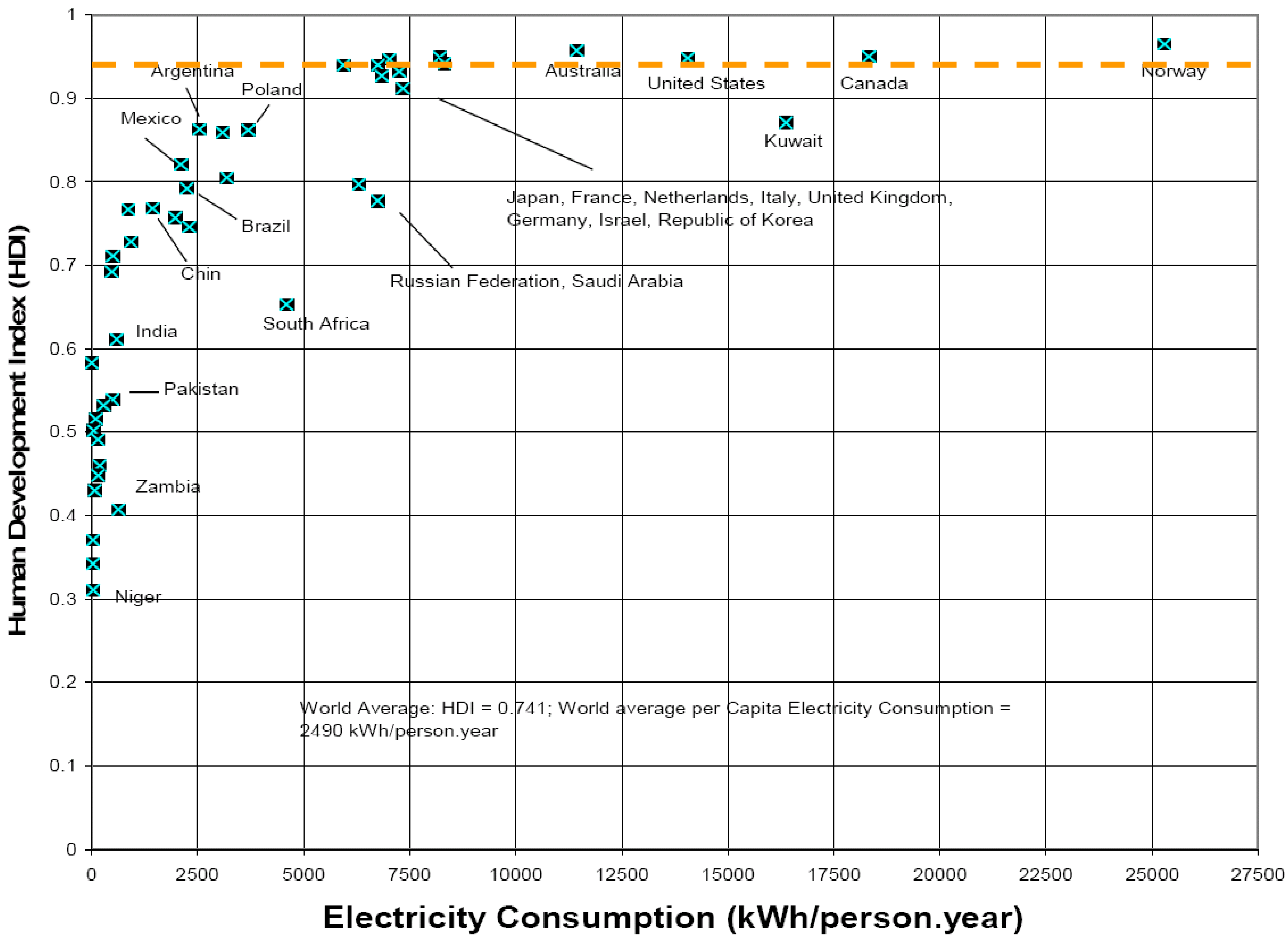
1. Meeting the basic energy needs of the poorest people on this planet is a moral and social imperative that must be pursued in concert with sustainability objectives.

2 - 3 billion people worldwide currently lack access to modern forms of energy:

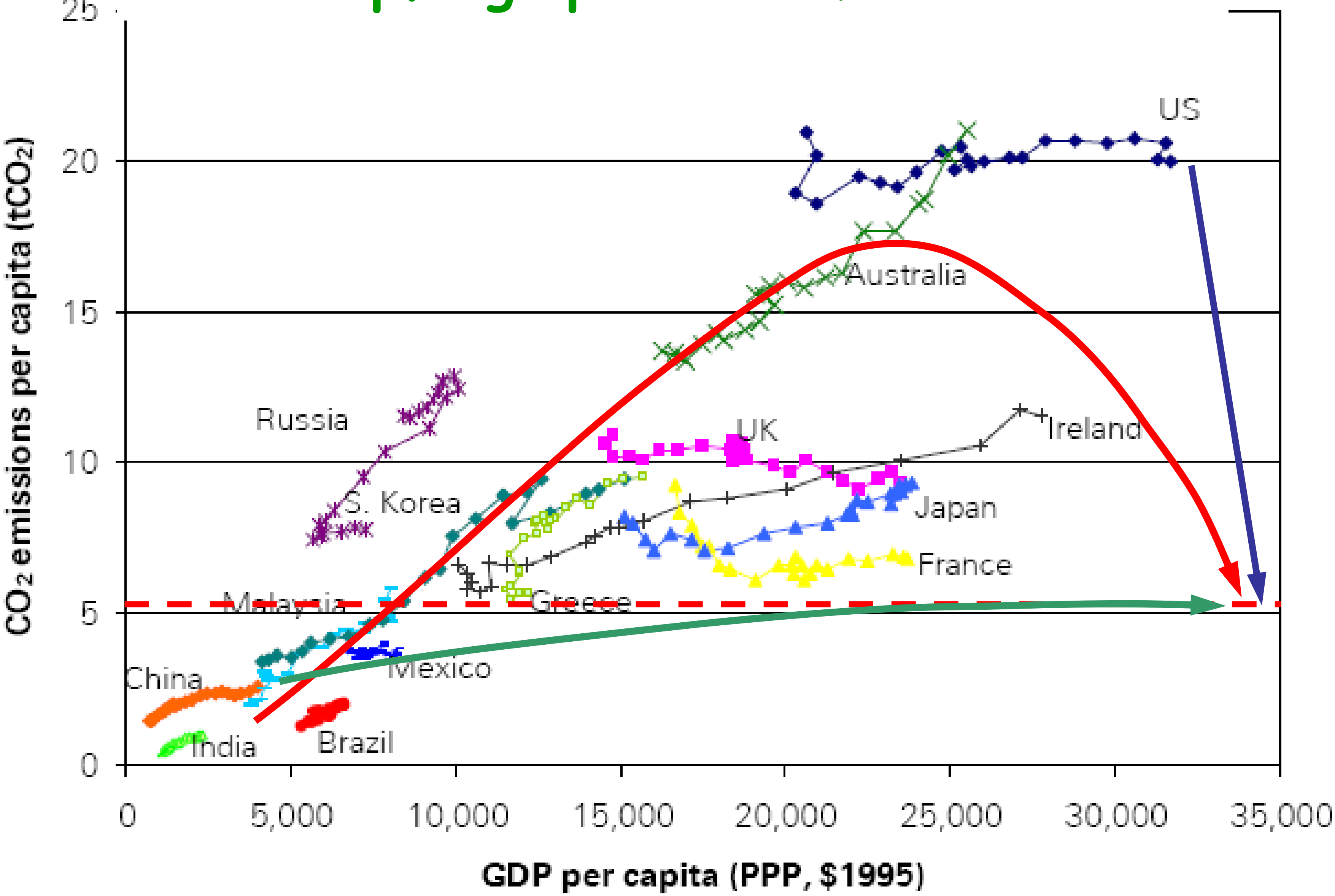
~ 2.6 billion people use coal, charcoal, firewood, agricultural residues, or dung as their primary cooking fuel.

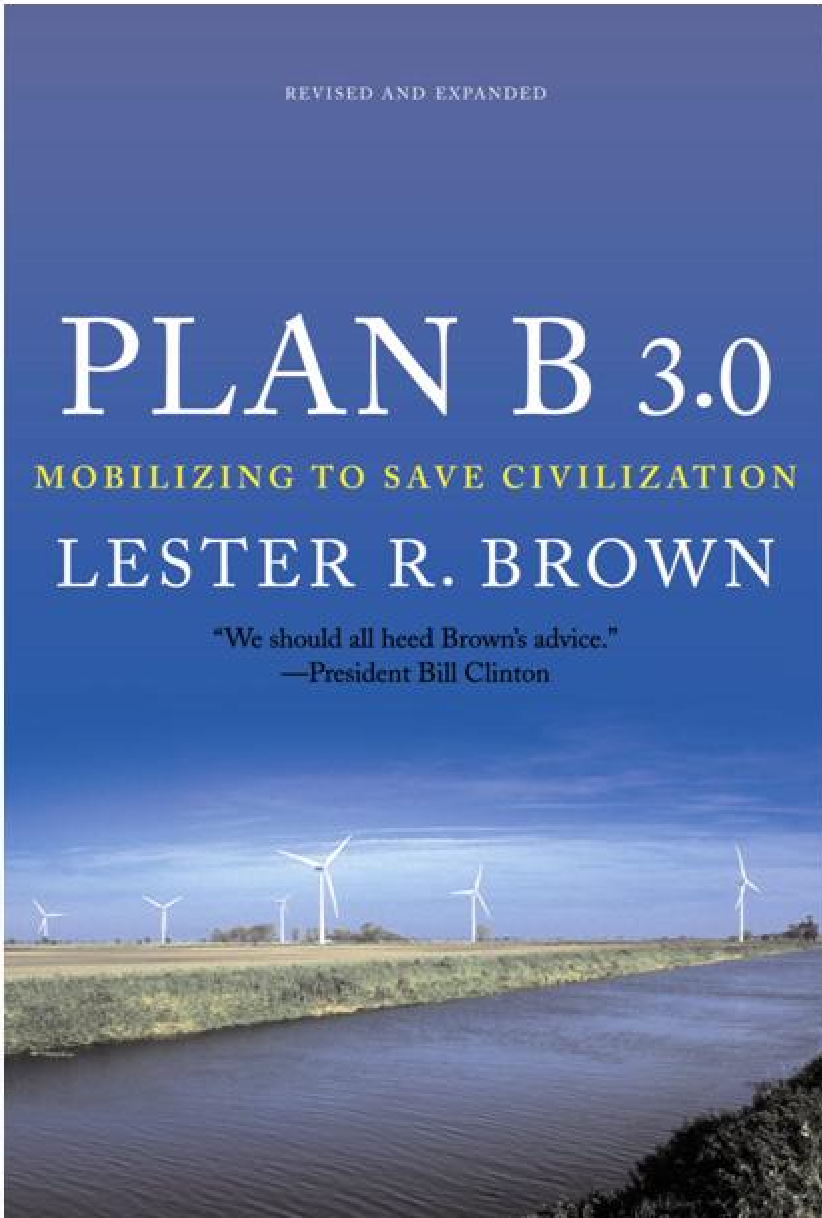
~ 1.6 billion people worldwide live without electricity.

Human Development Index vs. Energy consumption



We need to help developing countries "leapfrog" past our mistakes.





A Summary of
Plan B 3.0:
***Mobilizing to Save Civilization*,**
a book by
Lester R. Brown

EARTH POLICY INSTITUTE

Overview

A Civilization in Trouble

- Lessons from China
- Three New Stresses
  - Peak Oil
  - Rising Food Insecurity
  - Climate Change
- Failing States
- Tipping Points

Time for Plan B

- Stabilizing Population, Eradicating Poverty
- Restoring the Earth
- Plan B Budget
- Climate Action Plan
- Putting a Price on Carbon
- A Wartime Mobilization
- Pieces of the Puzzle
- Let’s Get to Work

Photo Credit: Yann Arthus-Bertrand

Lessons from China

If China's per capita income reaches U.S. levels by 2030 and consumption patterns follow, China would need:

- 2 times current world paper production
- > 1 billion cars, compared to the current world fleet of 860 million
- Paved area equal to its rice-growing area
- More oil than the world currently produces

Photo Credit: Yann Arthus-Bertrand

Lessons from China

- Western economic model – fossil fuel-based, automobile-centered, throwaway economy – will not work for China
- If it will not work for China, it will not work for India, nor for the other 3 billion people in developing countries
- In integrated global economy, it will no longer work for industrial countries either

Photo Credit: Yann Arthus-Bertrand

Three New Stresses

1. Peak Oil
2. Rising Food Insecurity
3. Climate Change

Peak Oil

- Top 20 oil fields were all discovered between 1917 and 1979
- Since 1981, oil extraction has exceeded new discoveries by a widening margin
- World conventional oil reserves drop each year, with most of the easily-recovered oil already pumped

Peak production of conventional oil is on our doorstep, if not already here. In a world where oil production is no longer expanding, one country can get more oil only if another gets less.

Photo Credit: iStockPhoto / Brasil2

Rising Food Insecurity

- Supply Tightening
  - Little unused arable land
  - Irrigation potential plateaued
  - Slowing growth in crop yields

- Demand Growing
  - Adding > 70 million to world population annually
  - 4 billion people desire to move up the food chain and eat more grain-intensive livestock products
  - Food vs. Fuel: Expanding biofuel production means that cars and people compete for crops

The number of hungry people in the world fell between 1970 and the 1990s. Now this number is growing and will continue to rise unless these trends are reversed.

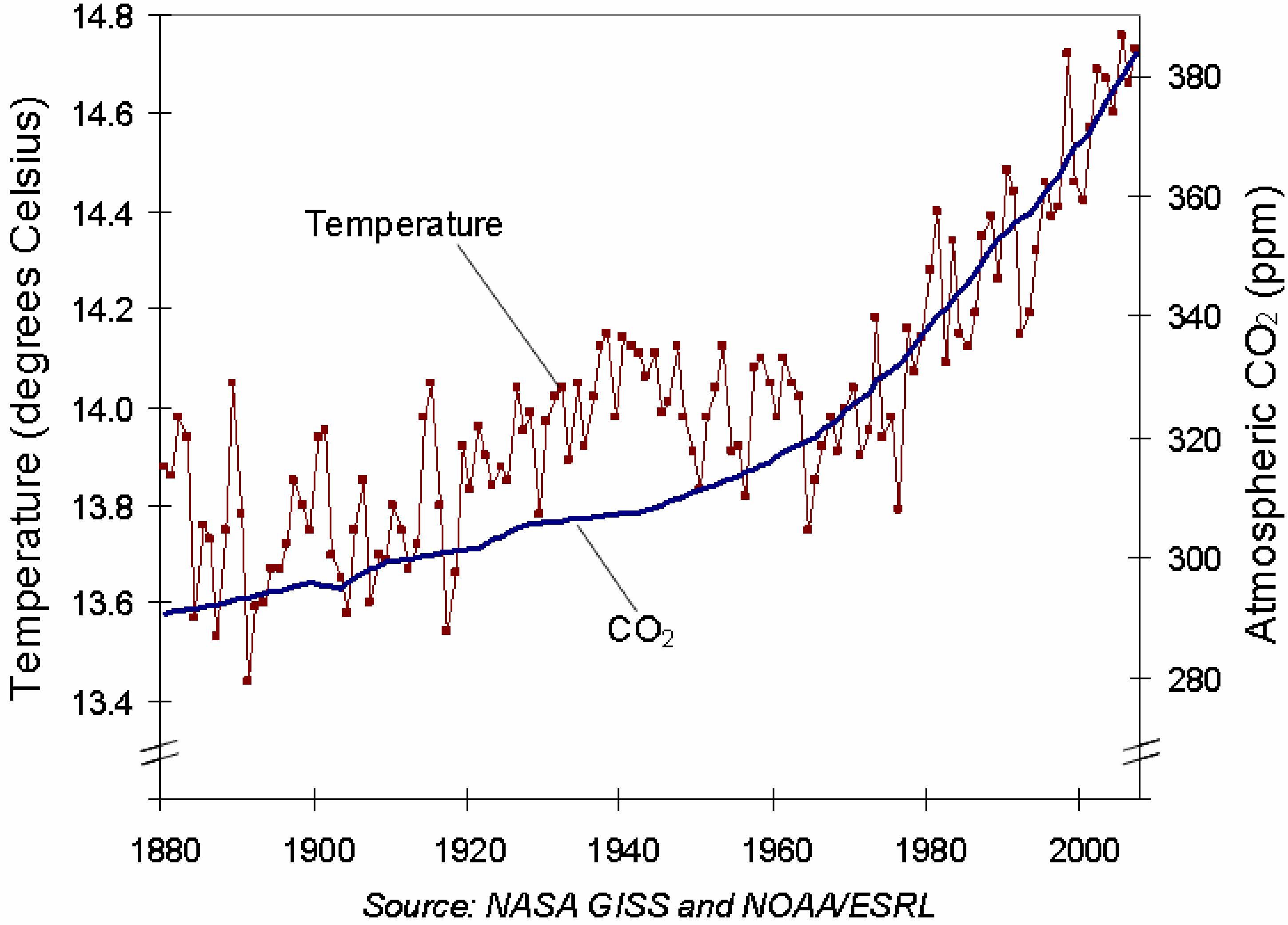
Photo Credit: Yann Arthus-Bertrand

Climate Change

- Since start of Industrial Revolution, carbon dioxide (CO_2) in the atmosphere has risen from 277 parts per million to 387 parts per million
- Burning fossil fuels – coal, oil, and natural gas – emits 7.5 billion tons of carbon each year
- Deforestation emits 1.5 billion tons each year
- Electricity generation and transportation are the largest sources of CO_2 emissions, with coal-fired power plants the biggest culprit
- As CO_2 accumulates, global temperature rises

Photo Credit: Yann Arthus-Bertrand

Average Global Temperature and Atmospheric Carbon Dioxide Concentrations, 1880-2007



Climate Change

- The earth has warmed an average 0.6°C (1.0°F) since 1970
- Rising temperatures fuel stronger storms and increase crop-withering heat waves
- The Intergovernmental Panel on Climate Change (IPCC) projects earth's average temperature will rise 1.1 - 6.4°C (2.0 - 11.5°F) during this century

Photo Credit: iStockPhoto / dra_schwartz

Plan B: Four Main Goals

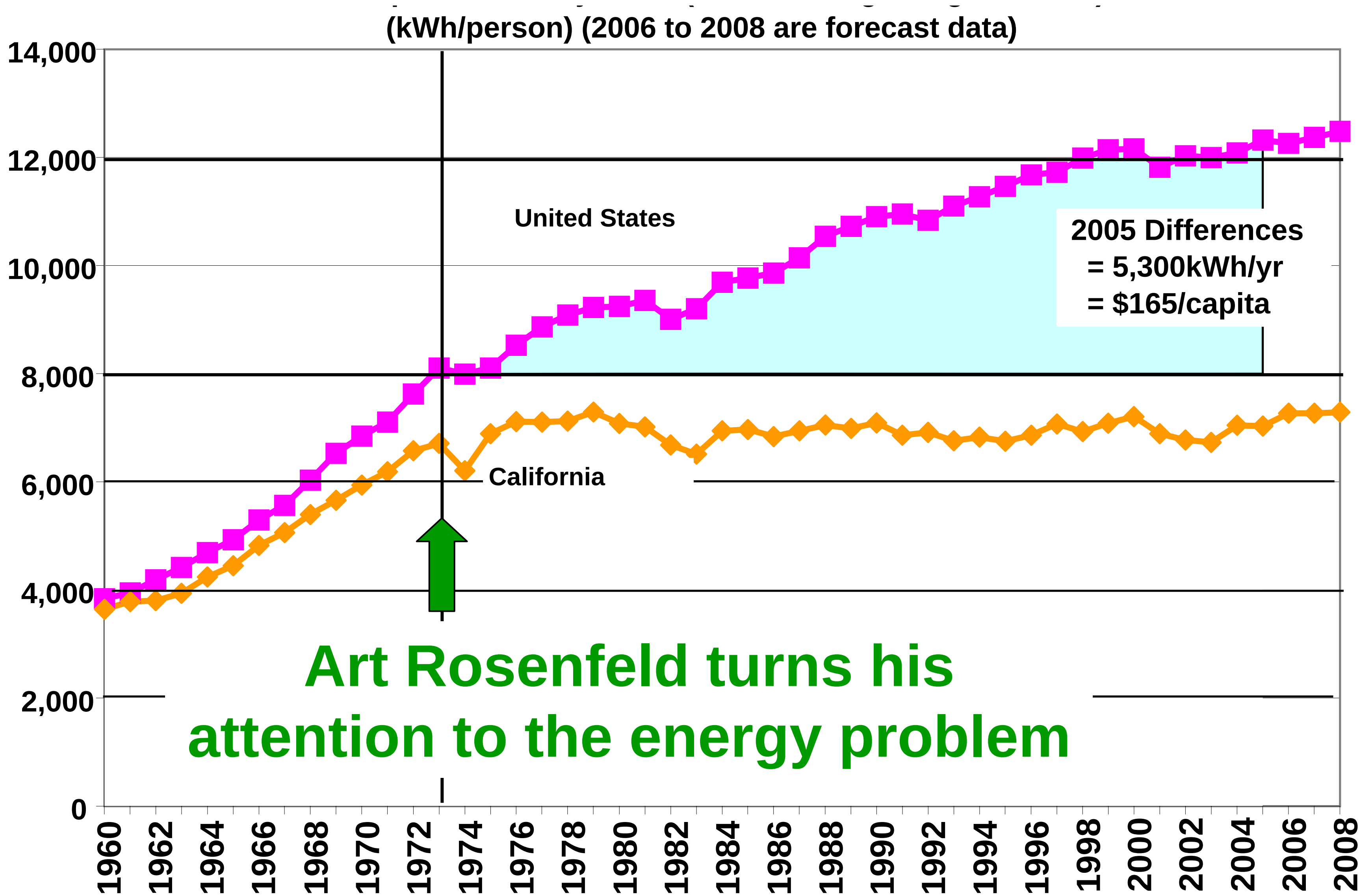
1. Stabilizing Population
2. Eradicating Poverty
3. Restoring the Earth’s Natural Support Systems
4. Stabilizing Climate

Photo Credit: iStockPhoto / Joe Gough

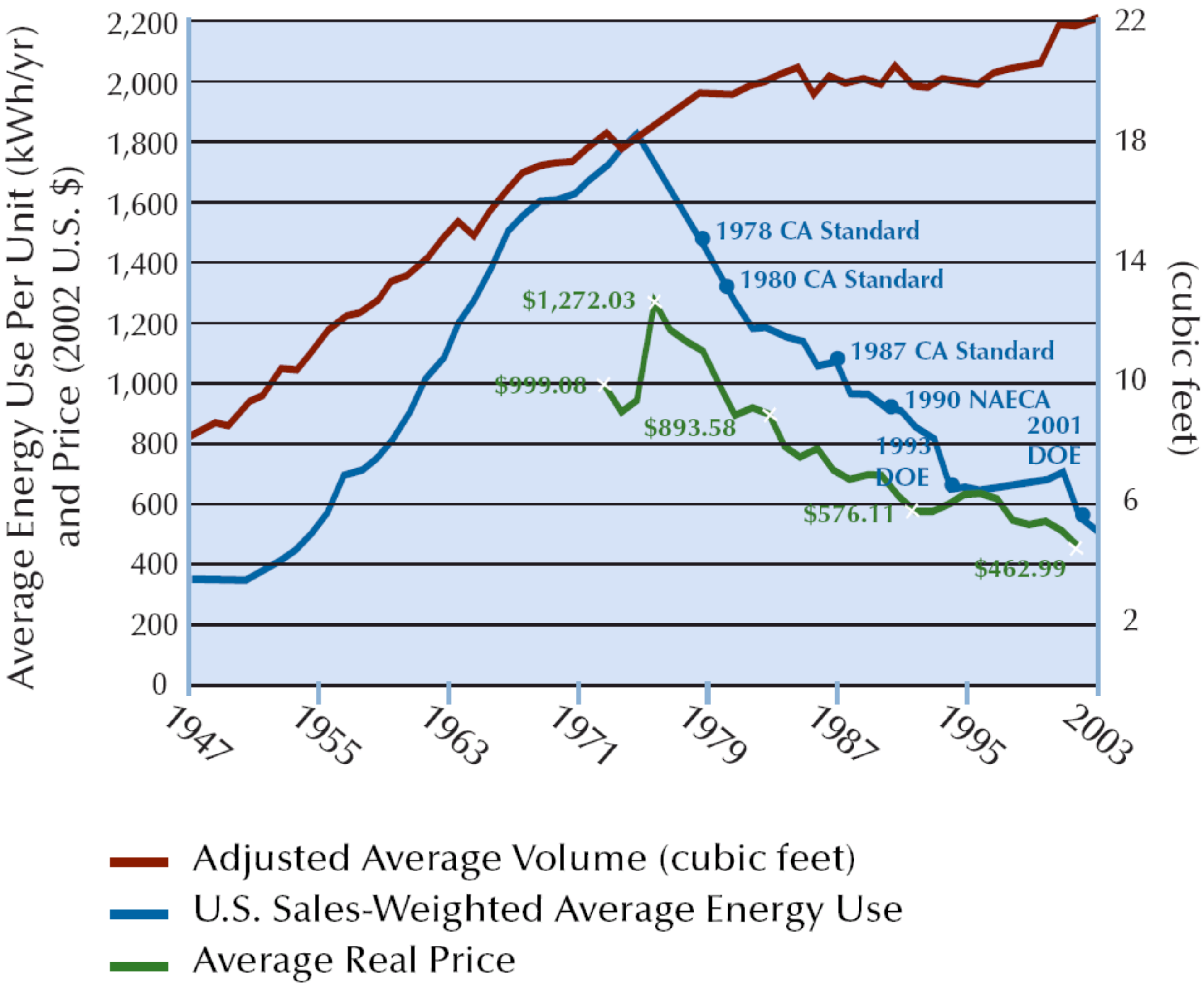
2. Concerted efforts must be made to improve energy efficiency and reduce the carbon intensity of the world economy.

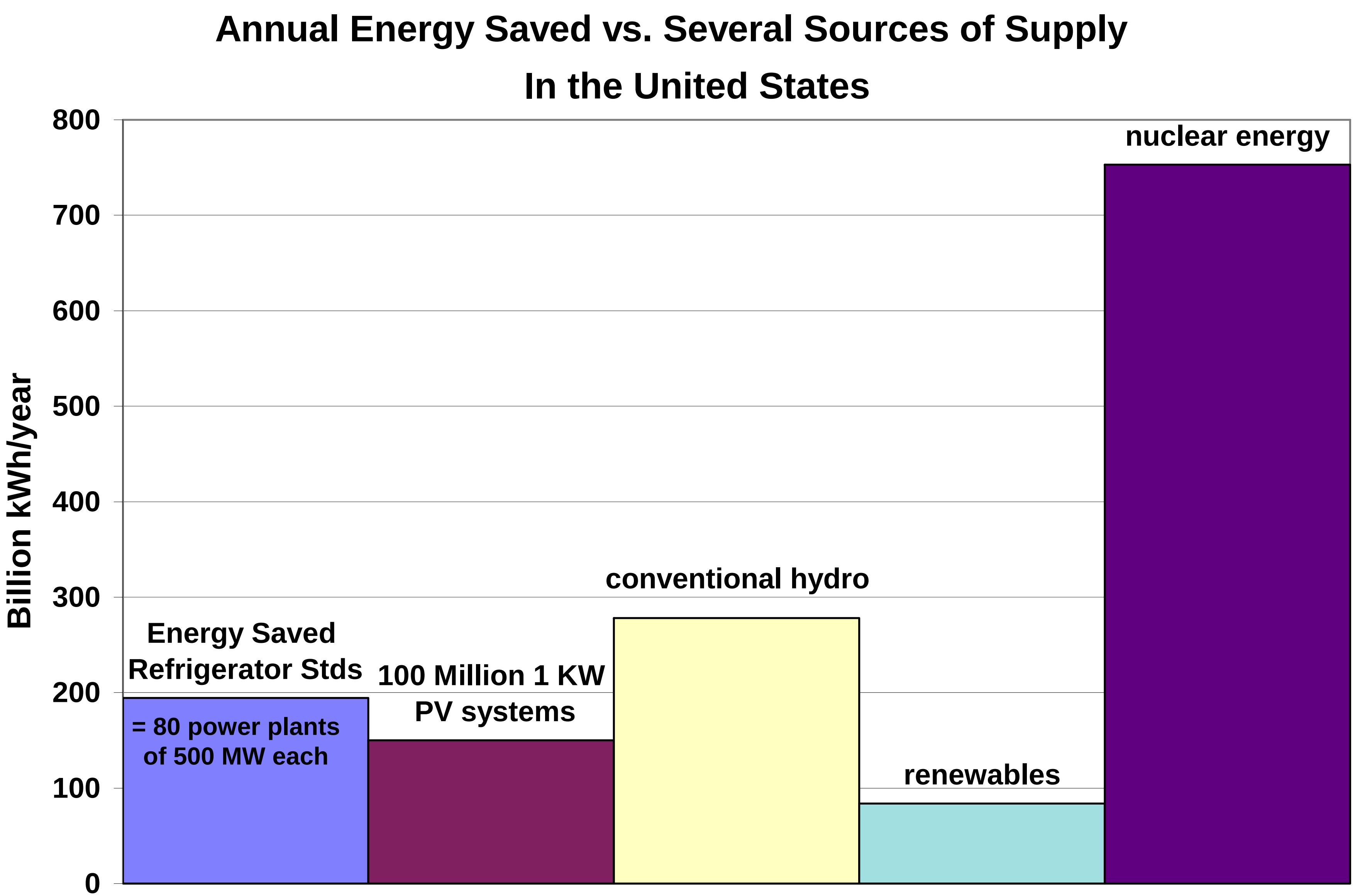
Maximizing energy efficiency and decreasing energy use will remain the lowest hanging fruit for the next few decades.

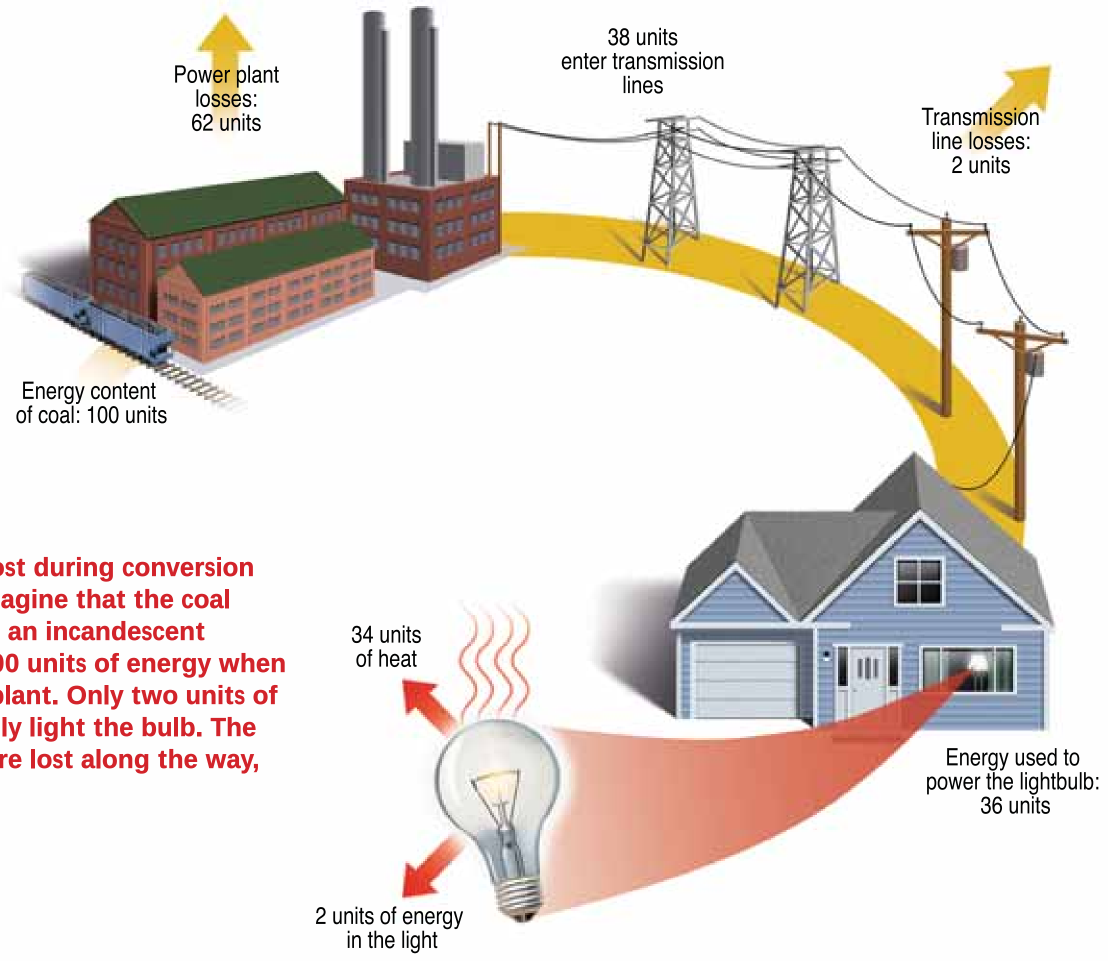
Electricity use per person (1960 – 2008)



Regulation stimulates technology: Refrigerator efficiency standards and performance. The *expectation* of efficiency standards also stimulated industry innovation




Annual Energy Saved vs. Several Sources of Supply
In the United States
Billion kWh/year
800
700
600
500
400
300
200
100
0
Energy Saved
Refrigerator Stds
= 80 power plants
of 500 MW each
100 Million 1 KW
PV systems
conventional hydro
renewables
nuclear energy



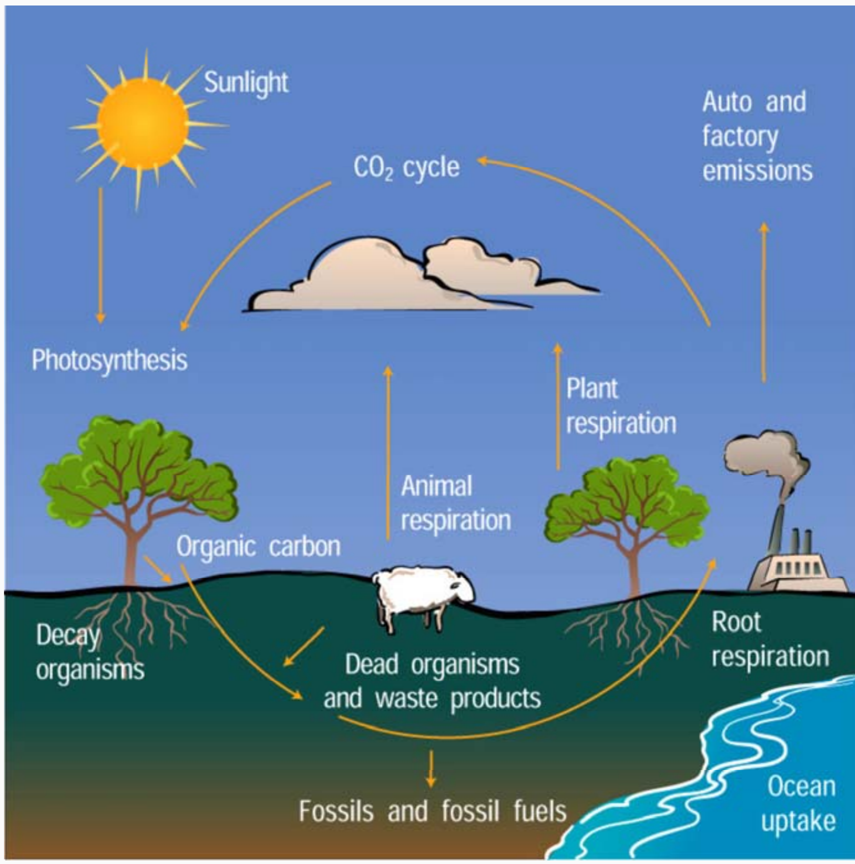
Example of energy lost during conversion and transmission. Imagine that the coal needed to illuminate an incandescent lightbulb contains 100 units of energy when it enters the power plant. Only two units of that energy eventually light the bulb. The remaining 98 units are lost along the way, primarily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

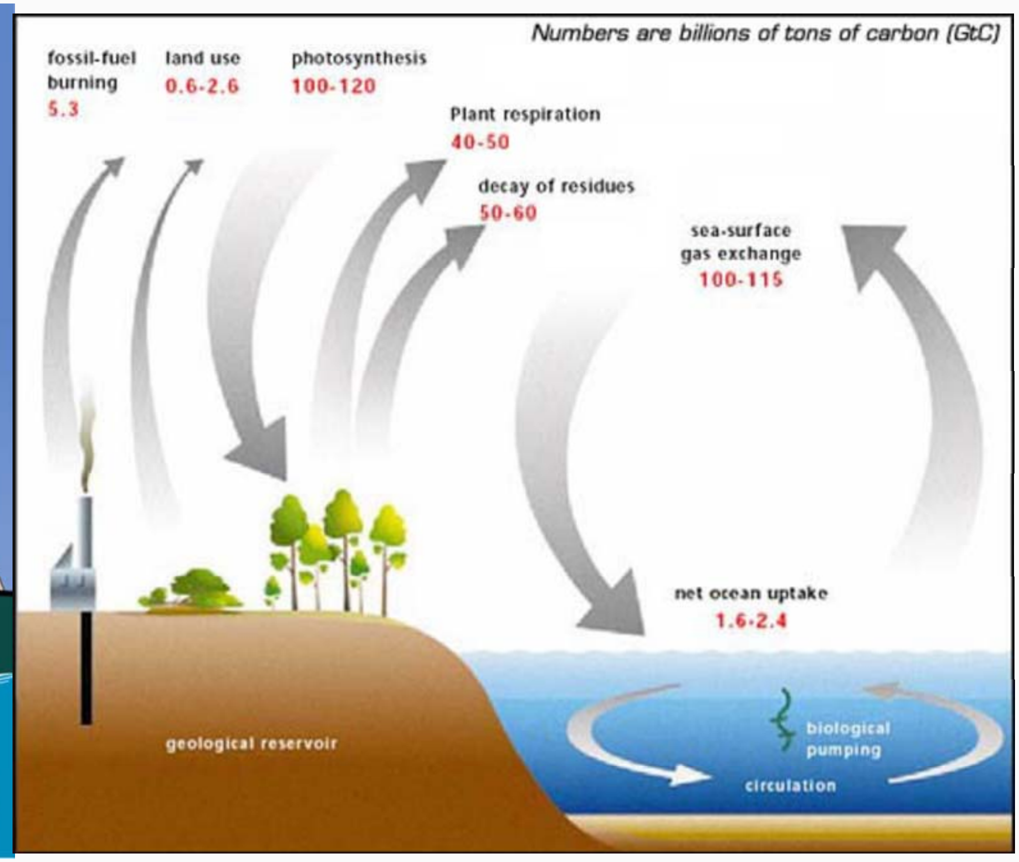
In the process, the original energy has taken on a series of four different identities and experienced four conversion losses. A typical coal-fired electrical plant might be 38% efficient, so a little more than one-third of the chemical energy content of the fuel is ultimately converted to usable electricity. In other words, as much as 62% of the original energy fails to find its way to the electrical grid. Once electricity leaves the plant, further losses occur during delivery. Finally, it reaches an incandescent lightbulb where it heats a thin wire filament until the metal glows, wasting still more energy as heat. The resulting light contains only about 2% of the energy content of the coal used to produce it. Swap that bulb for a compact fluorescent and the efficiency rises to around 5%—better, but still a small fraction of the original.

Another familiar form of conversion loss occurs in a vehicle's internal combustion engine. The chemical energy in the gasoline is converted to heat

3. Technologies for capturing and sequestering carbon from fossil fuels can play a central role in the cost-effective management of global carbon dioxide emissions.

Global Carbon Cycle



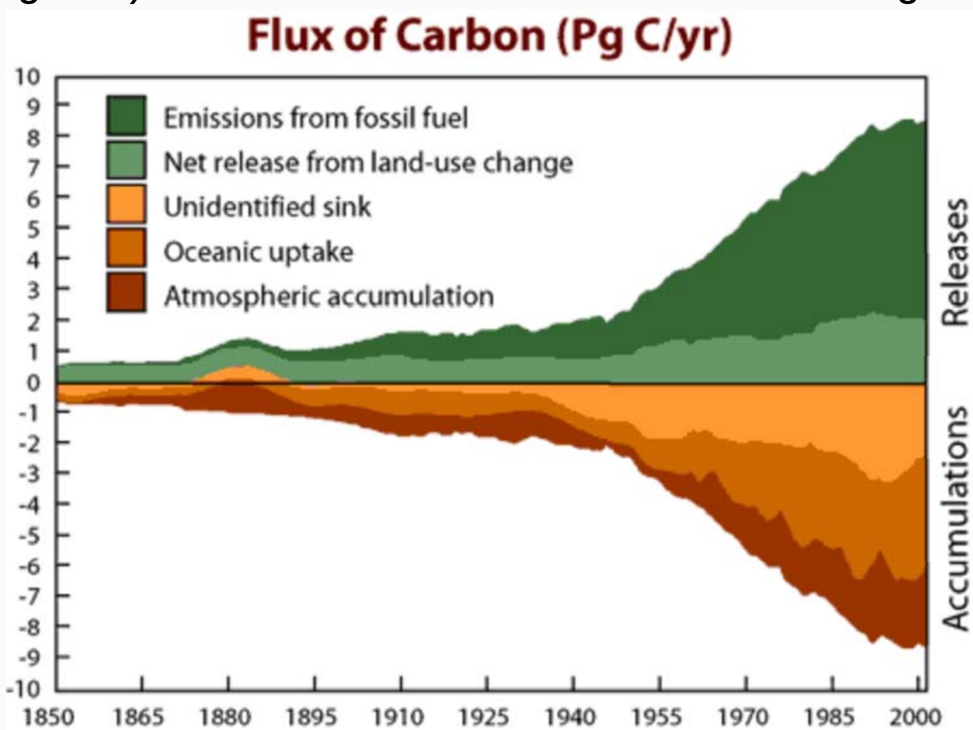


Global Carbon Equation

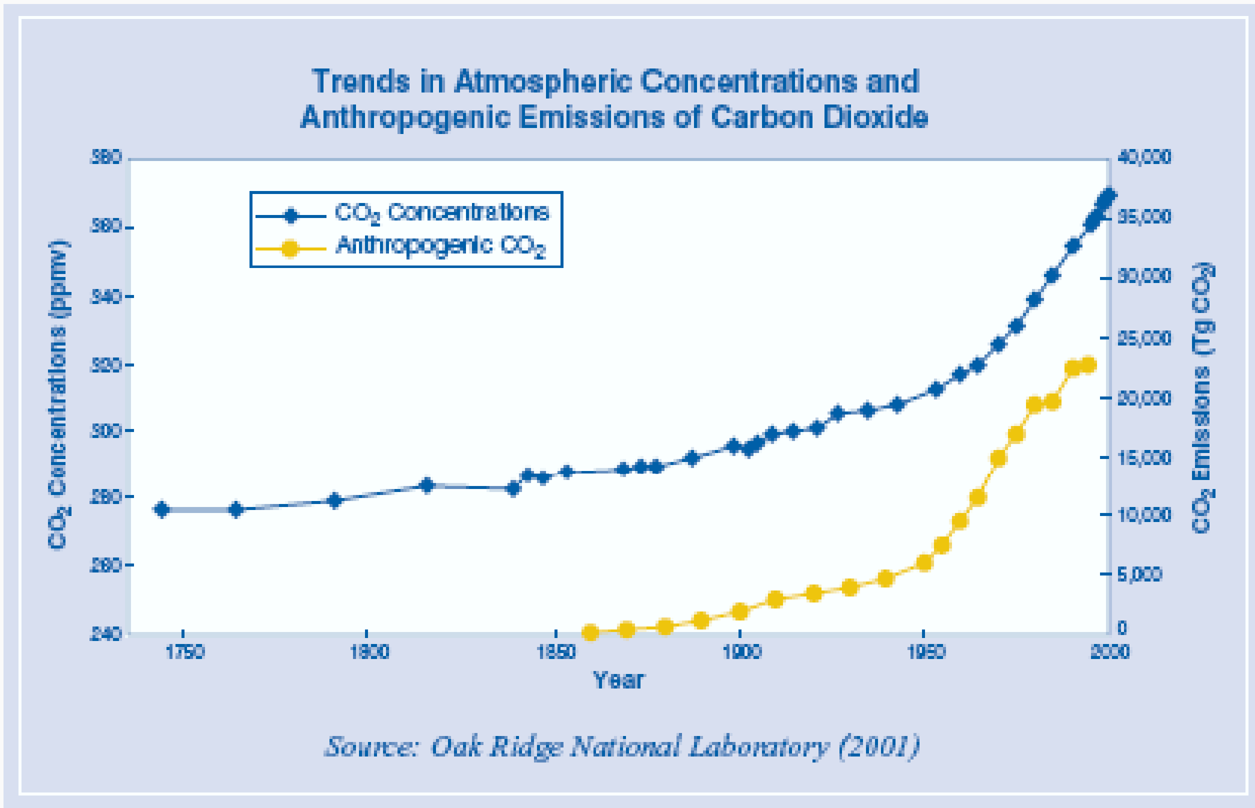
Atmospheric increase = Emissions from fossil fuels+Net emissions from changes in land use-Oceanic uptake-Missing carbon sink

3.2 (±0.2)=6.3 (±0.4)+2.2 (±0.8)-2.4 (±0.7)-2.9 (±1.1) in PgC

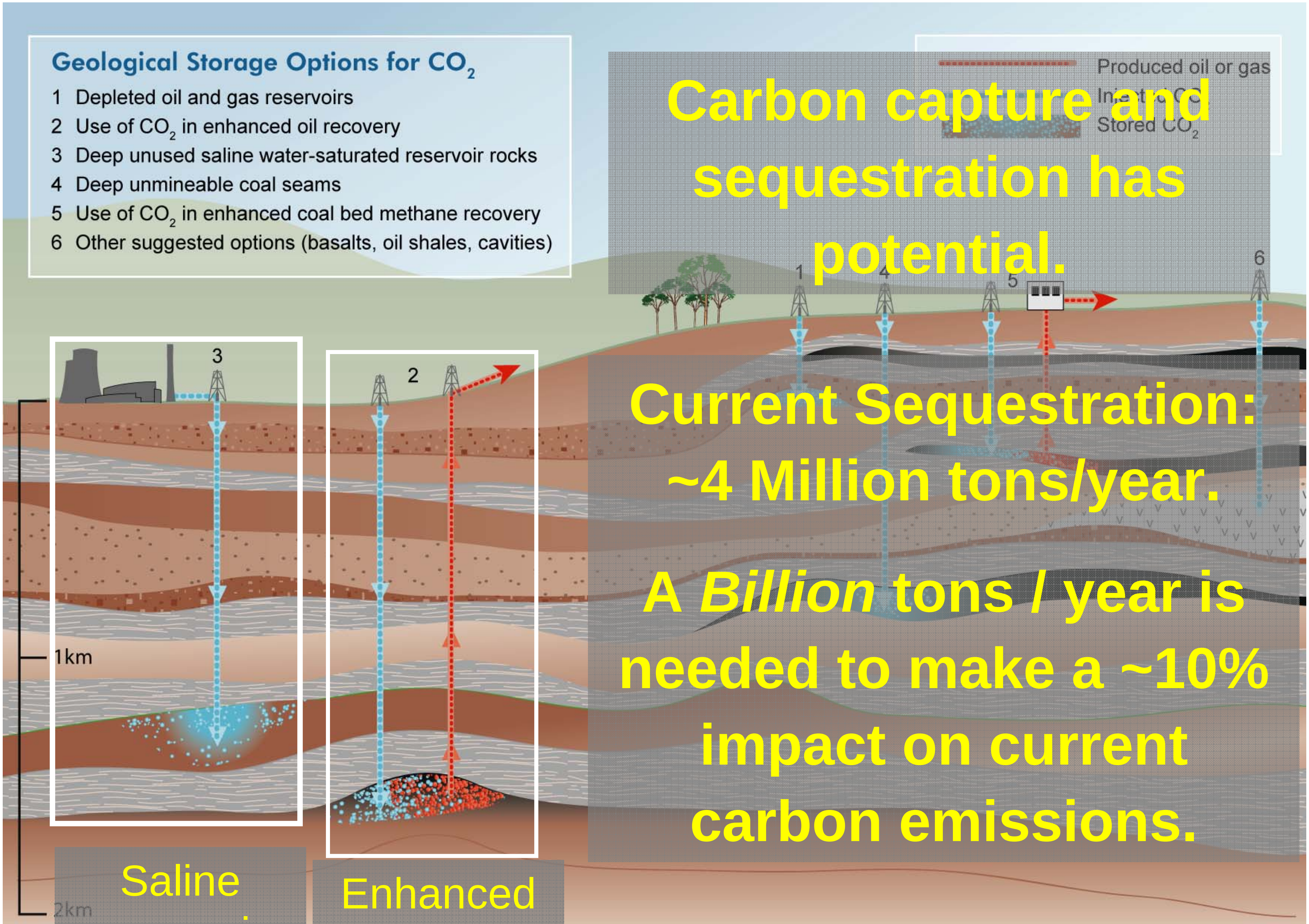
One Pg (pentagram) = one billion metric tones= 10^{12} kg



Human generated CO_2 Emissions



Source: http://www.epa.gov/globalwarming/publications/emissions



Carbon capture and sequestration has potential.

Current Sequestration: ~4 Million tons/year.

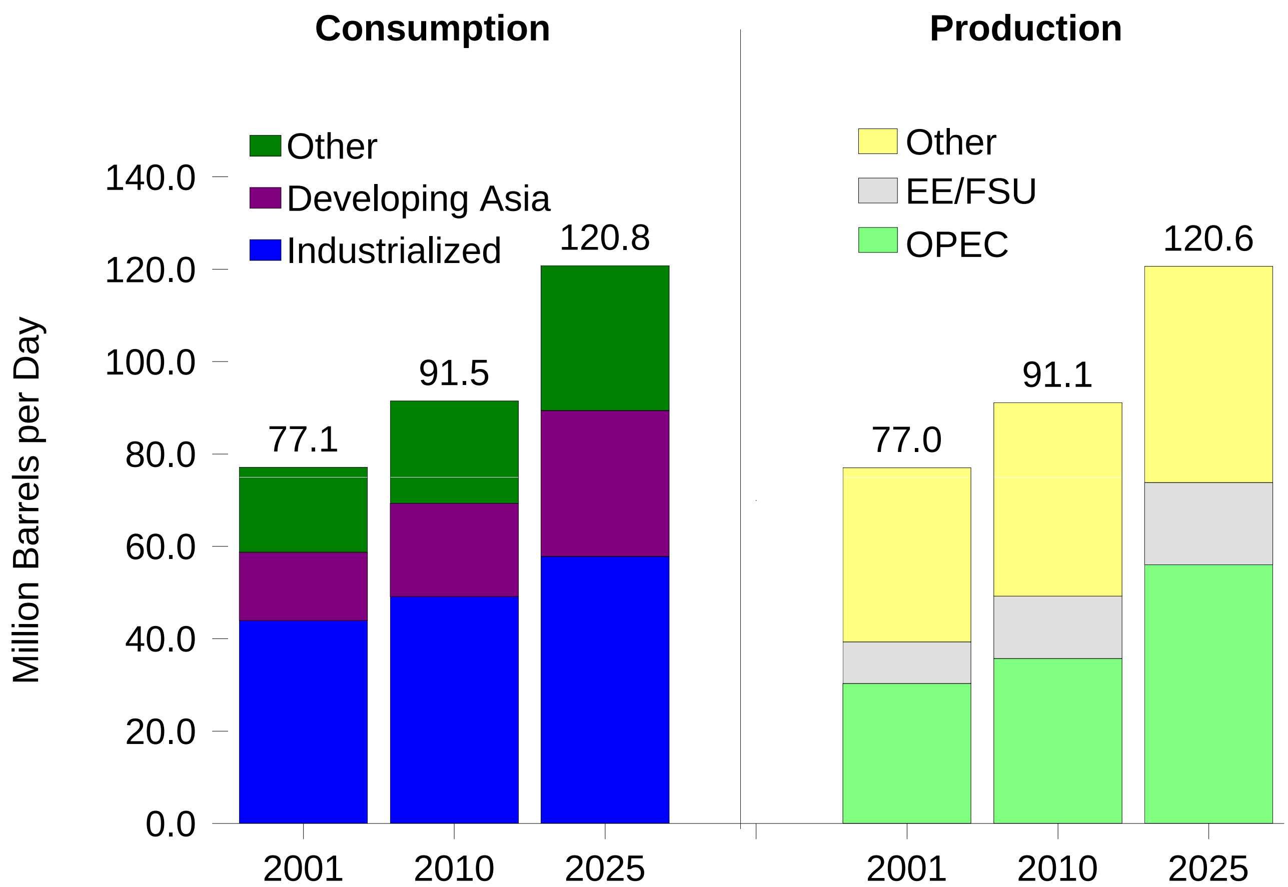
A *Billion* tons / year is needed to make a ~10% impact on current carbon emissions.

Saline reservoir

Enhanced oil recovery

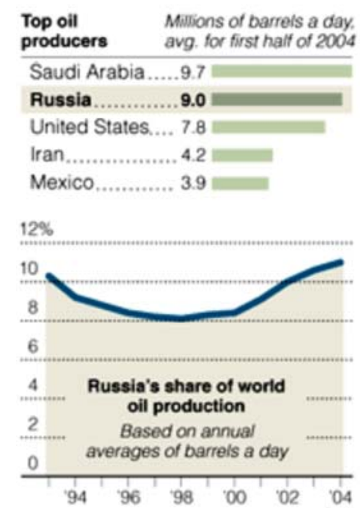
4. To reduce future geopolitical conflict and economic vulnerability associated with oil and natural gas, conservation and alternative sources must be developed.

World Oil Consumption and Production



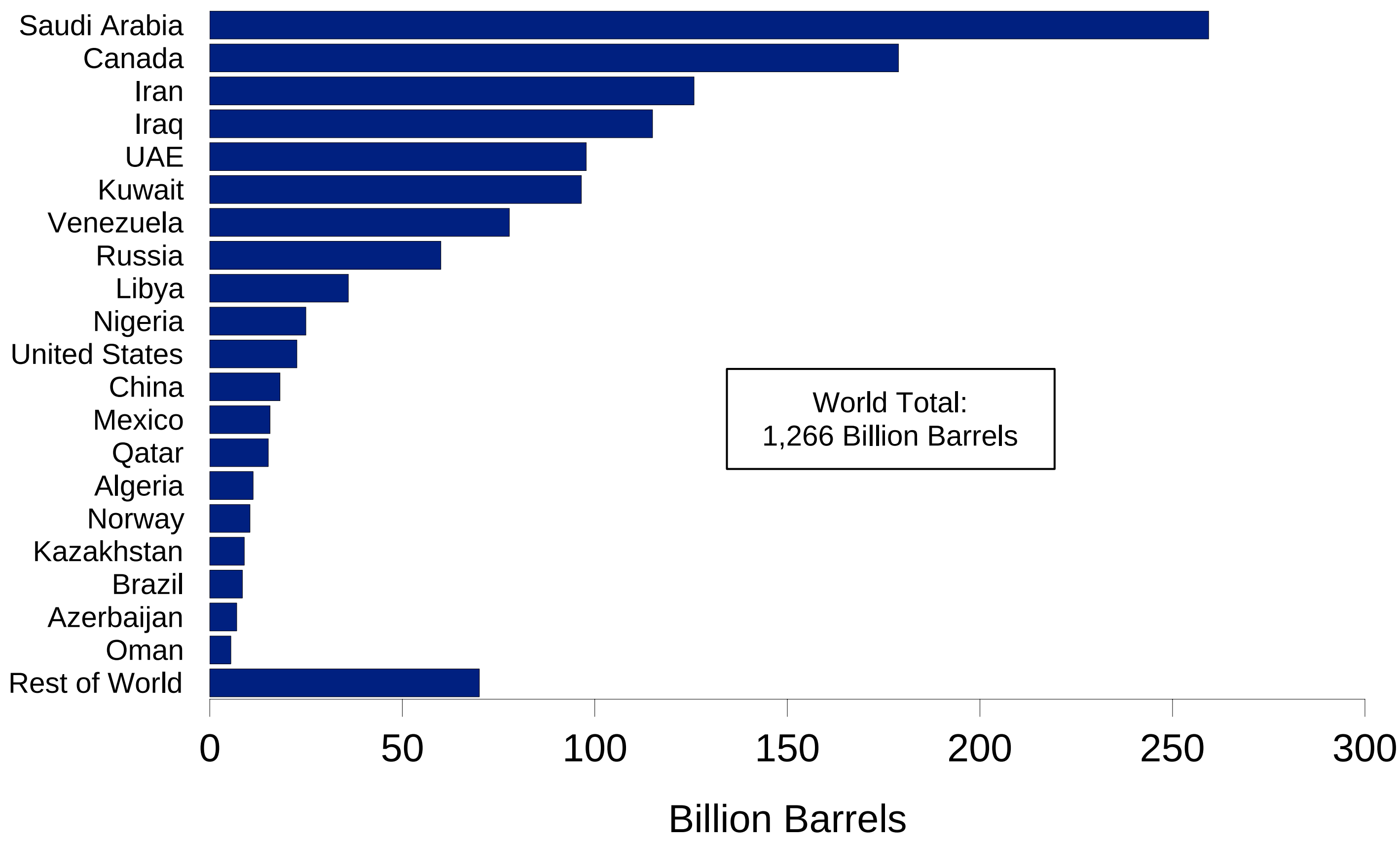
2004 Production:

NY Times, 8/15/04



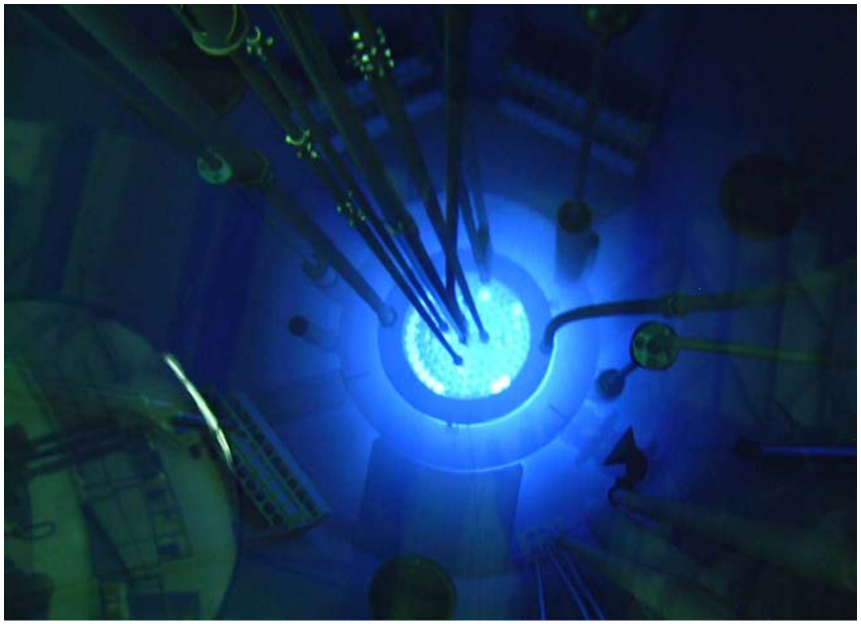
Source: EIA, *International Energy Outlook 2004*

World Oil Reserves by Country



Source: "Worldwide Look at Reserves and Production."*Oil & Gas Journal*, Vol. 100, No. 49 (December 22, 2003), pp. 46-47.

5. Nuclear power (currently ~16% of world electricity generation) can play a significant role.



The issues:

- Waste Storage
- Nuclear Proliferation
- Economic viability

Fuel re-cycling and fast neutron burning of long-lived actinides can dramatically reduce the amount *and* the lifetime of the nuclear waste.

6. Renewable energy offers immense opportunities.

Price on carbon (\$30 – \$40 / avoided ton of CO_2)

• Subsidies should be targeted to promising but not-yet-commercial technologies and decline gradually over time.

• Renewable portfolio standards and “reverse auctions” (renewable energy developers bid for a share of public funds on the basis of the minimum subsidy they require).

Policy Options towards a Sustainable Energy

Incentives: "Carrots"

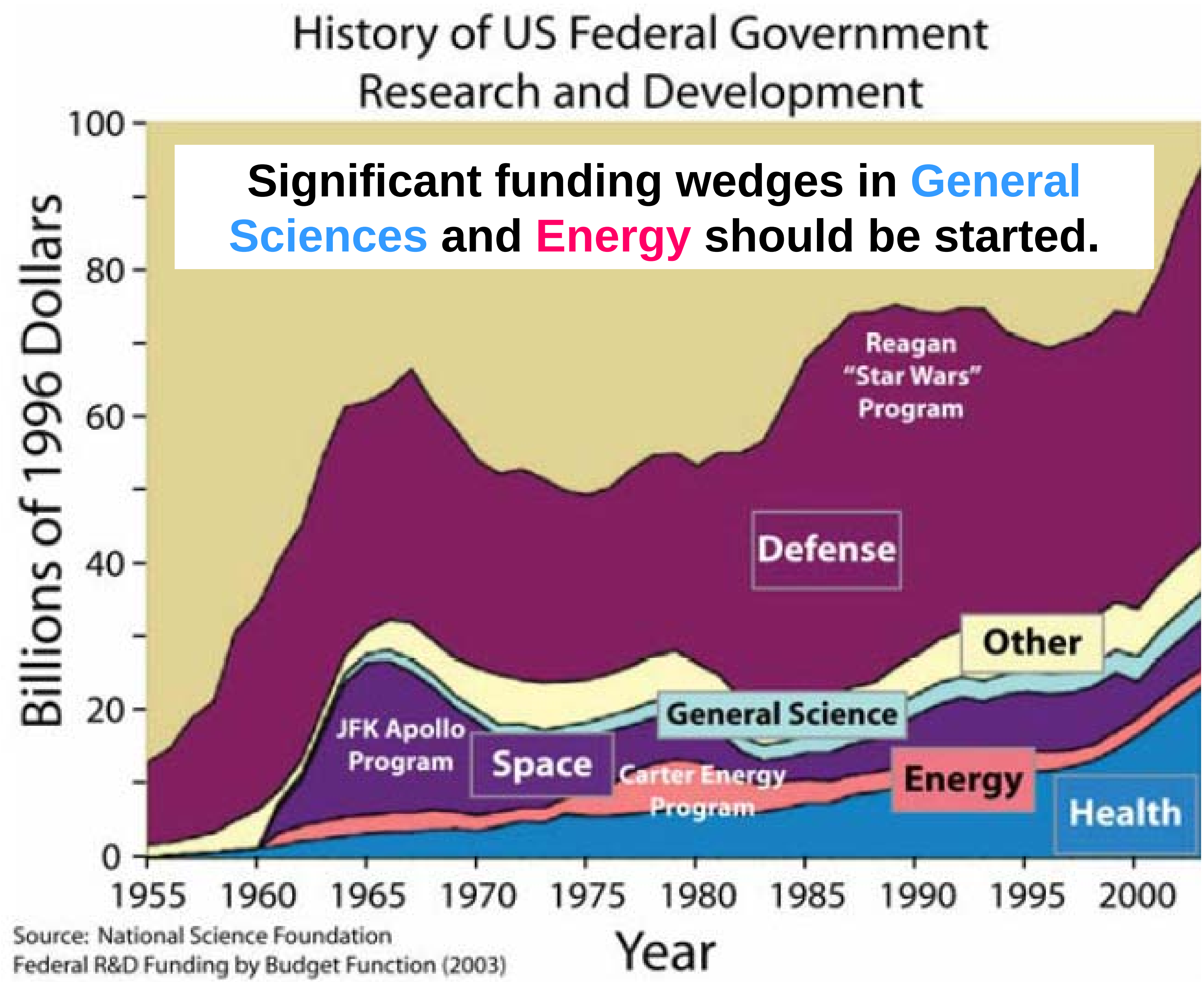
Financial incentives		Non-financial incentives	
• tax credits • subsidies • grants, other direct funding • loan guarantees • procurement policies • feed-in tariffs		• publicly-funded RD&D • infrastructure investments • education/information/labeling • technical assistance • award/recognition programs • grid access	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Potentially useful to advance 'cutting-edge' technologies. • Often politically popular. • Can be targeted to overcome particular market obstacles or promote specific technologies.	• Require government to spend money. • Spending may be politically influenced and not always cost-effective (e.g., subsidies continue even when no longer needed). • Results are difficult to predict. They tend to be biased toward well-understood options.	• Provide means to address other market failures/ barriers. • Usually politically popular. • May have a variety of spillover benefits. • Can help address competitiveness concerns.	• Difficult to target RD&D, infrastructure investments. • Institutional and technical capacity required to develop and deliver programs. • Benefits/impacts may be limited, especially without complementary financial incentives.

Disincentives: “Sticks”

Market-based policies • energy or emissions taxes • emissions cap-and-trade programs		**Prescriptive regulations** • emissions standards • efficiency standards • portfolio standards	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Can be applied economy-wide. • Markets deliver least costly reductions. • Individual firms, consumers retain choice, flexibility. • Generate revenues that can be used for other purposes. • Consistent price signals yield economically rational outcomes across all covered sectors. • Can be designed to meet specific objectives in terms of cost, emissions reductions, etc.	• May generate strong political opposition because they raise prices. • Energy-price impacts on poor households will be a concern (though should note that revenues generated by policy can be used to address this issue). • May raise concerns about impacts on domestic industry in terms of jobs and competitiveness in world markets. • Price signals may be inadequate to overcome other market failures or stimulate new technologies.	• Effective where price signals alone would not elicit all cost-effective responses (e.g., car, building, appliance markets). • Policy outcomes are relatively certain (though costs may not be). • Many manufacturers, industries already subject to some regulation. • Costs are less evident, potentially reducing political opposition. • No action needed on part of consumer.	• Usually do not encourage or reward better than minimal compliance. • Require technical and institutional capacity to develop, enforce standards. • Different policies needed for different sectors. • Defining cost-effectiveness is uncertain and often contentious, especially if regulators have to project future tech development. • Less flexible and (potentially) more costly than market-based approaches. • Policies need to be updated over time.

7. Invest in research and development on more transformational technologies.

Significant funding wedges in General Sciences and Energy should be started.



Basic Science for America's Energy Future

The National Academies Energy Summit

Dr. Raymond L. Orbach
Under Secretary for Science
U.S. Department of Energy
March 14, 2008
www.science.doe.gov

Five Examples:

Science Transforming Energy Technologies

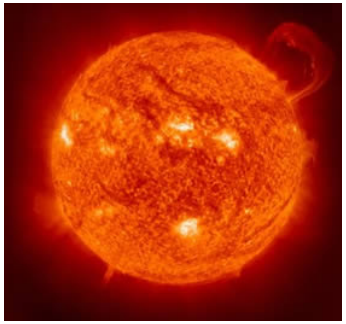
- Solar
- Electrical Energy Storage
- Bioenergy
- Nuclear
- Fusion

The Promise of Fusion

Science Transforming Energy Technologies

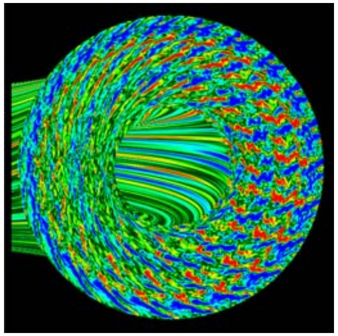
Imagine:	• Bringing the power of the sun and the stars to Earth

- Fusion – harnessing the sun's and stars' own method of energy production
- Uses abundant fuel, available to all nations - deuterium and lithium are easily available for millions of years
- No carbon emissions, short-lived radioactivity
- Low risk of nuclear materials proliferation
- Cost of power estimated similar to coal, fission
- Can produce electricity and hydrogen for fuel



Basic Science:

- Fundamental understanding of plasma science necessary to explore innovative, improved pathways to plasma confinement
- Materials for the extreme thermochemical environments and high neutron flux conditions
- Predictive capability of plasma confinement and stability for optimum experimental reactor design



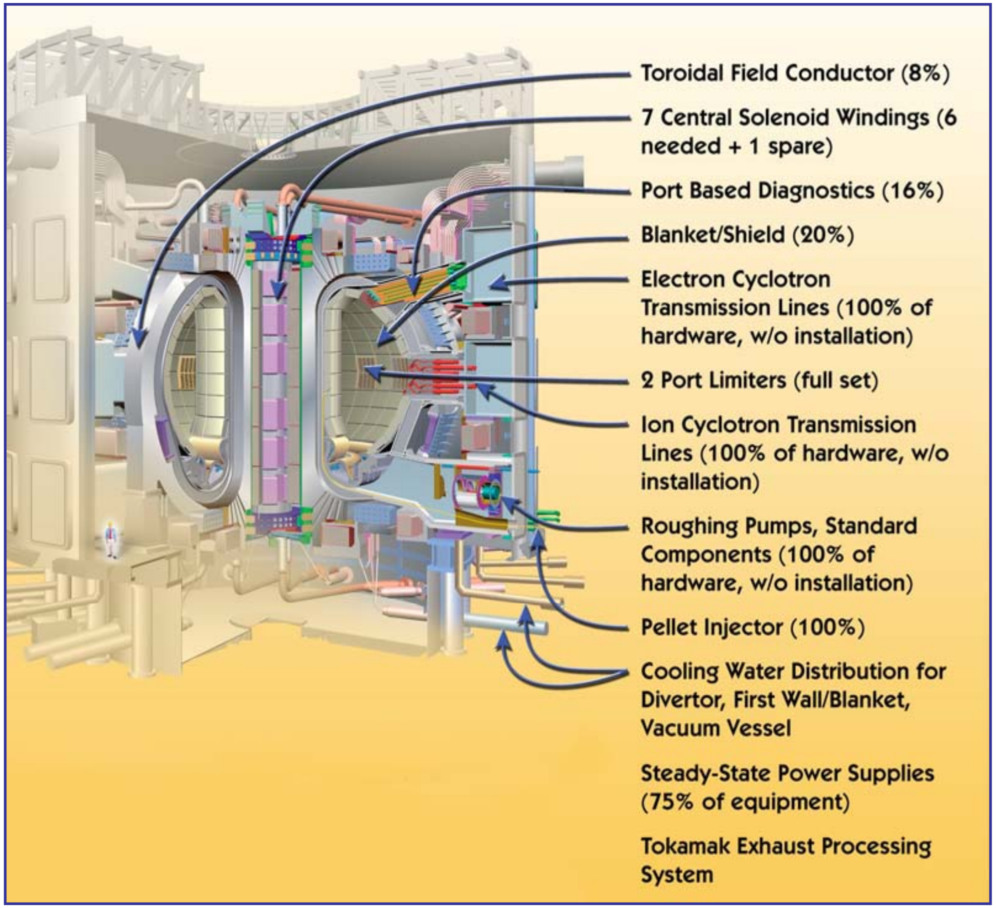
Computer simulation of plasma turbulence in a tokamak

ITER

Unprecedented International Cooperation on Fusion

ITER: Experimental fusion reactor designed to be the penultimate step to development of commercial fusion energy

- ITER is based on the tokamak concept in which a hot gas is confined in a torus-shaped vessel using a magnetic field. The gas is heated to over 100 million degrees and will produce 500 MW of fusion power.
- ITER will demonstrate the technical and scientific feasibility of a sustained fusion burning plasma—for power out/in (Q) up to 10. (A power reactor has a Q of ~30)
- Sited in Cadarache, France, ITER is a international partnership of the U.S., the European Union, Japan, Russia, China, Republic of Korea, and India.
- Historic international agreement signed on November 21, 2006. The first ITER Council Meeting was held November 27-28, 2007.



8. Assess and mitigate any negative environmental impacts associated with the large-scale deployment of renewable energy technologies.

9. Develop better energy storage technologies, new energy carriers, and improved transmission infrastructure (DC).

10. The science and technology community
- together with the general public –
must be effectively engaged.

MAKE SOLAR ENERGY ECONOMICAL

PROVIDE ENERGY FROM FUSION

DEVELOP CARBON SEQUESTRATION METHODS

MANAGE THE NITROGEN CYCLE

PROVIDE ACCESS TO CLEAN WATER

RESTORE AND IMPROVE URBAN INFRASTRUCTURE

ADVANCE HEALTH INFORMATICS

ENGINEER BETTER MEDICINES

REVERSE-ENGINEER THE BRAIN

PREVENT NUCLEAR TERROR

SECURE CYBERSPACE

ENHANCE VIRTUAL REALITY

ADVANCE PERSONALIZED LEARNING

ENGINEER THE TOOLS OF SCIENTIFIC DISCOVERY

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Earthrise from Apollo 8 (December 24, 1968)