The World Energy situation and the Role of Renewable Energy Sources and Advanced Nuclear Technologies in Solving the Energy and Environmental Problems

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Lecture at USTC

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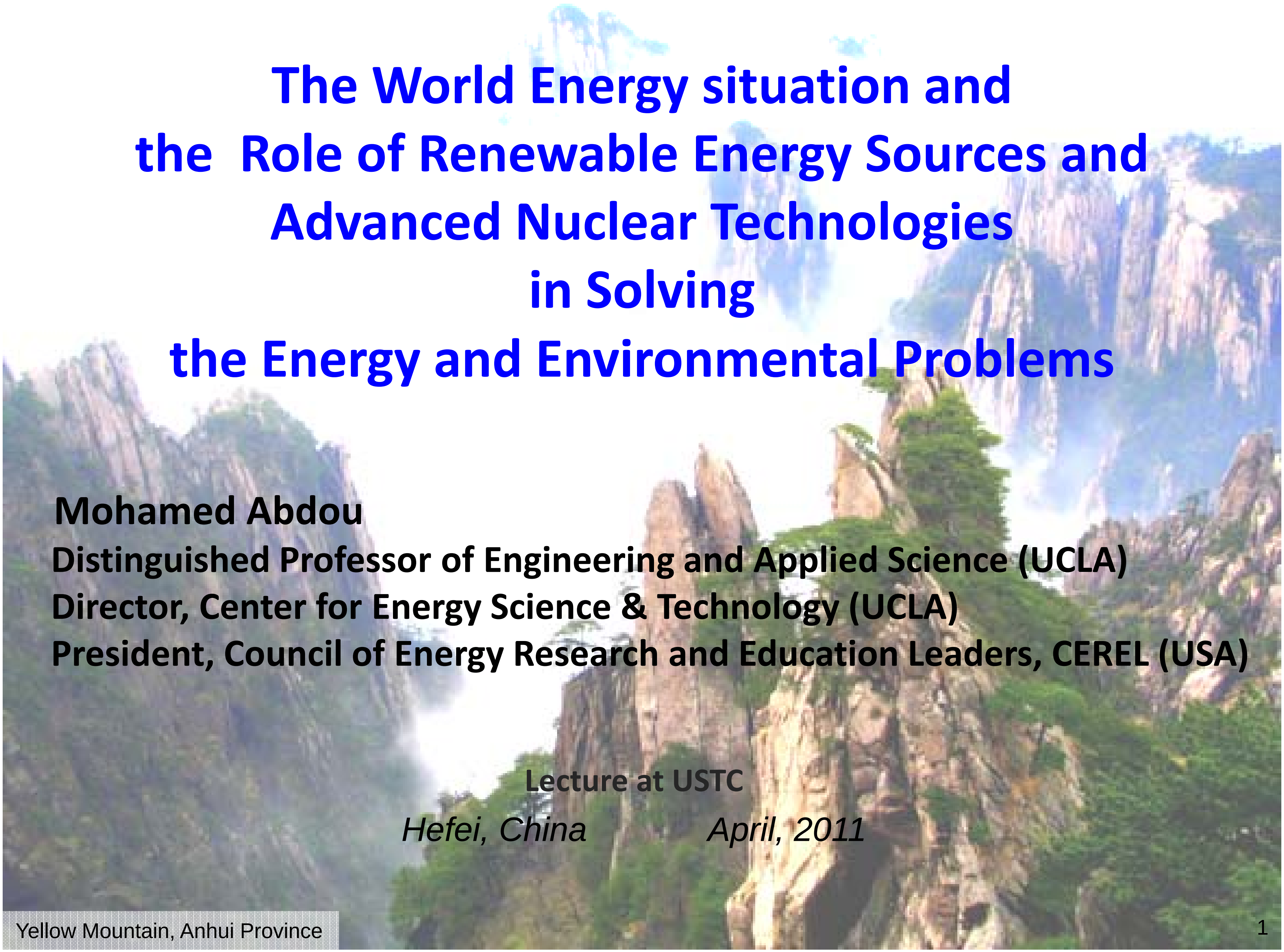


Yellow Mountain, Anhui Province

The World Energy situation and the Role of Renewable Energy Sources and Advanced Nuclear Technologies in Solving the Energy and Environmental Problems

OUTLINE

1. **The World Energy Situation**
   - Need for more energy, dominance of fossil fuels, impact on the environment, energy-water nexus
2. **Renewable Energy Sources**
   - Solar, wind, geothermal, biomass, hydro, etc.
3. **Nuclear Fission**
   - Existing plants, and contribution to current world energy needs
   - Nuclear renaissance and future outlook
4. **Fusion**
   - Incentives to fusion
   - Approaches to fusion and DEMO goal
   - When can we have fusion?
5. **Closing Remarks**

World Energy Situation

Energy Situation

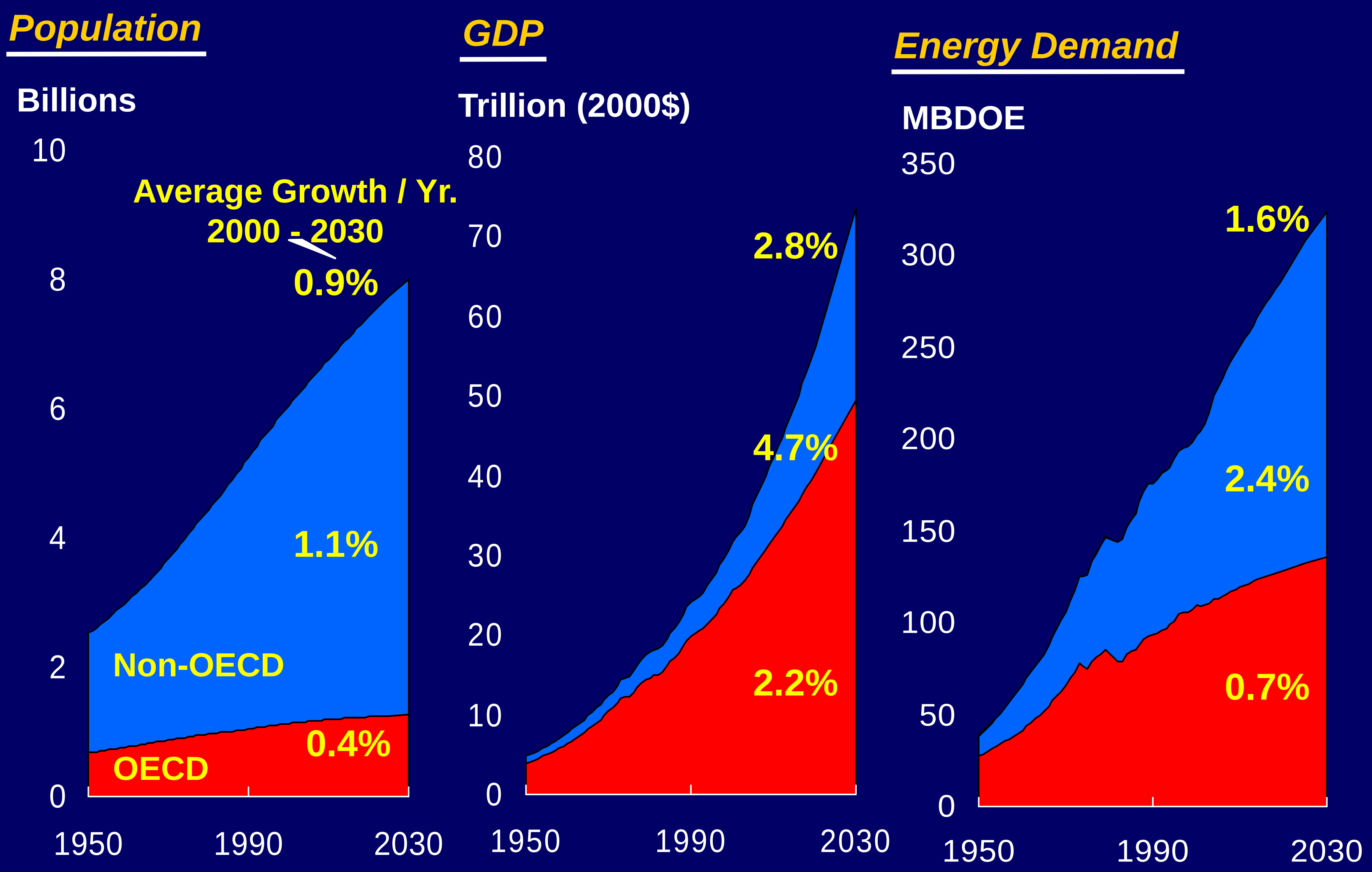
- **The world uses a lot of energy**
  - Average power consumption = 17 TW (2.5 KW per person)
  - World energy market ~ $3 trillion / yr (electricity ~ $1 trillion / yr)

- **The world energy use is growing**
  - To lift people out of poverty, to improve standard of living, and to meet population growth

- **Climate change and debilitating pollution concerns are on the rise**
  - 80% of energy is generated by fossil fuels
  - CO_2 emission is increasing at an alarming rate

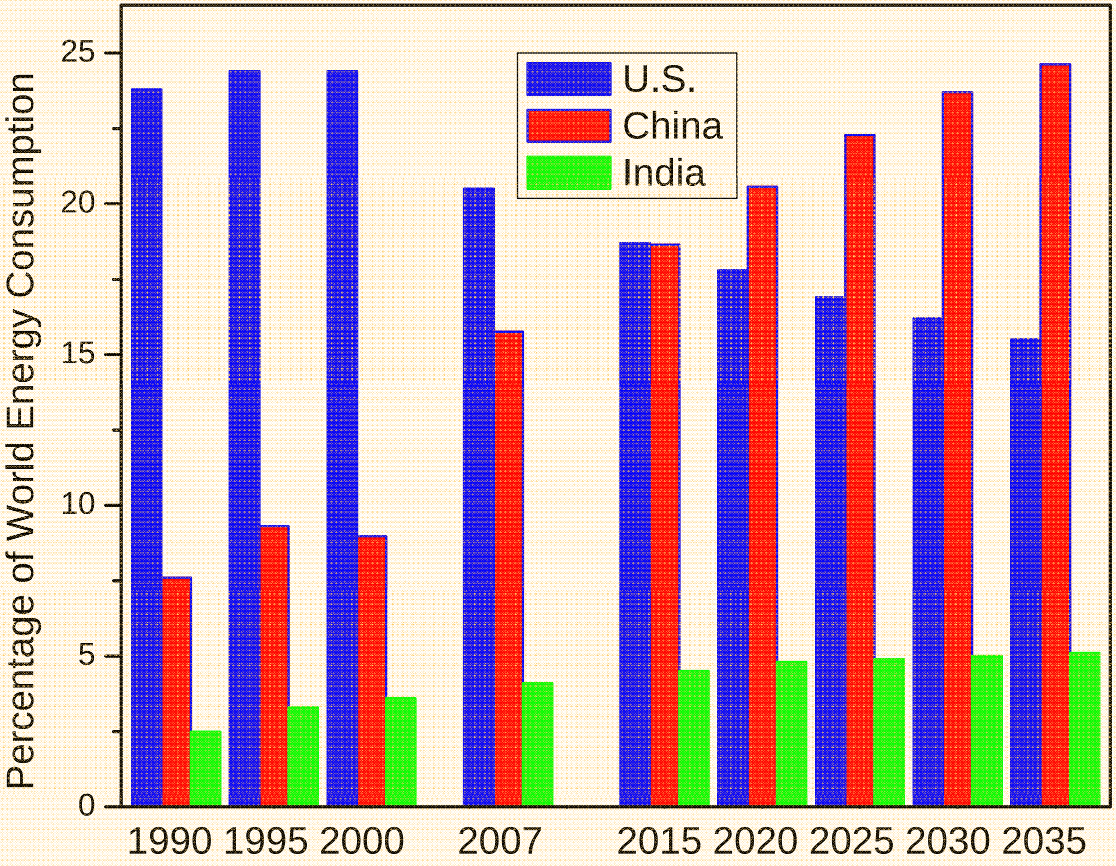
- **Oil supplies are dwindling**
  - Special problem for transportation sector (need alternative fuel)

Global Economics and Energy



Total Projected Energy Use for Selected Countries

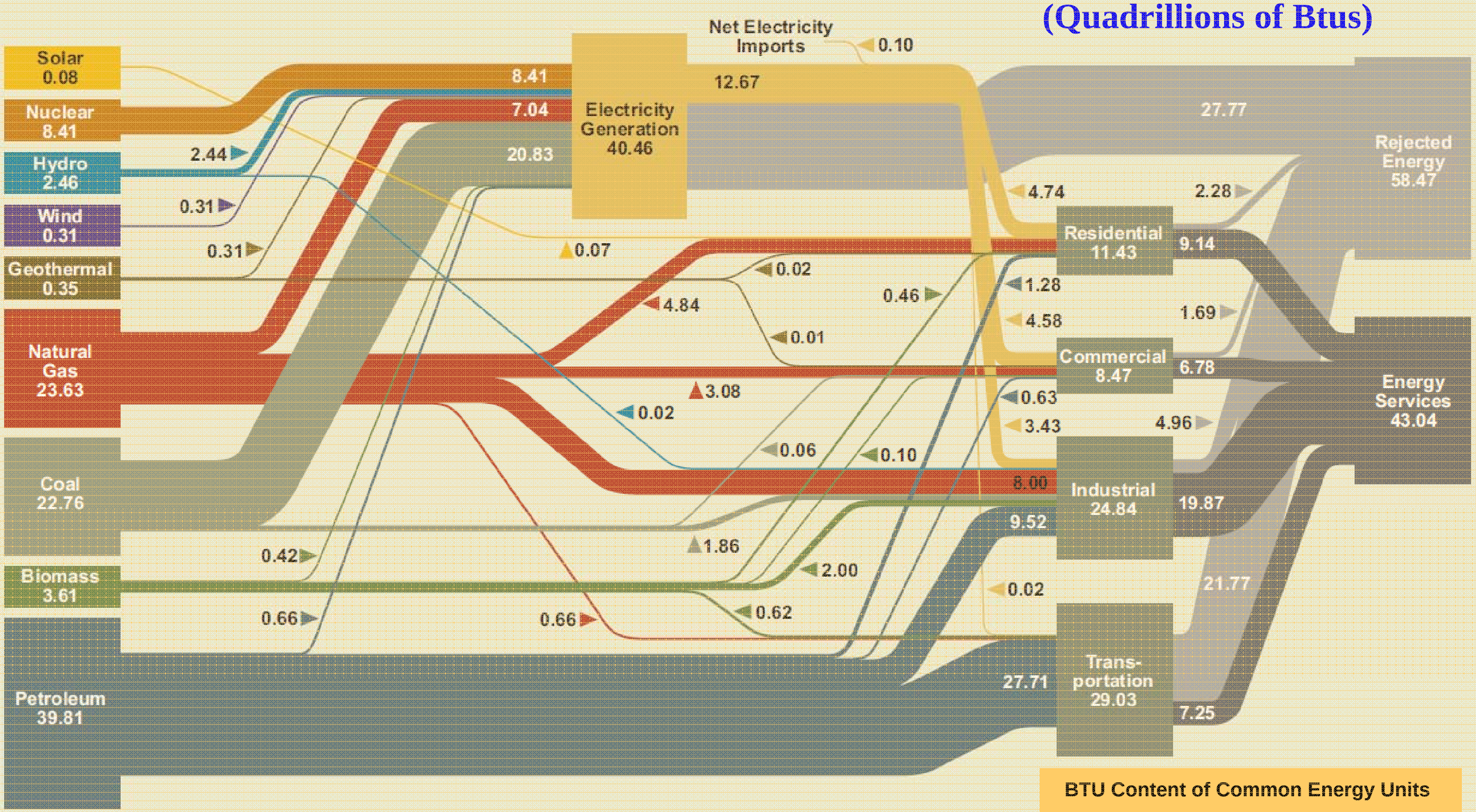
U.S. and China energy use will be the same in 2014



Source: Energy Information Administration, International Energy Outlook 2010

Energy Flows in the U.S. Economy, 2007

(Quadrillions of Btus)

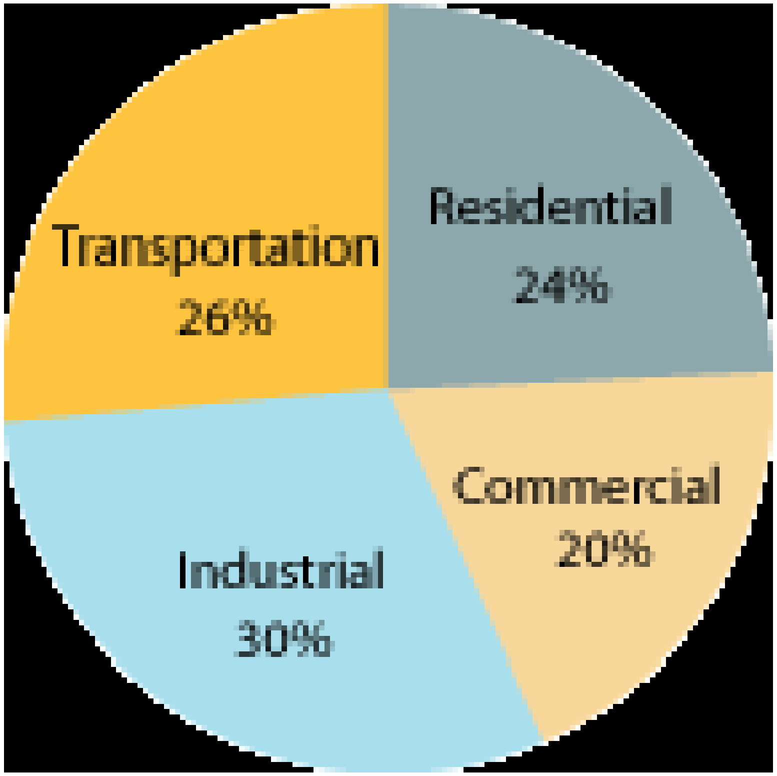


BTU Content of Common Energy Units

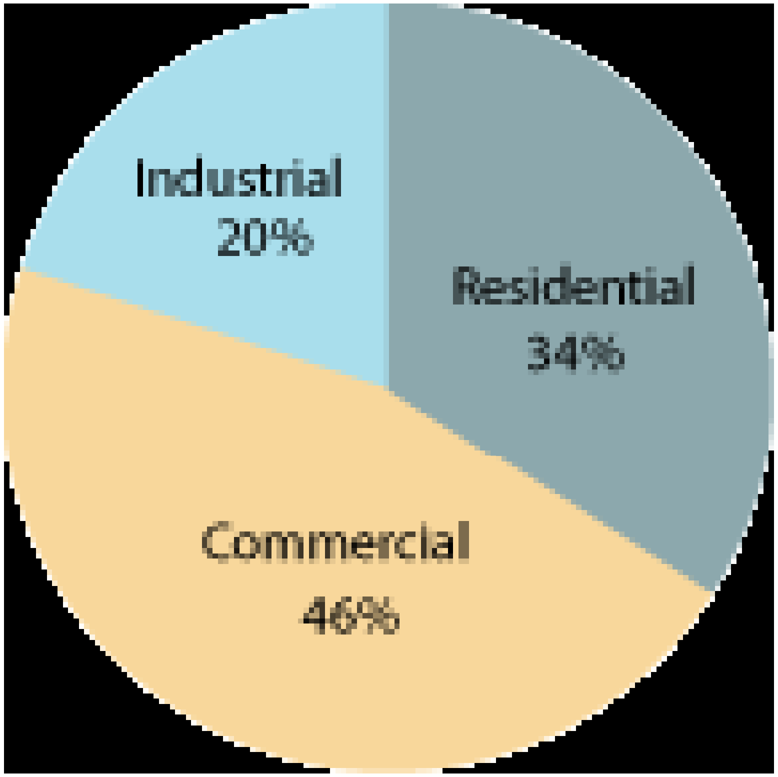
1 Quad = 1,000,000,000,000,000 Btu
1 barrel of crude oil = 5,800,000 Btu
1 gallon of gasoline = 124,000 Btu
1 cubic foot of natural gas = 1,028 Btu
1 short ton of coal = 20,169,000 Btu
1 kilowatthour of electricity = 3,412 Btu

Energy Use by Sector (2000)

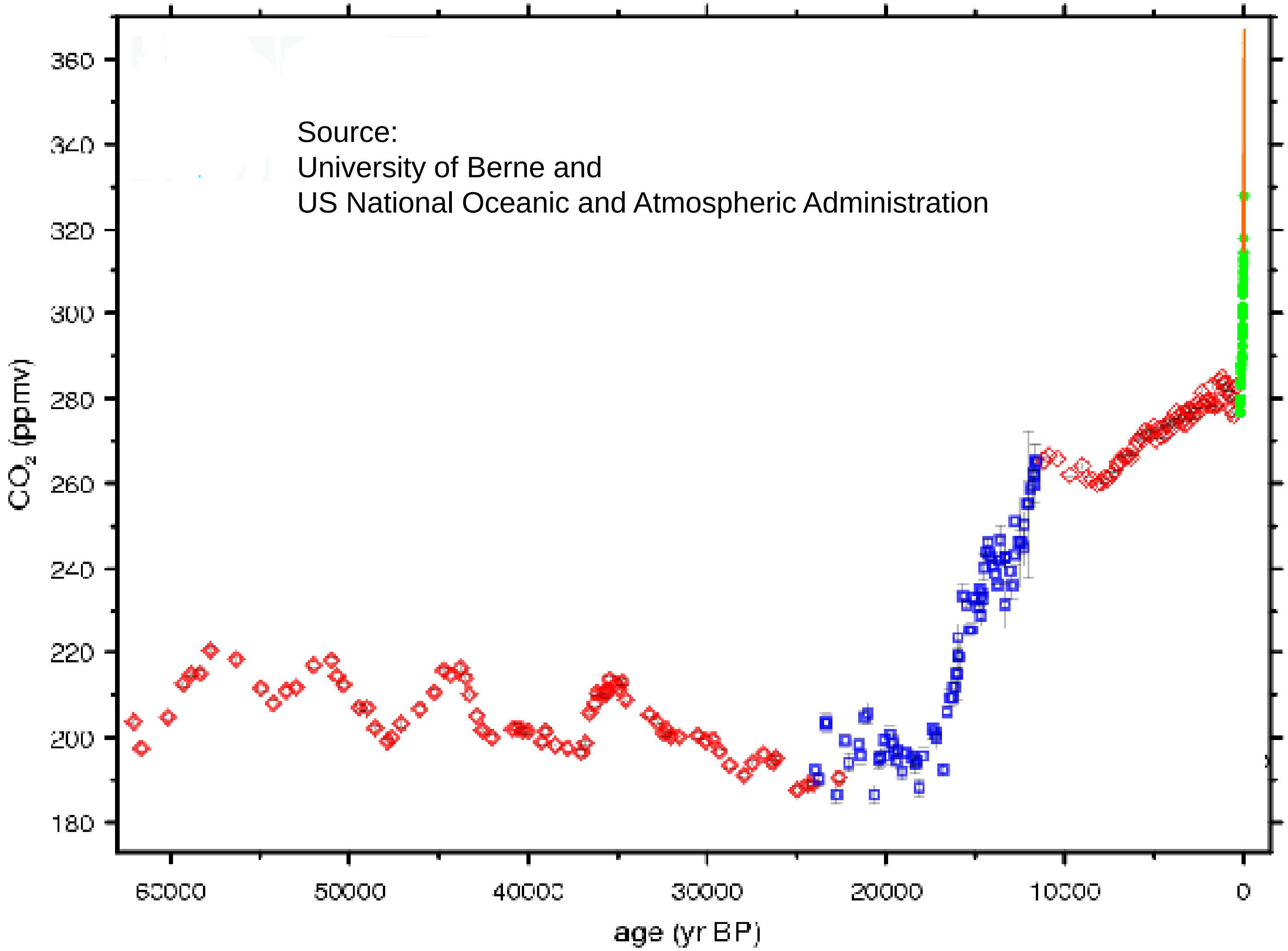
Total Energy



Electricity



Carbon dioxide levels over the last 60,000 years – we are provoking the atmosphere!

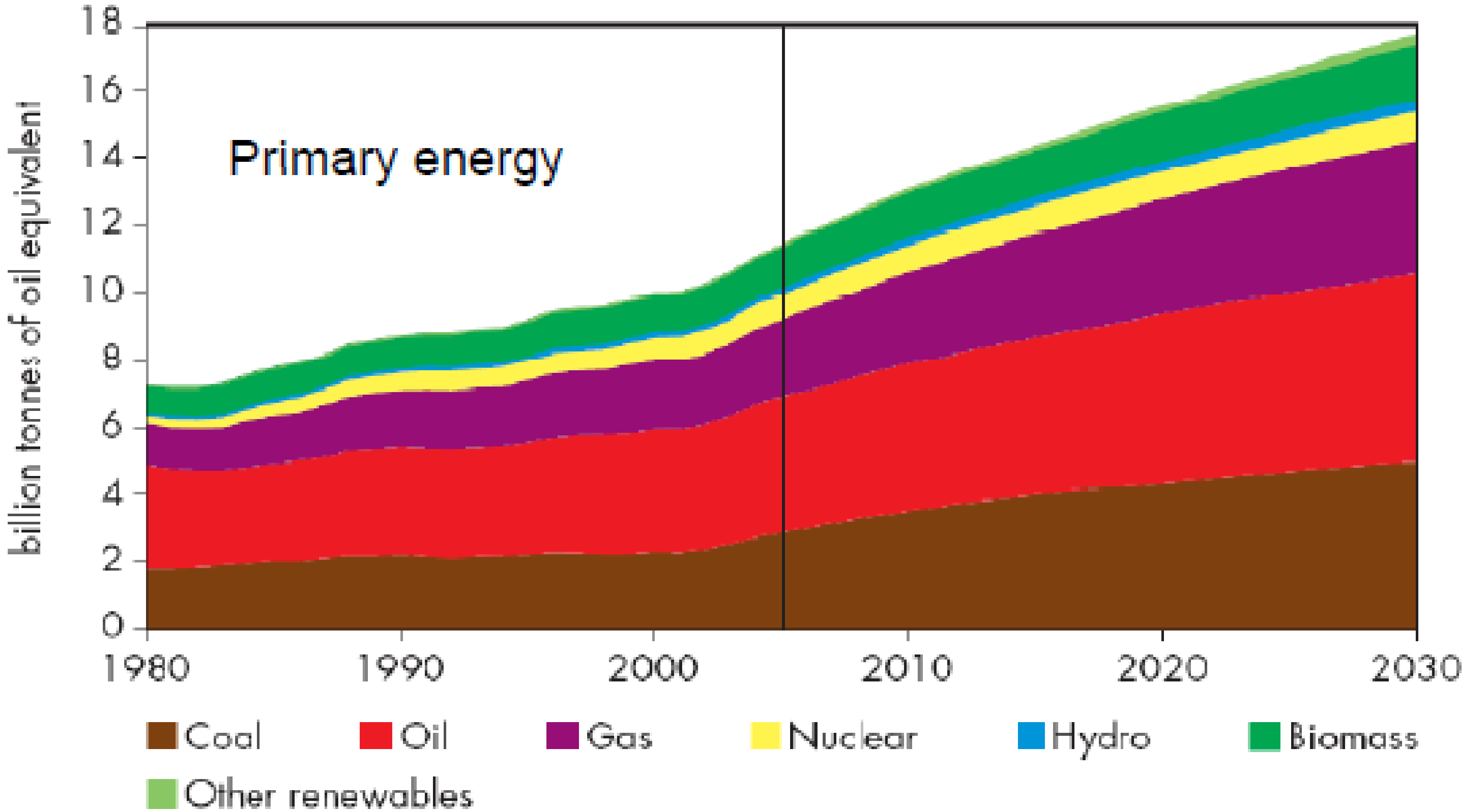


Where we are: energy and fossil CO_2 in 2008

	population (millions)	ppp-GDP (trillion $)	energy (EJ)	fossil E (percent)	fossil CO_2 (MtC)
World	6692	69.7	545	82%	8390
China	1326	7.9	99	85%	1910
USA	304	14.2	105	86%	1670
Russia	142	2.3	30	91%	440
India	1140	3.4	29	64%	390

World Bank 2009, BP 2009

Where we're headed under BAU: by 2030, energy +60%, electricity +75%, continued fossil dominance



WEO 2007

What is problematic about this future ?

The problem is <u>not</u> "running out" of energy

Some mid-range estimates of world energy resources. Units are terawatt-years (TWy). Current world energy use is ~17 TWy/year.

OIL & GAS, CONVENTIONAL	**1,000**
UNCONVENTIONAL OIL & GAS (excluding clathrates)	**2,000**
COAL	**5,000**
METHANE CLATHRATES	**20,000**
OIL SHALE	**30,000**
URANIUM in conventional reactors	**2,000**
…in breeder reactors	**2,000,000**
FUSION (if the technology succeeds)	**250,000,000,000**
RENEWABLE ENERGY (available energy <u>per year</u>)	
Sunlight on land	**30,000**
Energy in the wind	**2,000**
Energy captured by photosynthesis	**120**

From J. Holdren, OSTP

Real problems: the economic, environmental, and security risks of fossil-fuel dependence

- Coal burning for electricity & industry and oil burning in vehicles are main sources of severe urban and regional air pollution – SO_x, NO_x, hydrocarbons, soot – with big impacts on public health, acid precipitation.

- Emissions of CO_2 from *all* fossil-fuel burning are largest driver of global climate disruption, already associated with increasing harm to human well-being and rapidly becoming more severe.
- Increasing dependence on imported oil & natural gas means economic vulnerability, as well as international tensions and potential for conflict over access & terms.

Real problems: Alternatives to conventional fossil fuels all have liabilities & limitations

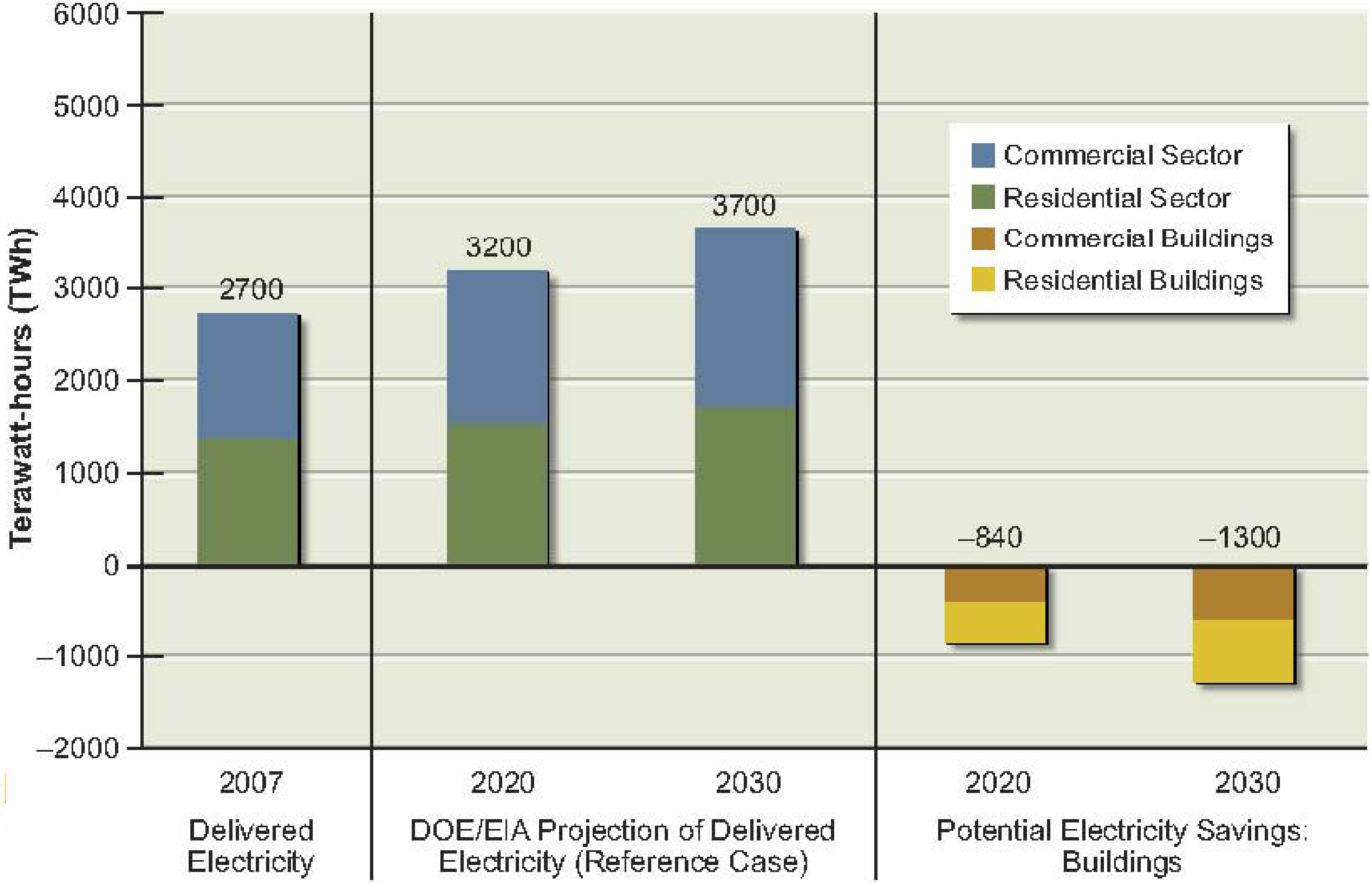
- Traditional biofuels (fuelwood, charcoal, crop wastes, dung) create huge indoor air-pollution hazard
- Industrial biofuels (ethanol, biodiesel) can take land from forests & food production, increase food prices
- Hydropower and wind are limited by availability of suitable locations, conflicts over siting
- Solar energy is costly and intermittent
- Nuclear fission has large requirements for capital & highly trained personnel, currently lacks agreed solutions for radioactive waste & links to nuclear weaponry
- Nuclear fusion doesn't work yet
- Coal-to-gas and coal-to-liquids to reduce oil & gas imports doubles CO_2 emissions per GJ of delivered fuel
- Increasing end-use efficiency needs consumer education

Solving the Energy Problem and Reducing Greenhouse Gas Emission Requires Pursuing a Diversified Portfolio Approach

- Improve energy efficiency
- Expand use of existing "clean" energy sources (e.g. nuclear and renewable sources – solar, wind, etc.)
- Develop technologies to reduce impact of fossil fuels use (e.g. carbon capture and sequestration)
- Develop major new (clean) energy sources (e.g. fusion)
- Develop alternate (synthetic) fuels and electrical energy storage for transportation

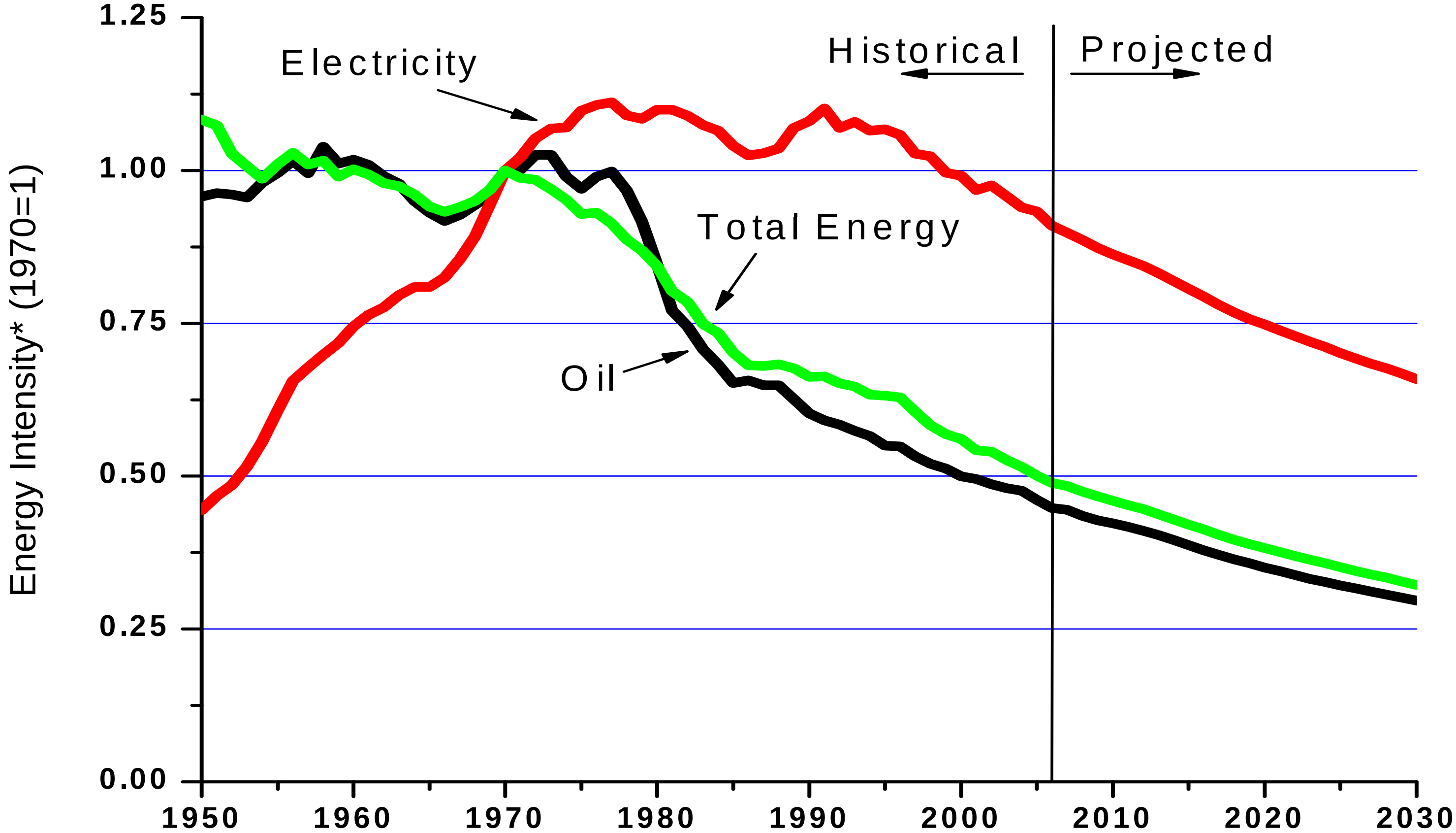
Potential for Increasing Energy Efficiency is Enormous

Potential Electricity Savings in Commercial and Residential Buildings in 2020 and 2030 (currently 73% of electricity used in US – space heating and cooling, water heating, and lighting)



Energy Intensity* (efficiency) of the U.S. Economy Relative to 1970 levels

***Energy consumed per dollar GDP**



*Energy consumed per dollar GDP (2000 constant dollars)
Source: Based on EIA, 2006

Renewable Energy Resources

Top Countries with Installed Renewable Electricity by Technology (2009)

Geothermal
1 U.S.
2 Philippines
3 Indonesia
4 Mexico
5 Italy

Wind
1 U.S.
2 China
3 Germany
4 Spain
5 India

Solar PV
1 Germany
2 Spain
3 Japan
4 U.S.
5 Italy

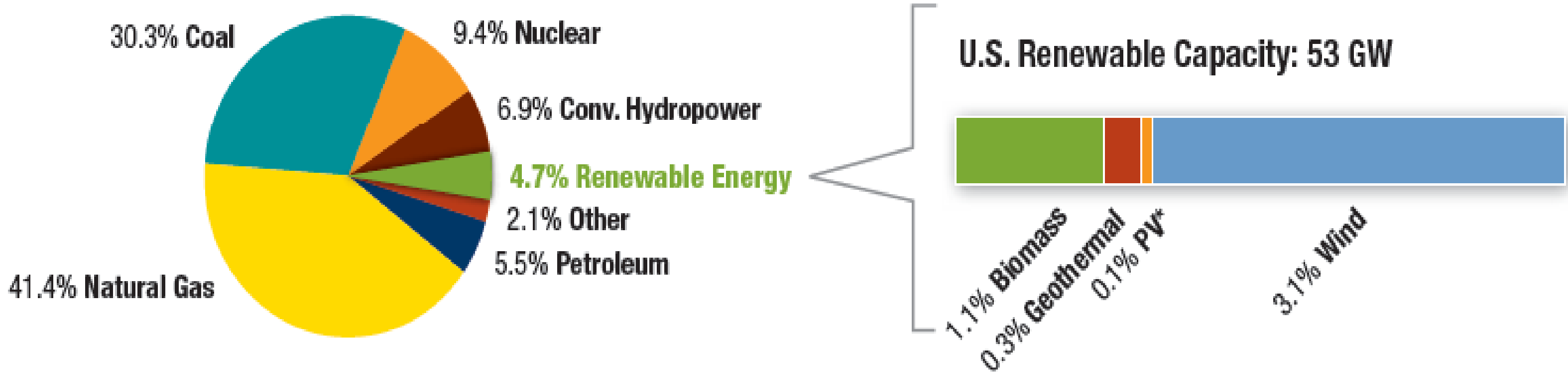
CSP
1 U.S.
2 Spain

Biomass
1 U.S.
2 Brazil
3 Germany
4 China
5 Sweden

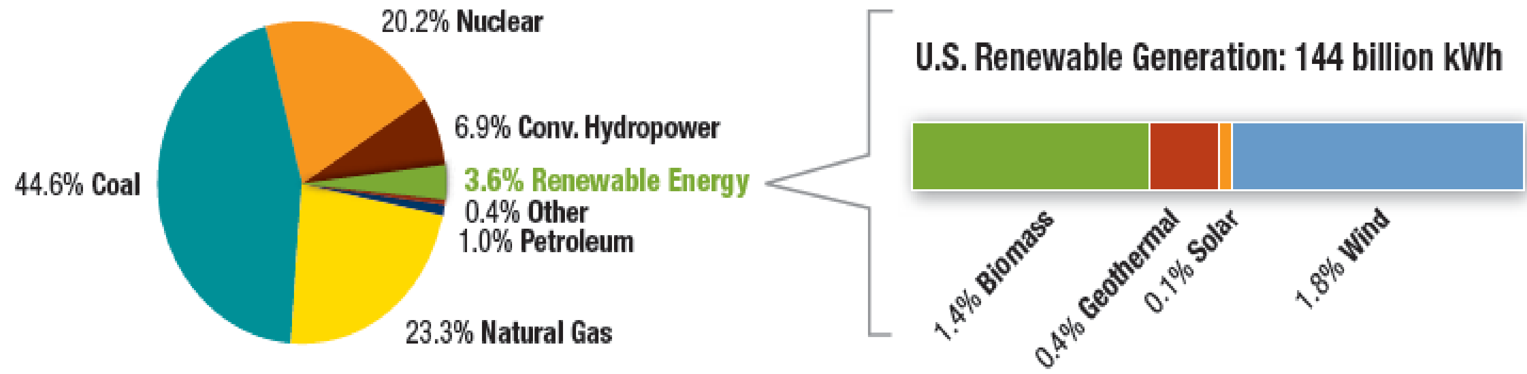
Source: REN21, GWEC, GEA, SEIA

U.S. Nameplate Capacity and Generation (2009)

U.S. Electric Nameplate Capacity (2009): 1,121 GW



U.S. Electric Net Generation (2009): 3,954 billion kWh

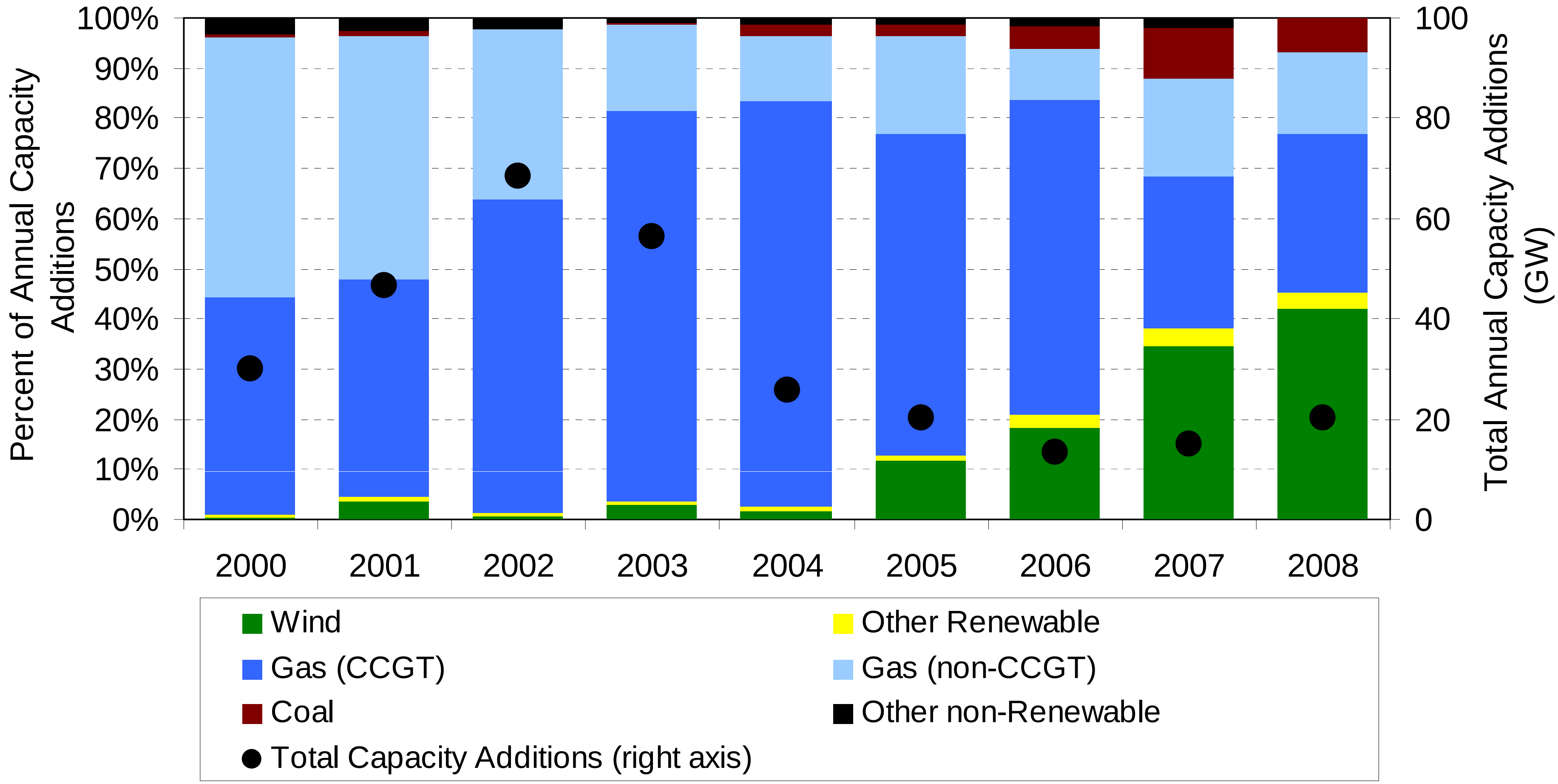


Source: EIA, AWEA, SEIA, GEA

Other includes: pumped storage, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, tire-derived fuels, and miscellaneous technologies.

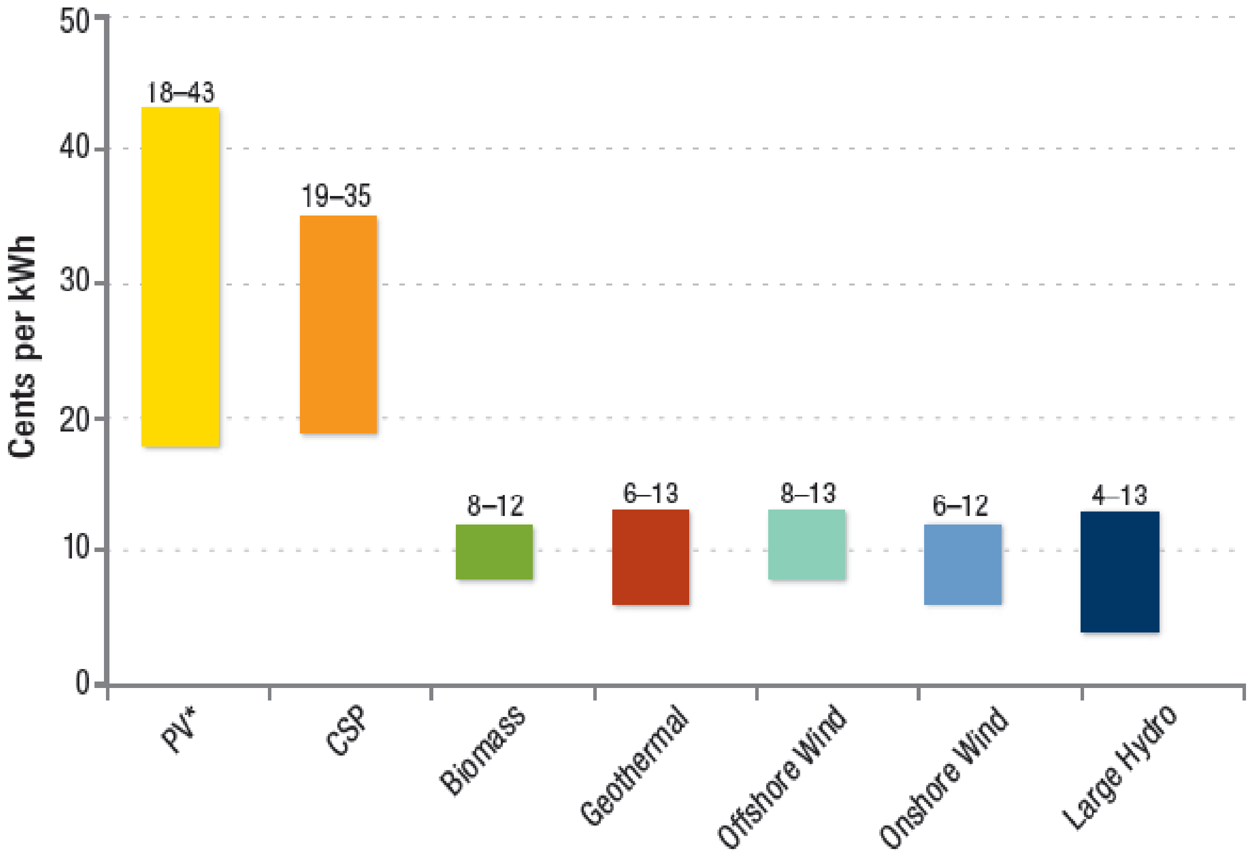
* Includes on- and off-grid capacity.

Status of Renewable Electricity Technologies



Renewable energy has been contributing to a growing portion of U.S. electric capacity additions (45% in 2008)

Levelized Cost of Energy (LCOE) of Renewable Electricity by Technology (2009)



Assumptions

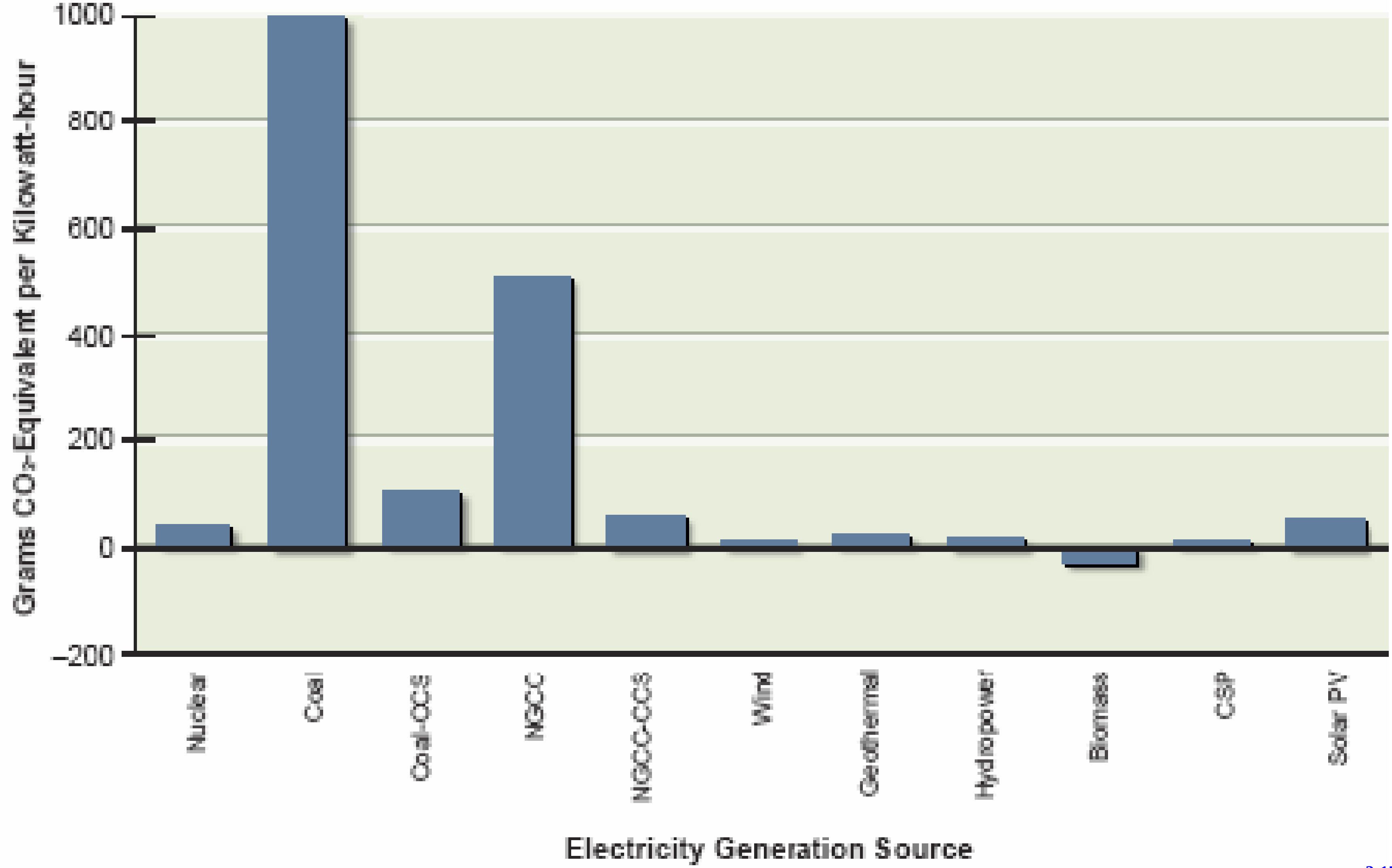
Currency: 2009 US $ (real)
Real Discount Rate: 10.5%
Inflation Rate: 3%
Economic Lifetime: 30 years
Taxes: none
Tax credits: none
Debt/Equity Financing: none
Biomass Fuel Costs: AEO 2009
PV Degradation: none
CSP Technology: no storage
Geothermal Technology: hydrothermal

* Current range of utility scale (greater than 5MW) PV in the U.S.

Sources: AEO, EPA, EPRI, NREL, McGowin, DeMeo et al.

Estimated Greenhouse Gas Emissions from Electricity Generation

Nuclear and Renewable Energy Sources are essential to addressing Climate Change



2-15

Nuclear Fission

Nuclear Renaissance

Internationally, there are ongoing plans for nuclear energy expansion (Nuclear Renaissance)

- **Worldwide**: About 440 fission power plants totaling 375 GWe of capacity in 33 countries. Additionally,60 more reactors with~55 GWe currently under construction.

  - *about 350 of the 440 reactors are light-water reactors (LWRs). The rest are heavy-water reactors, gas cooled reactors, and graphite-moderated light-water reactors*.

- **US** has currently 104 nuclear power plants. As of 1 October 2010: 1 more under construction and 9 additional are planned

- **China** has the most aggressive program

  -- China's nuclear energy plan
  - Present: 6.1 GWe
  - 2020: 32 GWe
  - 2050: 240 Gwe

  -- China's fast reactor plans
  - Experimental: 25MWe (2006)
  - Prototype:300-600 MWe(2020)
  - Large: 1000-1500 MWe (2025)

But managing nuclear materials and proliferation is becoming increasingly complex, requiring a modernized international approach.

Impressive Improvements in Economics of Nuclear Power in Existing Fission Power Plants

- Incremental improvements enabled currently operating fission power plants to produce more energy than anticipated over their lifetimes. **The average plant capacity factor increased** from 66% in 1990 to **91.8%** in 2007.

- From Australian National Affairs Article:

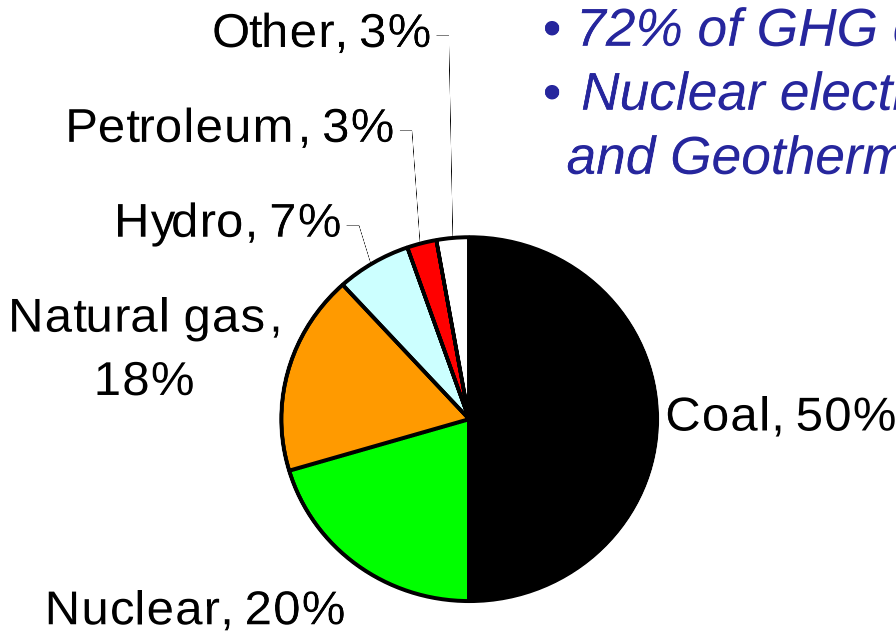
The standout technology, from a cost perspective, is nuclear power. From the eight nuclear cost studies we reviewed (all published in the past decade, and adjusted to 2009 dollars), the median cost of electricity from current technology nuclear plants was just above new coal plants with no carbon price. Having the lowest carbon emissions of all the fit-for-service technologies, **nuclear remains the cheapest solution at any carbon price. Importantly, it is the only fit-for-service baseload technology that can deliver the 2050 emission reduction targets…………………………**

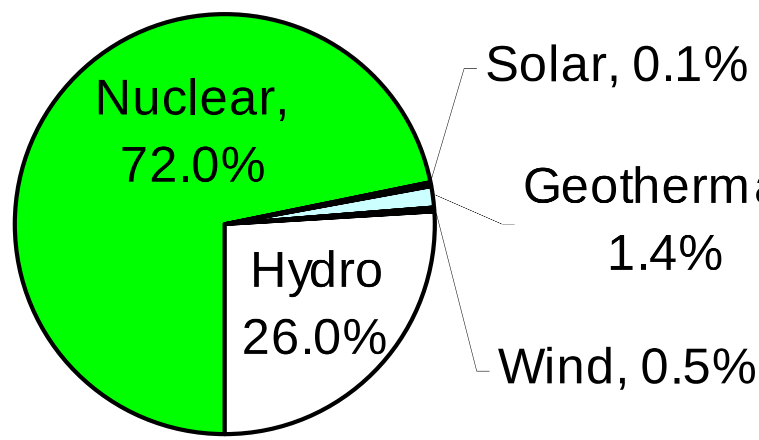
- Also, other improvements in safety and reduced generation of high level waste.

Nuclear Power Must Remain a KEY Part of Our Energy Portfolio

Nuclear is the second largest source of U.S. electricity

- *20 % of electricity generation*
- *72% of GHG emission-free electricity*
- *Nuclear electricity is10 times more than Solar, Wind and Geothermal combined*





Nuclear energy is the dominant non-fossil energy technology

Evolution of Nuclear Power

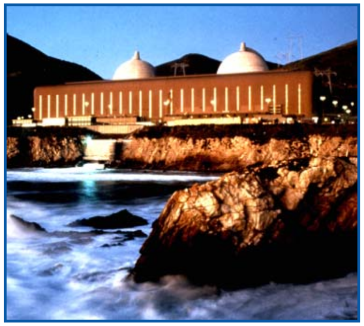
Generation I

Early Prototype Reactors

- Shippingport
- Dresden
- Fermi I
- Magnox

Generation II

Commercial Power Reactors



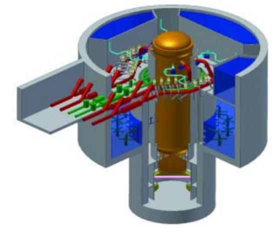
- LWR-PWR, BWR
- CANDU
- VVER/RBMK

Generation III

Advanced LWRs

- ABWR
- System 80+
- AP600
- EPR

Generation III+

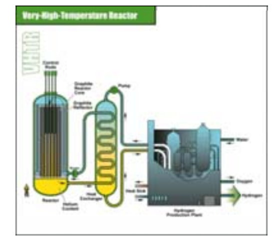


Near-Term Deployment

- AP1000
- PBMR
- SWR-1000
- ABWR-II

Evolutionary Improved Economics

Generation IV



- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant

Gen I	Gen II	Gen III	Gen III+	Gen IV

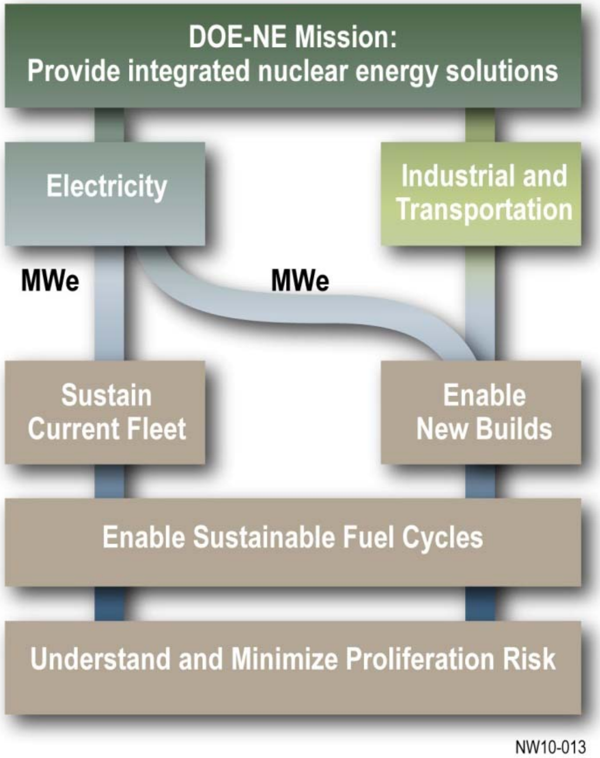
1950 1960 1970 1980 1990 2000 2010 2020 2030

1. U.S. Department of Energy Gen-IV Roadmap Report

U.S. DEPARTMENT OF ENERGY

Current Nuclear Energy Research Objectives

- **Extend life of currently operating plants**
  - **Goal is to extend currently operating LWRs plant life from design life (40 years) to beyond 60 years**
- **Enable new builds for electricity and process heat production and improve the affordability of nuclear energy-**
  - Develop and demonstrate next generation advanced plant concepts and technologies
- **Enable sustainable fuel cycles**
  - high burnup fuel
  - Develop optimized systems that maximize energy production while minimizing waste
- **Understand and minimize proliferation risks**
  - Goal is limiting proliferation and security threats by protecting materials, facilities, sensitive technologies and expertise



An implementation plan has been developed for each objective

CREATING a Star on Earth
Fusion: The Ultimate Energy Source for Humanity

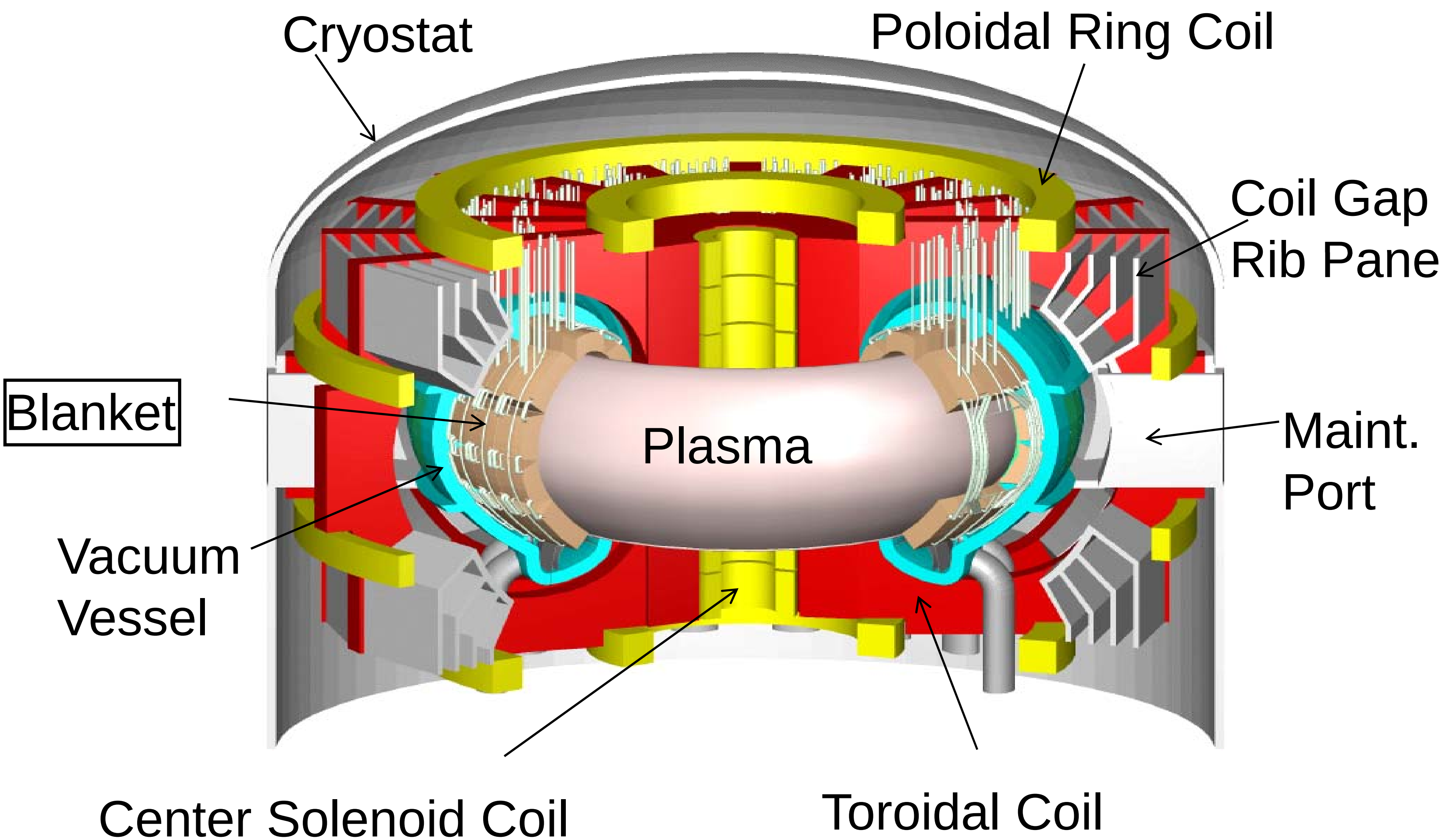
Incentives for Developing Fusion

- Sustainable energy source
  (for DT cycle: provided that Breeding Blankets are successfully developed and tritium self-sufficiency conditions are satisfied)
- No emission of Greenhouse or other polluting gases
- No risk of a severe accident
- No long-lived radioactive waste

Fusion energy can be used to produce electricity and hydrogen, and for desalination.

The World Fusion Program has a Goal for a Demonstration Power Plant (DEMO) by ~2040(?)

Plans for DEMO are based on Tokamaks



(Illustration is from JAEA DEMO Design)

"The Time to Fusion is always 40 years away" and "expanding"

Recent remarks from key influential people (Implications and What to Do: Oral Remarks)

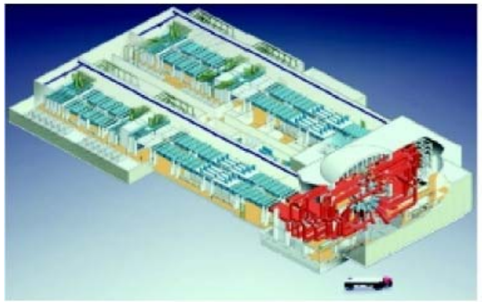
The problem with fusion is that it is not being developed fast enough (taking too long!)

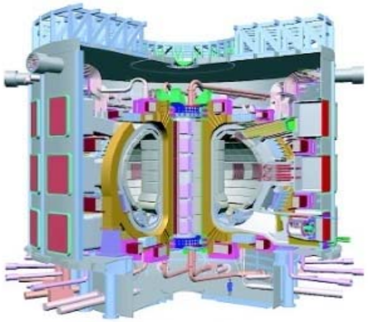
Launching an aggressive FNST Program NOW
is essential to realizing fusion in the 21st Century

ITER

- The World has started construction of the **next step** in fusion development, a device called ITER.
- ITER will demonstrate the **scientific and technological feasibility** of fusion energy
- ITER will produce **500 MW** of fusion power.
- Cost, including R&D, is ~15 billion dollars.
- **ITER is a collaborative effort among Europe, Japan, US, Russia, China, South Korea, and India. ITER construction site is Cadarache, France.**
- ITER will begin operation in hydrogen in ~2019. **First D-T Burning Plasma in ITER in ~ 2027.**
- **Challenges: delayed schedule, increased cost, reduced mission**

Fusion Research is about to transition from Plasma Physics to Fusion Nuclear Science and Engineering


National Ignition Facility


ITER

- **1950-2010**
  - **The Physics of Plasmas**
- **2010-2035**
  - **The Physics of Fusion**
  - **Fusion Plasmas-heated and sustained**
    - **$Q = (E_f / E_{input})$~10**
    - **ITER (MFE) and NIF (inertial fusion)**
- **ITER is a major step forward for fusion research. It will demonstrate:**
  1. **Reactor-grade plasma**
  2. **Plasma-support systems (S.C. magnets, fueling, heating)**

But the most challenging phase of fusion development still lies ahead:
The Development of Fusion Nuclear Science and Technology

The cost of R&D and the time to DEMO and commercialization of fusion energy will be determined largely by FNST.

Closing Remarks

- **Energy plays a critical role in economic development, economic prosperity, national security, and environmental quality**
- **Solving the Energy Problem and Reducing Greenhouse Gas Emission Requires Pursuing a Diversified Portfolio Approach**
- **Key Major Transformations required:**
  - **Efficient use of energy, e.g., buildings (lighting, heating and cooling), cars and trucks, and industry.**
  - **New sources of energy for producing electricity that reduce emissions of CO_2—nuclear, coal with CO_2 removed and stored, solar, wind, and geothermal.**
  - **Transportation fuels that derive from alternatives to petroleum, e.g., liquids from biomass, coal and electricity.**

Closing Remarks (cont'd)

- **Fusion is the most promising long-term energy option**
  - Renewable fuel, no emission of greenhouse gases, no long-term radioactive waste, inherent safety
- But the problem is that fusion is not being developed fast enough. **"The Time to Fusion seems to be always 40 years away" and "expanding"**
- **The most challenging Phase of Fusion development still lies ahead: It is the development of Fusion Nuclear Science and Technology (FNST)**
- ***The cost of R&D and the time to DEMO and commercialization of fusion energy will be determined largely by FNST.***

Fusion research requires the talents of many scientists and engineers in many disciplines. Need to attract and train bright young students and researchers.

References

For References and Additional Reading:

1. Abdou's presentations and publications on: (*http://www.fusion.ucla.edu/abdou/*)

2. UCLA Energy Center *(http://cestar.seas.ucla.edu/)*

3. CEREL *(http://ncseonline.org/cerel/)*

4. Additional Information on the America's Energy Future Effort: *(http://www.nationalacademies.org/energy)*

5. *John P. Holdren, Assistant to the (US) President for Science and Technology, OSTP: http://www.whitehouse.gov/administration/eop/ostp*

Thank You for Your Attention!