

# **Understanding the World's Energy and Environmental Problems and a Diversified Portfolio Approach for solving them**

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# **Understanding the World's Energy and Environmental Problems and a Diversified Portfolio Approach for solving them**

## **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 plans, 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
  - CO2 emission is increasing at an alarming rate
- **Oil supplies are dwindling**
  - Special problem for transportation sector (need alternative fuel)

# Global Economics and Energy

## Population

Billions

10

8

6

4

2

0

1950

1990

2030

Average Growth / Yr.  
2000 - 2030  
0.9%

1.1%

Non-OECD

OECD

0.4%

## GDP

Trillion (2000\$)

80

70

60

50

40

30

20

10

0

1950

1990

2030

2.8%

4.7%

2.2%

## Energy Demand

MBDOE

350

300

250

200

150

100

50

0

1950

1990

2030

1.6%

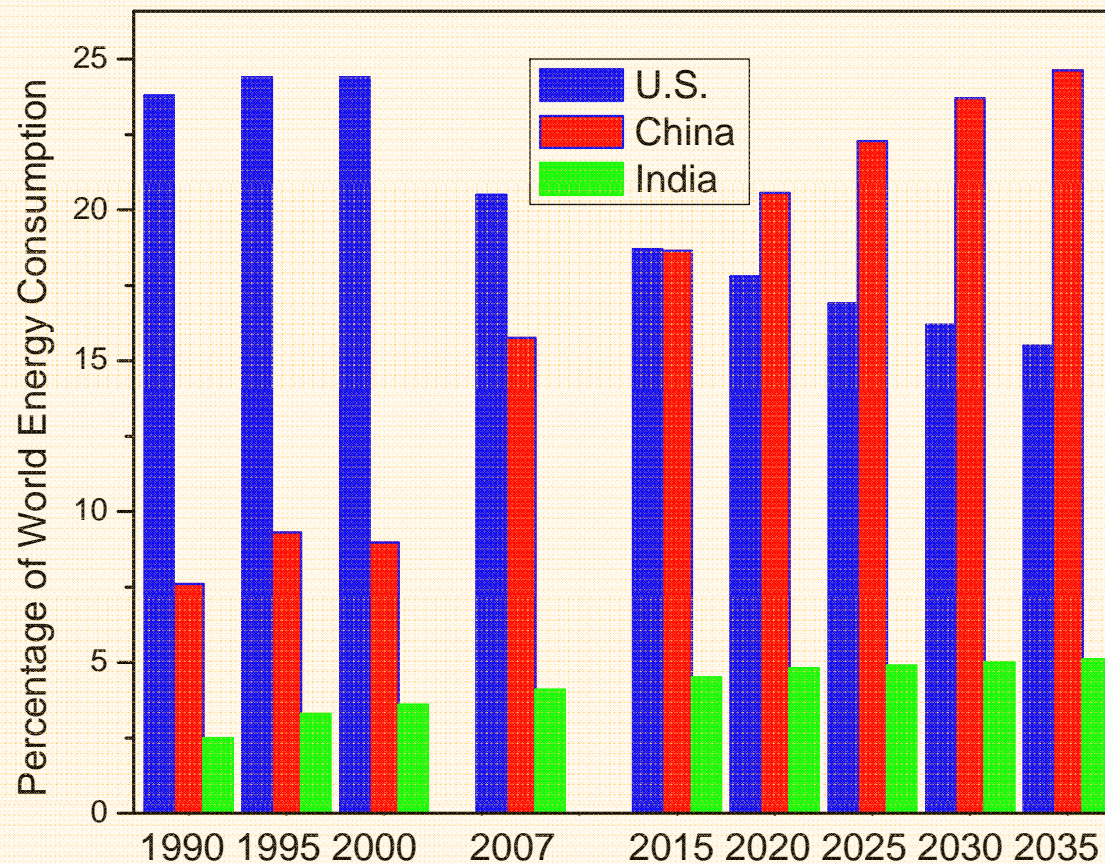
2.4%

0.7%



# Total Projected Energy Use for Selected Countries

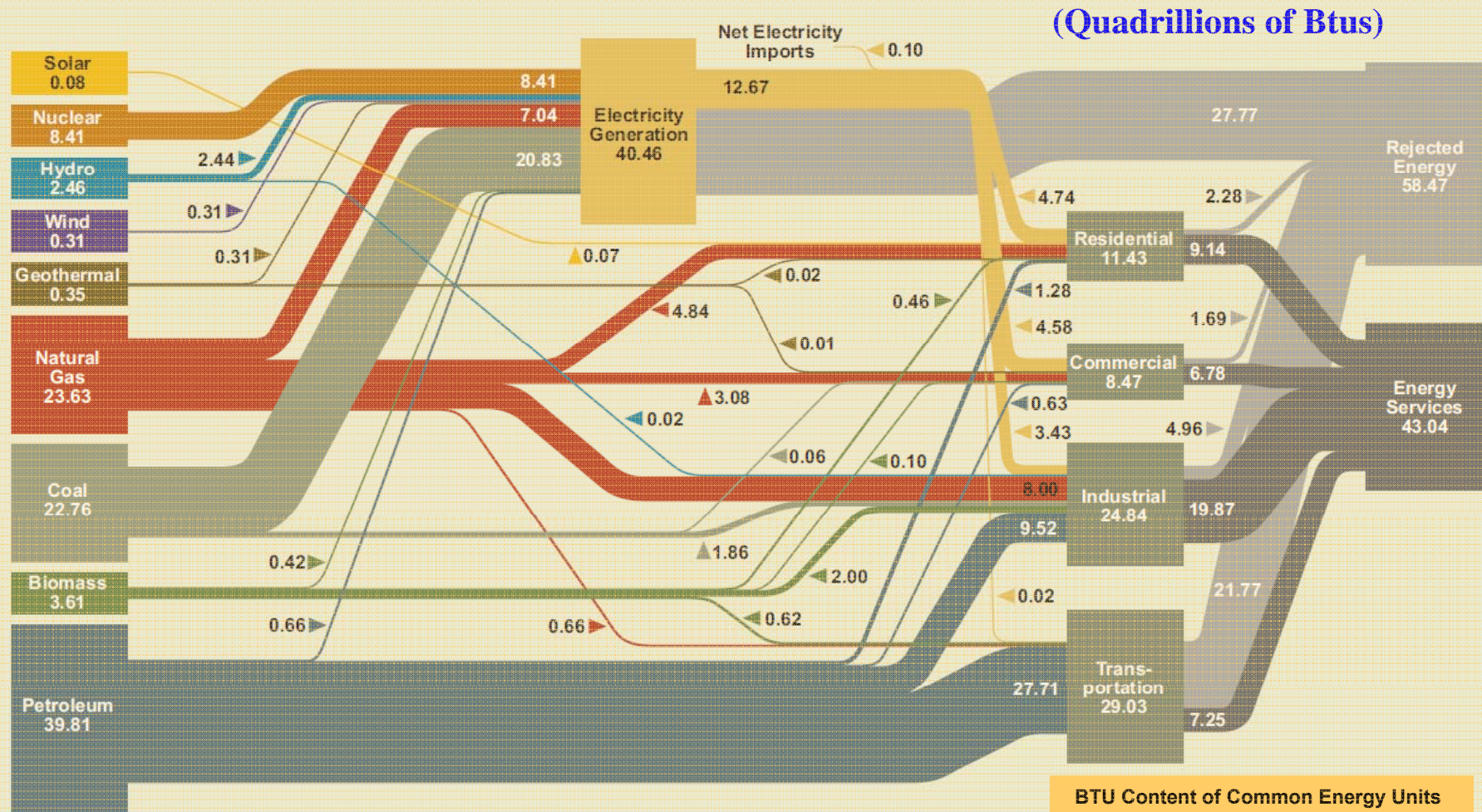
**U.S. and China energy use will be the same in 2014**



Source: Energy Information Administration, International Energy Outlook 2010

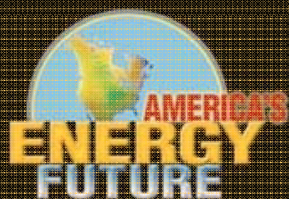


# Energy Flows in the U.S. Economy, 2007



## BTU Content of Common Energy Units

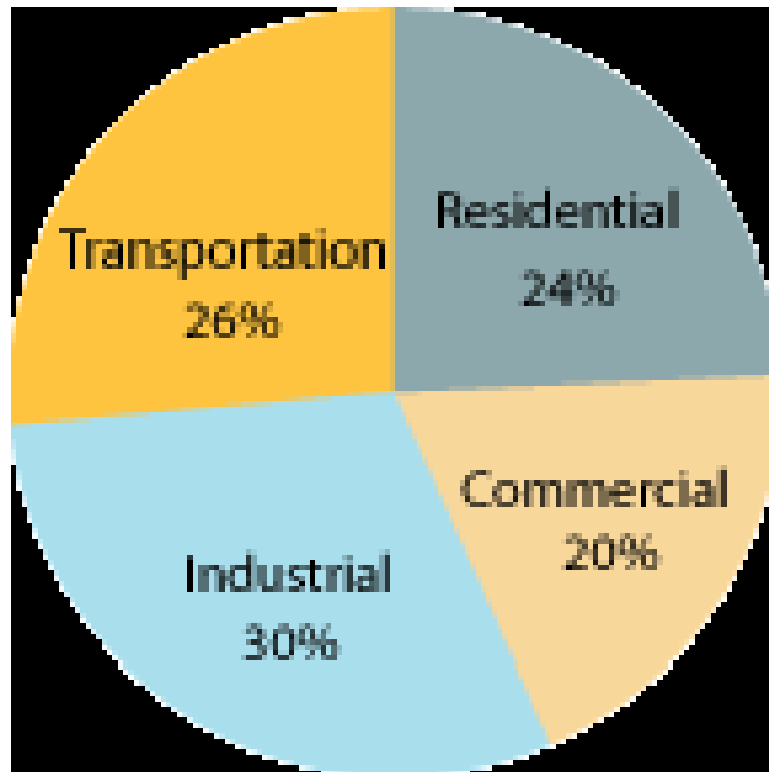
- 1 Quad = 1,000,000,000,000 Btu
- 1 barrel of crude oil = 5,800,000 Btu
- 1 gallon of gasoline = 124,000 Btu
- 1 cubic foot of natural gas = 1,028 Btu
- 1 short ton of coal = 20,169,000 Btu
- 1 kilowatthour of electricity = 3,412 Btu



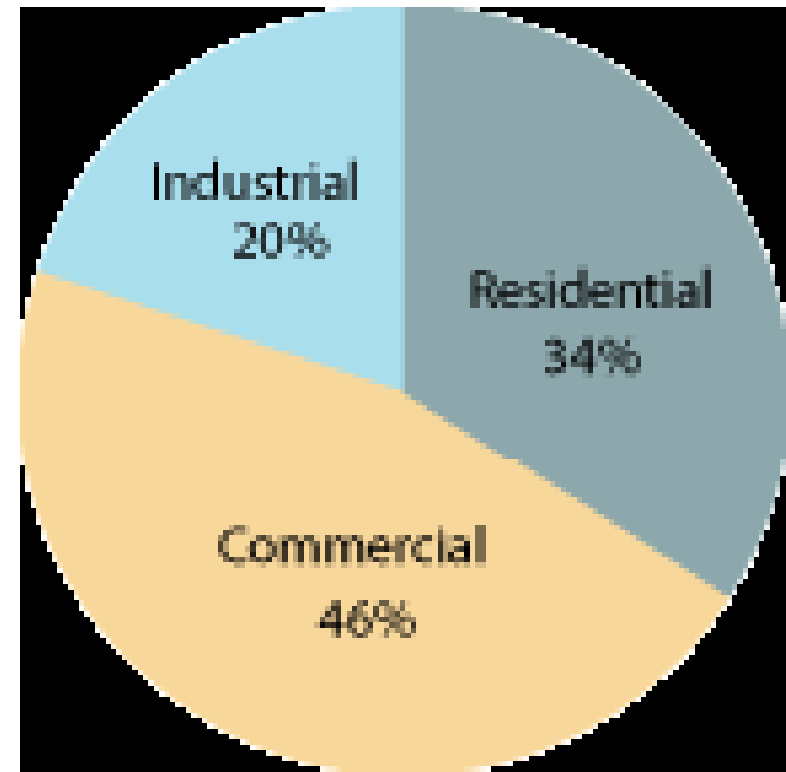


# Energy Use by Sector (2000)

Total Energy



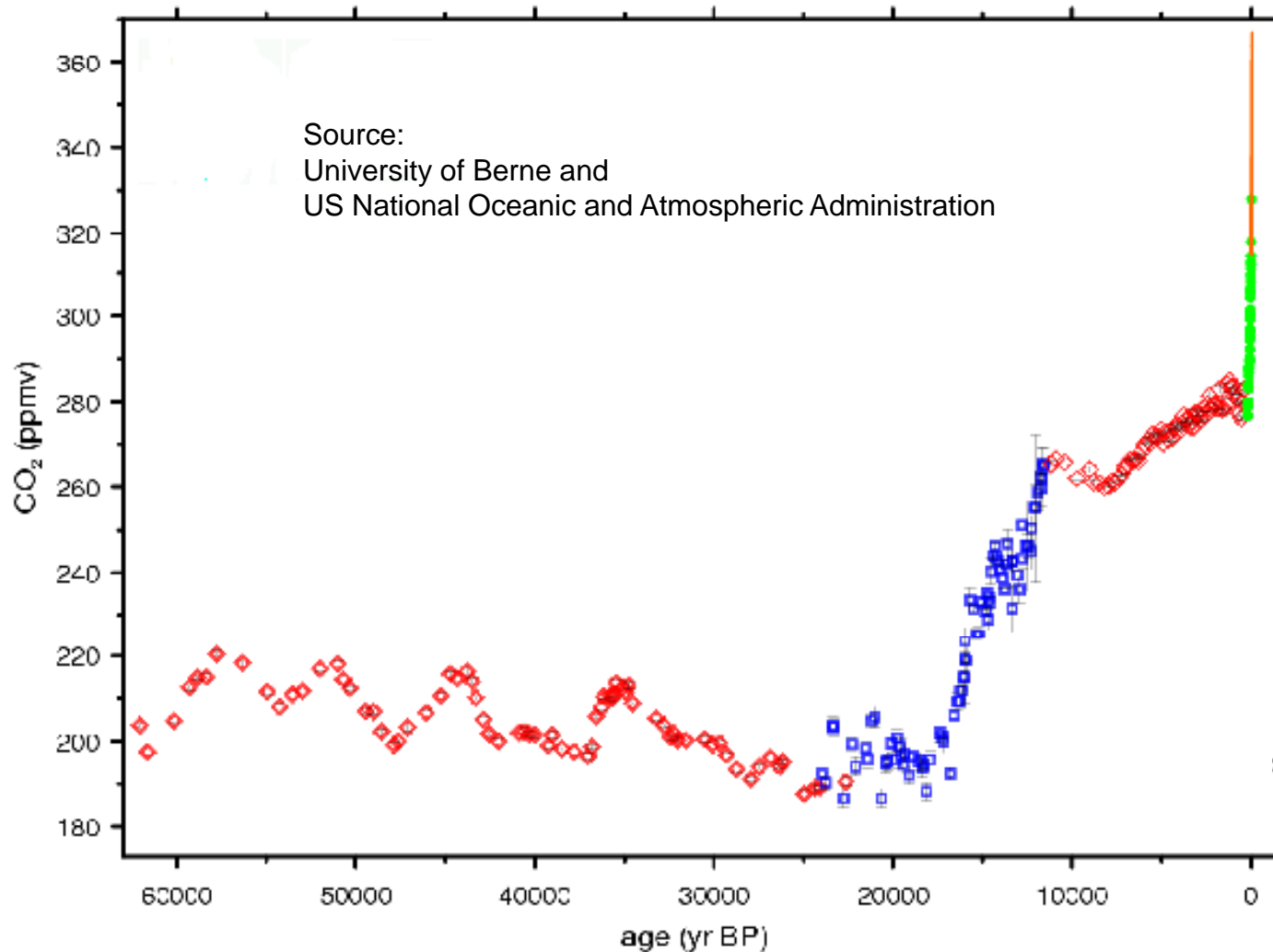
Electricity





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

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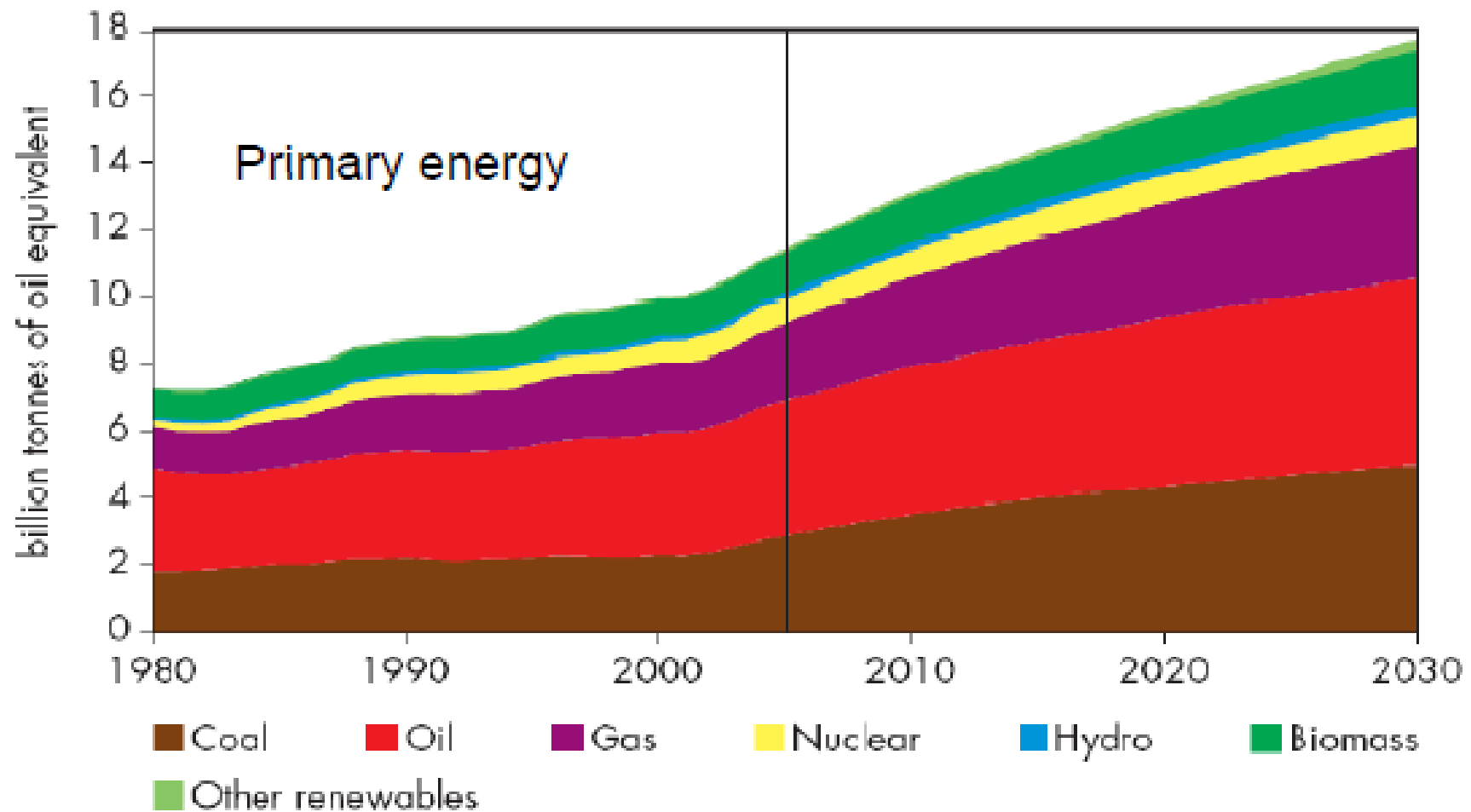


## Where we are: energy and fossil CO<sub>2</sub> in 2008

	population (millions)	ppp-GDP (trillion \$)	energy (EJ)	fossil E (percent)	fossil CO <sub>2</sub> (MtC)
<b>World</b>	6692	69.7	545	82%	8390
<b>China</b>	1326	7.9	99	85%	1910
<b>USA</b>	304	14.2	105	86%	1670
<b>Russia</b>	142	2.3	30	91%	440
<b>India</b>	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 not “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

# 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 –  $\text{SO}_x$ ,  $\text{NO}_x$ , hydrocarbons, soot – with big impacts on public health, acid precipitation.
- Emissions of  $\text{CO}_2$  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<sub>2</sub> emissions per GJ of delivered fuel
- Increasing end-use efficiency needs consumer education

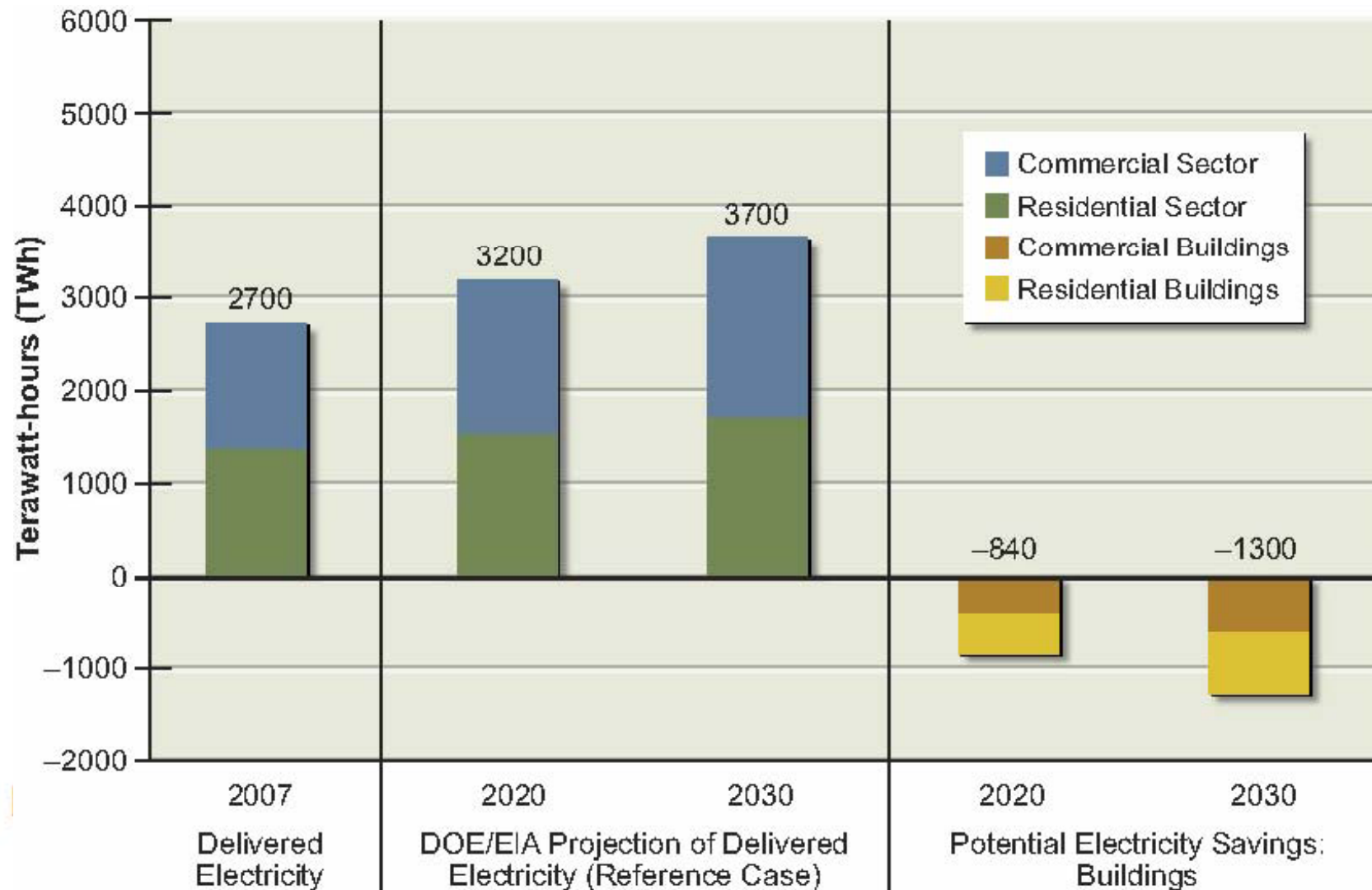
# **Solving the Energy Problem and Reducing Greenhouse Gas Emission Requires Pursuing a Diversified Portfolio Approach**

- 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**

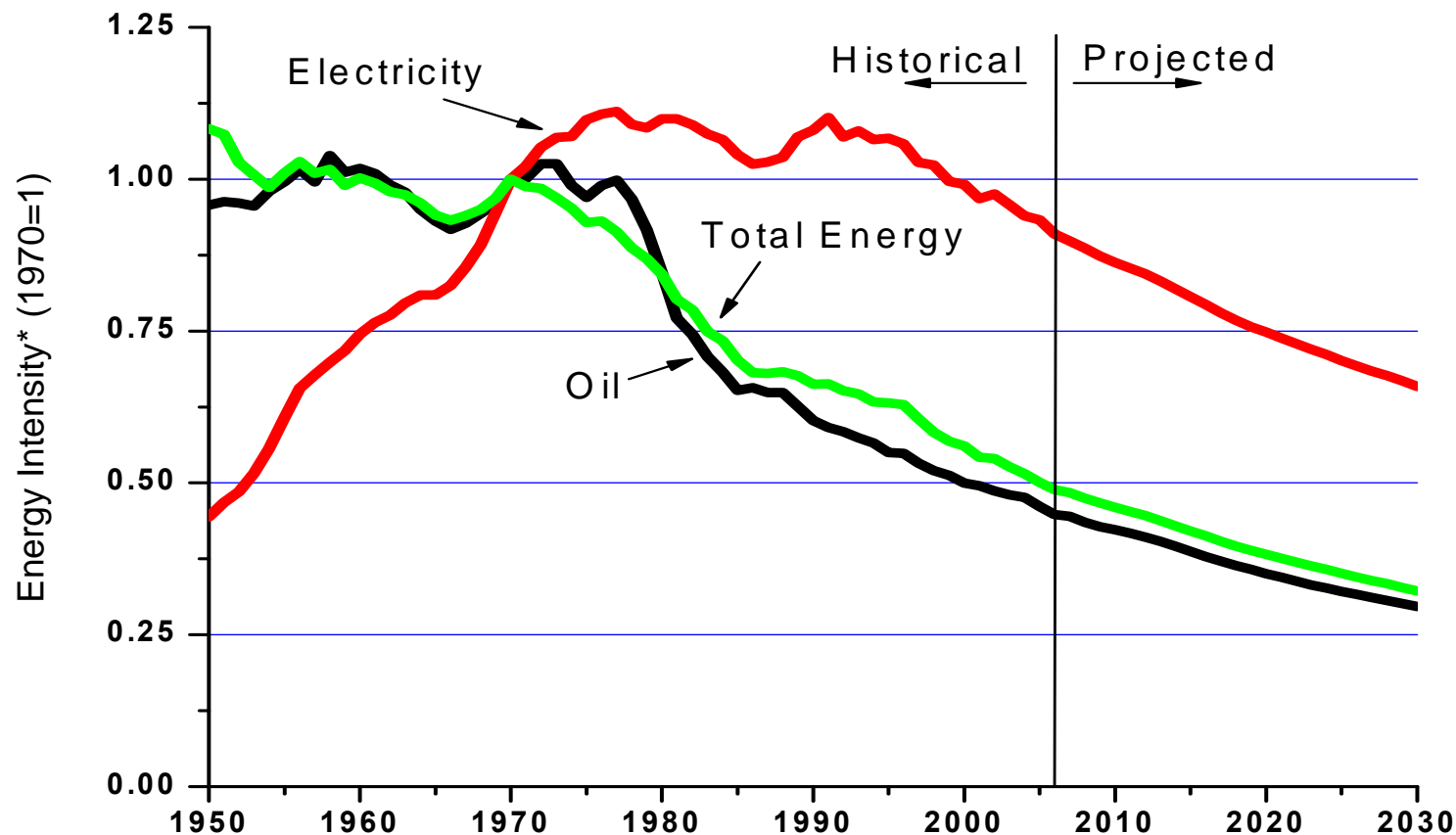


## Potential Electricity Savings in Commercial and Residential Buildings in 2020 and 2030 (currently 73% of electricity used in US – space heating and cooling, water heating, and lighting)



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

\*Energy consumed per dollar GDP

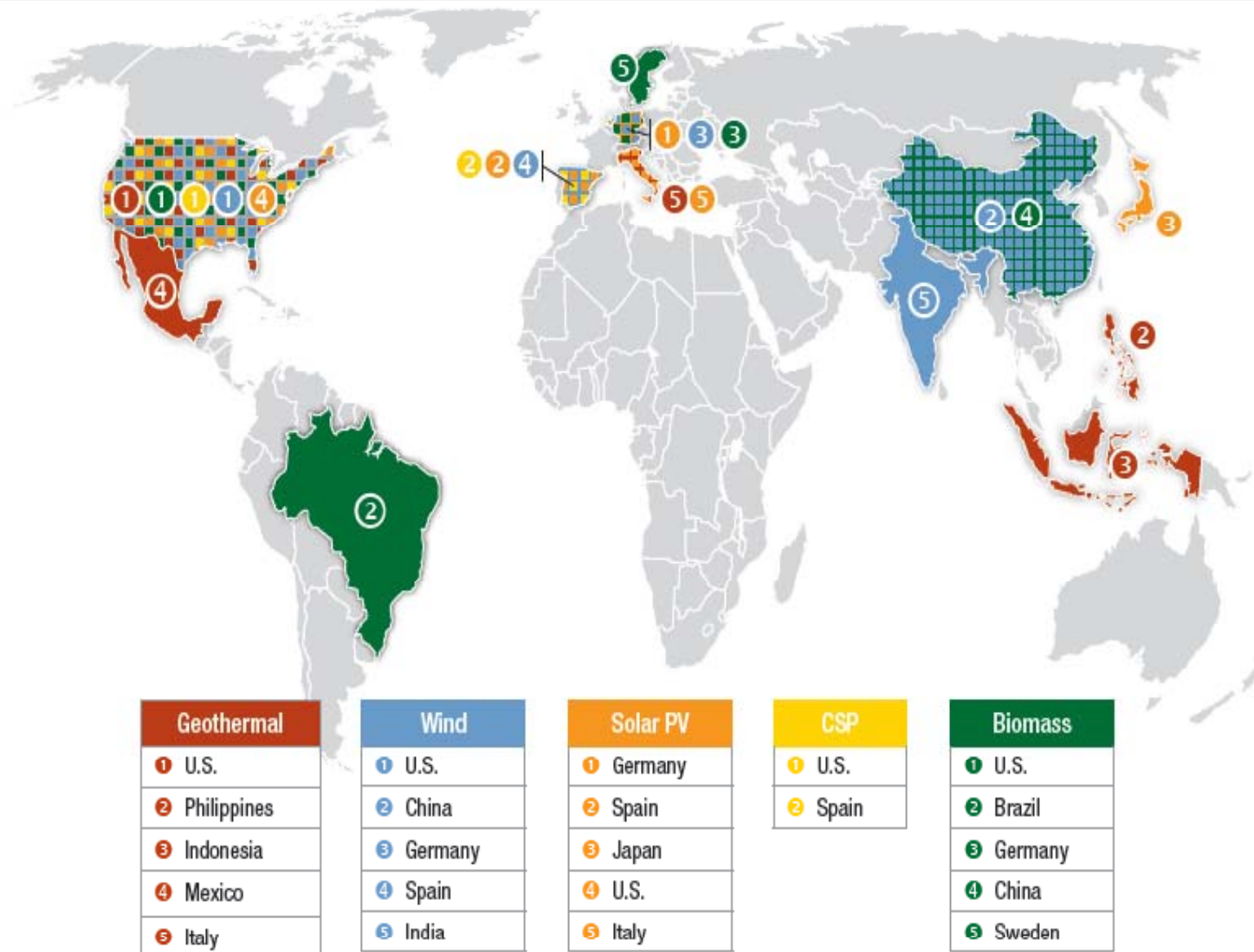


\*Energy consumed per dollar GDP (2000 constant dollars)

Source: Based on EIA, 2006

# Renewable Energy Resources

# Top Countries with Installed Renewable Electricity by Technology (2009)



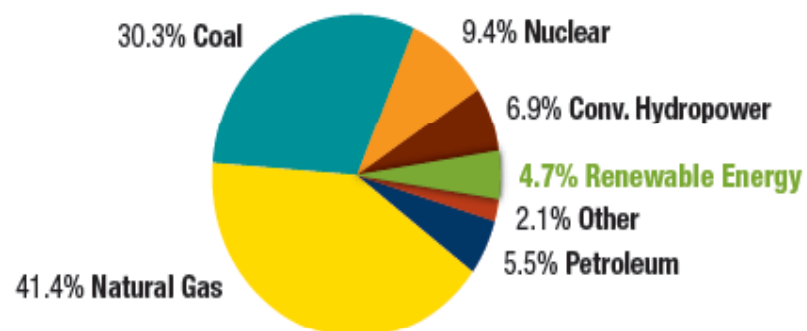
Source: REN21, GWEC, GEA, SEIA

Global Renewable Energy Development | August 2010

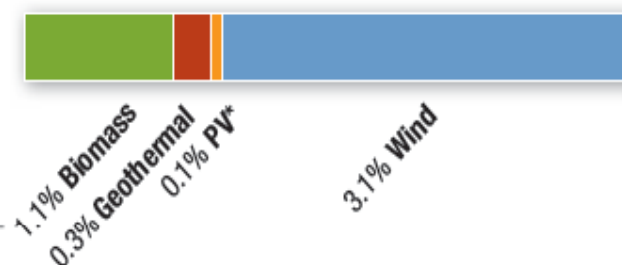


# U.S. Nameplate Capacity and Generation (2009)

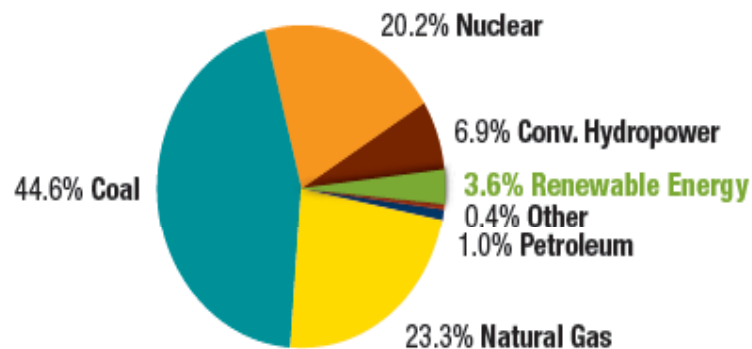
**U.S. Electric Nameplate Capacity (2009): 1,121 GW**



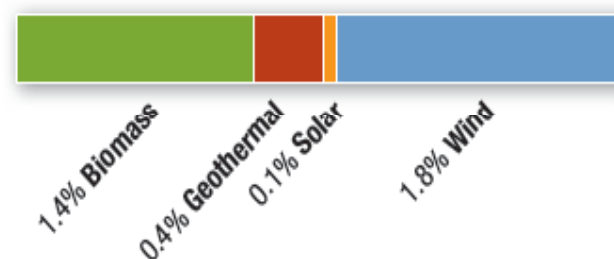
**U.S. Renewable Capacity: 53 GW**



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



**U.S. Renewable Generation: 144 billion kWh**



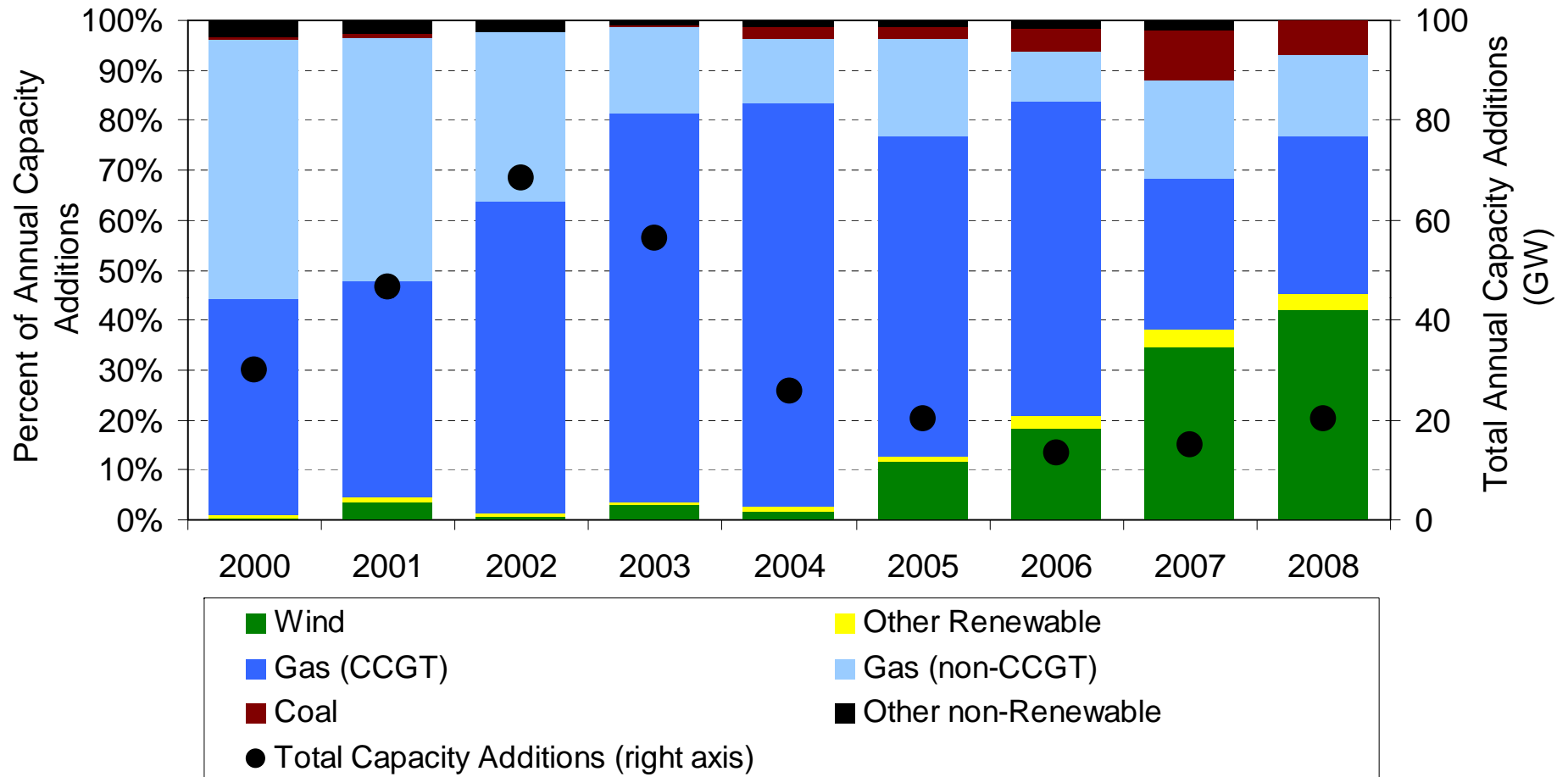
Source: EIA, AWEA, SEIA, GEA

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

\* Includes on- and off-grid capacity.

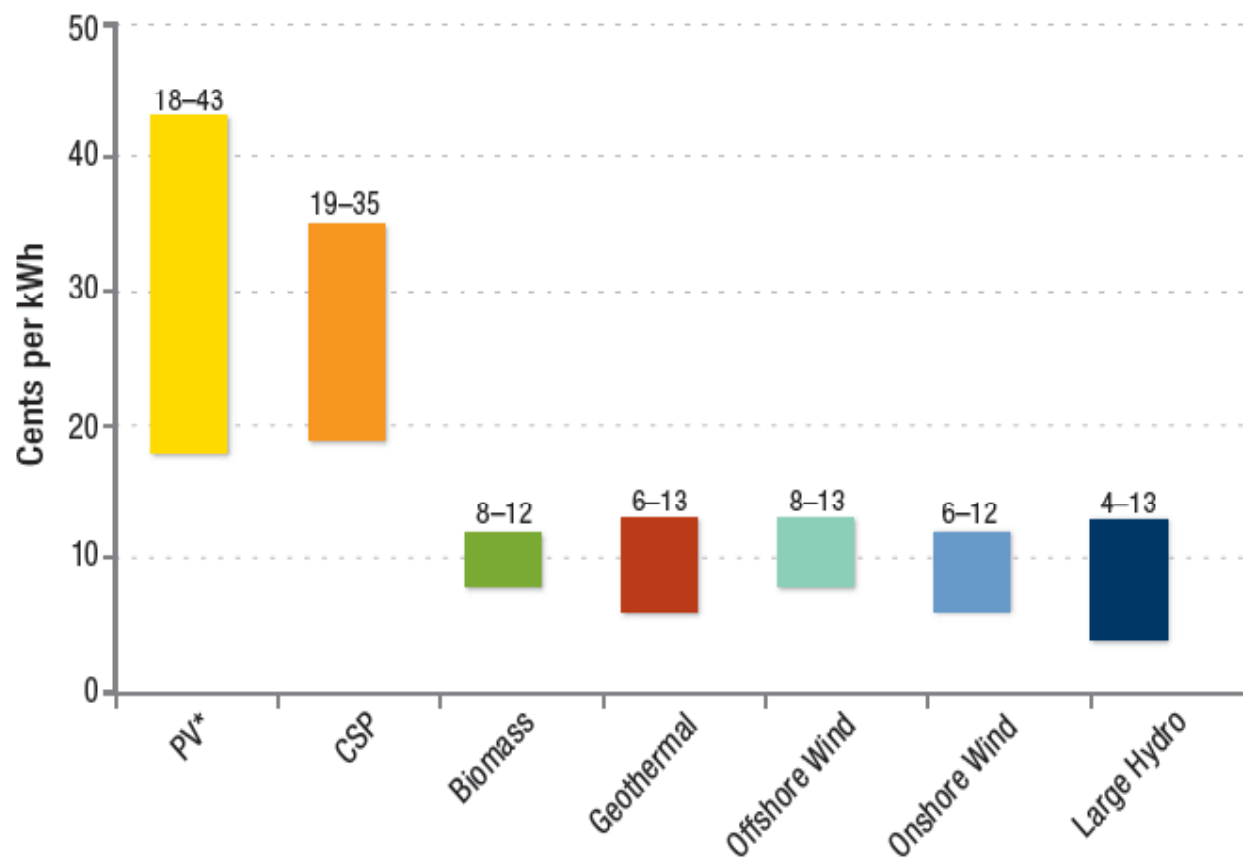
U.S. Energy Background Information | August 2010

# 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

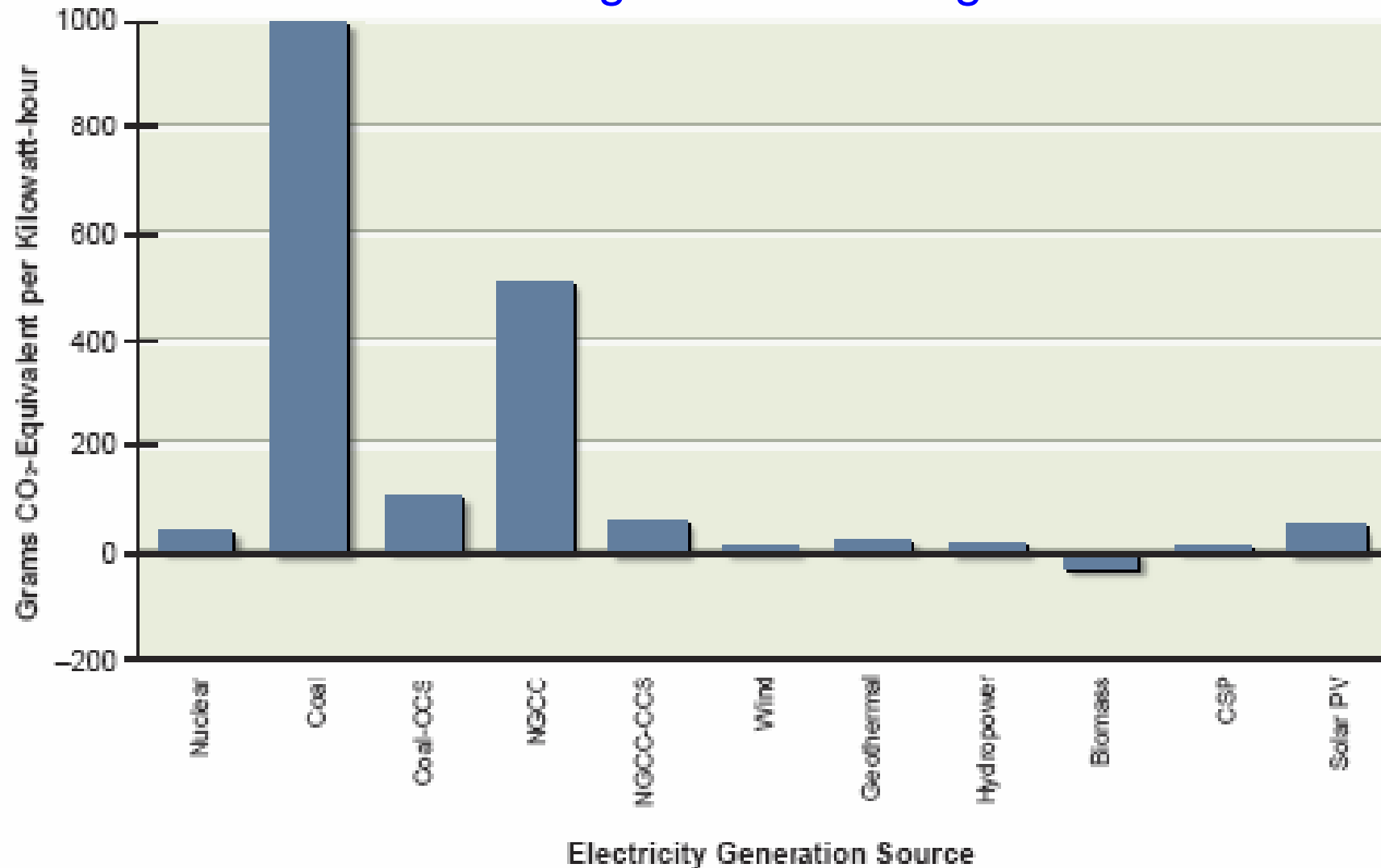
Currency: 2009 US \$ (real)  
Real Discount Rate: 10.5%  
Inflation Rate: 3%  
Economic Lifetime: 30 years  
Taxes: none  
Tax credits: none  
Debt/Equity Financing: none  
Biomass Fuel Costs: AEO 2009  
PV Degradation: none  
CSP Technology: no storage  
Geothermal Technology: hydrothermal

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

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

U.S. Energy Background Information | August 2010

Estimated **Greenhouse Gas Emissions from Electricity Generation**  
**Nuclear and Renewable Energy Sources are essential to  
addressing Climate Change**





# **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:

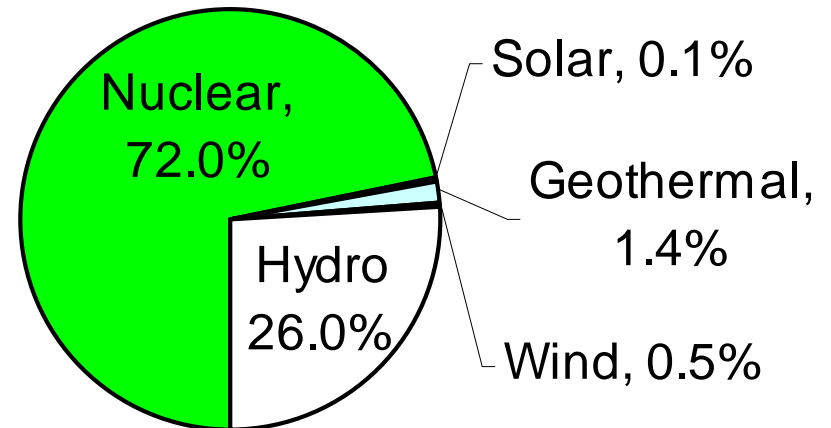
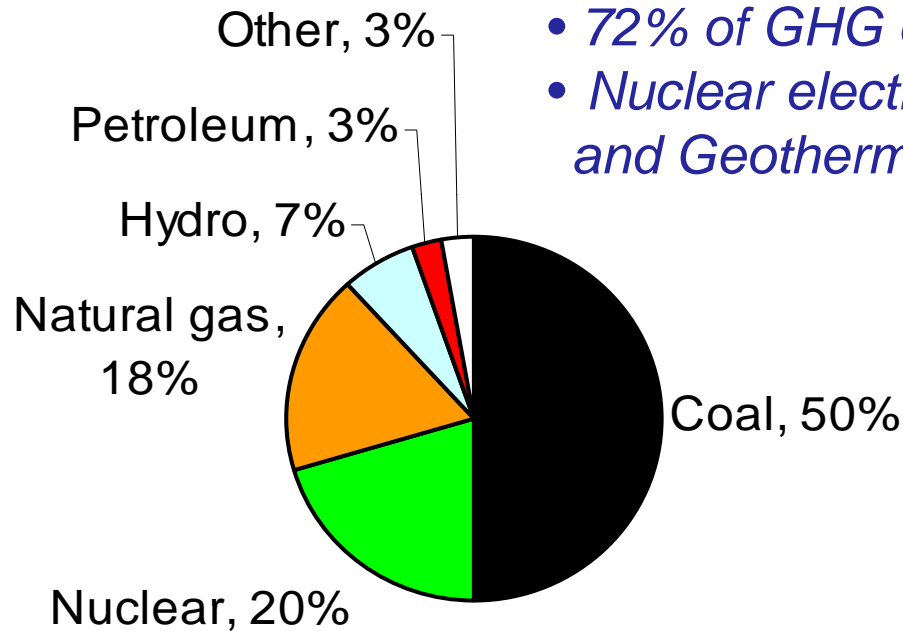
**The standout technology, from a cost perspective, is nuclear power.** From the eight nuclear cost studies we reviewed (all published in the past decade, and adjusted to 2009 dollars), the median cost of electricity from current technology nuclear plants was just above new coal plants with no carbon 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 is 10 times more than Solar, Wind and Geothermal combined



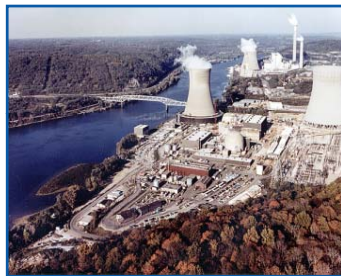
***Nuclear energy is the dominant non-fossil energy technology***



# Evolution of Nuclear Power

## Generation I

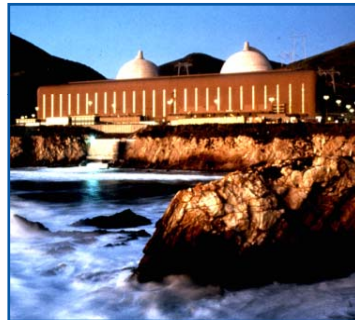
### Early Prototype Reactors



- Shippingport
- Dresden
- Fermi I
- Magnox

## Generation II

### Commercial Power Reactors



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

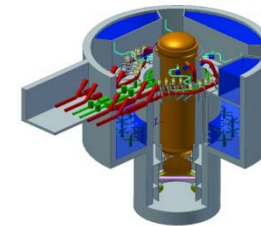
## Generation III

### Advanced LWRs



- ABWR
- System 80+
- AP600
- EPR

## Generation III+

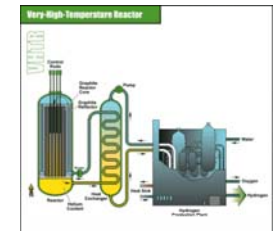


### Near-Term Deployment

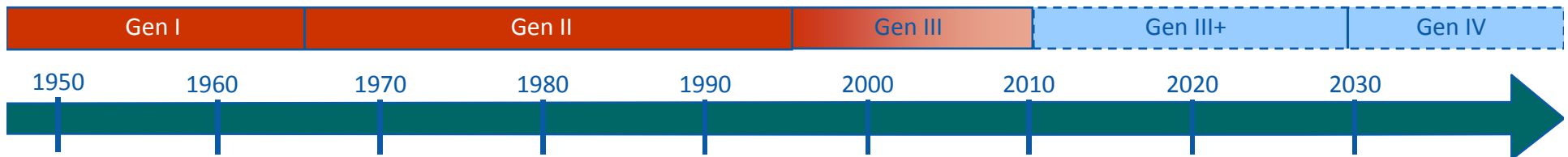
- AP1000
- PBMR
- SWR-1000
- ABWR-II

### Evolutionary Improved Economics

## Generation IV



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

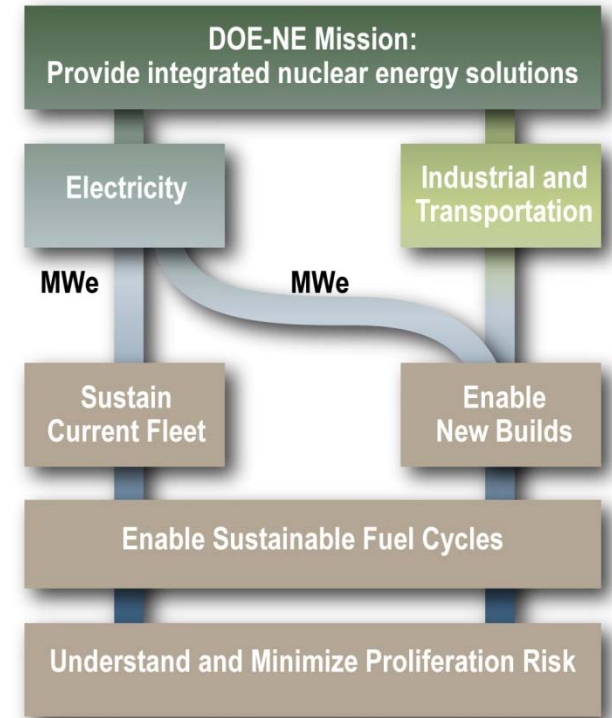


1. U.S. Department of Energy Gen-IV Roadmap Report



## 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



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**Enhancing SAFETY is a MAJOR PRIORITY**

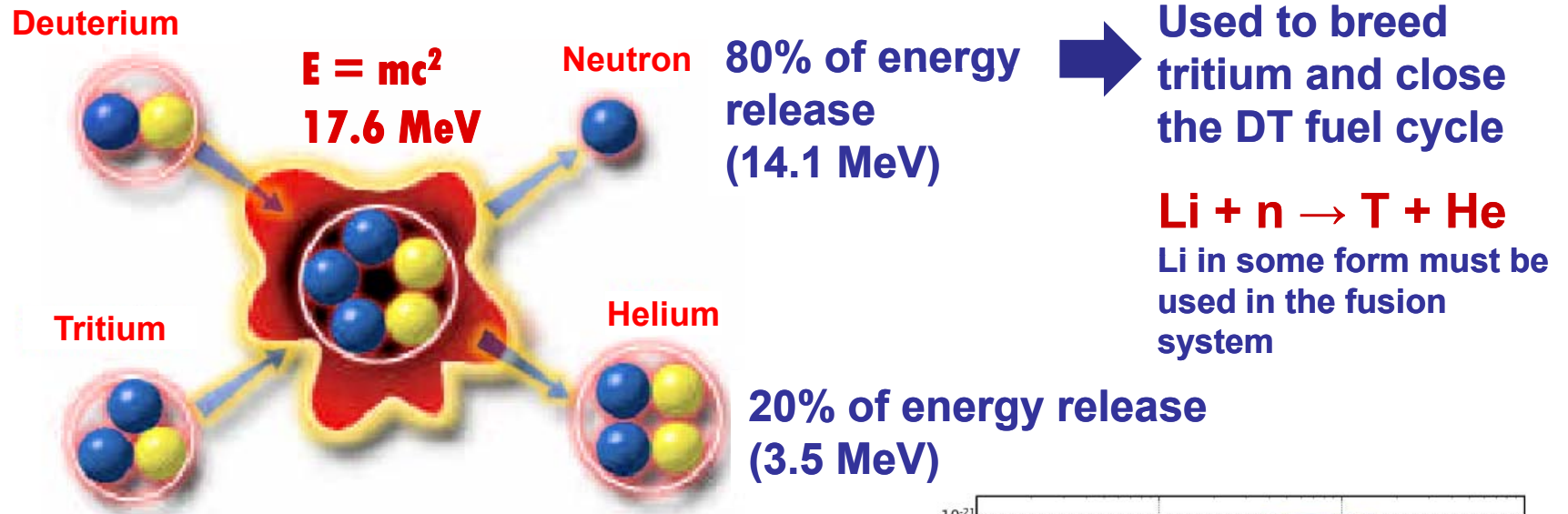
# **CREATING a Star on Earth**

## **Fusion: The Ultimate Energy Source for Humanity**



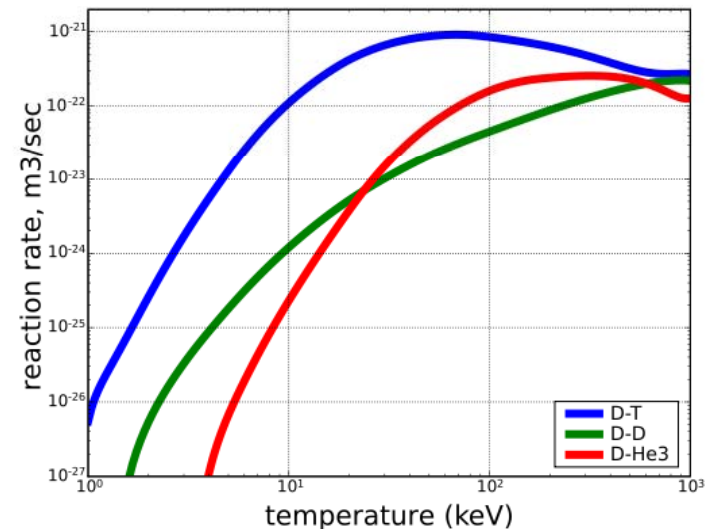
# What is fusion?

- **Fusion powers the Sun and Stars.** Two light nuclei combine to form a heavier nuclei (the opposite of nuclear fission).



*Illustration from DOE brochure*

- Deuterium and tritium is the easiest, attainable at lower plasma temperature, because it has the largest reaction rate and high Q value.
- The World Program is focused on the D-T Cycle





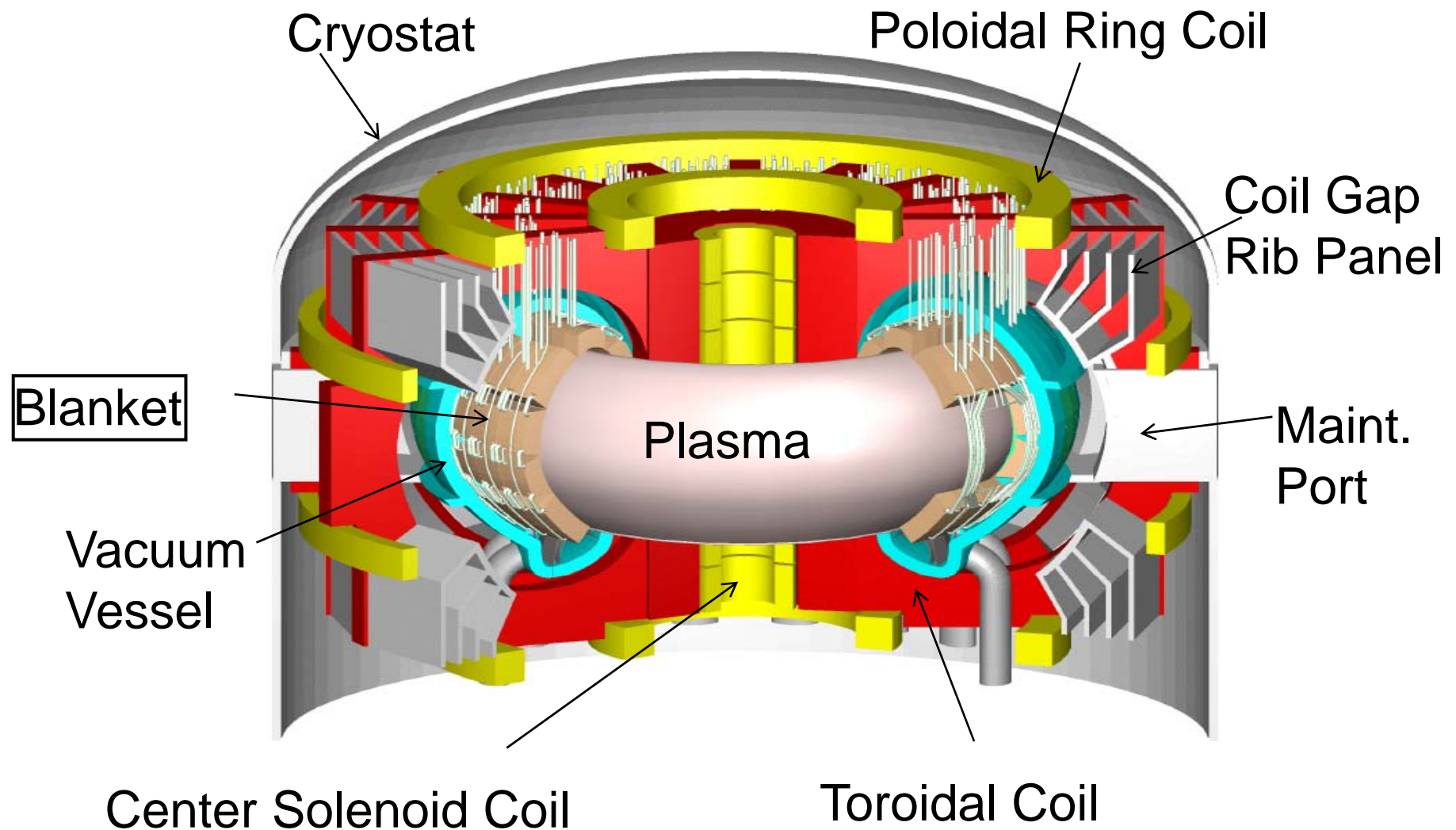
# Incentives for Developing Fusion

- 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)

# ITER

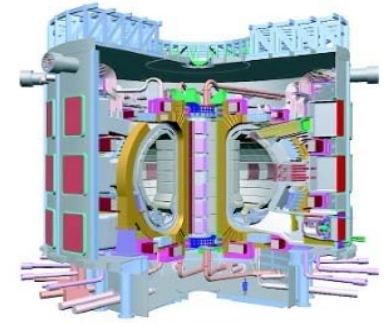
- The World has started construction of the **next step** in fusion development, a device called **ITER**.
- **ITER** will demonstrate the **scientific and technological feasibility** of fusion energy
- **ITER** will produce **500 MW** of fusion power.
- Cost, including R&D, is ~15 billion dollars.
- **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

- 1950-2010
  - The Physics of Plasmas
- 2010-2035
  - The Physics of Fusion
  - Fusion Plasmas-heated and sustained
    - $Q = (E_f / E_{input}) \sim 10$
    - 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)



National Ignition Facility



ITER

**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.*



**The problem with fusion is that it is not being developed fast enough (taking too long!)  
“The Time to Fusion seems to be always 40 years away”**

The World Needs Fusion.

To accelerate the development of fusion energy requires a change in Governments Policies and in the Fusion Community strategy/focus:

- **Need More Substantial Funding : Governments must invest in long-term solutions for the future**
- **Problems are challenging: Need More Ingenuity**
- **Fusion Community strategy/focus need to change: Need to Focus on the Major Remaining Challenge: Launch an aggressive FNST Program NOW**

**This is essential to realizing fusion in the 21<sup>st</sup> Century**

## 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<sub>2</sub>—nuclear, coal with CO<sub>2</sub> 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”**. **Need more funding, more ingenuity, and focus on the most difficult remaining challenge : 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!**