Global Energy Crisis and Renaissance of Nuclear Engineering

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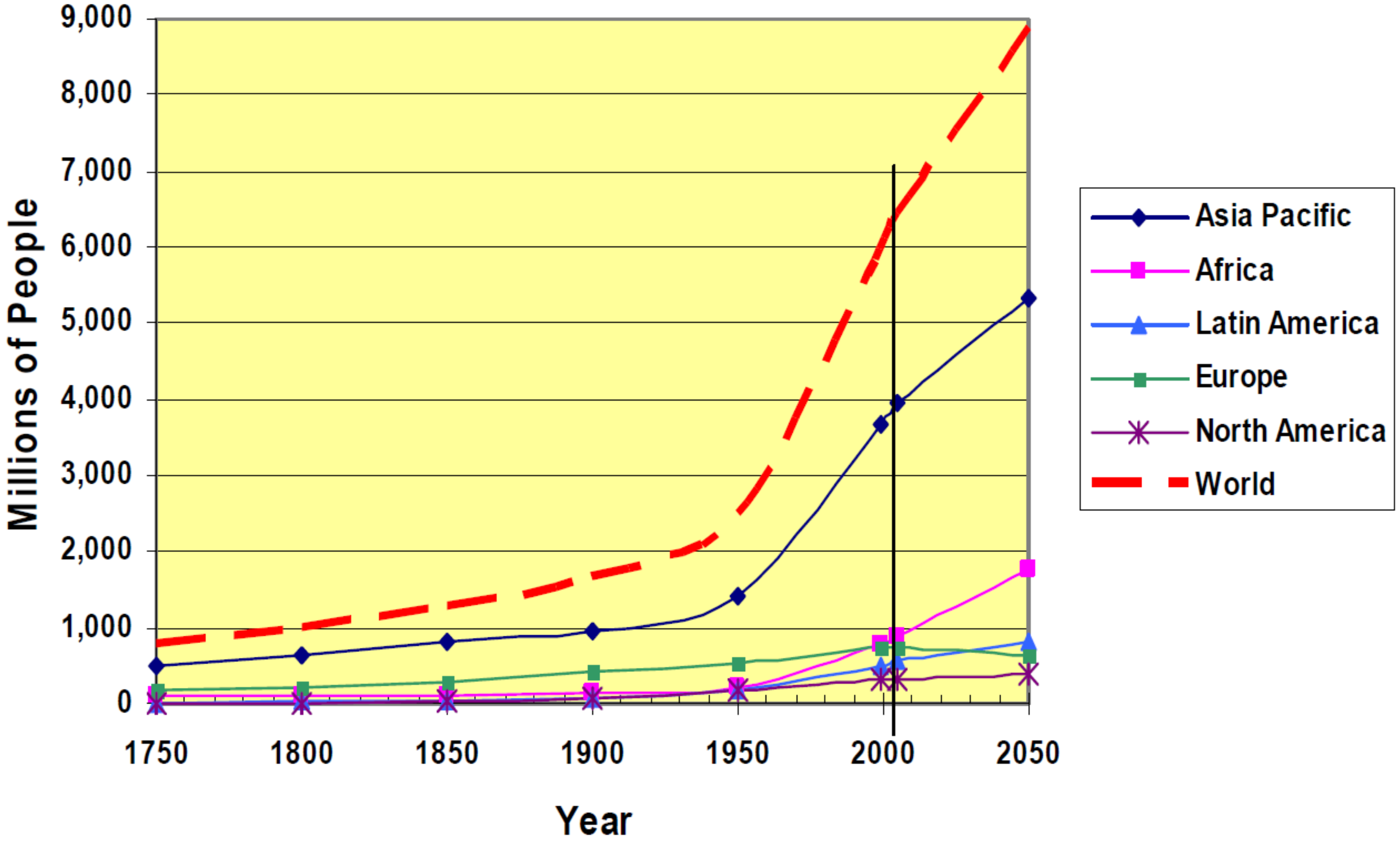
Content

- Global Energy Condition
- Oil Crisis (Hubbert's Peak)
- Requirement for Future Energy Source
- Future Possibilities
- Renaissance of Nuclear Engineering & Power
- Challenge to Nuclear Community
- Development of Passively Safe Reactors
- Fuel Cycle and Waste Management
- Summary and Conclusion

Global Energy Condition

- World Population Growth: 6 to 9 Billion (2050)
- Industrialization of Developing Countries: China, India, etc.
- Prosperity – Per Capita (Electrical) Energy Consumption
- Expected Significant Increase of Fossil Fuel Usage
- Significant Increase in Electrical Power Demand
- Environmental Problem of Fossil Fuel (Global Warming)

Population Projection

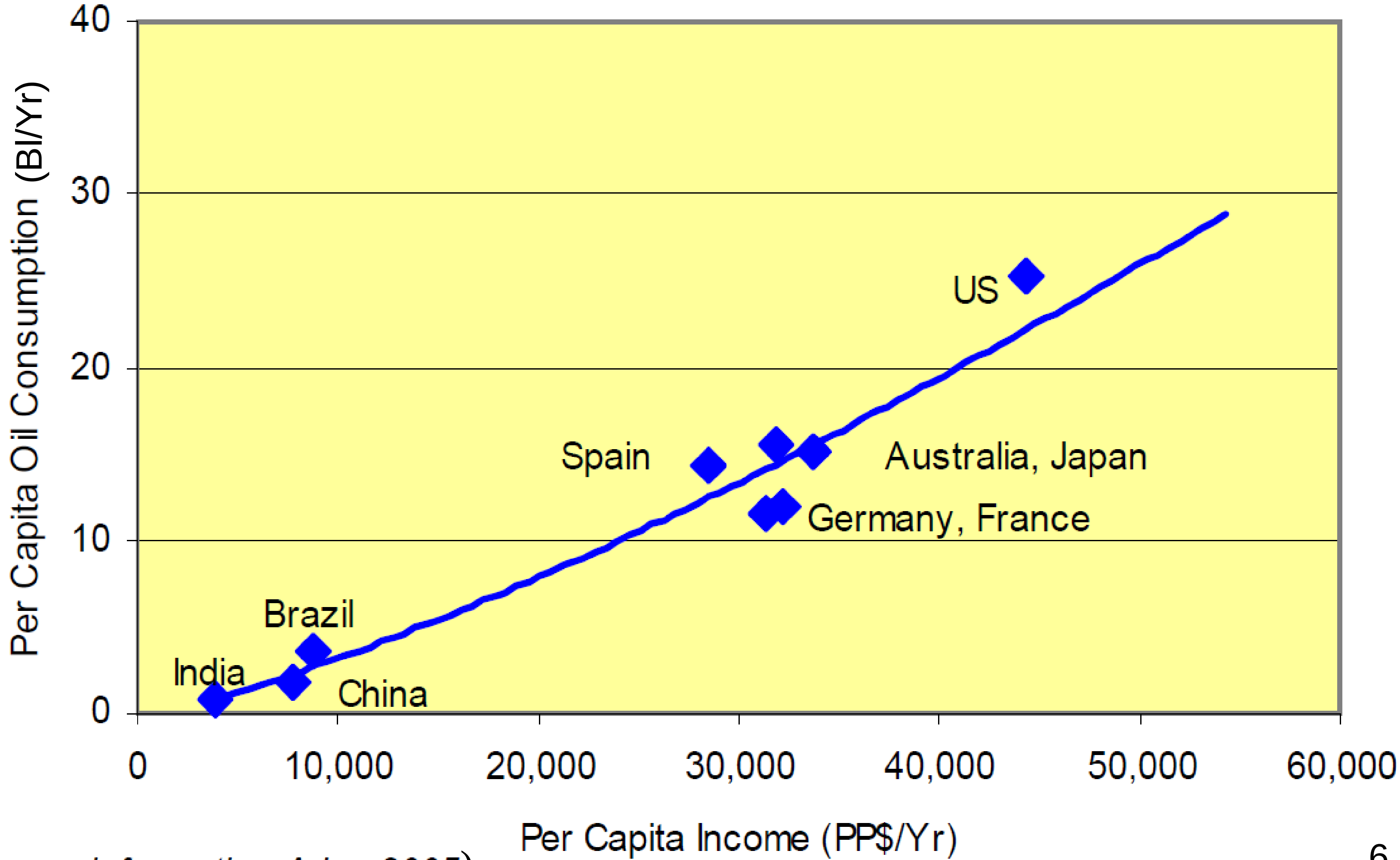


(UN data)

Global Energy Problem

- No.1 Technological Challenge in This Century
- Energy – Prosperity – Food – Water – Population
- Coming Oil Crisis
  - Peaking of Reserve and Production in Near Future (Hubbert's Peak)
  - Runaway Demand from China, India and Others
- Global Warming (CO_2 Problem) and Environmental Problems
- Need of Clean Reliable Energy for Long Term
- Several Possibilities – Conservation, Renewable, Nuclear, etc

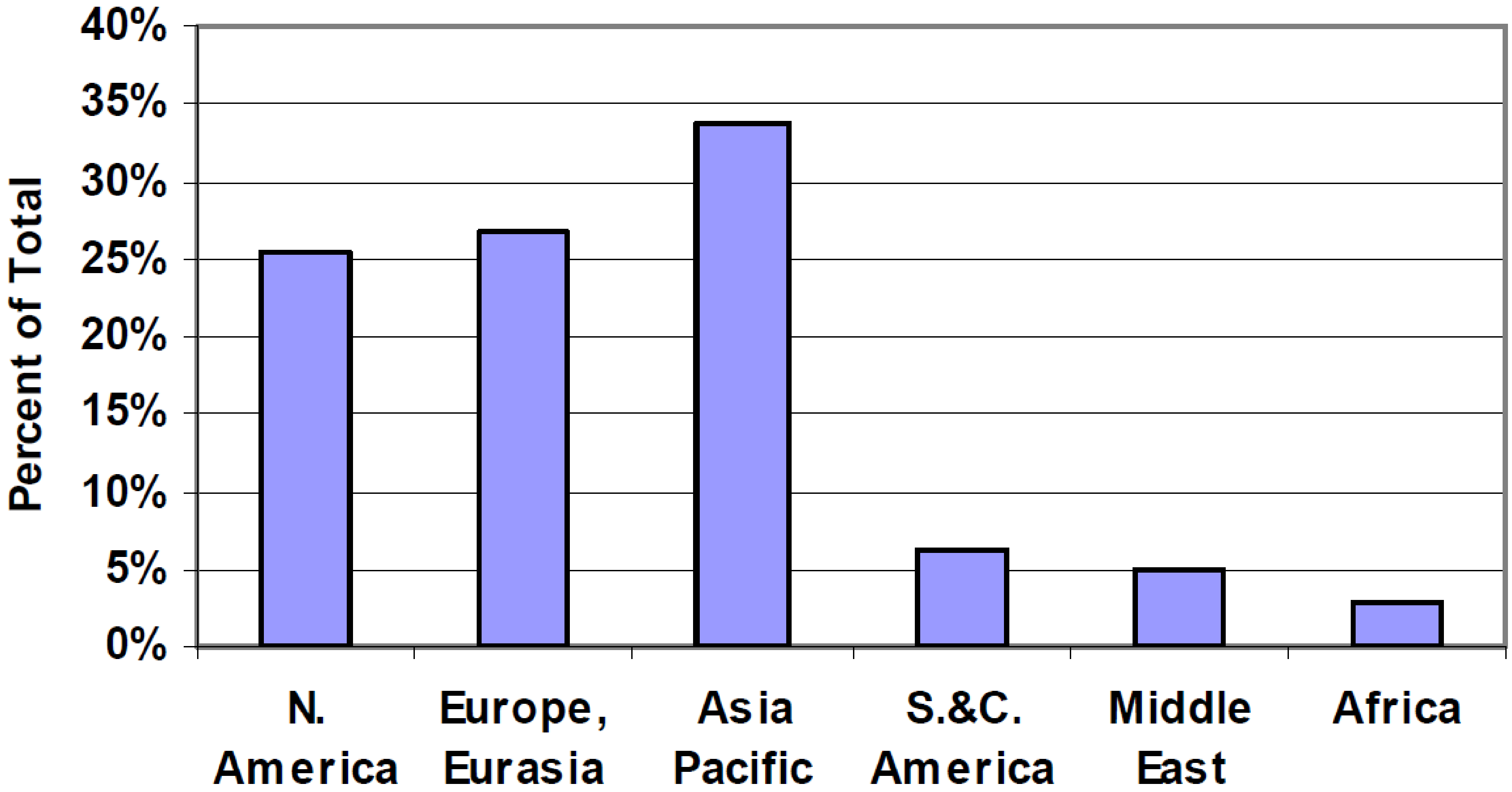
Energy & Prosperity Curve
(per capita Income and Oil Consumption)



(*US Energy Information Adm. 2005*)

Share in World

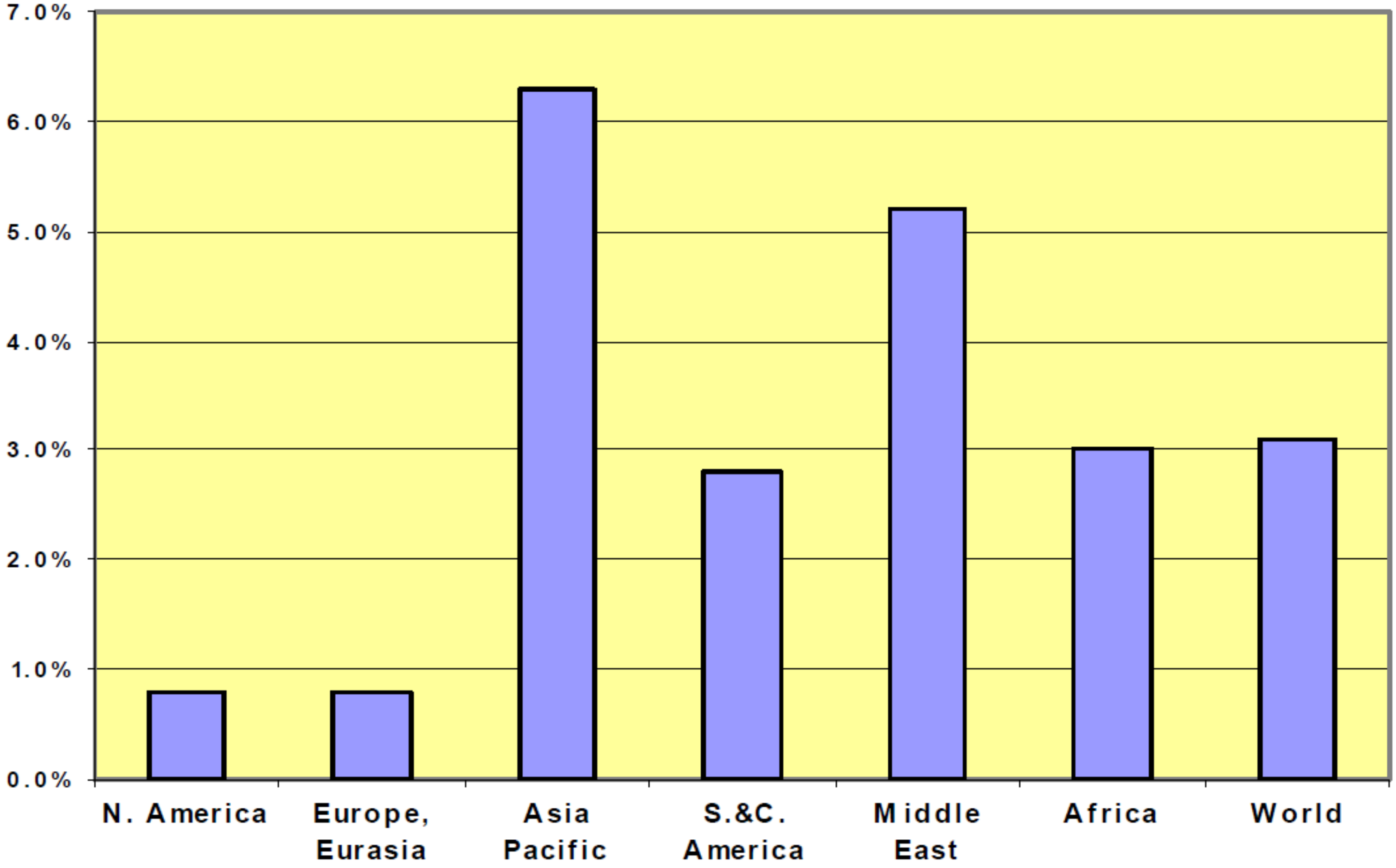
Out of 2007 Total of 16 TW



(*BP Statistical Review, June 2008*)

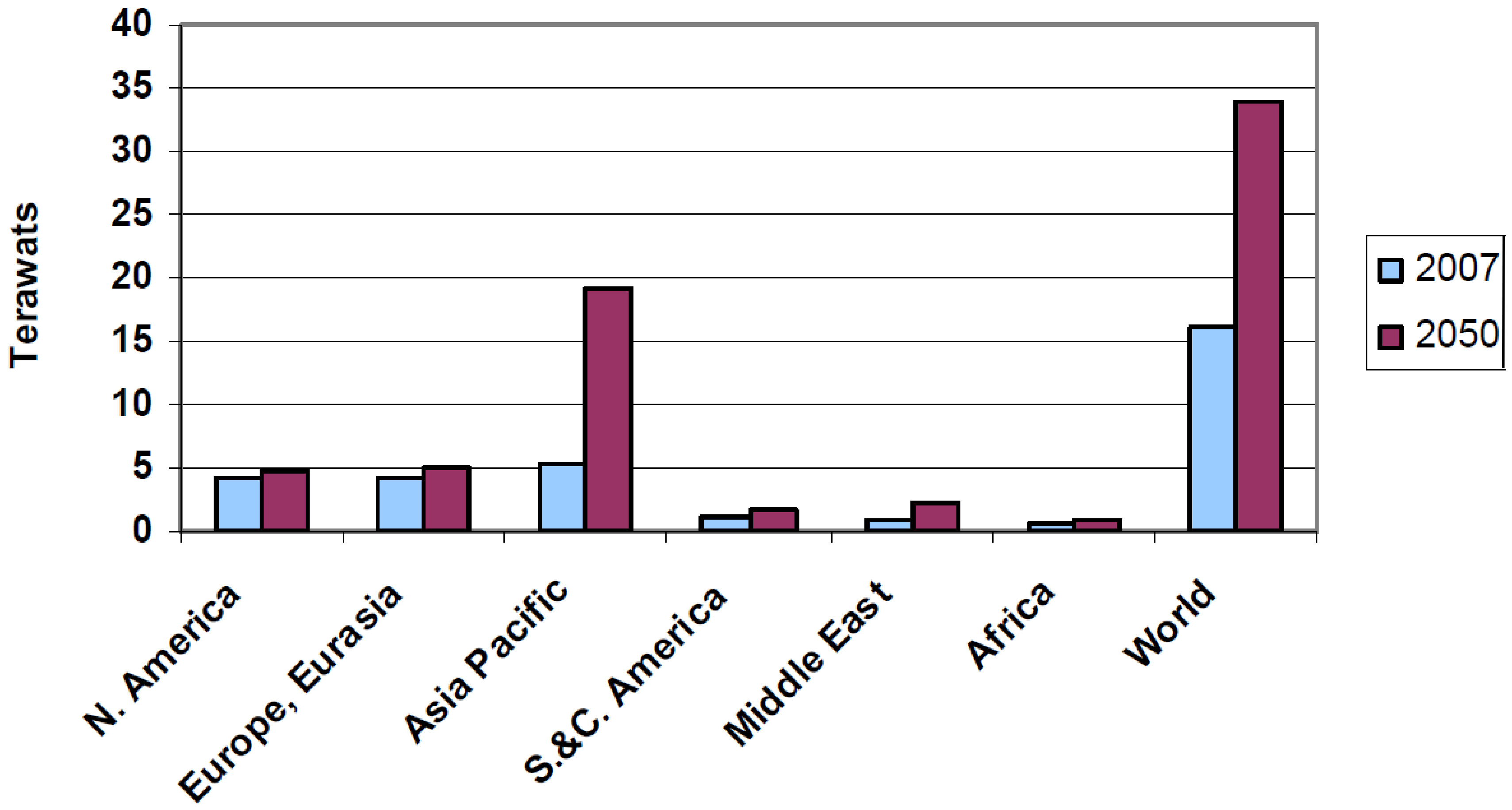
Increasing Rate of Energy Consumption

Average over 2001 through 2007



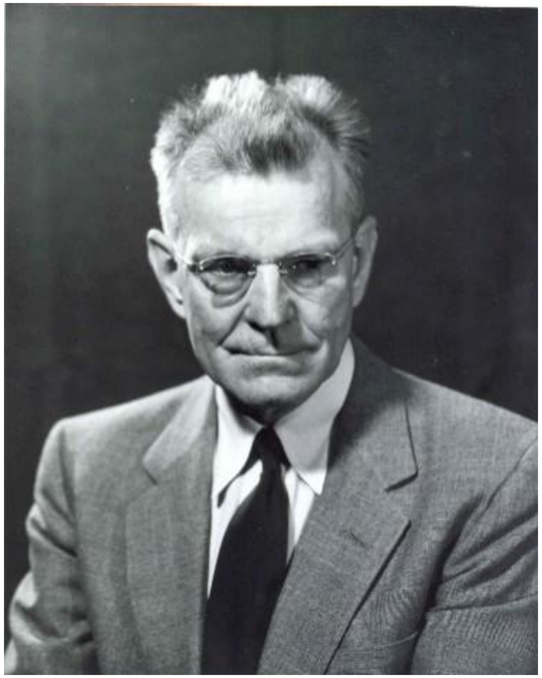
(*Calc'd from BP Stat. Rev., June '08*)

Energy Demand
Expected Changes in Next 40 years



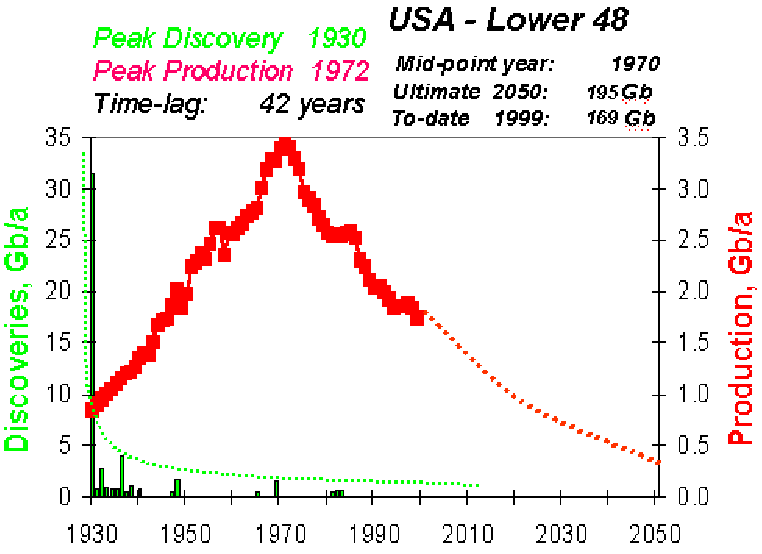
(EIA Estimate)

Hubbert's Peak



King Hubbert (1903 – 1989)

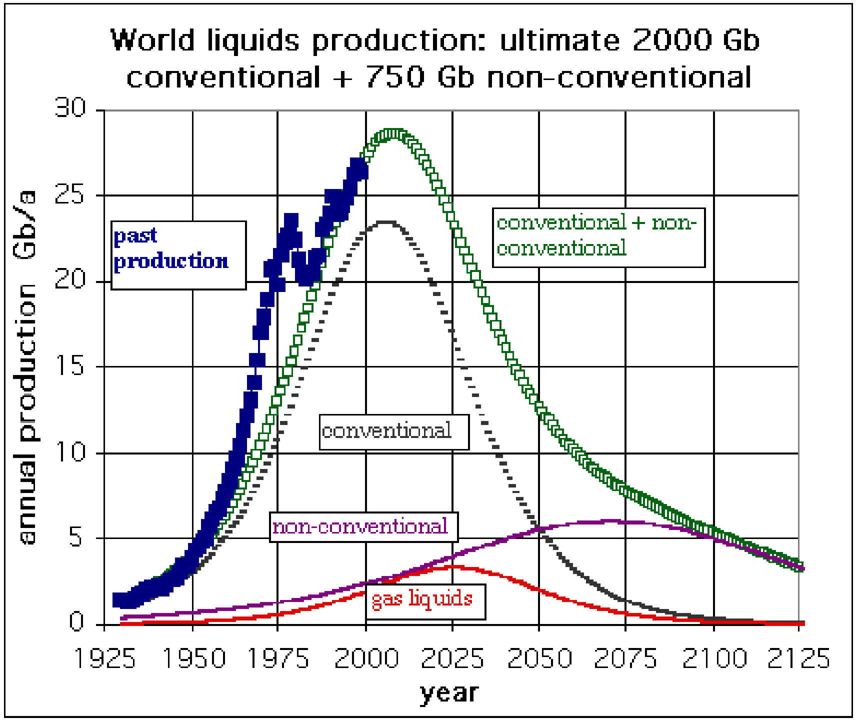
- Predicted in 1956 that U.S. oil production peak in 1970



USA Lower 48 Peak Discovery and Peak Production (*Colin J.Campbell, 2002*)

Peak in World Oil Production?

THE HUBBERT CURVE



Production in 2006 ~81 mb/day

in 2020 ~50 mb/day

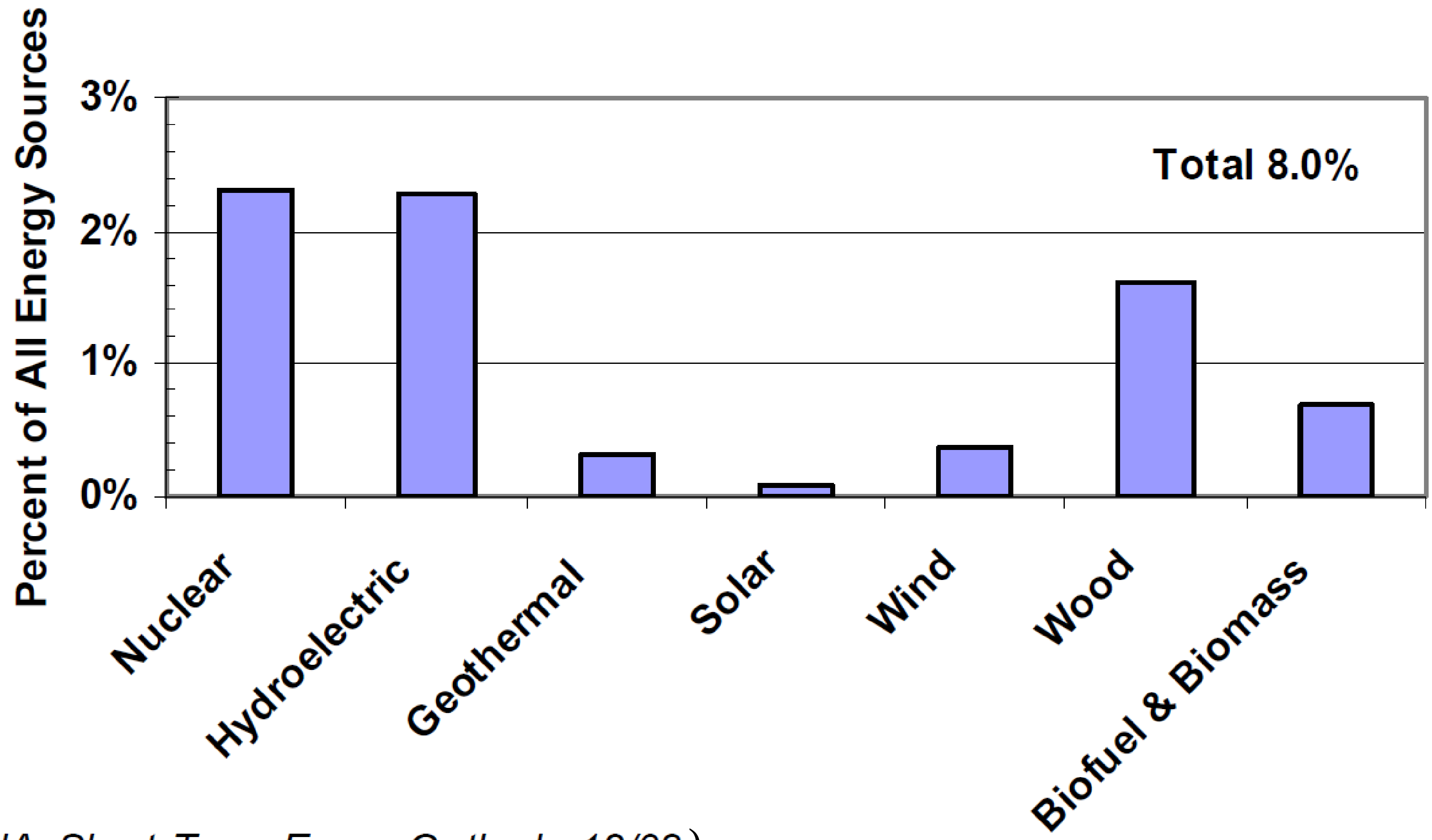
Important Factors and Requirements for Future Energy Source

- Primary Energy Source
- Environmentally Clean and Safe to Use
- Cost Effective
- Energy In (to System) << Energy Out
- Large Scale of Source → Large Impact in Future
- Long Term Resource (At least 50~100 years)
- Relatively Cheap Infrastructure Requirements
- Should not have Significant Negative Impact
- Central Power Station and Distributed Source Requirements

Future Possibilities

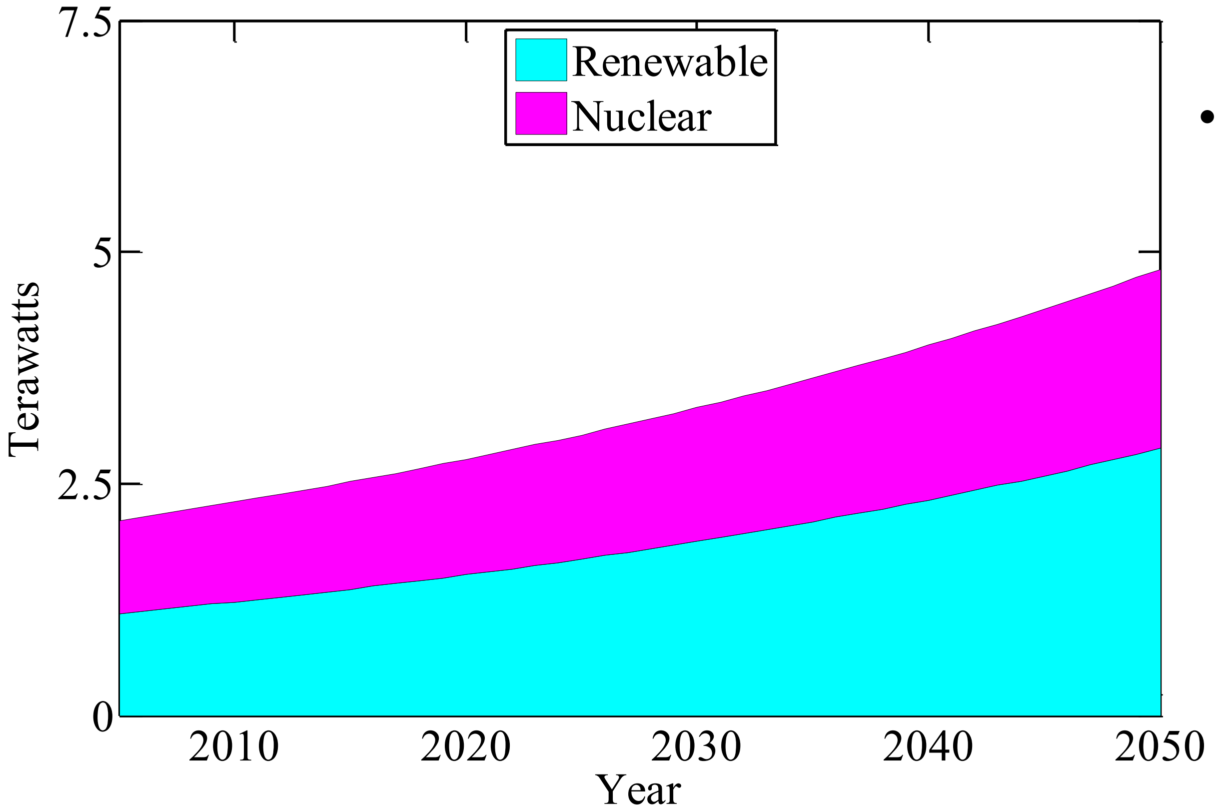
- Energy Conservation (In US it is more challenging)
  - Smaller & Efficient Cars
  - Smaller & Efficient Homes
  - Public Transportation Utilization
  - More Densely Populated City ↔ Suburban Spread
- Solar Radiation Utilization (Sun's Nuclear Fusion Energy)
  - Solar, Wind, Hydro, etc.
- Nuclear Fission
- Nuclear Fusion (At this point, it is only a dream)
- Improved Fossil Fuel Utilization (?)
- Other Alternatives: Bio Fuel, etc.

Energy from Alternatives
2008 in USA out of Total 4 TW



(*EIA, Short-Term Enegy Outlook, 12/08*)

Energy from Alternatives



(Ref: Intern. Energy Outlook, EIA, June 2008)

- Adding this much energy in 2050
  - Nuclear ~$5 Trillion (~800 reactors)
  - Renewable ~$12 Trillion
  - S&P 500 Capitalization ~$8 Trillion

Renaissance of Nuclear Engineering & Power
Advantage of Nuclear Power

- **<u>Fission Nuclear Power</u>** (Technologically Mature)
  - Chicago Pile I (Enrico Fermi) 1942
    - First Fission Reactor
  - EBR I (W. H. Zinn et al. at ANL) 1951
    - First Demonstration of Power Generation
  - Shippingort PWR 1957
    - First Nuclear Power Station
  - Experimental BWR (ANL) 1955
  - Dresden 1 1960
    - First Commercial BWR
- Primary Energy Source (Very Large Scale)
- Nuclear Power: Nuclear, Mechanical, Electrical, Chemical and Material Engineering

Important Aspect of Nuclear Fuel (Fission)

- Natural Uranium
  - 0.7 % Fissionable U^{235} (Fuel)
  - 99.3% Potentially Useful U^{238}
- With Natural Uranium Fuel
  - Size of Total Nuclear Energy: Very Limited
- U^{238} can be converted to fuel

$$U^{238} + n \rightarrow Pu^{239} \quad (Fuel)$$

(1) Spent LWR Fuel → Reprocessing

(2) High Conversion by Fast Reactor

- Irradiation of Thorium in Fission Reactor
- Both Options Make

Nuclear Energy → Very Large Scale Source

World Renaissance of Nuclear Energy

- Substitute for Fossil Fuel for Electricity Production
- H_2 Production through Nuclear Energy for Transportation (Hydrogen Fuel or Fuel Cell)
- Development of New Reactor Technology
  - Generation III Plus – Passively Safe Reactor → Design Certification
  - Generation IV – Highly Efficient Reactor
- New Development for Nuclear Reactor Construction
  - China, India
  - Finland, England, East European Countries
  - US – Site Licensing Consideration

Challenge to Nuclear Community

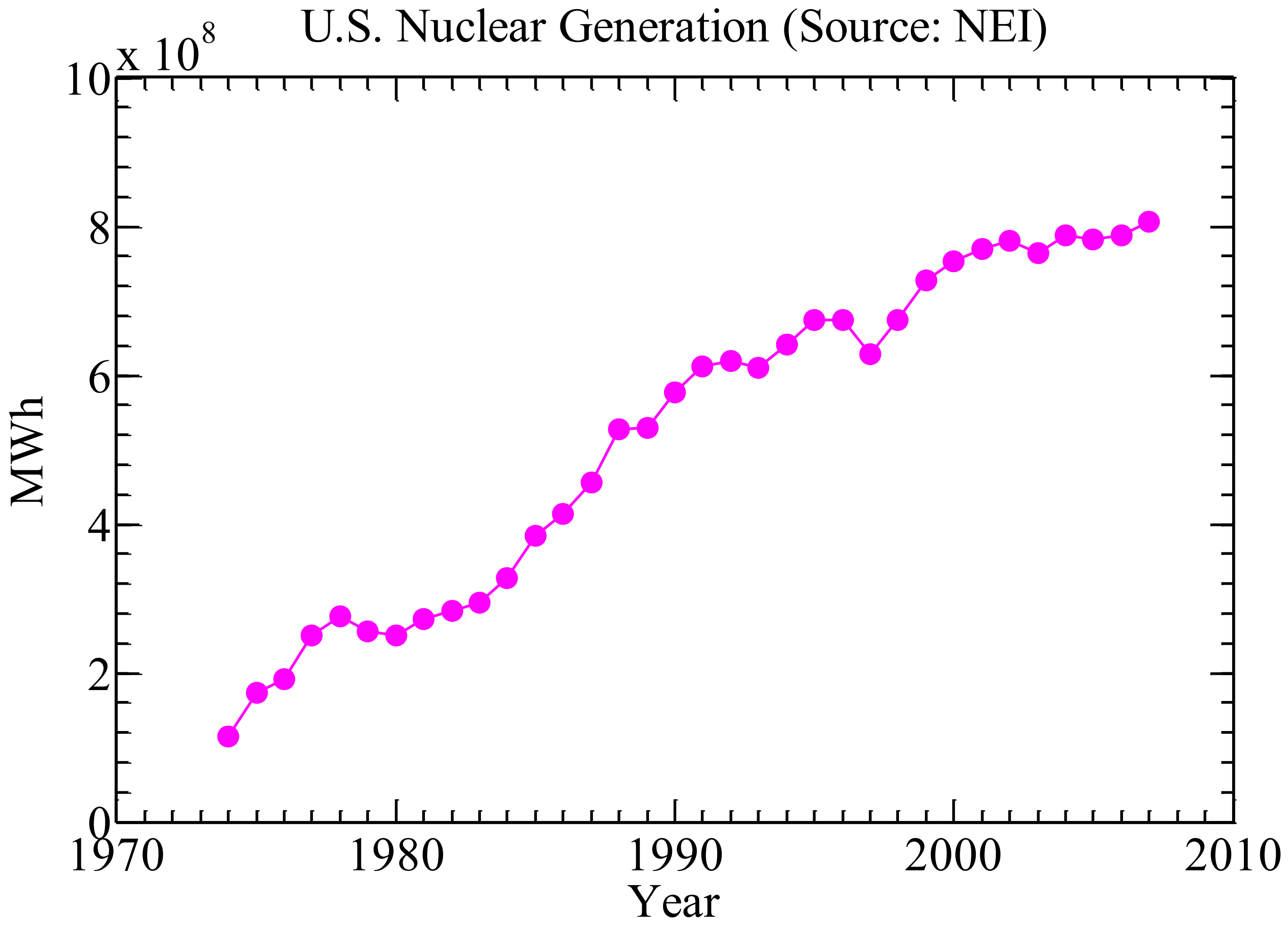
- Public Perception and Acceptance of Nuclear Energy
- Correction of Mismanagement of Nuclear Power

  (U.S. Utilities, Manufacturers, Regulator)
- Reduction of Cost for Nuclear Power
- Development of Safe and Efficient Technology
- Globalization of Nuclear Power
- Maintenance of Technological Infrastructure
- Transmission of Technology to Developing Countries
- Comprehensive Waste Management

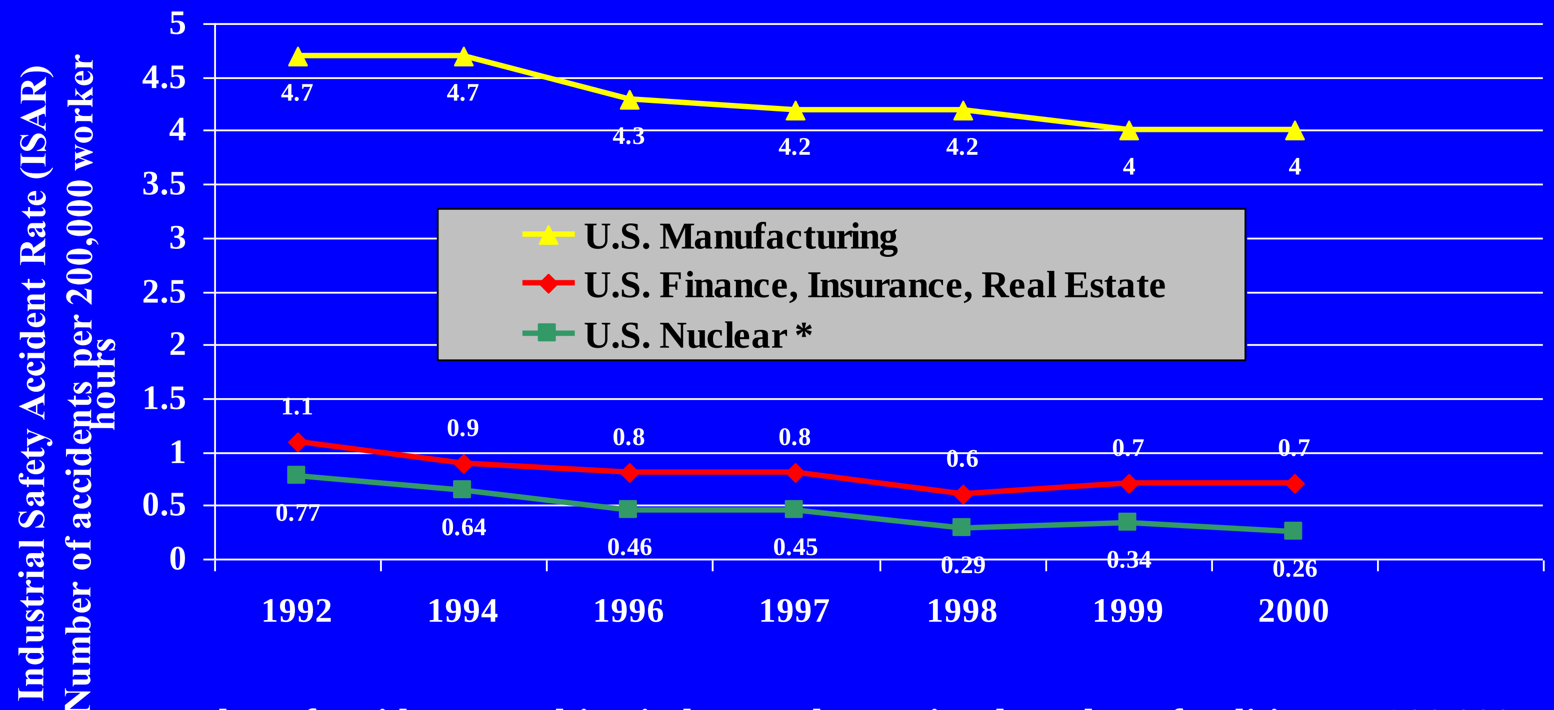
Nuclear Energy Renaissance in USA and World

- High Efficiency of Existing Nuclear Power Plants
- High Level of Safety
- Lowest Electricity Production Cost
- Clean Energy with Almost No CO_2 Emission
- New Programs to Develop Safer and Better Reactors
- Increased Demand for Manpower
- Worldwide Renaissance of Nuclear Energy

Record Nuclear Electricity Production is Sustainable



Very High Levels of Safety in Nuclear Industry

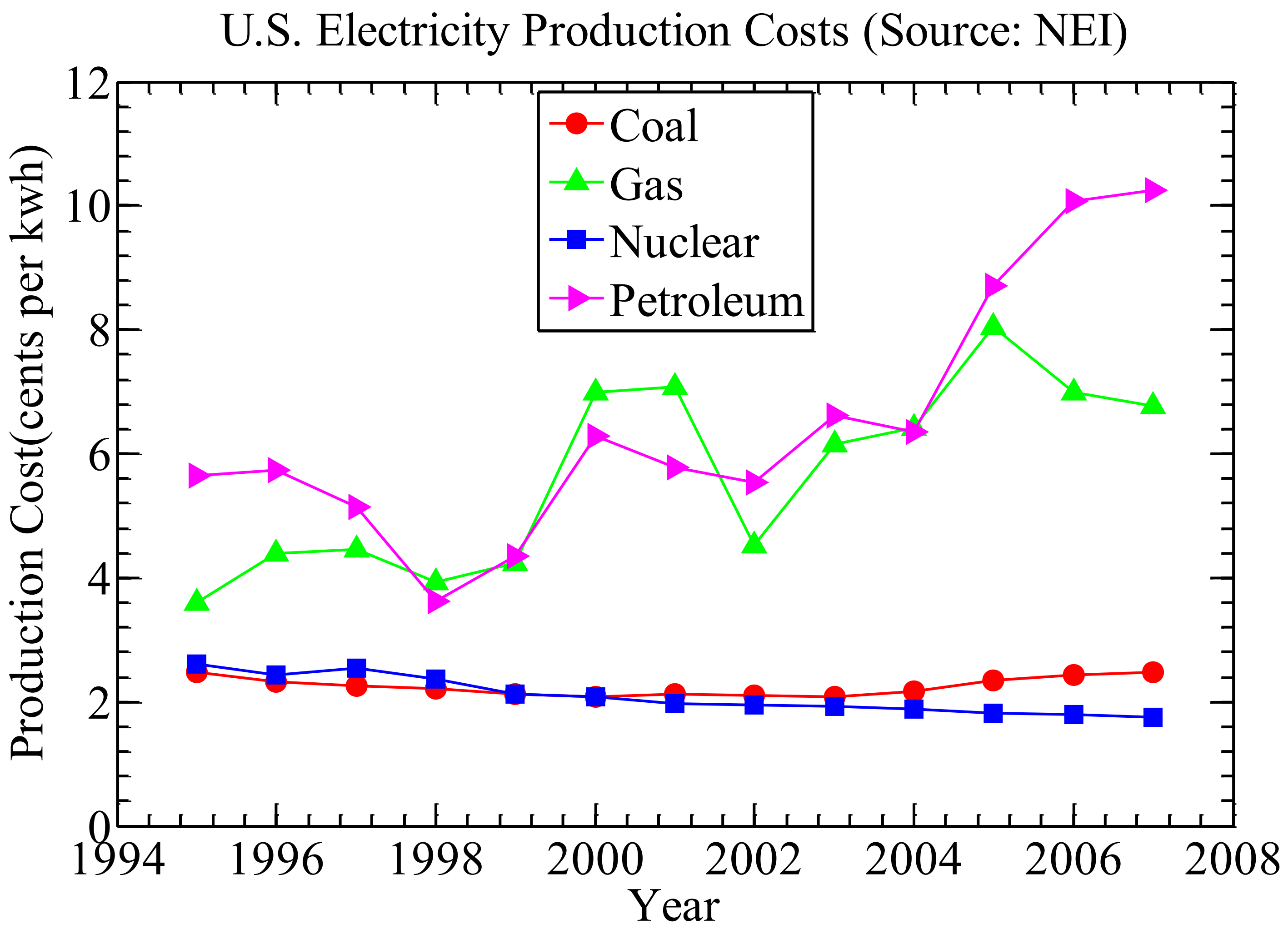


Number of accidents resulting in lost work, restricted work, or fatalities per 200,000 worker-hours

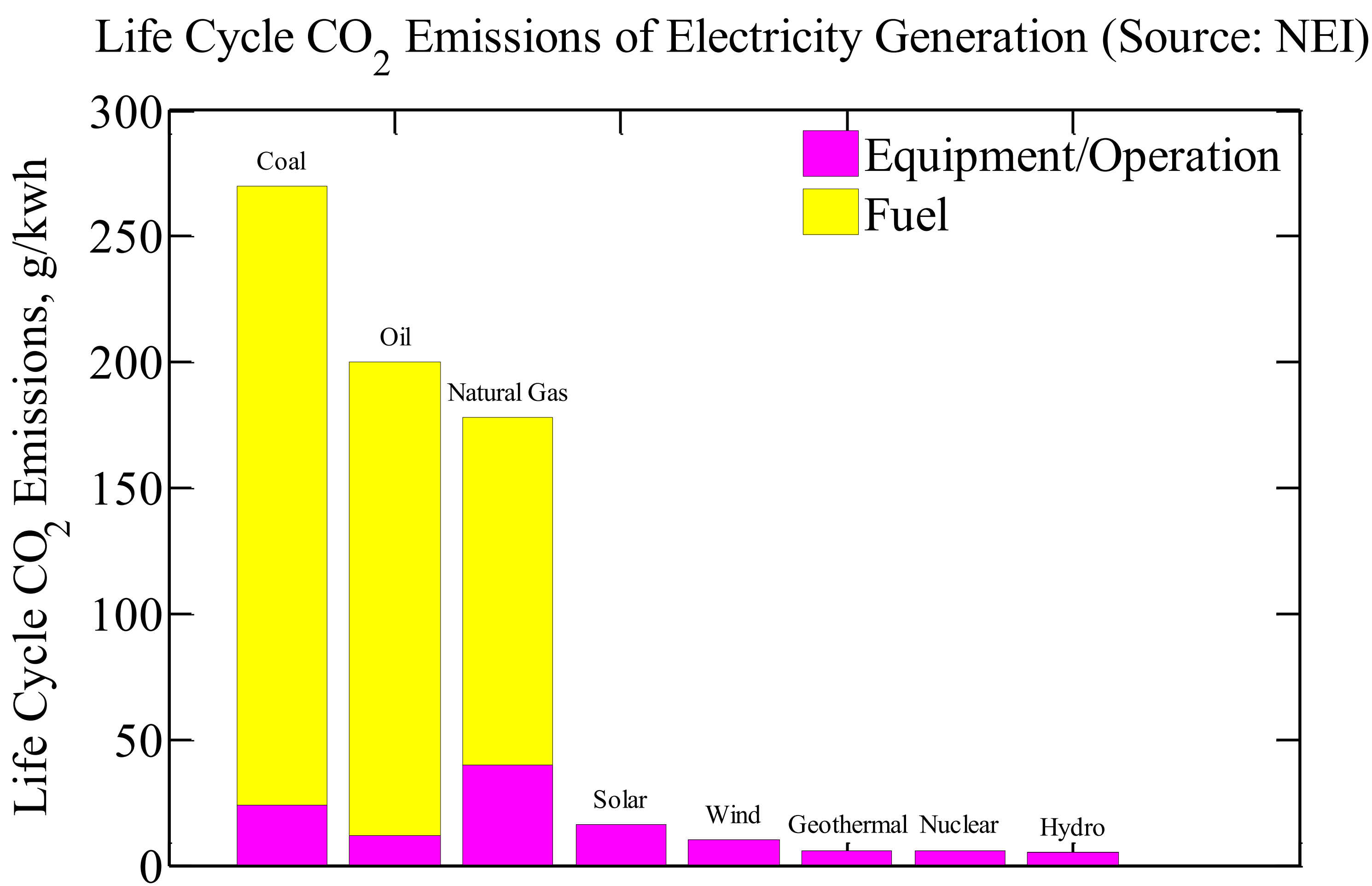
*** Full- time, on- site employees**

Source: NEI

Electricity Production Costs



Life Cycle CO_2 Emissions from Sources of Electricity Generation



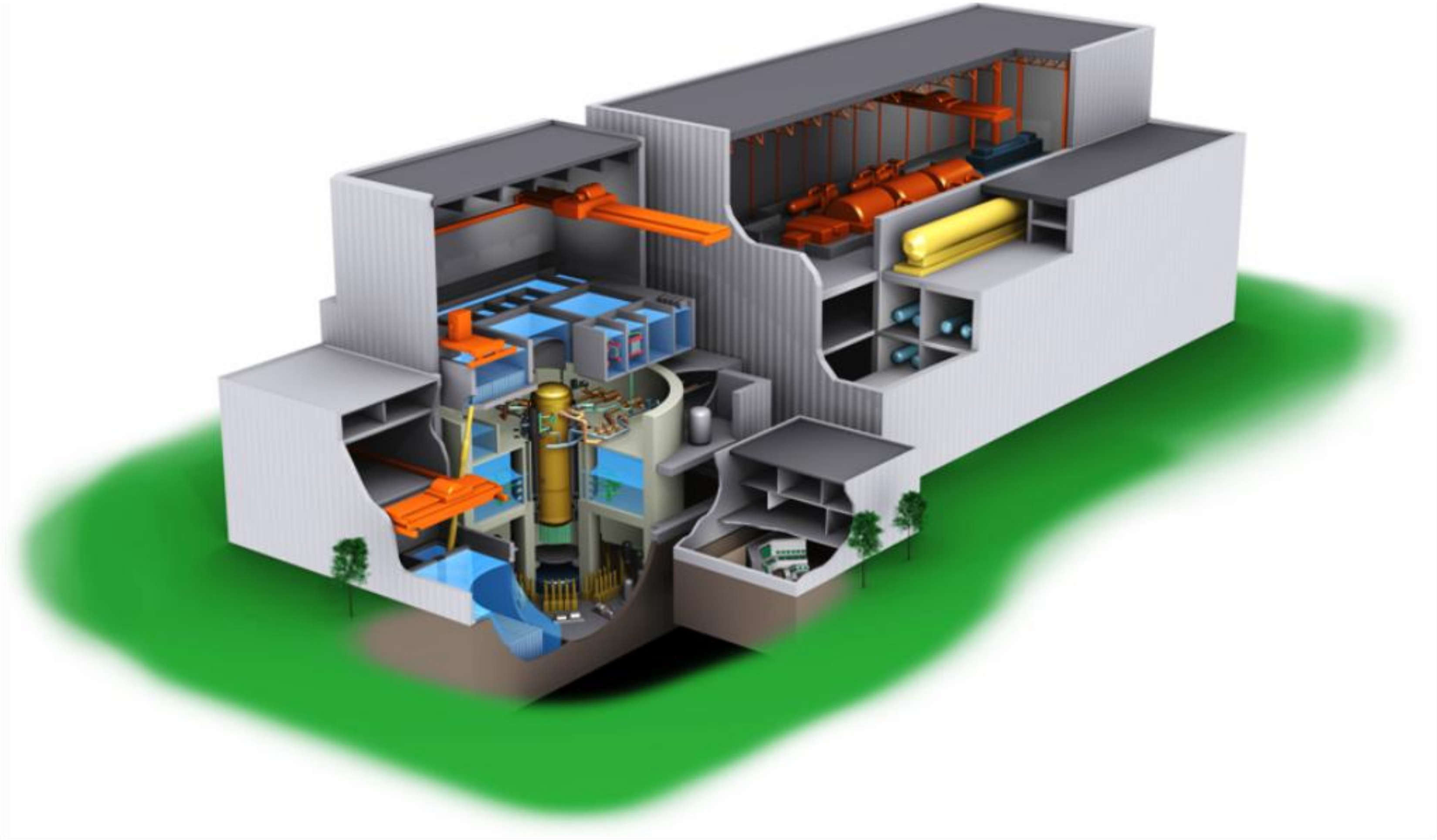
Development of Passively Safe Reactors

- Motivation:
  - Wide Acceptance of Nuclear Power in Developed Country
    - 10 Fold Increase in Reactor Safety Possible
    - Simpler Engineering System and Easier Operation and Maintenance
    - Failure Proof (Human Errors)
    - Potential Cost Down
  - Wide Acceptance of Nuclear in Developing Countries
    - Reduced Demand for Engineering Infrastructure
- Requirement:
  - Simple and Safer Design
  - Lower Development, Construction and Operating Cost
  - Rapid Commercialization Potential

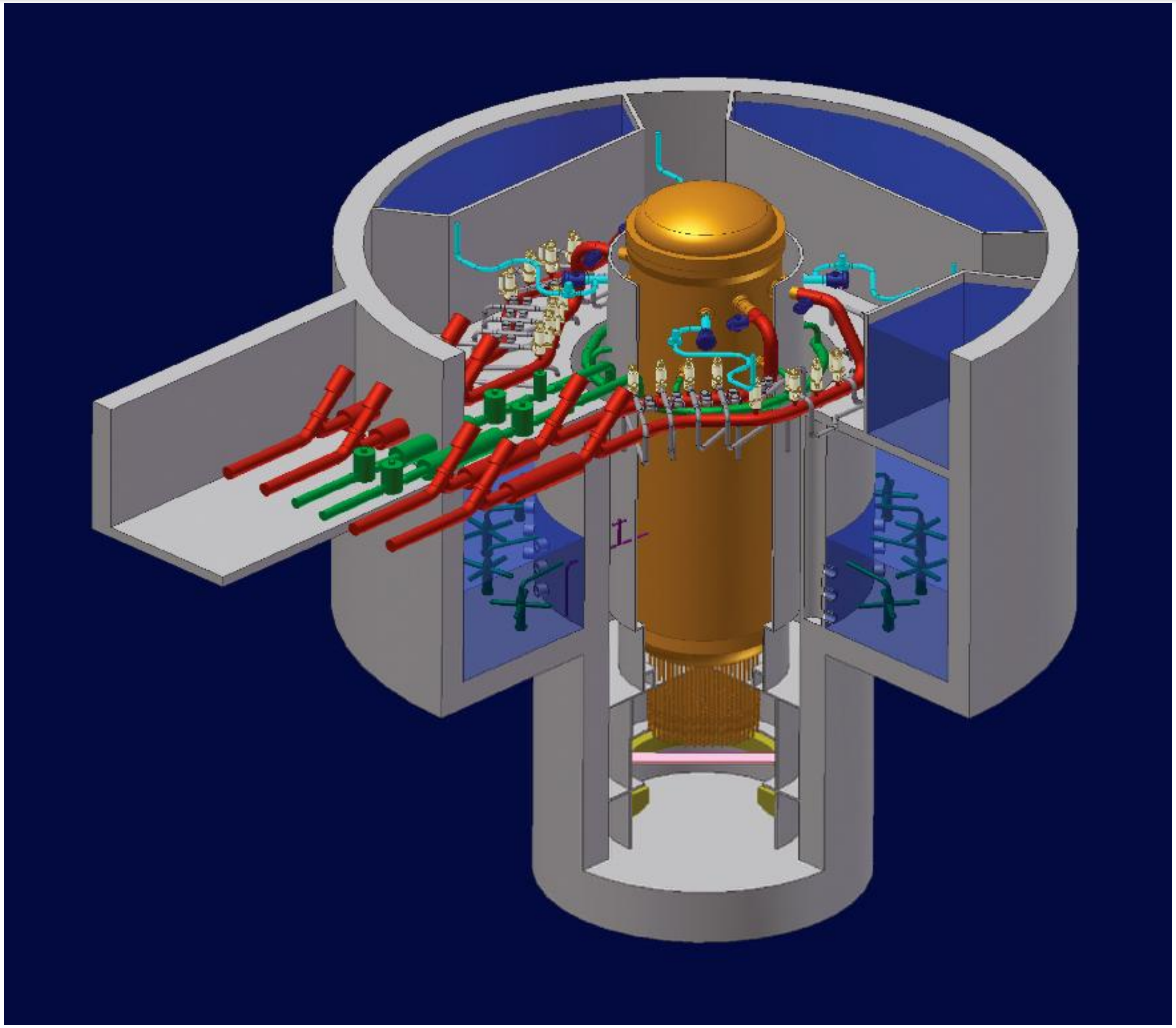
Development of Passively Safe Reactors

- Possible Approaches: Three Examples
  - Flexible Application and Extension of Current Technology
    - Simplified Boiling Water Reactor (SBWR, ESBWR)
    - Westinghouse AP1000
    - Purdue NMR 50
  - Completely New Technology
    - Liquid Metal Reactor (Integral Fast Reactor)

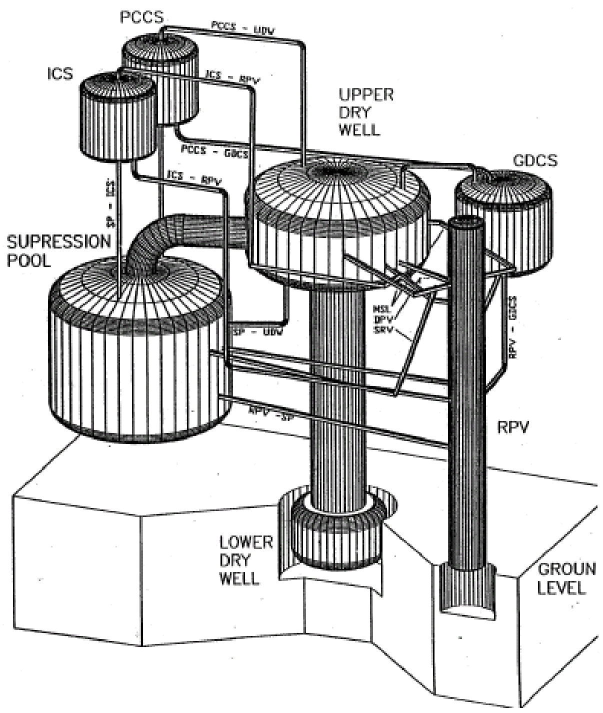
Economic Simplified Boiling Water Reactor (ESBWR)



Economic Simplified Boiling Water Reactor (ESBWR)



Purdue University Multi-Dimensional Integral Test Assembly (PUMA)

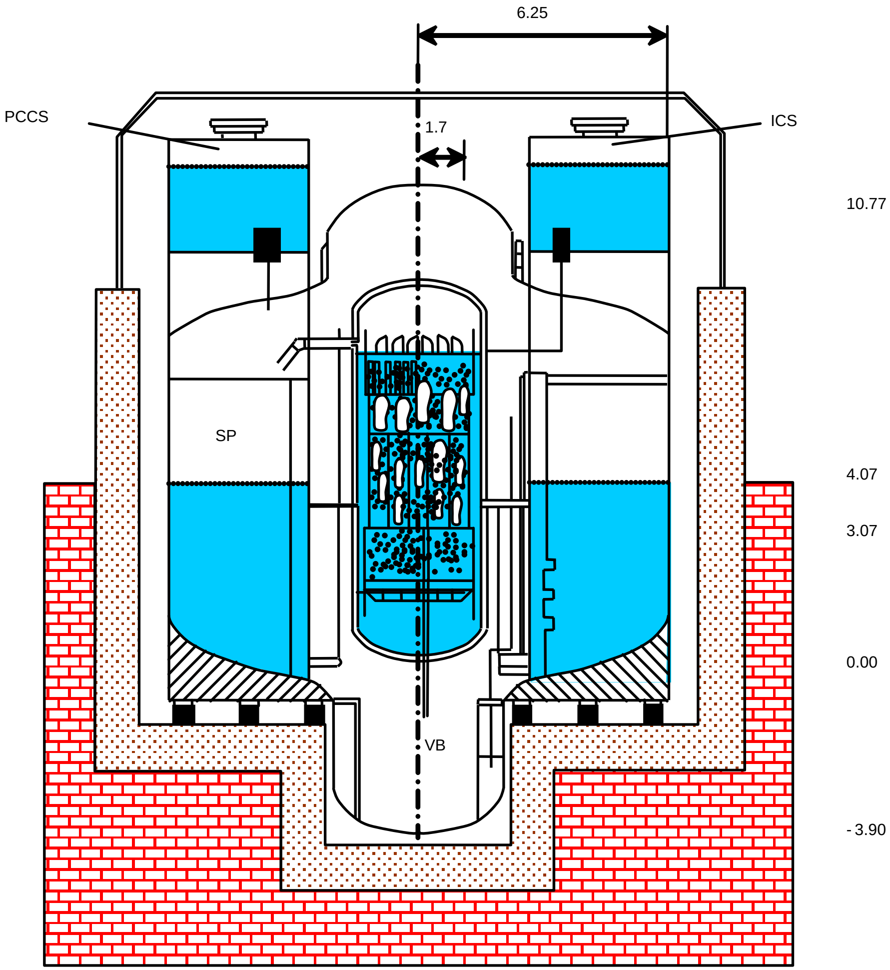


3D view of the PUMA facility

PUMA facility (Top view)

PUMA facility (Front view)

Purdue Novel Modular Reactor (NMR)

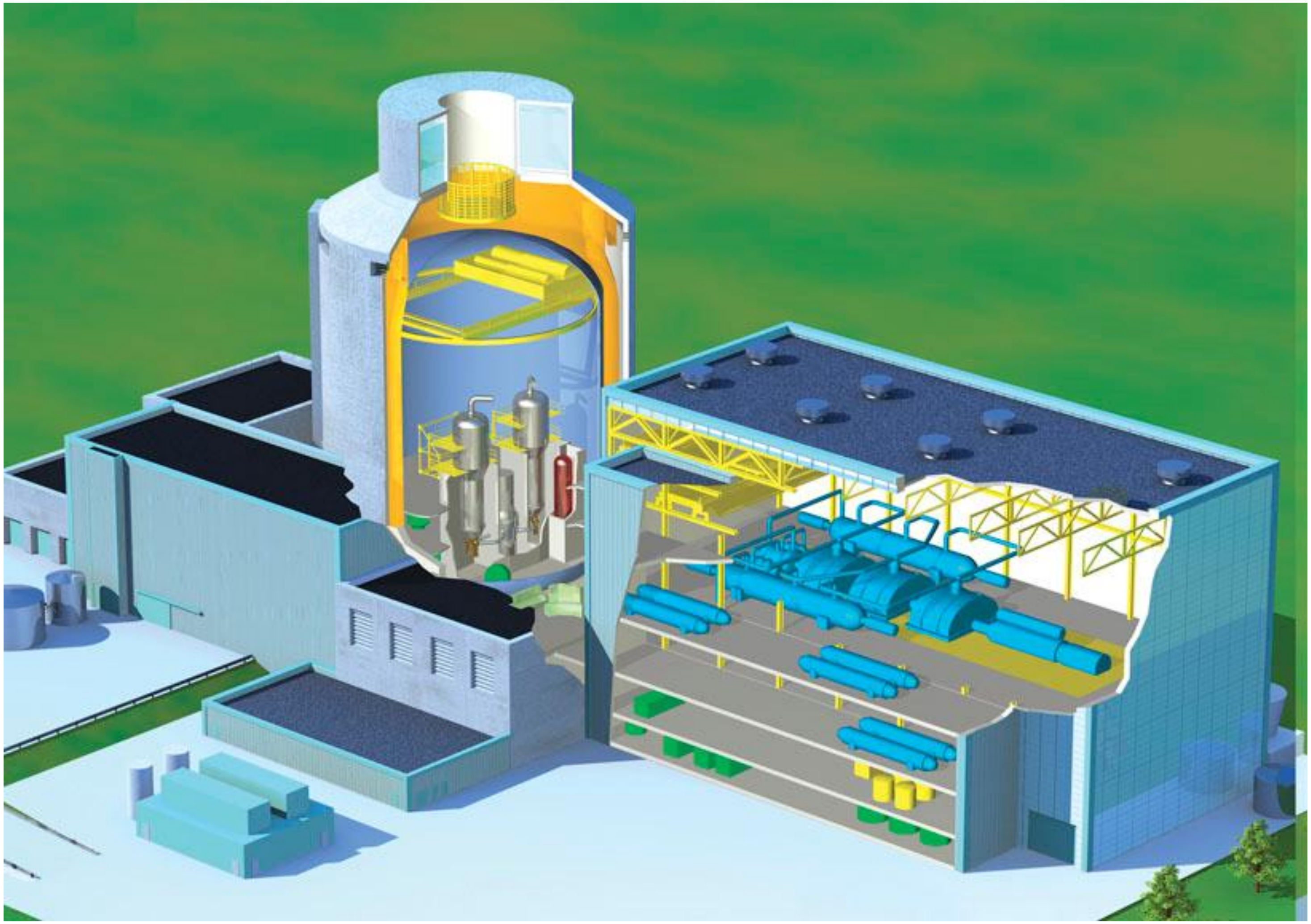


Type	BWR
Rating	50 MWe
Vessel Height	8.5 m
Vessel Diameter	3.5 m
Core Height	1.9 m
Core Diameter	3.1m
Average Power density	8.3 kW/m
Fuel /Type	UO_2 pins
Fuel Enrichment	5%
Refueling frequency	10 yrs
Coolant flow rate	620 kg/s
Core inlet temperature	279 ^oC
Core outlet steam quality	14.3 %

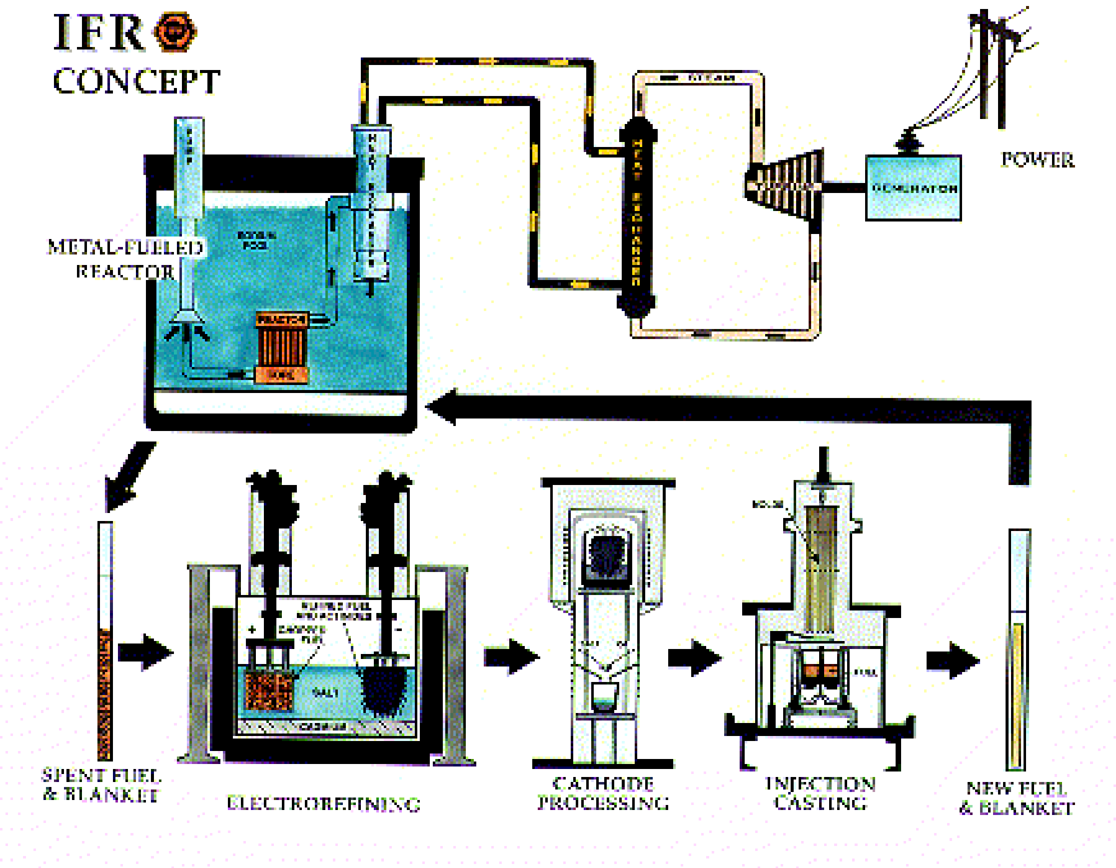
Characteristic of Purdue NMR

- 50 MWe Power Generation
- A Passive Safety System
- Modular & Transportable: Reactor & Containment
- Waste Heat → Desalination or District Heating
- Export to Developing Country & Remote Location

AP1000 Pressurized Water Reactor



The Integral Fast Reactor (IFR)



Fuel Cycle and Waste Management

I. Purex Reprocessing and Waste Storage (France, Japan…)

– Use Oxide Fuel in LWR

– Purex Reprocessing (G. Seaborg)

U-235, U-238 → Fission → Fission Products, Pu-239

Reprocessing

Pu-239, U → Fuel

Fission Product → Waste

Actinides

Fuel Cycle and Waste Management
Purex Reprocessing (Continued)

- High Level Waste (~600 years)
- Mixed Oxide of U and Pu as Fuel
- Very Expensive Reprocessing
- Too Pure Pu Production
- Nuclear Material Proliferation Problem

  (Originally from Metallurgical Laboratory for Weapons)
- Waste: Powder, Glass, Stainless Steel Case
- Very Small Volume of Waste ~1 cup/family life
- Use of Oxide → Smaller Conversion to Pu

  (Slowing Down of Neutrons)

Fuel Cycle and Waste Management

II. Once-Through System (U.S. Policy)

No Reprocessing of Spent Oxide Fuel

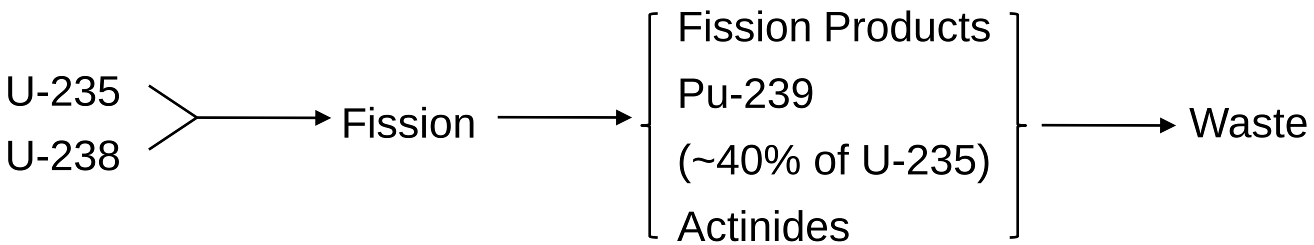
Large Waste of Uranium Resources (Only 0.4% Used)

Waste Includes Fuel (Transuranic)

Long Life of High Level Waste (~10,000 years)

Technologically Worst Solution

Mismanaged (Industry, Policy Maker, DOE)



Fuel Cycle and Waste Management

III. IFR Concept (ANL)

Combination of Liquid Metal Fast Breeder Reactor → Passively Safe

Electrorefining Reprocessing → Onsite Fuel Cycle

U-235, U-238 → Fission → Fission Products → Waste

Pu-239, (~40% of U-235), Actinides → Fuel → Back to Reactor

High Level Waste (~200 years)

Proliferation Resistant Fuel

Summary and Conclusion

- Global Energy Condition

  Prosperity – Energy (Base of Civilization)

- Expected Large Demand for Asia Pacific Region
- Coming Oil Crisis (Hubbert's Peak)
- Energy: No. 1 Technological Problem in This Century
- Future Possibilities of Energy Source
- Renaissance of Nuclear Energy & Engineering
- Challenge and Opportunity to Nuclear Community
- Passively Safe Reactor Development
- Fuel Cycle and Waste Management