Nuclear Energy

Current Trends,
the Next Decade,
and Beyond!

Paul Wilson

Engineering Physics

10.24.2008
Engineers Day

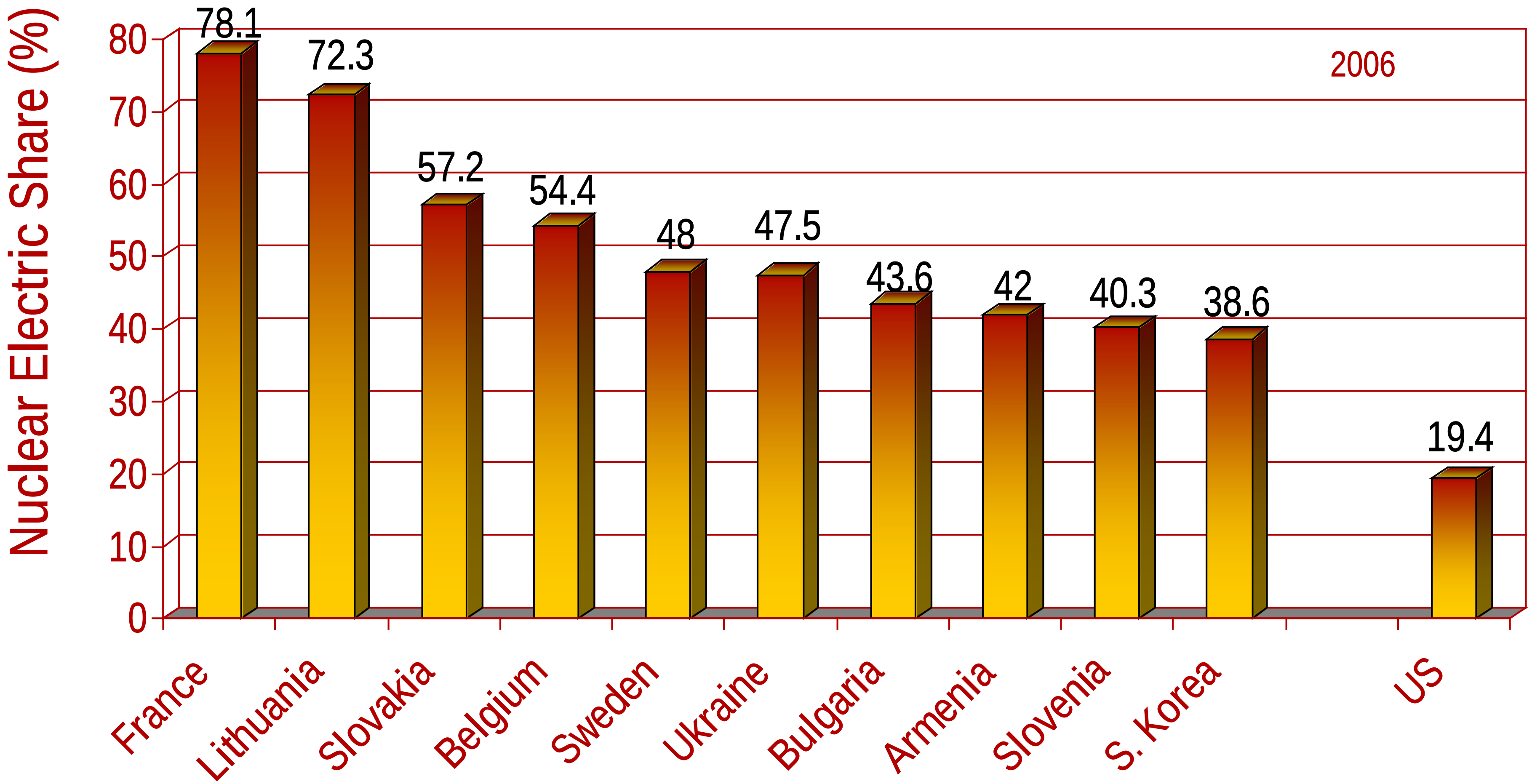
THE UNIVERSITY of WISCONSIN MADISON

Outline

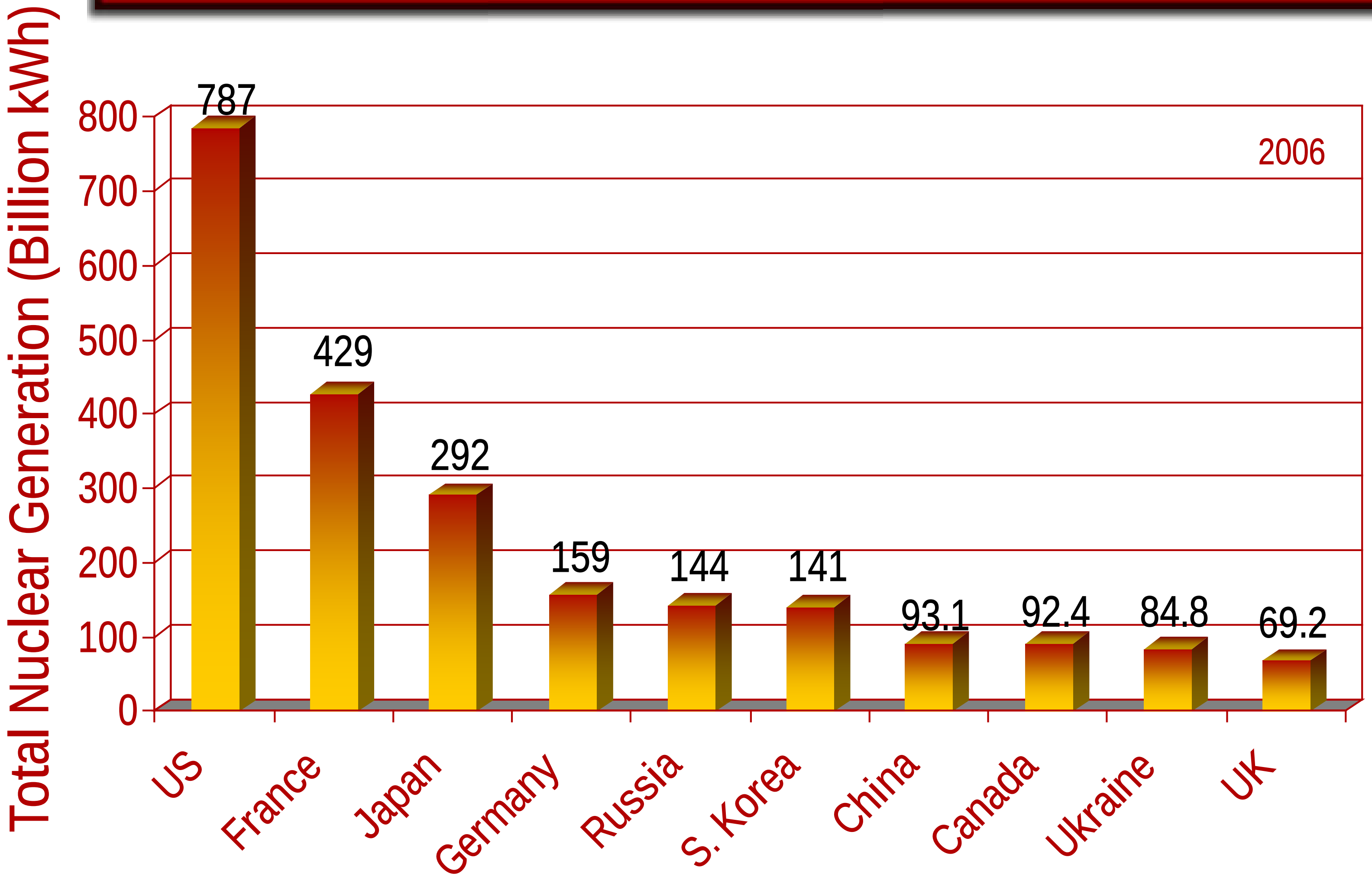
- Who uses nuclear energy
- Current Trends
  - US Nuclear industry improvements
- The Next Decade
  - New nuclear construction for a balanced energy portfolio
- Beyond
  - Sustainable nuclear fuel cycles for a secure global nuclear future

Who uses nuclear energy?

- 16% of world's electricity production



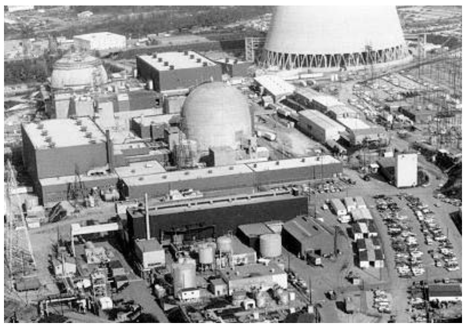
Who uses nuclear energy?



Current Trends

Generation I

Early Prototype Reactors

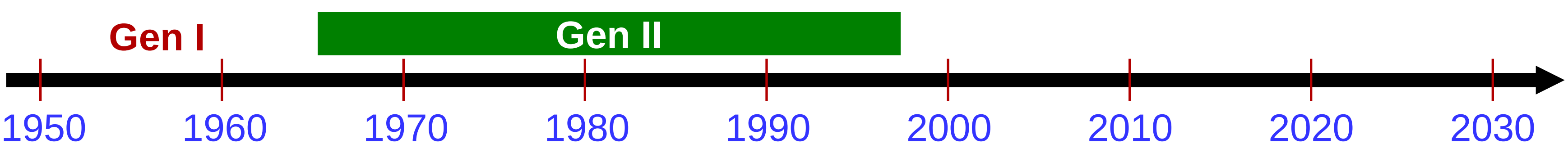


- Shippingport
- Dresden,Fermi-I
- Magnox

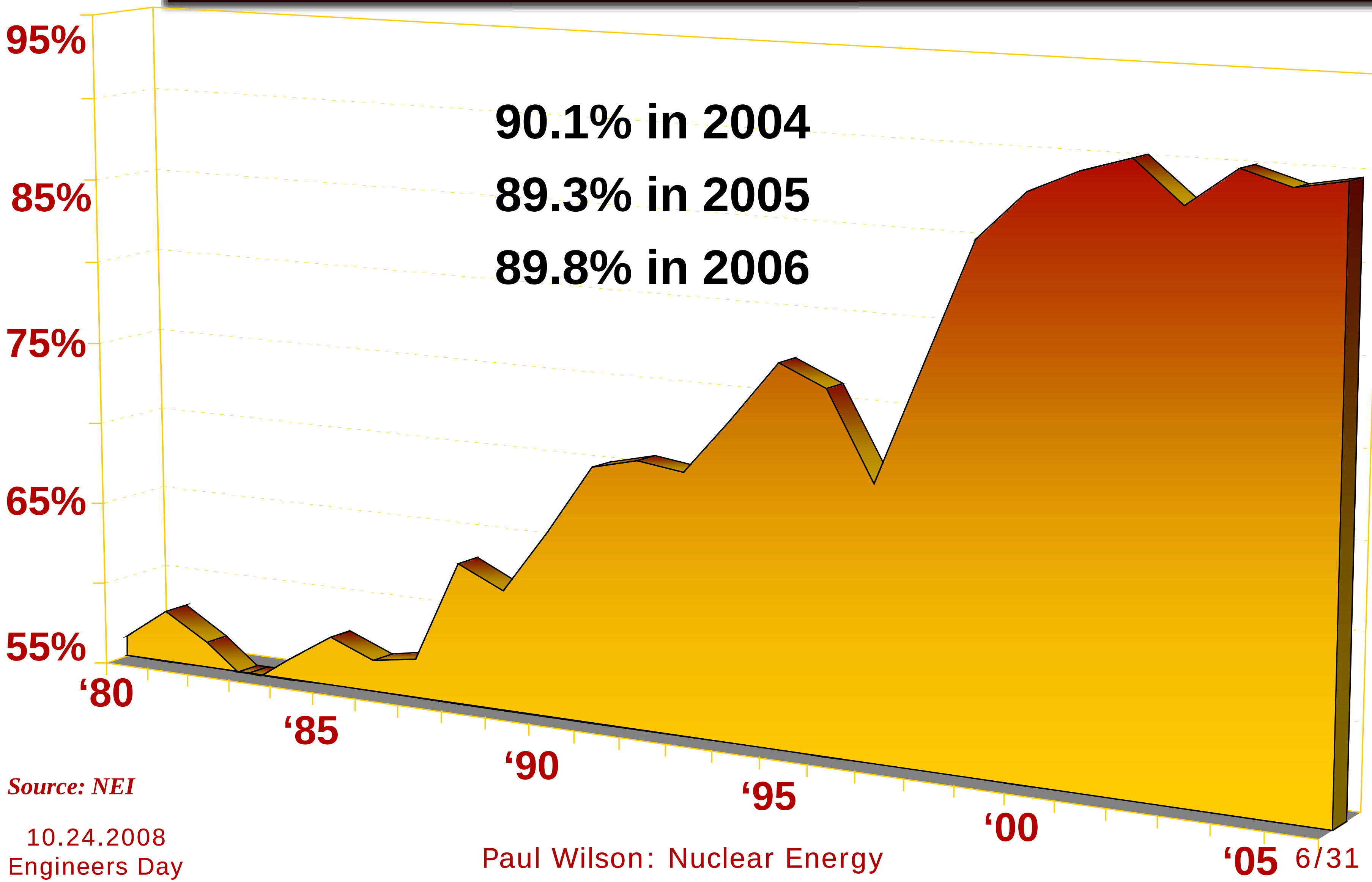
Generation II

Commercial Power Reactors

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

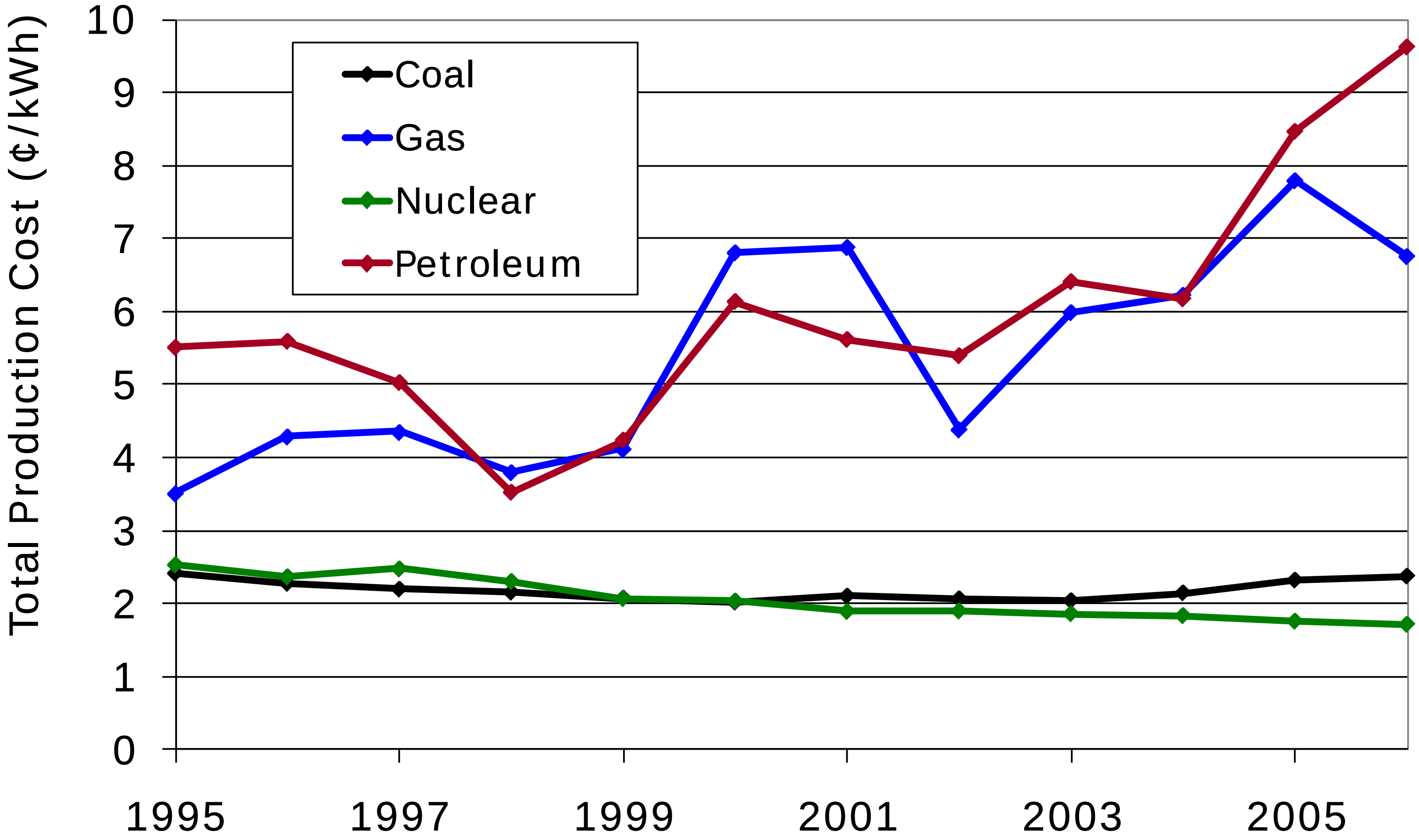


Capacity Factors Improve



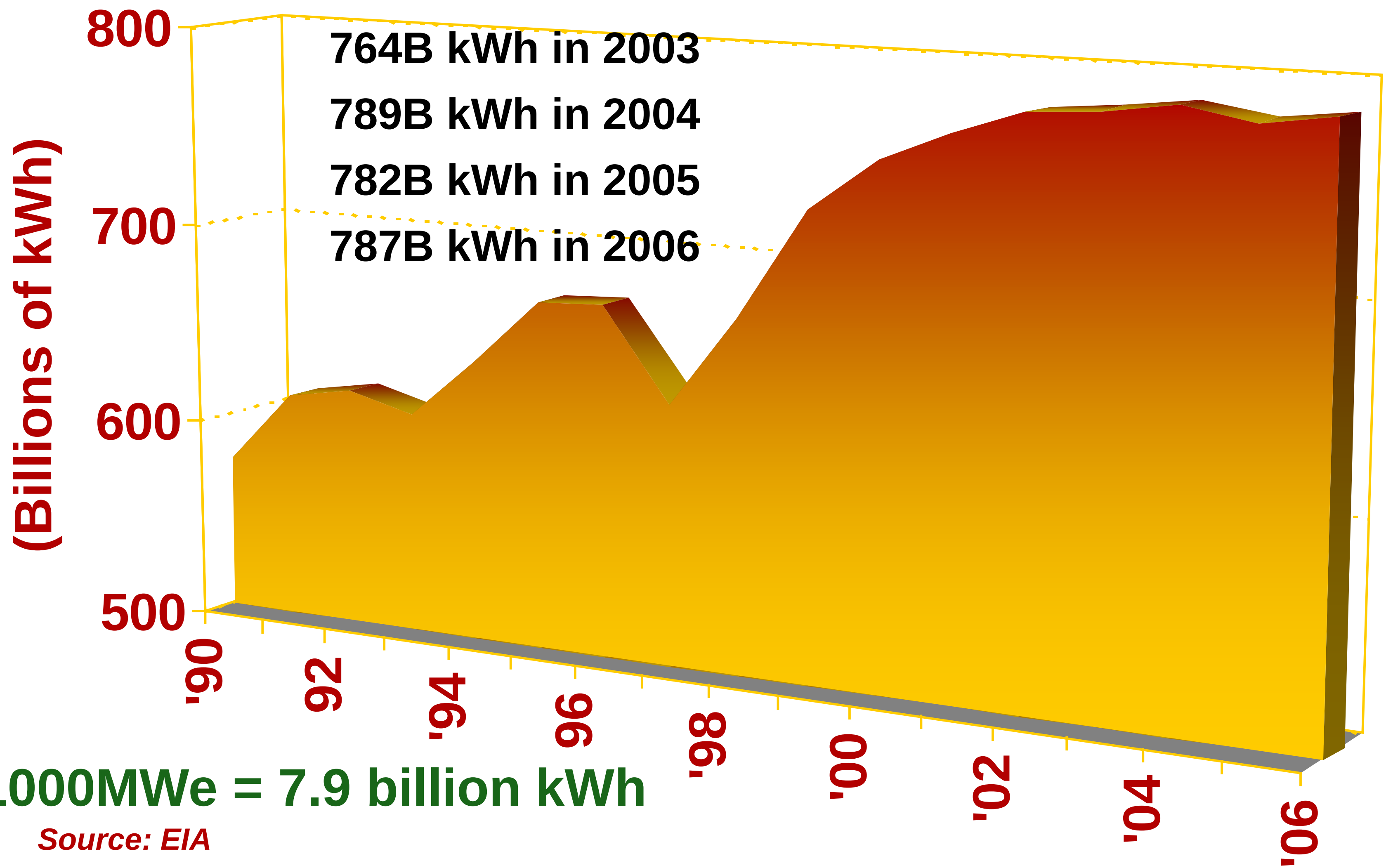
Source: NEI

Nation's Lowest Production Costs



Source: NEI

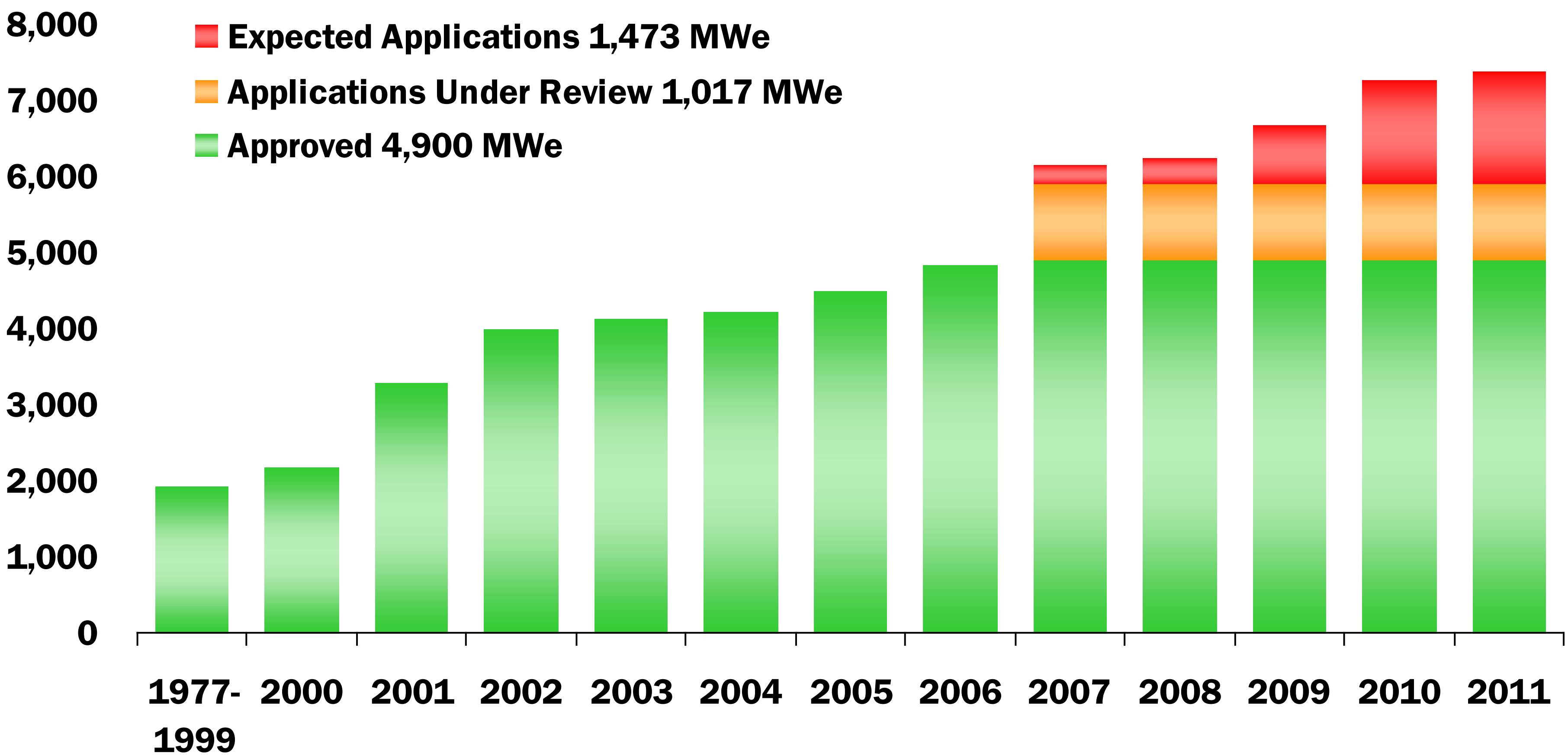
Record U.S. Nuclear Electricity Production



1000MWe = 7.9 billion kWh

Source: EIA

Extending Assets: Power Uprates



Source: NEI

Extending Assets: License Renewals

- License Renewals
  - 20 year license renewals
  - Must demonstrate continued safe operation

- **48 units renewed**
- **19 units pending**
- **26 plants considering**

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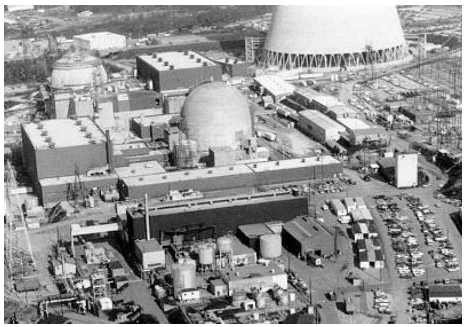
93 out of 104 operating reactors

… the Next Decade …

Generation I

Early Prototype Reactors



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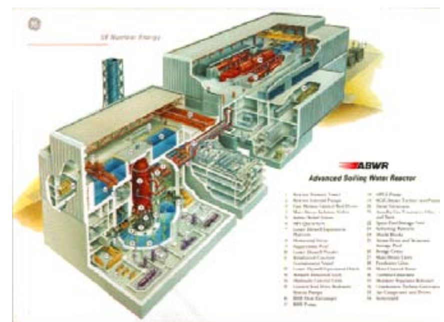
Generation III

Advanced LWRs



- **System 80+**
- **AP600**
- **EPR**
- **ABWR**

Gen I | **Gen II** | **Gen III**

1950 1960 1970 1980 1990 2000 2010 2020 2030

Nuclear Power 2010

Goal

New Advanced LWR operating in 2010's

- New Licensing Process (1992)
  - Three steps
    - Design Certification (5 certified designs)
    - Early Site Permit (3/4 ESP applications granted)
    - Construction & Operation License
- Renewal of Price-Anderson Act (2005)
- Federal loan guarantees (2005)

New Nuclear Plant Status

30+ reactors planned, 17 COLAs for 26 reactors

Company	Site(s)	Early Site Permit (ESP)	Design, # of units	Construction / Operating License Submittal Timeline
TVA (NuStart)	**Bellefonte (TN)**		W: AP1000 (2)	***October 2007***
South Carolina E & G	**Summer (SC)**		W: AP1000 (2)	***March 2008***
Duke	Cherokee County, SC		W: AP1000 (2)	***Dec 2007***
Progress Energy	**Harris (NC)** Levy County, FL		W: AP1000 (2) AP1000 (2)	***Feb 2008*** ***July 2008***
Constellation (UniStar)	**Calvert Cliffs (MD)** **Nine Mile Point (NY)** + one other sites	Will go to COL with early submittal of siting info	Areva: EPR (1) EPR (1) EPR (1)	***March 2008*** ***Oct 2009*** TBD
Dominion	**North Anna (VA)**	**Approved 11/2007**	GE: ESBWR (1)	***Nov 2007***
Entergy (NuStart)	**Grand Gulf (MS)** **River Bend (LA)**	**Approved 04/2007**	GE: ESBWR (1) ESBWR (1)	***Feb 2008*** ***Sep2008***
NRG Energy (STP)	**South Texas Project (TX)**		GE: ABWR (2)	***Sep 2007***
Southern Company	**Vogtle (GA)**	Submitted August 2006, Approval expected early 2009	W: AP1000 (2)	***March 2008***
Luminant	**Comanche Peak (TX)**	Straight to COL	MHI: APWR (2)	***Sep 2008***
Detroit Edison	**Fermi (MI)**	Not yet determined	GE: ESBWR (1)	***Sep 2008***

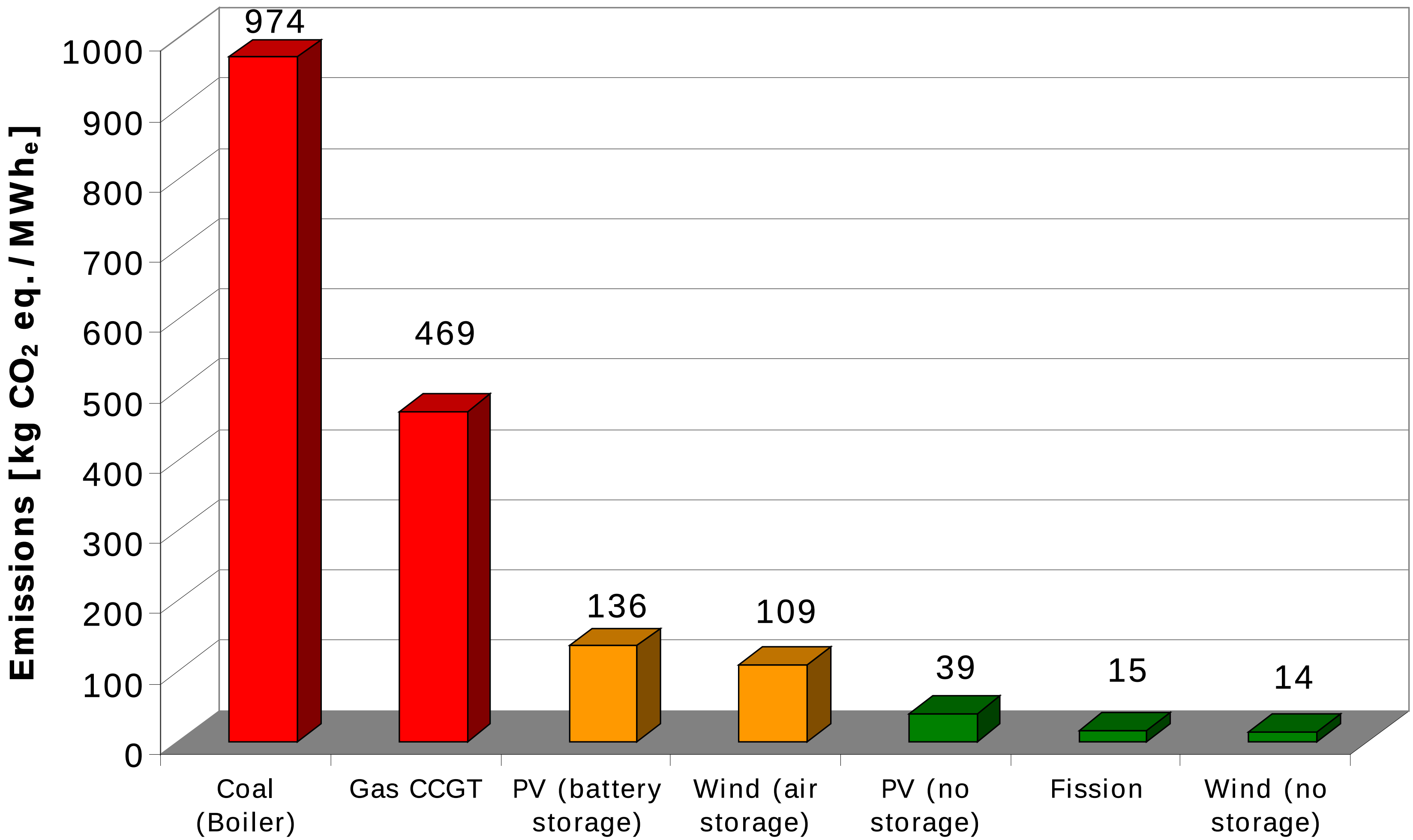
Source: NEI/NRC 10/2008

New Nuclear Plant Status

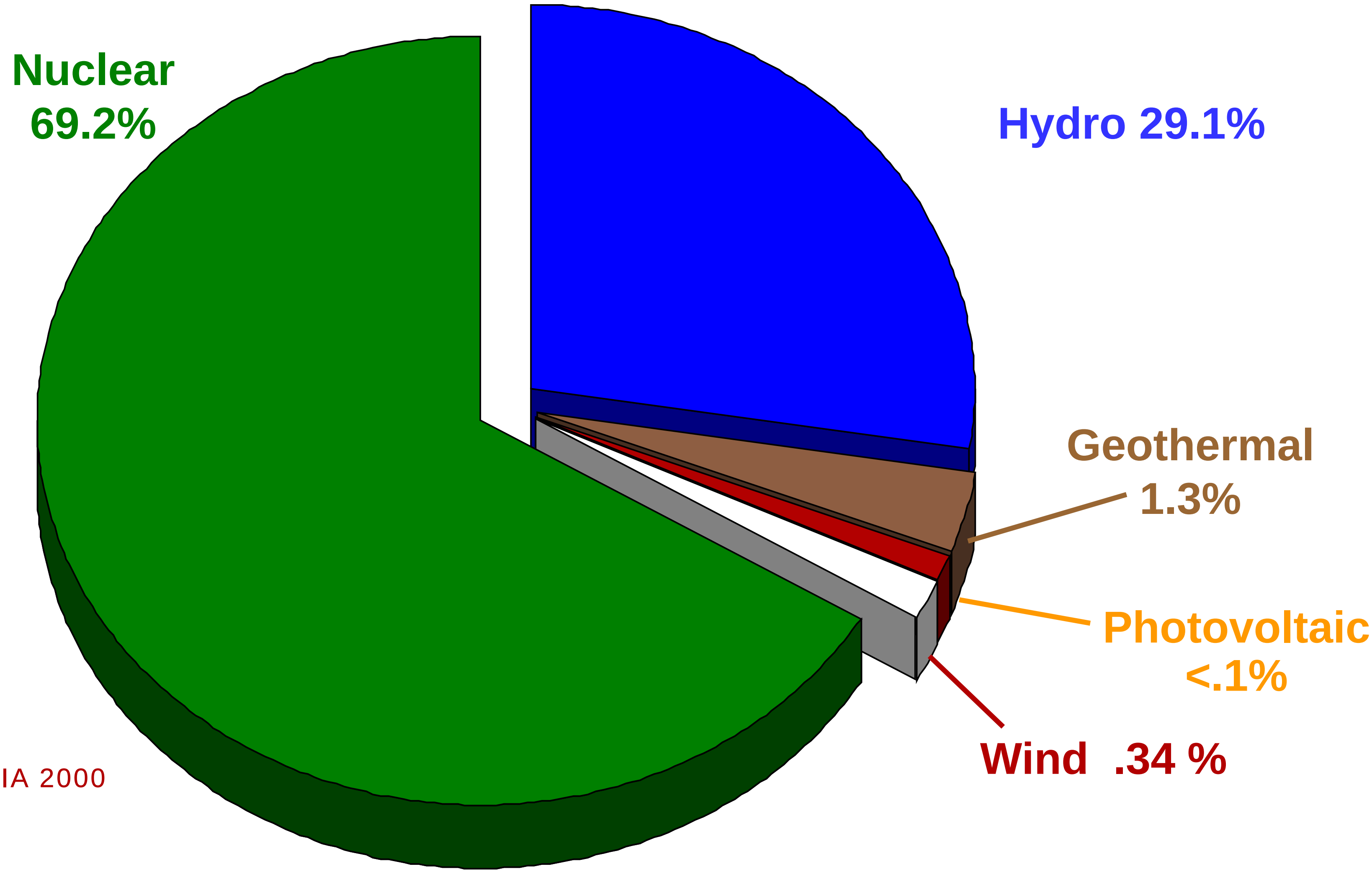
Company	Site(s)	Early Site Permit (ESP)	Design, # of units	Construction / Operating License Submittal Timeline
Amarillo Power	**Near Amarillo, TX**		EPR	FY 2009
Florida Power & Light	**Turkey Point (FL)**	TBD	TBD (2)	FY 2009
Alternate Energy Holdings	**Bruneau, ID**		EPR	FY 2009
AmerenUE	**Callaway (MO)**		EPR	***July 2008***
Exelon	Matagorda & Victoria County, TX		ESBWR(2)	***September 2008***
Duke	**Davie County (NC)**	Under consideration	TBD	TBD
Duke	**Oconee County (SC)**	Under consideration	TBD	TBD
Exelon	**Clinton (IL)**	**Approved 03/2007**	TBD	TBD
PPL Corp	**Susquehanna, (PA)**	TBD	EPR	***October 2009***

Source: NEI/NRC 10/2008

Life-cycle Emissions



Nuclear Supplies Most Low-Emission Electricity



Source: EIA 2000

Issues: Waste
The 3 C's of Used Nuclear Fuel

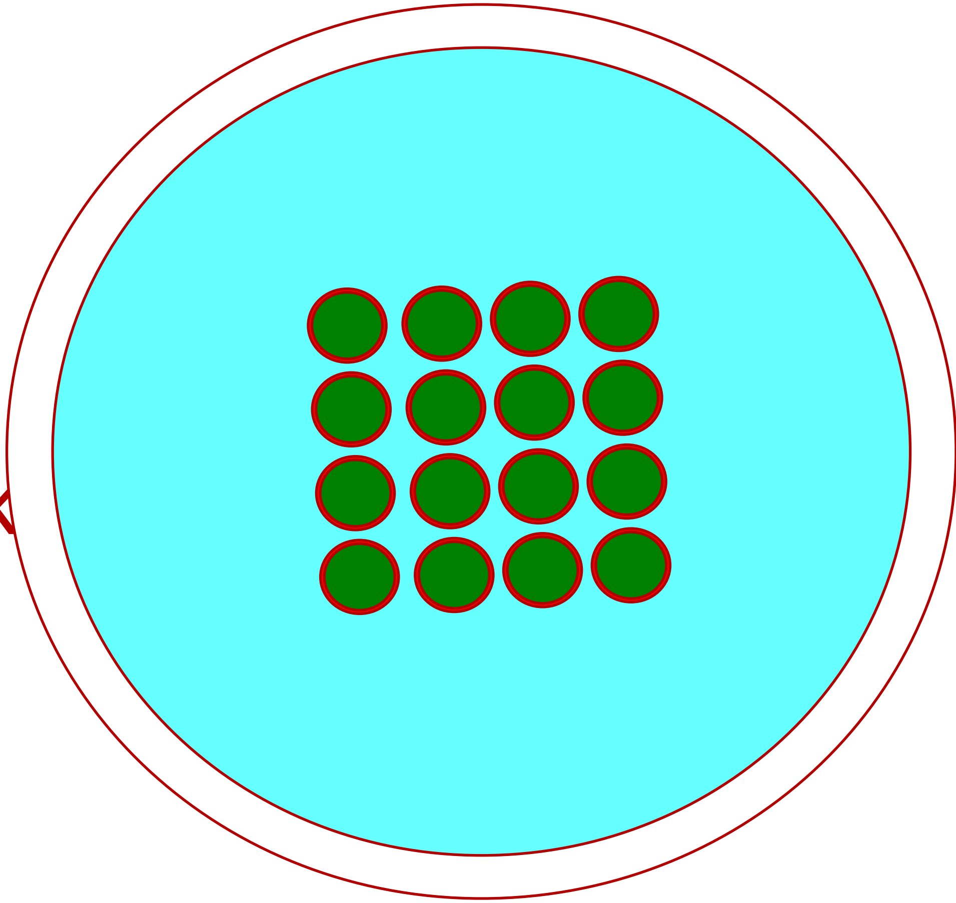
Compact ... Contained ... Cared for

- Imagine all your electricity for an entire lifetime was generated by nuclear energy
  - About 1 million kWh (2004 EIA)
- About 1 soda-can of used nuclear fuel

The 3 C's of Used Nuclear Fuel

Compact ... **Contained** ... Cared for

- Fuel itself is **solid**
- Wrapped in metal
- Stored in pool/cask



The 3 C's of Used Nuclear Fuel

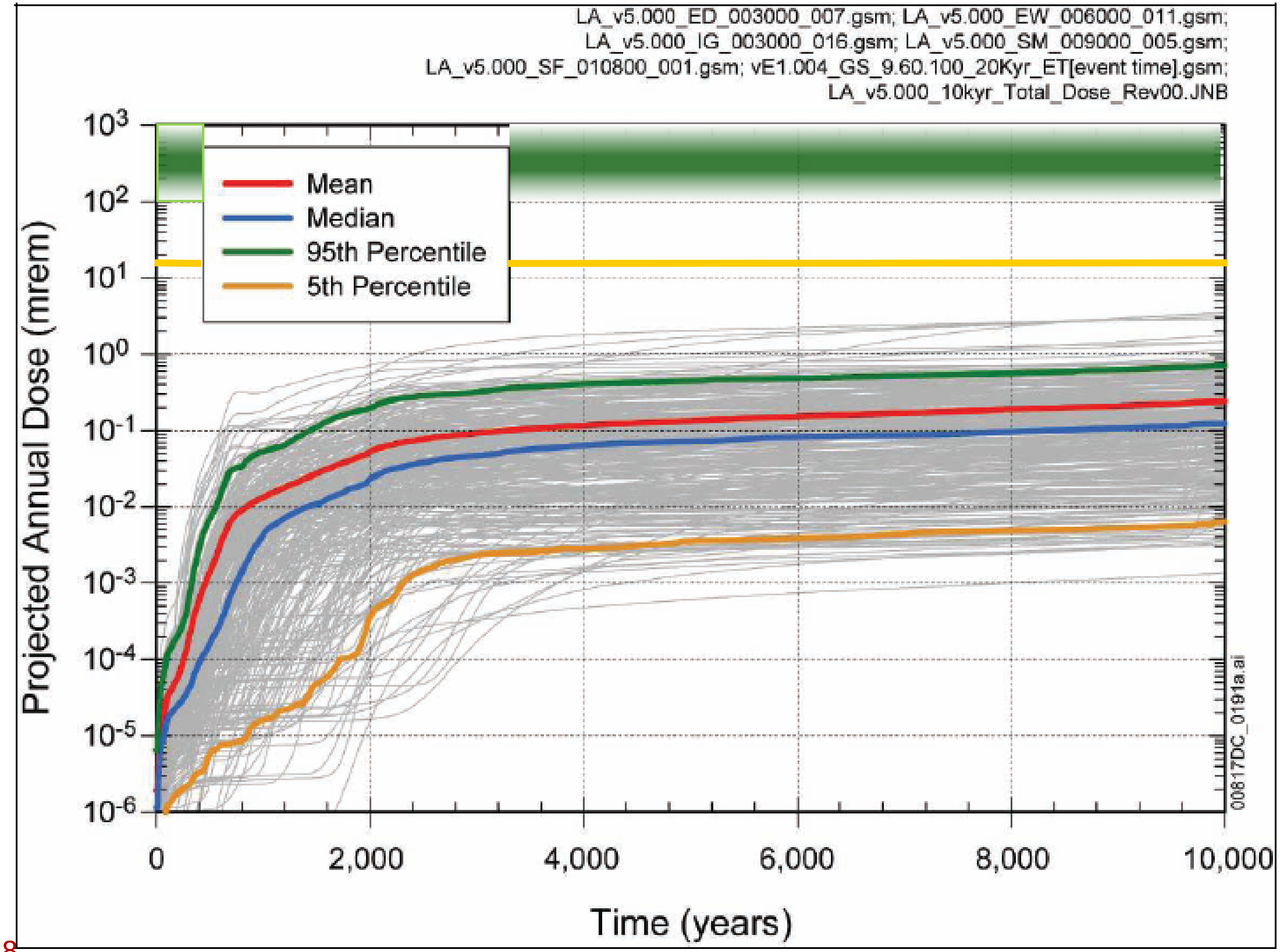
Compact ... Contained ... **Cared for**

- Carefully tracked
- Decades of experience in safe handling
- Easy to detect and monitor
- Paid for in Nuclear Waste Fee

Yucca Mountain Timeline

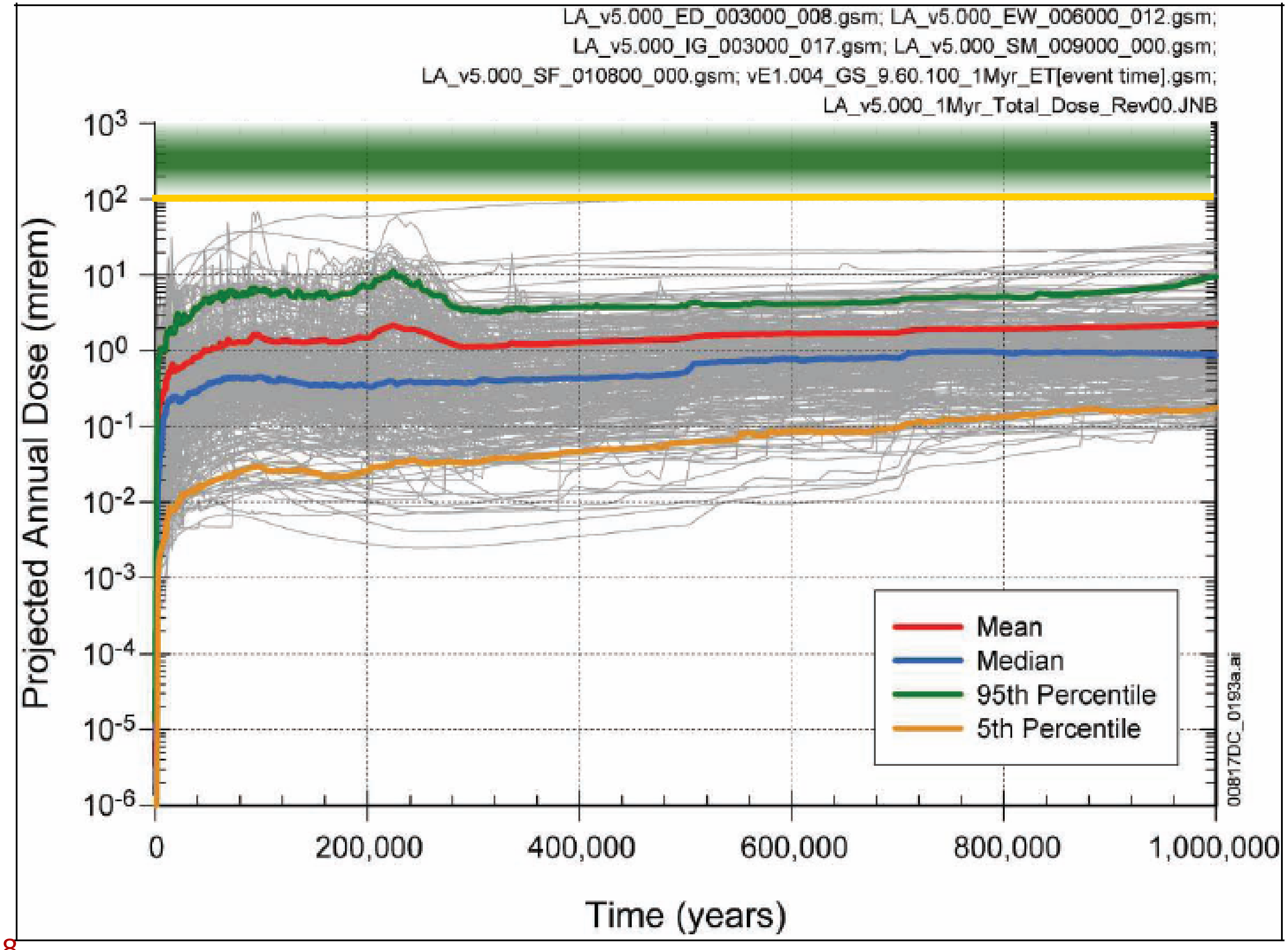
- 1957: National Academy recommends deep geologic disposal as preferred solution
- 1978: Study begins @ Yucca Mtn
- 1982: Nuclear Waste Policy Act
  - 63,000 metric tonnes of spent nuclear fuel in first repository
- 1985: Three sites approved for intensive study
- 1987: Yucca Mtn selected as preferred site
- 2002: Yucca Mtn suitability affirmed by President & Congress
- 2006: New Senate Majority leader
  - Sen. Harry Reid (D-NV)
- 2008: Application for license expected at US Nuclear Regulatory Commission for 2017 opening
  - Current funding level means schedule in question (2021?)

Estimated Dose from Yucca Mtn



Ref: DOE Supplemental Environmental Impact Statement

Estimated Dose from Yucca Mtn



Ref: DOE Supplemental Environmental Impact Statement

… and Beyond !

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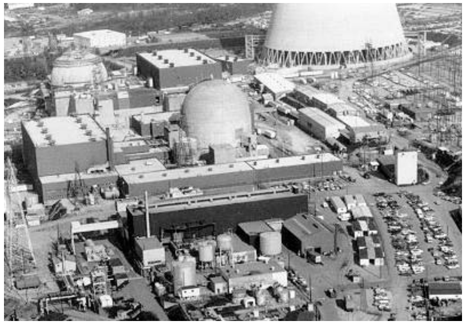

•Shippingport
•Dresden,Fermi-I
•Magnox

Generation II

Commercial Power Reactors

•LWR: PWR/BWR
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Generation III

Advanced LWRs

•System 80+ •AP600
•EPR •ABWR

Generation IV

- ➢ Highly economical
- ➢ Enhanced Safety
- ➢ Minimized Wastes
- ➢ Proliferation Resistance

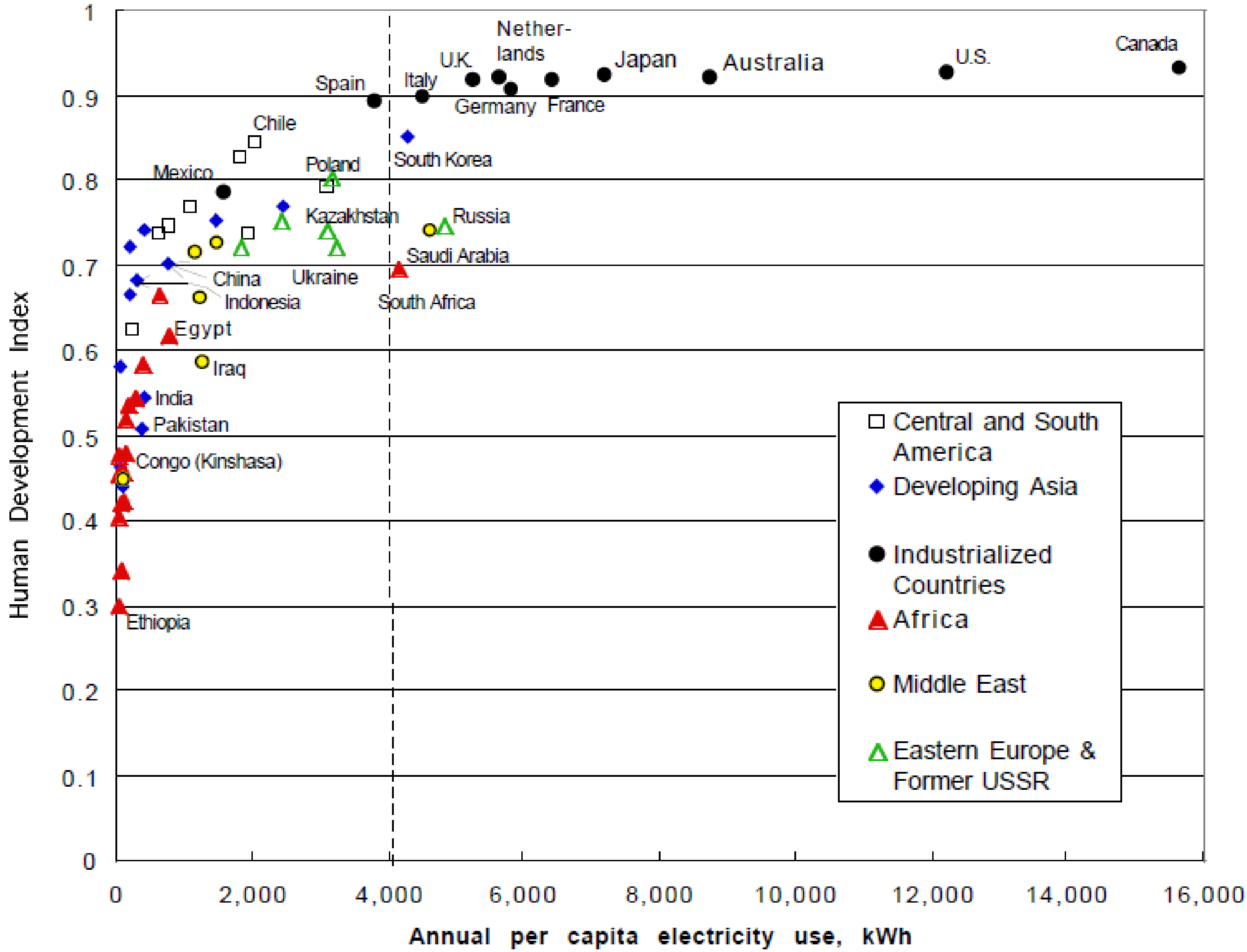
Gen I | Gen II | Gen III | Gen IV

1950 1960 1970 1980 1990 2000 2010 2020 2030

Preparing for Global Energy Needs

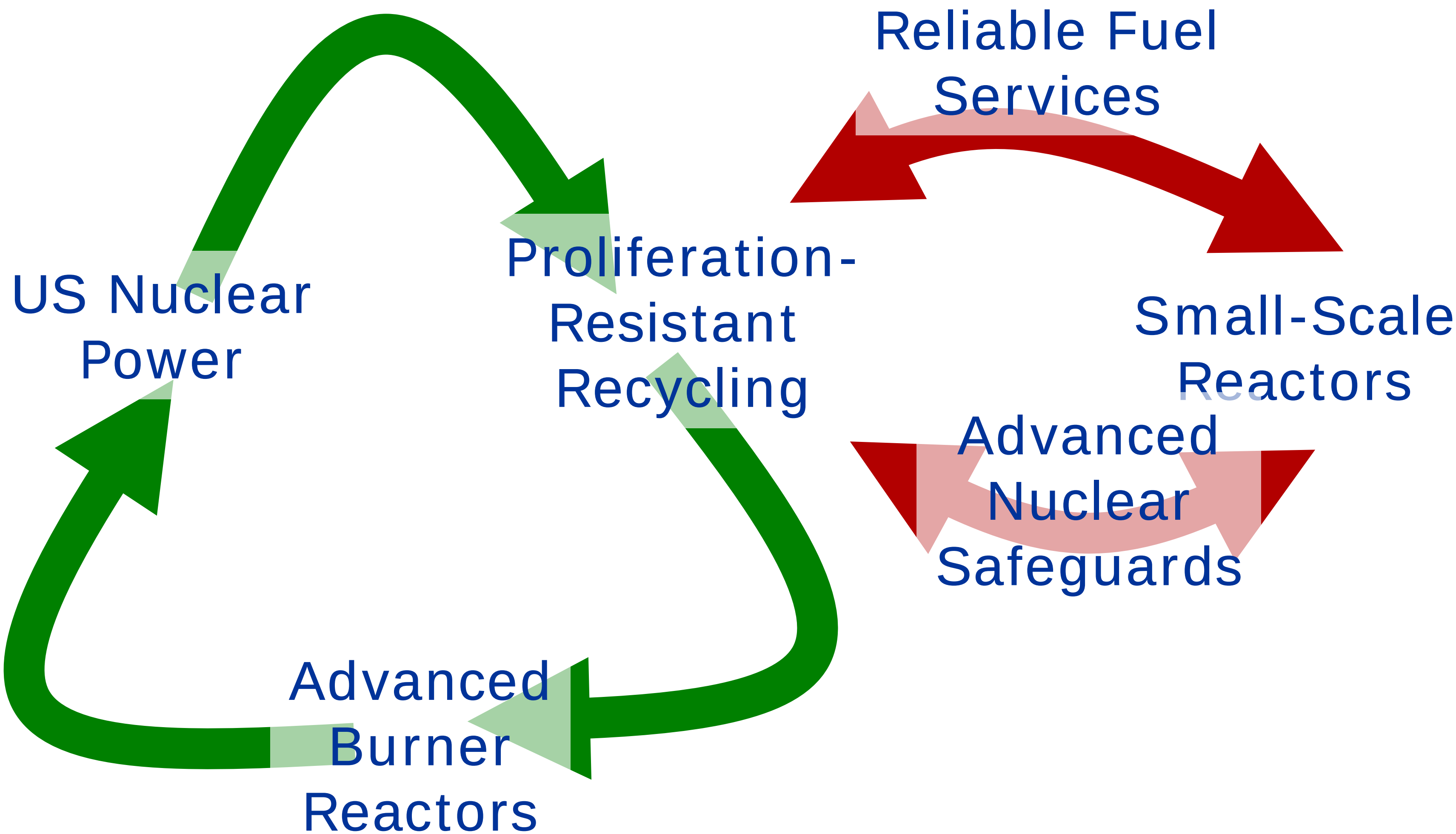
- Improvement in global standard of living will require increased energy/electricity supply
- Even a modest nuclear share requires large global deployment:
  - Differing economic environments & energy products
  - Large spent fuel inventories
  - Proliferation concerns
  - Varying safety cultures

Global Energy Use

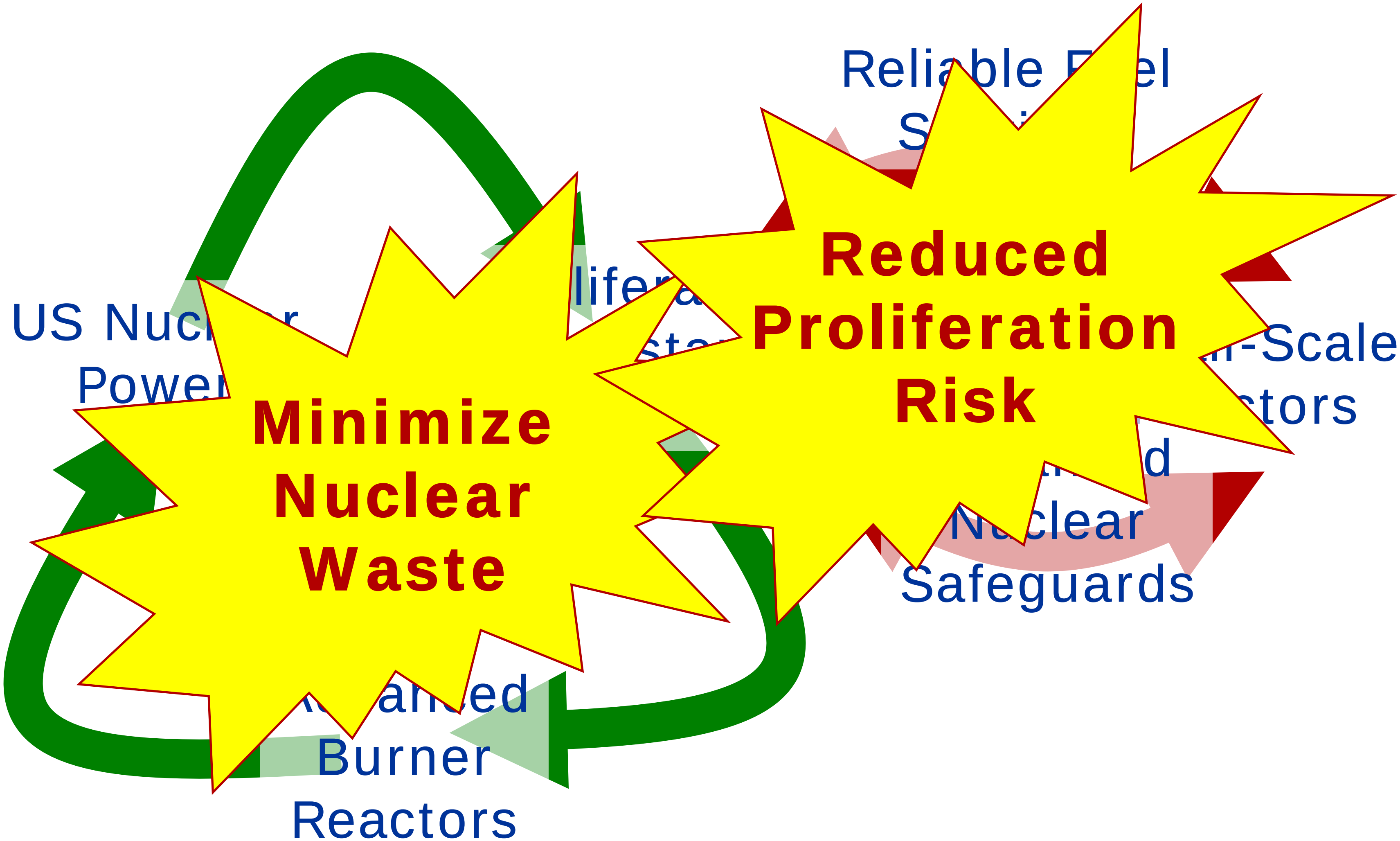


Pasternak, "Global Energy Futures and Human Development: A Framework for Analysis", UCRL-ID-140773 (2000)

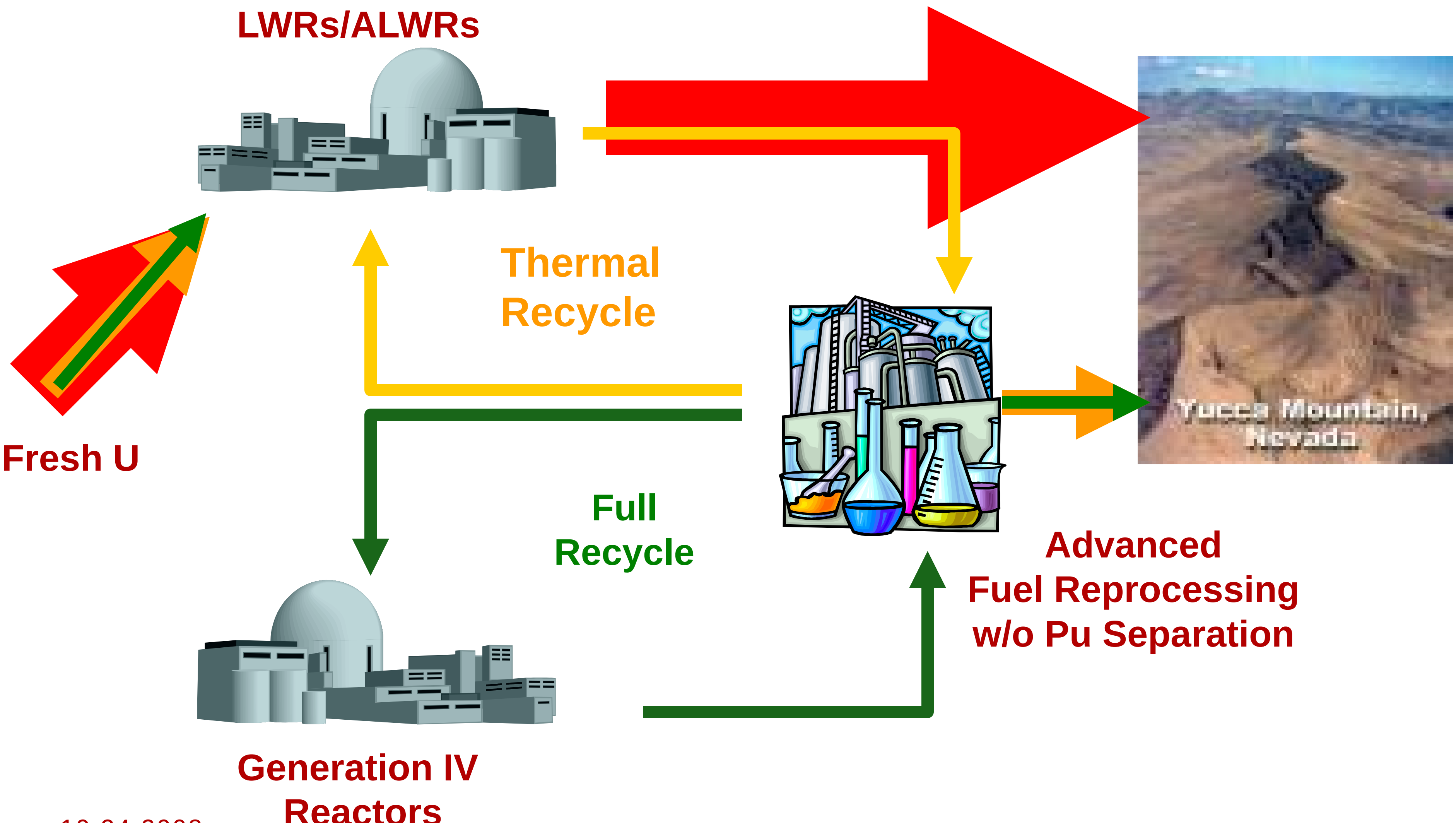
Global Nuclear Energy Partnership



Global Nuclear Energy Partnership



Advanced fuel cycles



Minimize Nuclear Waste

Nuclear Futures	Legal Limit	Extended License for Current Reactors	Continued Constant Energy Generation	Constant Market Share	Growing Market Share
Total Discharged Fuel by *2100*, MTHM	63,000	120,000	240,000	600,000	1,300,000
Current approach	1	2	4	9	21
Expanded capacity		1	2	5	11
Thermal Recycle			1	2	5
Full Recycle					1

Reduce Proliferation Risk

- Reliable fuel services
  - Supplier states are most economically attractive option
  - Internationally guaranteed supply
- Small-scale reactors
  - Small size for growing economies with limited access to capital
  - Long life cores to minimize refueling
- Advanced Safeguards
  - Technology & diplomacy

On this day....

- Presidential election politics
- Credit crunch
- Economic slowdown

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UNIVERSITY OF WISCONSIN ENERGY INSTITUTE

TECHNOLOGY • RESOURCES • SUSTAINABILITY

10.24.2008 Engineers Day

Issues: Safety
History

- 1979: Three Mile Island
  - Reactor valve malfunctions
  - Small radioactivity release
  - No radiation-related health impacts
  - Economic disaster for owner
- 1986: Chernobyl
  - Flawed reactor design & operations
  - Large radioactivity release
  - 50-1000 radiation-related deaths/illnesses
  - Regional socio-economic catastrophe

Issues: Safety
Current Trends

- Technology improvements continually reduce risk
  - Risk-based regulation
- Human training & performance critical
  - Safety culture
  - US nuclear industry one of the safest
- US Nuclear Regulatory Commission
  - Fee-based regulator
  - Credible & effective

Issues: Insurance
Where Safety & Economics Meet

- Price-Anderson Act
  - Group insurance policy
  - All reactor operators share liability for any accident
  - Total liability capped with US Gov't as insurer of last resort
    - Similar to other industries

Issues
Economics

- Large capital cost
  - $1500-2000/kWe
  - Construction delays
- Small fuel costs
- Regulatory uncertainty
  - 1989: Shoreham $6B

Advanced Light Water Reactors

- Evolutionary changes to current reactor designs
- Focus on passive safety systems
- Improved economics
  - Modern/modular construction practices
  - Standardized designs
- Currently being built in Pacific Rim, Finland & France

ALWR Example: Westinghouse AP1000

- Simplicity
  - 50 percent fewer valves
  - 83 percent less piping
  - 87 percent less control cable
  - 35 percent fewer pumps, and
  - 50 percent less seismic building volume than a similarly sized conventional plant
- Cheaper, Faster, Less Maintenance

Energy Recovery

- ~1 MWd_{th}/g of fissions
- Nat. abundance of ^{235}U is only 0.71%
- 140x as much energy in ^{238}U as in ^{235}U
- 50 y (??) of energy in ^{235}U

  = 7000 y of energy in ^{238}U (and actinides)

Note: we are ignoring Th