Nuclear Power - Contributing to U.S. Energy Needs in the 21st Century?

- Waste Management Challenges, and Advanced Nuclear Fuel Cycle R&D

University of Wisconsin, Women in Nuclear seminar

W. Mark Nutt

Nuclear Engineering Division

Argonne National Laboratory

November 19, 2010

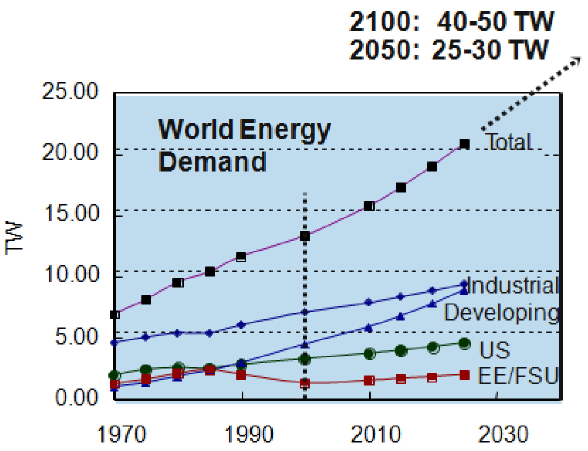
Outline

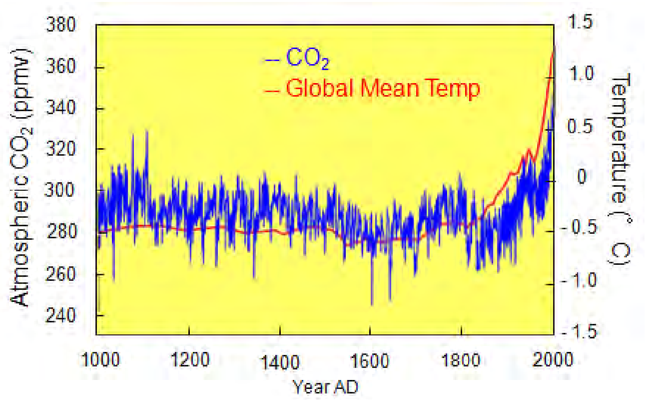
- The "Problem"
- Electricity Sources: Distributed and Concentrated
- Current U.S. and World-Wide Reactors
- Performance of the Current Fleet
- Relicensing and Continued Sustainability
- New Builds and Issues (the "Renaissance")
- Use Fuel Management and Disposition
- Advanced Fuel Cycles R&D

Nuclear power is part of a complex technical, social, political , environmental decision-making "framework. " The objective is to shed some light on nuclear power within this "framework"

Electricity Demand

- The demand for electricity is increasing world-wide
- Demand is growing in the U.S., but even more so abroad
  - The developing world is showing tremendous growth
  - China is a prime example
- Move to further "electrify" would further increase demand
  - Plug-in hybrids replacing internal combustion engines
- Strong evidence that man may be affecting the global climate – CO_2 emissions
  - Kyoto Protocol
  - International Panel on Climate Change
  - Voluntary goals established by countries





- Question: How do we meet our energy needs while at the same time reducing our CO_2 footprint to mitigate the potential for global climate change

HOW DO WE FEED THE GRID?

The “Problem”

Need to Continue Meeting This Demand as it Grows, But With Reduced Emissions

Desire to Reduce Emissions from Transportation Sector

Sources of Electricity


Biomass


Wind


Coal


Solar


Natural Gas


Hydroelectric

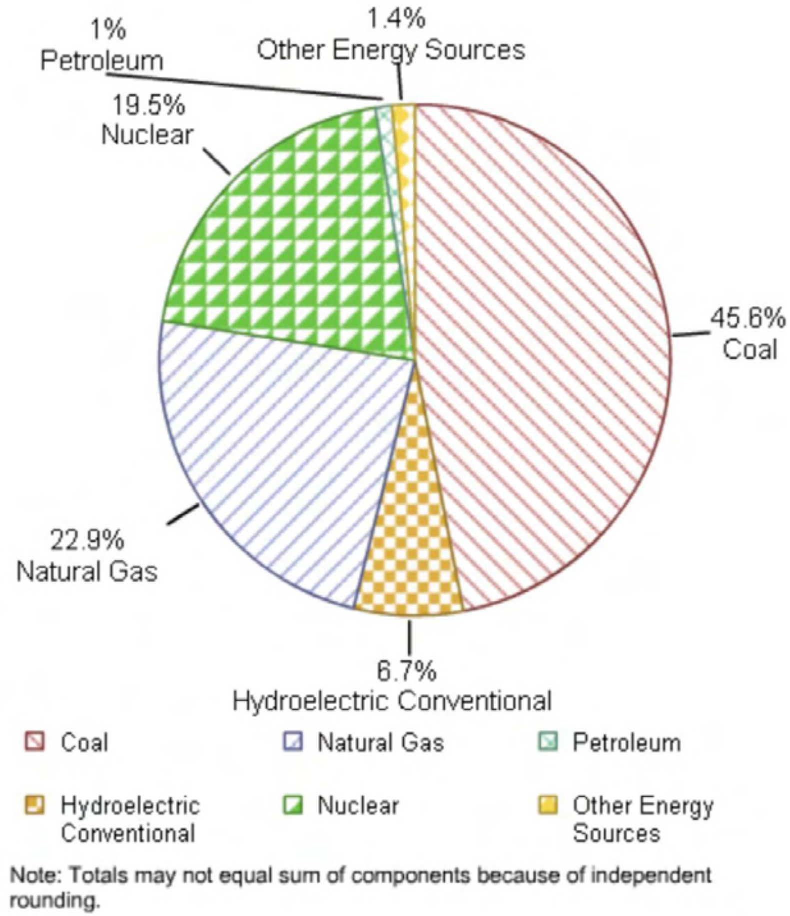

Nuclear

There is no Single Solution to the Complex Set of Issues Facing the Energy System

These Solutions Require Parallel Development of New Energy Technologies

Electricity Generation in the U.S. - 2010 Through July

- **2,393,612,000 MW-hr**
  - **~470 large (1000 MWe) power plants**
  - **~1500 medium (300 MWe) power plants**
- 4% growth over same period in 2009



DOE Energy Information Agency, Electric Power Monthly, October 2010, DOE/EIA-0226 (2010/10). Available at www.eia.gov/cneaf/electricity/matrix96-2000.html

Electricity Generation in the Great Lakes Region

State	Net Electricity Generation By State (all Sectors) - July 2010 1000 MW-hr					Change, July 2009 - July 2010	
	Total	Coal	Natural Gas	Nuclear	Other Renewable	Total	Other Renewable
Illinois	18,645	8,767	1,416	8,477	254	10.3%	44.8%
Indiana	12,045	10,589	1,071	--	141	25.5%	113.1%
Iowa	5,321	3,953	387	445	455	21.8%	21.1%
Michigan	11,672	6,440	2,061	2,844	235	23.7%	14.9%
Minnesota	5,316	2,865	714	1,184	453	19.2%	13.3%
Ohio	14,431	11,514	1,105	1,572	52	20.1%	-0.3%
Wisconsin	6,674	4,167	981	1,118	180	23.2%	5.0%
Source	Table 1.6.A	Table 1.7.A	Table 1.10.A	Table 1.12.A	Table 1.14.A	Table 1.6.A	Table 1.14.A

Other Renewables: wood, black liquor, other wood waste, biogenic municipal solid waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, wind

DOE Energy Information Agency, Electric Power Monthly, October 2010, DOE/EIA-0226 (2010/10). Available at www.eia.gov/cneaf/electricity/matrix96-2000.html

- Coal is the largest source of electricity generation
  - ~47% (Illinois, Nuclear is ~45%) - ~80% (Ohio)
- Electricity generation, and demand, is increasing -- ~ 20% from July 2009 to July 2010
  - July is one of the peak months
- Other Renewable Generation is increasing, but total generation is not keeping up with demand growth
  - Primarily natural gas

Renewable Electric Generation - 2008 (1000 MW-hr)

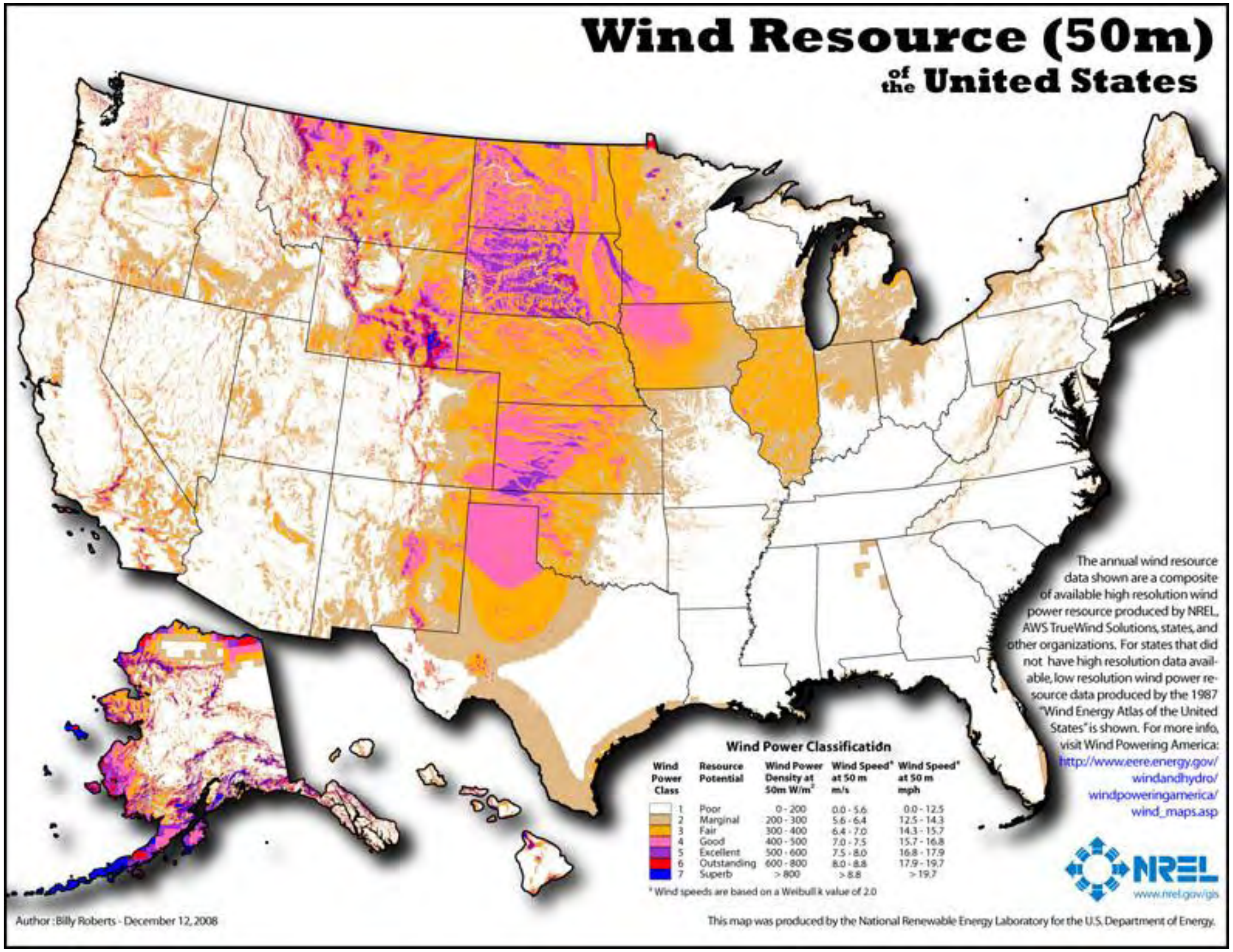
State	Wind	Wood/Wood Waste	MSW/ Landfill Gas	Other Biomass
Illinois	2,337	1	697	
Indiana	238		273	
Iowa	4,084		98	69
Michigan	141	1,710	738	1
Minnesota	4,355	725	399	372
Ohio	15	418	183	8
Wisconsin	487	775	474	18

Source: DOE Energy Information Agency, Renewable and Alternative Fuels. www.eia.doe.gov/fuelrenewable.html

Distributed or Concentrated Energy Sources?

- Distributed
  - Solar
  - Wind
- Concentrated
  - Coal
  - Natural Gas
  - Nuclear
- What will work best depends on many factors (location, population density)
  - Both can and should play a role
  - Consider best source for powering the major metropolitan areas

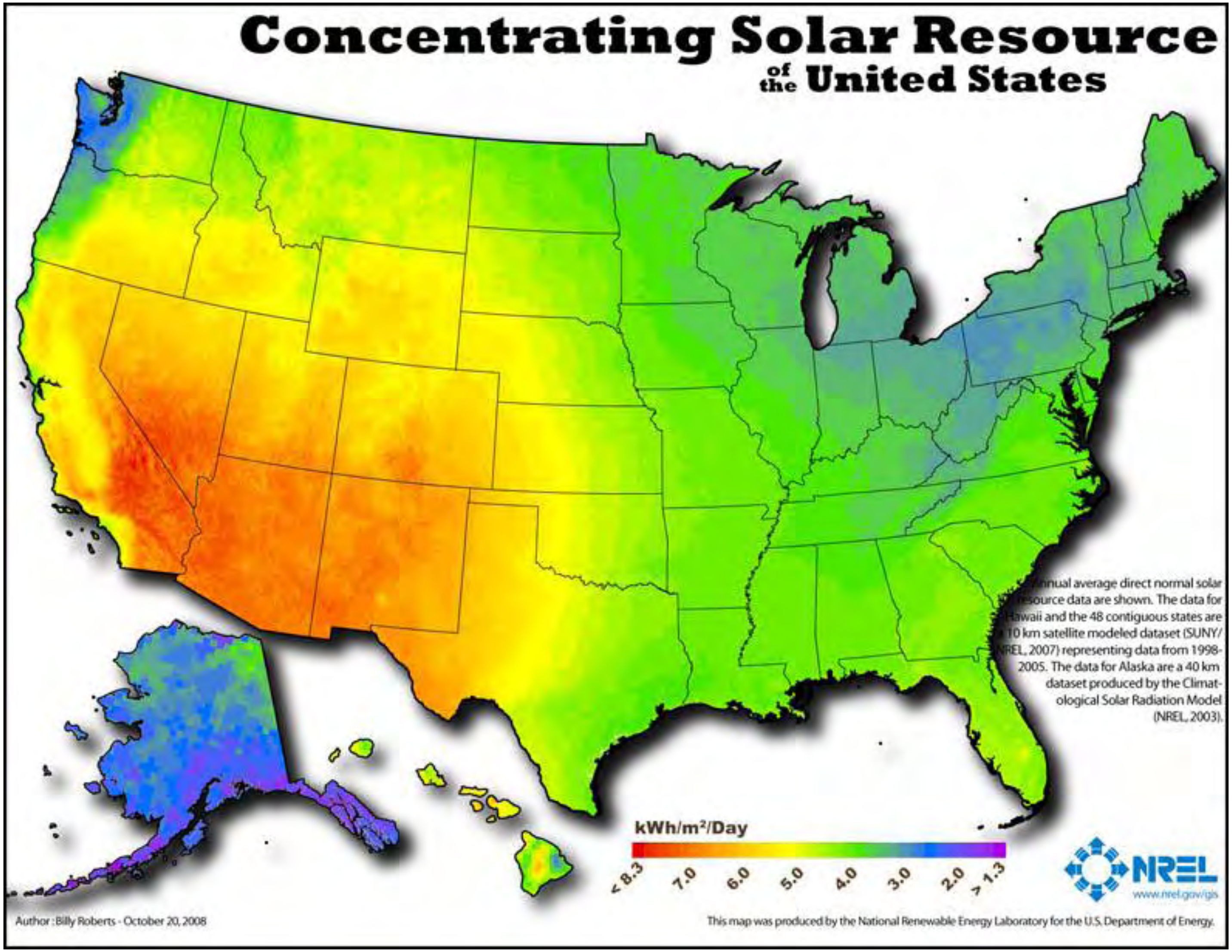
Wind Resource Potential



- Class 3 or greater suitable for most utility-scale wind turbine applications
- Class 2 areas are marginal for utility-scale applications but may be suitable for rural applications
- Class 1 areas are generally not suitable, although a few locations (e.g., exposed hilltops not shown on the maps) with adequate wind resource for wind turbine applications may exist

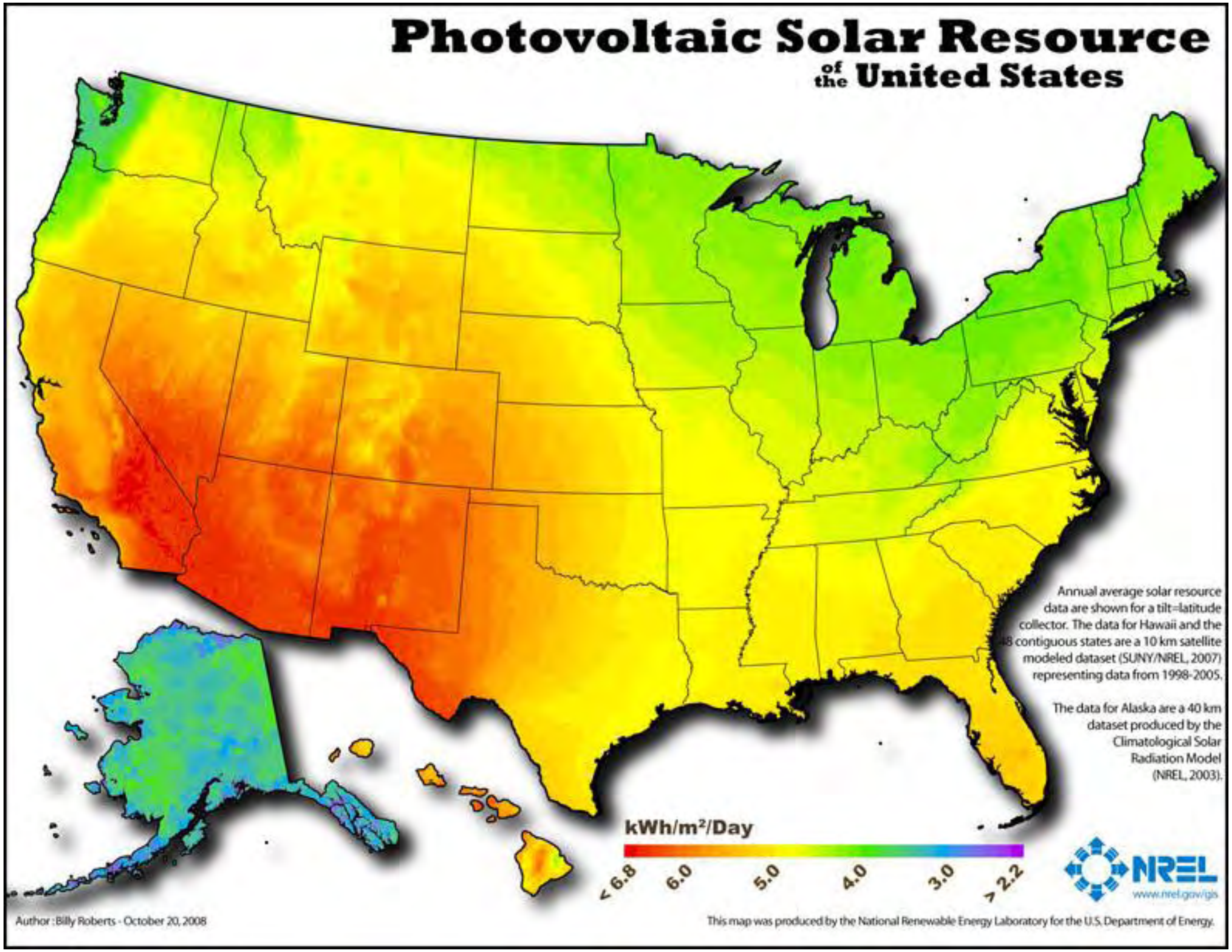
National Renewable Energy Laboratory; http://www.nrel.gov

Solar Energy Resource Potential - Concentrated



National Renewable Energy Laboratory; http://www.nrel.gov

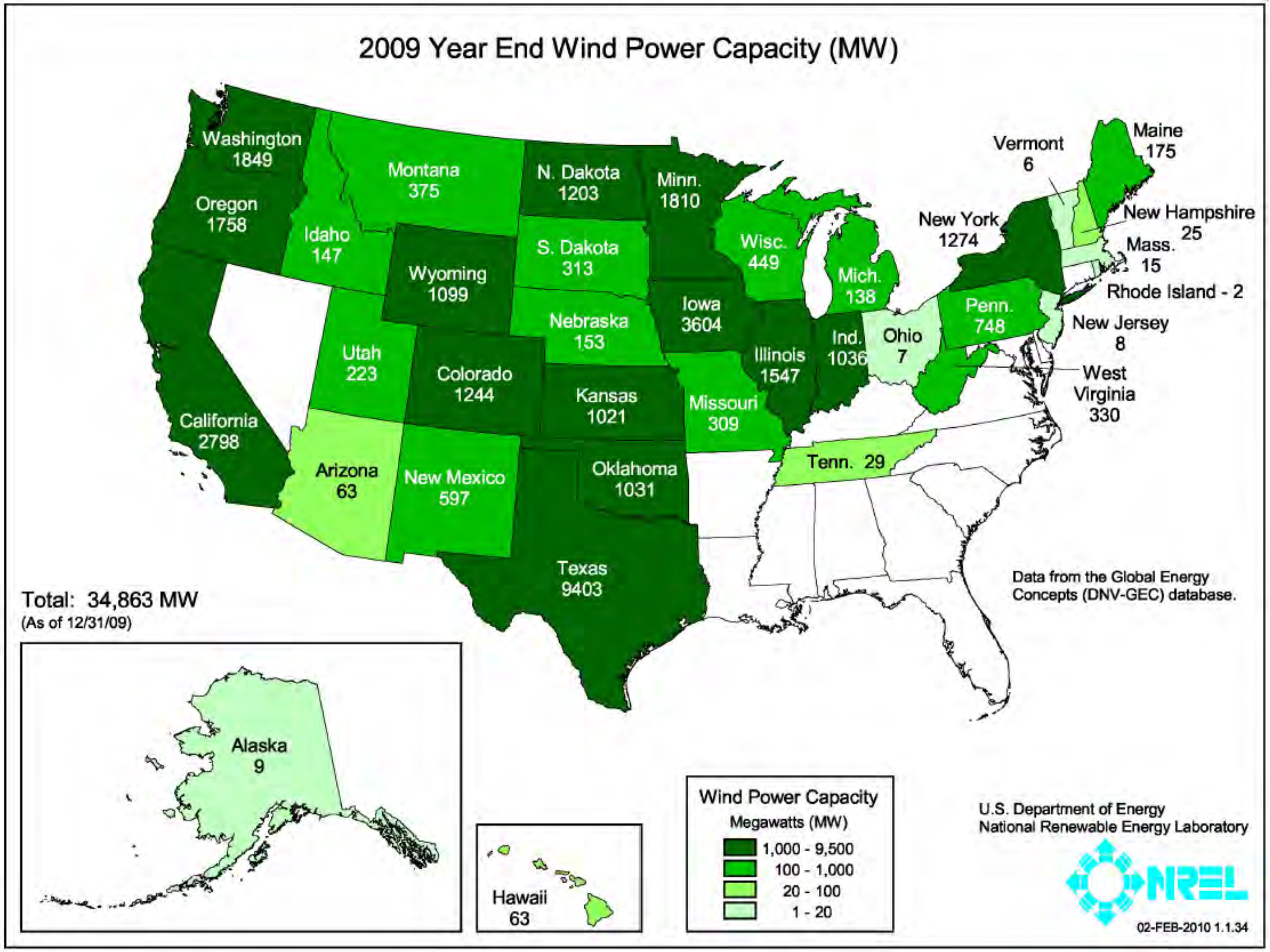
Solar Energy Resource Potential - Photovoltaic



National Renewable Energy Laboratory; http://www.nrel.gov

Installed Wind and Solar Capacity

Wind



U.S. Department of Energy; www.windpoweringamerica.gov/wind_installed_capacity.asp#current

Solar

State	Grid-Connected PV Capacity (MW_{DC})
California	768
New Jersey	128
Colorado	59
Arizona	46
Florida	39
Nevada	36
New York	34
Hawaii	26
Connecticut	20
Massachusetts	18
All Other States	83
Total	1,257

- ~430 MW of installed grid-connected concentrated solar power
- ~170 MW_{th} of installed solar home heating/cooling
- ~700 MW_{th} of installed solar pool heating

Interstate Renewable Energy Council, U.S. Solar Market Trends 2009. irecusa.org/wp-content/uploads/2010/07/IREC-Solar-Market-Trends-Report-2010_7-27-10_web1.pdf

Byron Nuclear Power Plant – Near Rockford, IL

- Two Westinghouse Pressurized Water Reactors
- > 2,000 MW capacity;
- > 48,000 MW-hr / Day generation (Day or Night, Sunny or Cloudy, Windy or Not)
- ~ 1/3 square mile “footprint”
- Large fossil station would have a similar footprint

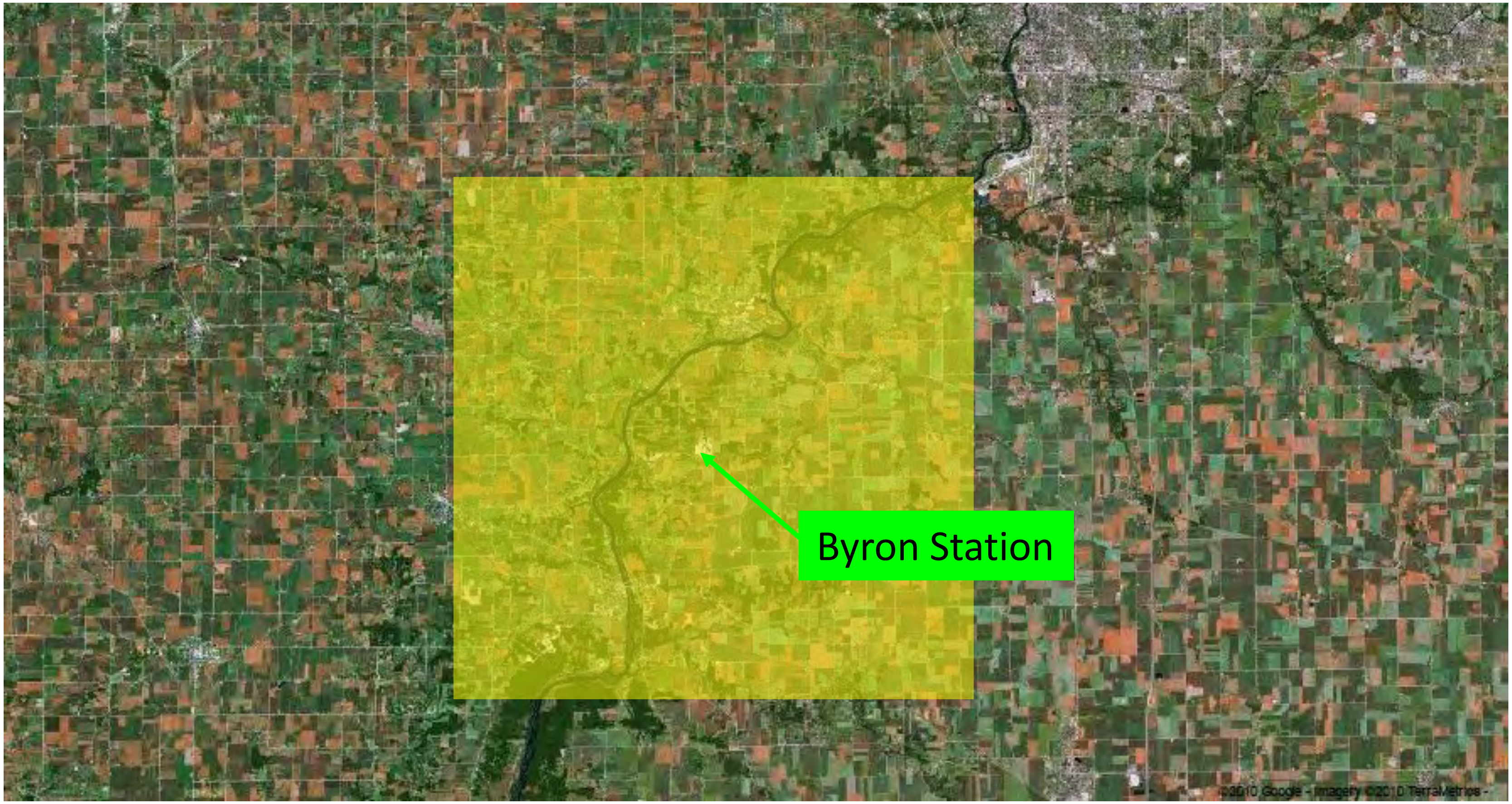
Energy Density - Distributed vs. Local: Size Comparison

- Wind[1]
  - Installed Capacity Density: 3.4 – 12.2 MW / square mile (total wind farm "footprint")
  - 2,000 MW → 160 – 590 square miles (12 miles x 12 miles – 24 miles x 24 miles)
  - Direct impact (turbine, roads, ancillary structures) about 1% of total "footprint"
- Solar[2] (based on photovoltaic resource)
  - Annual Average Resource: 9,100 – 11,700 MW-hr / square mile /Day
  - 48,000 MW-hr → 4.1 – 5.3 square miles (> 2 miles x 2 miles)
  - All direct impact
- Estimates simple – does not account for variability in generation
  - Geographic; Month to Month; Day to Day; Hour to Hour
- Nellis Air Force Base Solar Power Plant: 14 MW: 0.2 square miles (0.5 x 0.5 miles)
  - Capacity Factor of 20%
  - Provides 20% of power needs to the base

[1] 3.0 ± 1.7 MW / km^2 Wind Capacity Density, National Renewable Energy Research Laboratory "Land-Use Requirements for Modern Wind Power Plants in the United States," NREL/TP-6A2-45834, August 2009. Available at www.nrel.gov/docs/fy09osti/45834.pdf
[2] 3.5 – 4.5 KW-hr/m2/day from Solar Photovoltaic Map (Illinois, Indiana, Iowa, Minnesota, Michigan, Ohio, Wisconsin)

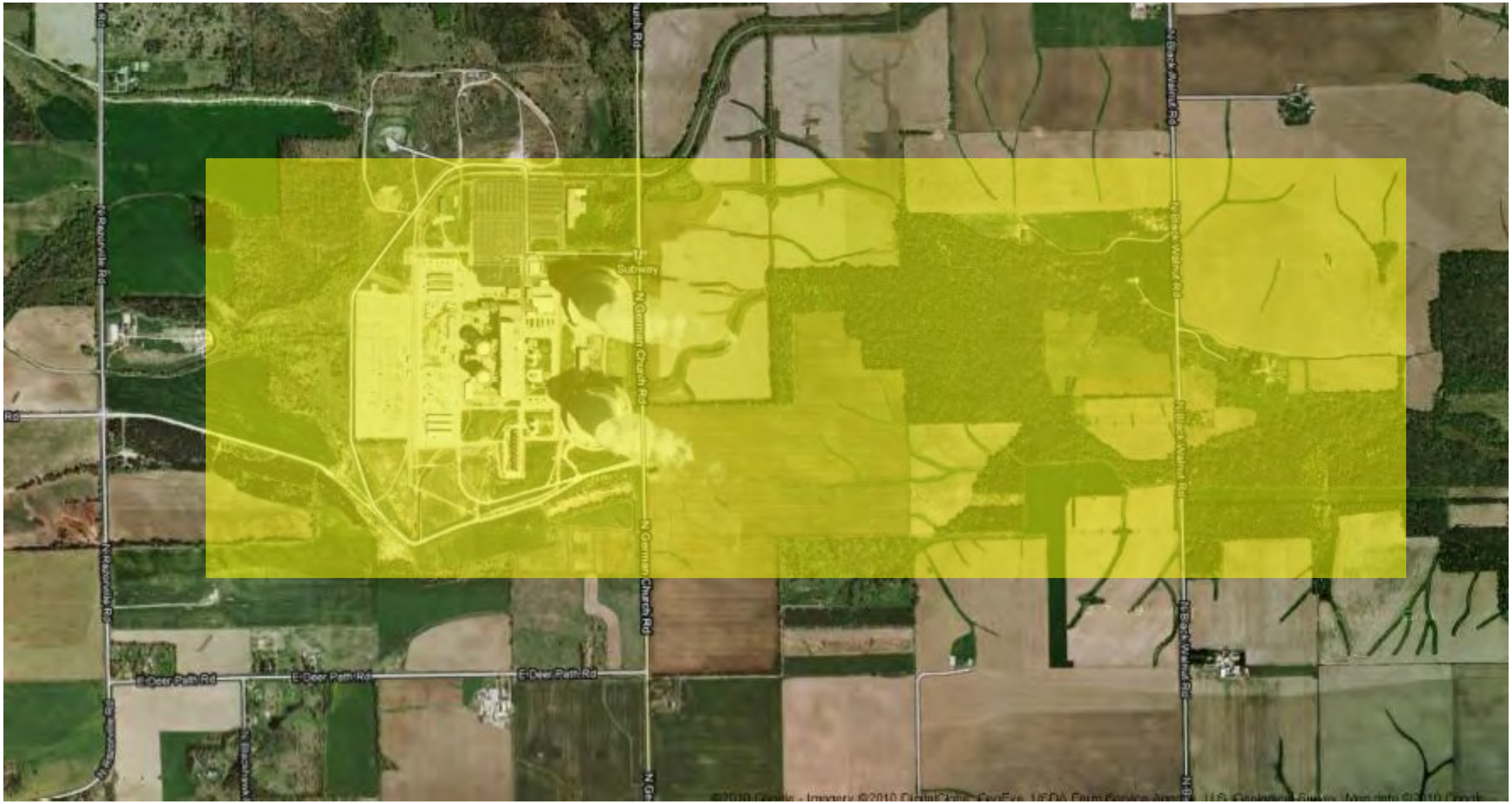
Energy Density – Distributed vs. Local: Size Comparison

Wind

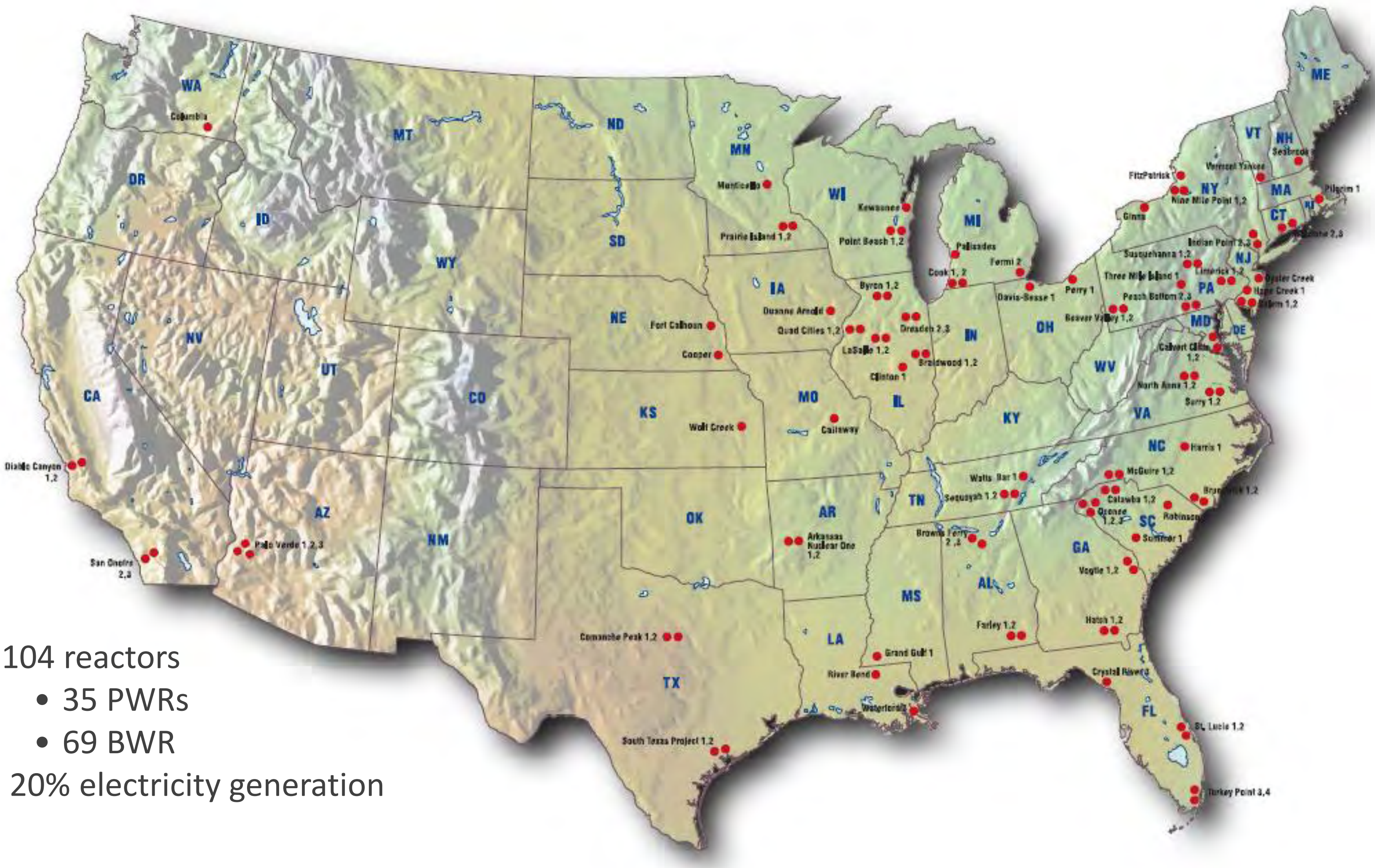


Energy Density - Distributed vs. Local: Size Comparison

Solar - Photovoltaic



U.S. Reactors



104 reactors
- 35 PWRs
- 69 BWR

20% electricity generation

http://www.nei.org/filefolder/u.s._nuclear_plants_country-wide_map.pdf

Reactors World-Wide

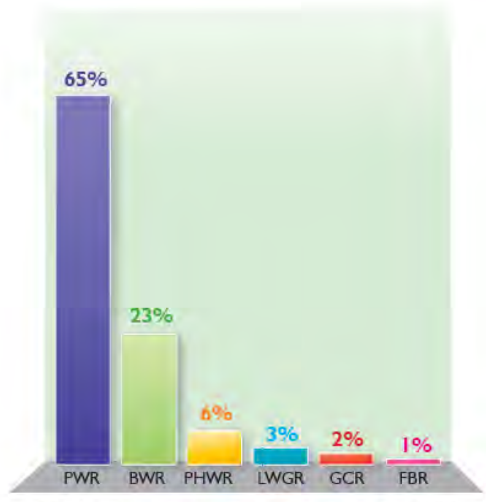
Nuclear power and reactors worldwide

	Nuclear electricity generation, 2008 (billion kWh)	Share of total electricity production, 2008 (%)	Number of reactors in operation*	Nuclear generating capacity* (MWe)
Argentina	6.8	6	2	935
Armenia	2.3	39	1	376
Belgium	43.4	54	7	5728
Brazil	14.0	3	2	1901
Bulgaria	14.7	33	2	1906
Canada	88.6	15	18	12 652
China	65.3	2	11	8587
Czech Rep	25.0	33	6	3472
Finland	22.0	30	4	2696
France	418.3	76	59	63 473
Germany	140.9	28	17	20 339
Hungary	14.0	37	4	1826
India	13.2	2	17	3779
Japan	240.5	25	53	46 236
Korea (S.)	144.3	36	20	17 716
Lithuania	9.1	73	1	1185
Mexico	9.4	4	2	1310
Netherlands	3.9	4	1	485
Pakistan	1.7	2	2	400
Romania	7.1	18	2	1310
Russia	152.1	17	31	21 743
Slovakia	15.5	56	4	1688
Slovenia	6.0	42	1	696
South Africa	12.7	5	2	1842
Spain	56.4	18	8	7448
Sweden	61.3	42	10	9016
Switzerland	26.3	39	5	3237
Ukraine	84.3	47	15	13 168
UK	52.5	14	19	11 035
USA	809.0	20	104	101 119
Total**	**2601**	**15**	**436**	**372 500**

* as of 01.06.09 Sources: WNA, IAEA

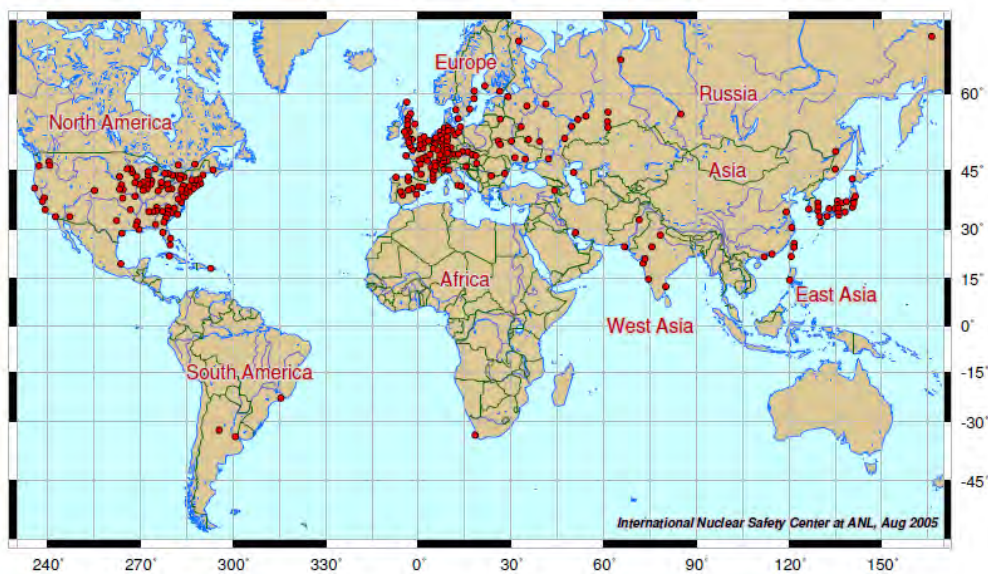
** The world total includes 6 reactors on Taiwan with a combined capacity of 4927 MWe, which generated a total of 39.3 billion kWh in 2008, accounting for 17.1% of its electricity generation.

World Nuclear Association
www.world-nuclear.org/uploadedFiles/Pocket Guide 2009 Reactors.pdf



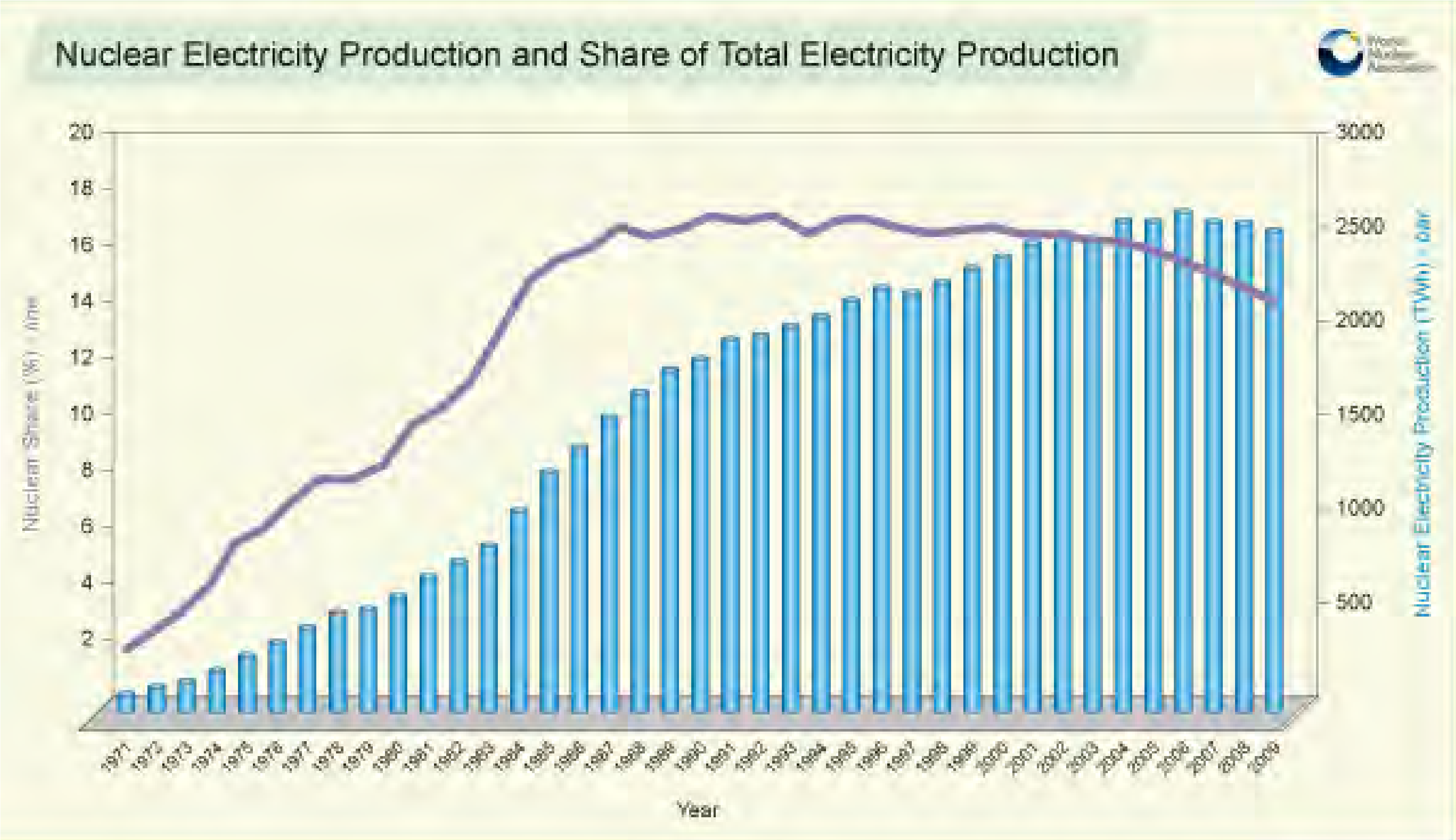
World nuclear power generation by reactor type, 2008

World Nuclear Association
www.world-nuclear.org/uploadedFiles/Pocket Guide 2009 Reactors.pdf



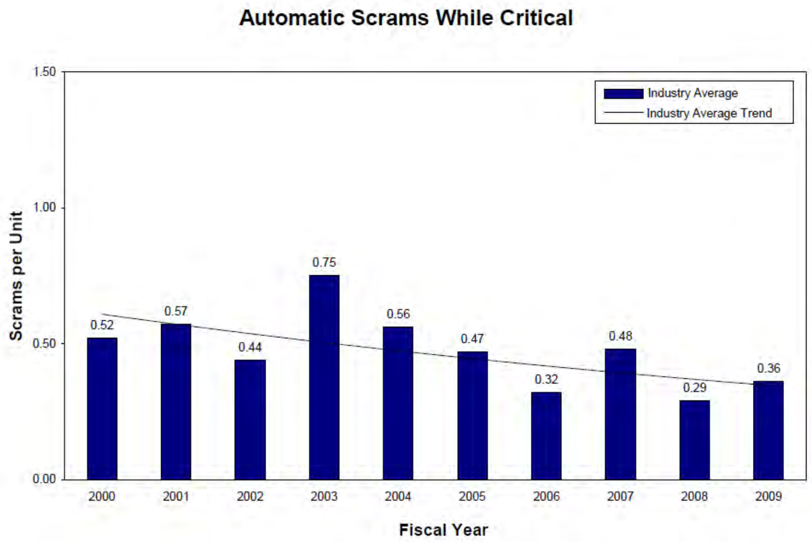
www.insc.anl.gov/pwrmaps/map/world_map.php

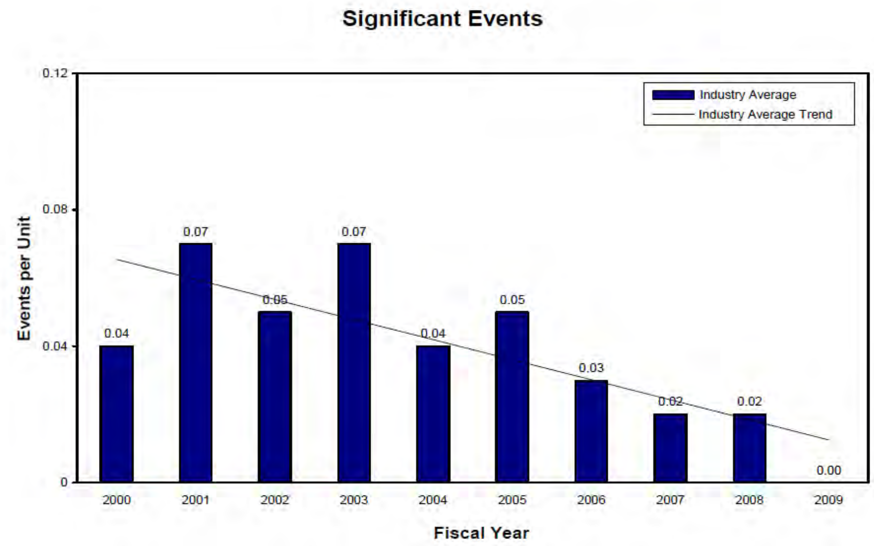
Growth of World Nuclear Generation Capacity

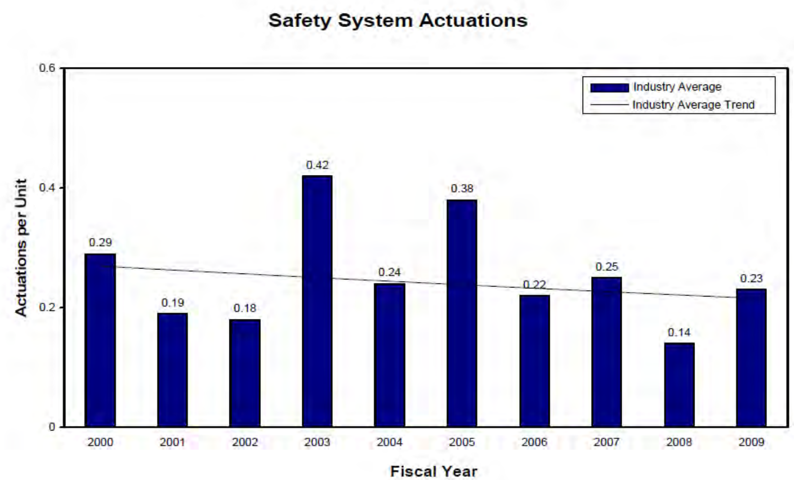


World Nuclear Association
www.world-nuclear.org/info/inf01.html

Current Fleet: Safety Indicators



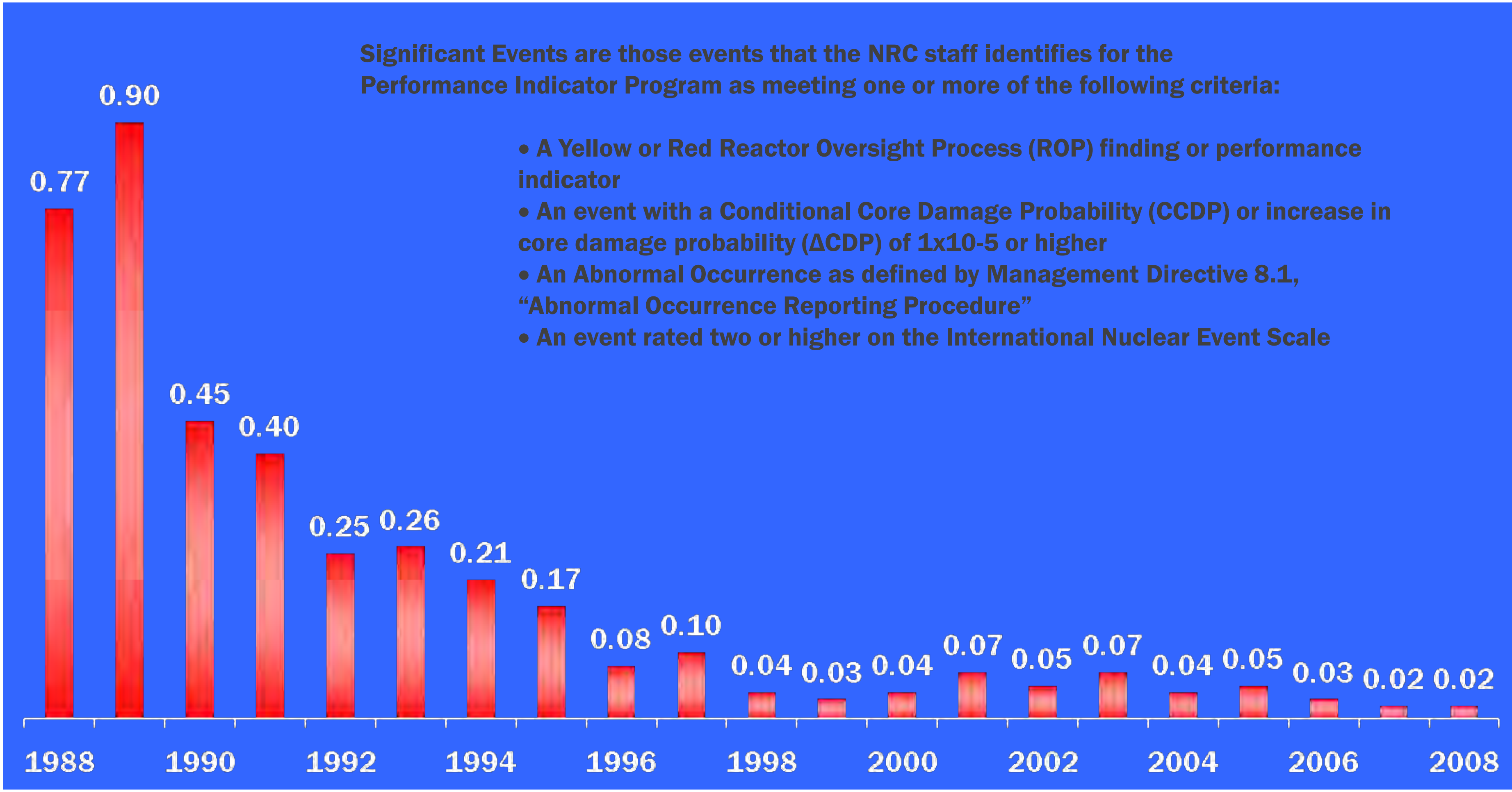




U.S. Nuclear Regulatory Commission analysis indicates decreasing trends in safety indicators

FISCAL YEAR 2009 RESULTS OF THE INDUSTRY TRENDS PROGRAM FOR OPERATING POWER REACTORS, SECY-10-0028, U.S. Nuclear Regulatory Commission

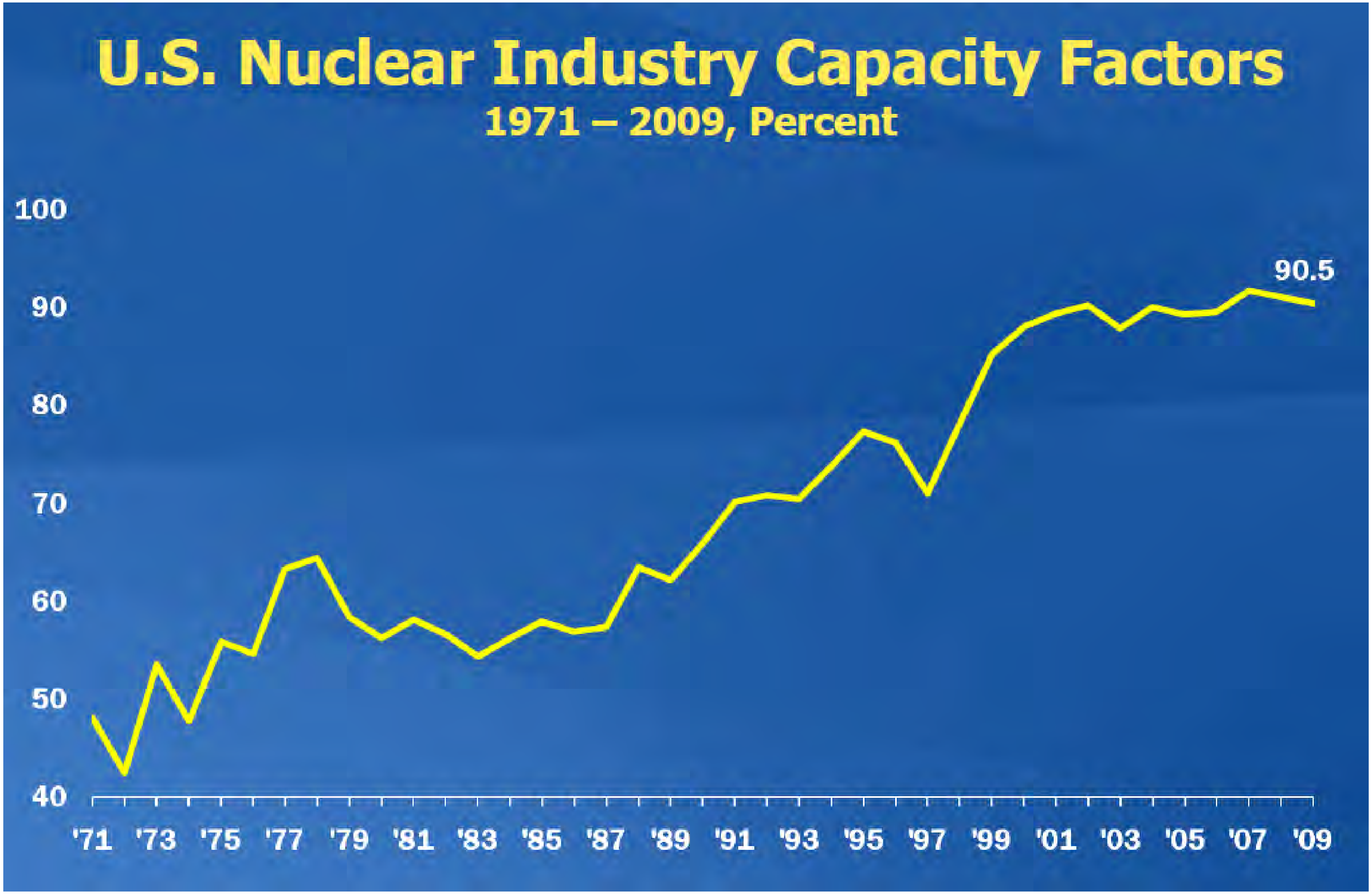
Significant Events at U.S. Nuclear Plants
Annual Industry Average, Fiscal Year 1988-2008



Source: Nuclear Energy Institute – from NRC Information Digest, 1988 is the earliest year data is available. Updated: 4/10

http://www.nei.org/resourcesandstats/documentlibrary/safetyandsecurity/graphicsandcharts/significanteventsatusnuclearplants/

Nuclear Industry Capacity Factor

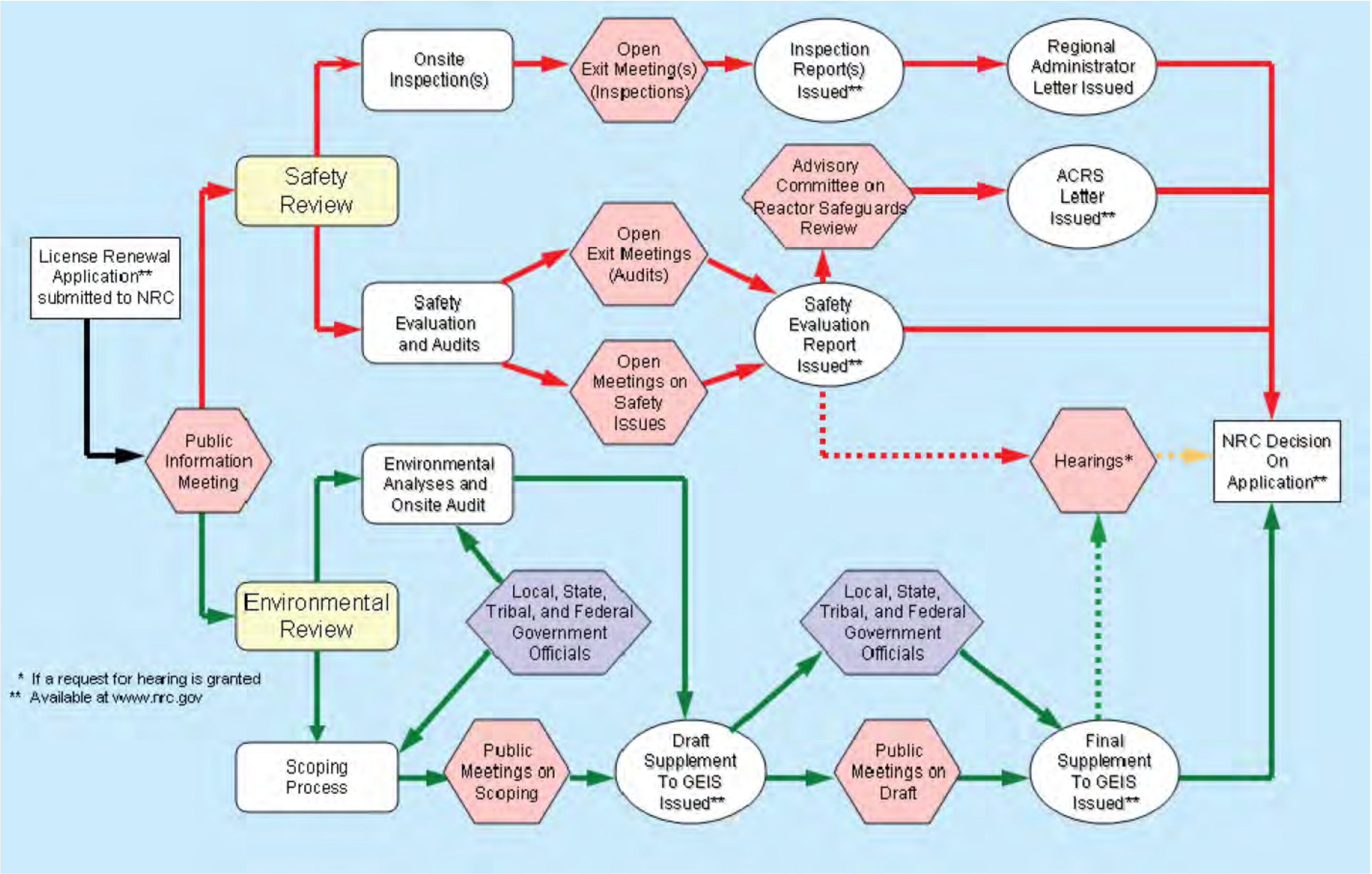


Source: Nuclear Energy Institute, http://www.nei.org/filefolder/US_Nuclear_Industry_Capacity_Factors.ppt

Nuclear License Renewal

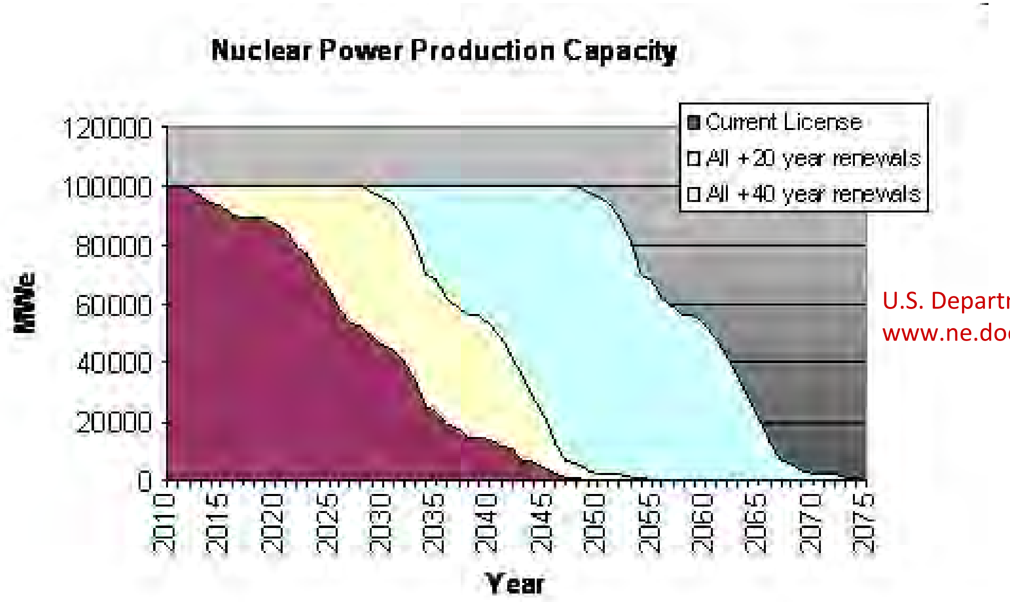
- The NRC has established a license renewal process with clear requirements to assure safe plant operation for up to an additional 20 years of plant life.
- Hinges around aging management - NRC program for Nuclear Plant Aging Research
  - Concluded many aging phenomena are readily manageable and do not pose technical issues that would preclude life extension
- NRC published safety requirements for license renewal (Title 10 of the Code of Federal Regulations, Part 54)
- Renewal Status
  - 59 extensions granted
  - 21 under review
  - 18 anticipated

Nuclear License Renewal



U.S. Nuclear Regulatory Commission, Frequently Asked Questions on License Renewal of Nuclear Power Reactors, NUREG-1850, March 2006
www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1850/sr1850_faq_lr.pdf

Nuclear Reactor Sustainability R&D

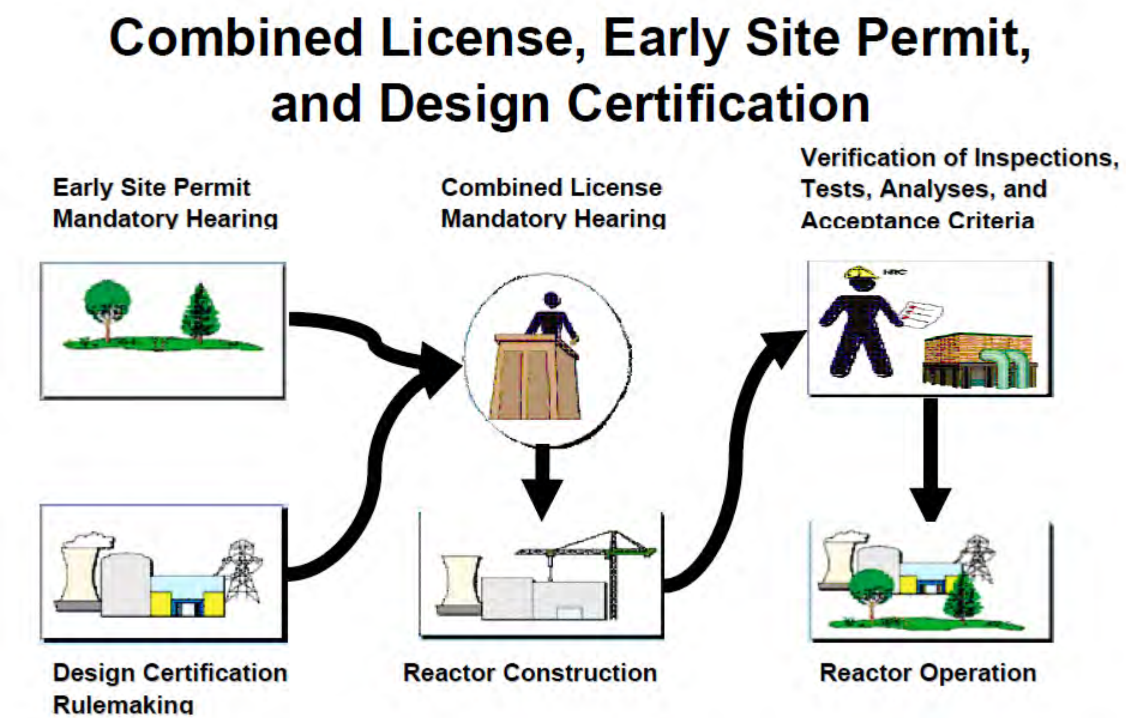


U.S. Department of Energy
www.ne.doe.gov/LWRSP/overview.html

- The DOE-Nuclear Energy *Reactor Sustainability Research and Development (R&D) Program*
  - Develop the scientific basis to extend existing nuclear power plant operating life beyond the current 60-year limit and ensure their long-term reliability, productivity, safety, and security
- R&D projects in the following pathways
  - Nuclear Materials Aging and Degradation; Advanced Light Water Reactor Fuel Development; Advanced Instrumentation, Controls, and Information Systems Technology; and Risk-Informed Safety Margin Characterization.

Licensing of Nuclear Power Plants

- Licensing of nuclear power plants has changed
  - "Old" Way – two step process with separate reviews for construction permit and operating licensing
    - All reactors operating in the U.S. were licensed using this process
  - "New" Alternative Way – to improve regulatory efficiency and predictability in process



U.S. Nuclear Regulatory Commission
Frequently Asked Questions About License Applications for New Nuclear Power Reactors, NUREG/BR-0468, December 2009.
www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0468/br0468.pdf

Licensing of Nuclear Power Plants

- Early Site Permit
  - allows an applicant to obtain approval for a reactor site without specifying the design of the reactor(s) that could be built there
  - Resolves issues involving site safety and environmental characteristics and emergency preparedness that are independent of a specific nuclear reactor design
  - Provides an applicant with an opportunity to “bank” a site for up to 20 years, reduces licensing uncertainty, and resolves siting issues before construction
  - Public involvement
    - Meetings, reviewing application, reviewing EIS, reviewing Safety Evaluation Report, participating in hearings
- Design Certification
  - Approves a standard nuclear power plant design, independent of a site approval application or an application to construct or operate a plant
  - Valid for 15 years and can be renewed for additional 15-year periods.
  - Describes the design basis and the limits of reactor operation
  - Includes a safety analysis of the structures, systems and components of the facility
    - Level of detail included in the design certification application is equivalent to the level of detail found in a final safety analysis report for a currently operating plant
  - Public involvement
    - Meetings, participation in rulemaking

Source: Frequently Asked Questions About License Applications for New Nuclear Power Reactors, NUREG/BR-0468, www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0468/br0468.pdf

Licensing of Nuclear Power Plants

- Combined Operating License
  - A COL authorizes construction and conditional operation of a new nuclear facility
  - Can reference an early site permit, a standard design certification, both, or neither
    - Must include equivalent information if not referenced
  - Once the required inspections, tests, and analyses are performed, and the acceptance criteria are met, the NRC can authorize the operation of the facility
  - Public involvement
    - Meetings, reviewing application, participating in hearings
- Limited Work Authorization
  - allows holders of ESPs, as well as COL applicants, to perform certain limited construction activities before the issuance of the COL, at their own risk

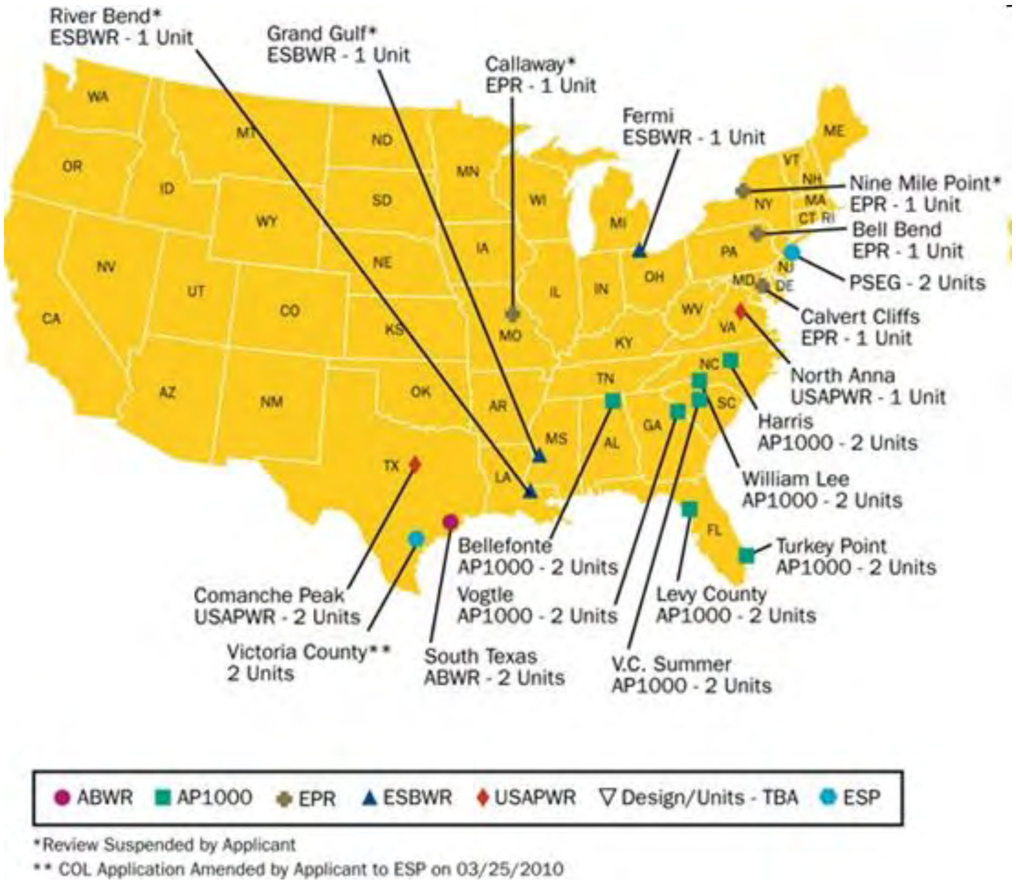
Source: Frequently Asked Questions About License Applications for New Nuclear Power Reactors, NUREG/BR-0468, www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0468/br0468.pdf

Has the “Nuclear Renaissance” Begun?

- Current Status
  - Four Early Site Permits have been issued
    - Two are under review
  - Four Design Certifications have been issued
    - Two are being reviewed following amendment
    - Three are under review
  - COLs for 22 reactors under active review at NRC
    - First license late 2011, early 2013
  - First Movers: Site Preparation is underway (LWAs) and long lead-time components have been ordered
  - Four – Eight reactors in commercial operation 2016 – 2018

Source: Nuclear Regulatory Commission (www.nrc.gov/reactors/new-reactors.html); “The Future of Nuclear Energy,” presentation by Marvin Fertel (NEI) (www.nei.org/resourcesandstats/documentlibrary/newplants/presentations/sept-1-2010-presentation/)

Location of Projected New Nuclear Power Reactors



U.S. Nuclear Regulatory Commission
www.nrc.gov/reactors/new-reactors/col/new-reactor-map.html

Courtesy of Southern Company
www.southerncompany.com/nuclearenergy/photos.aspx

Generations of Nuclear Reactors

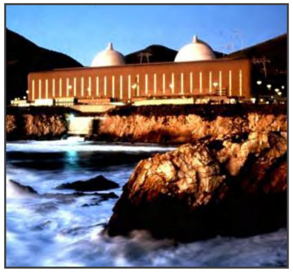
Generation I

Early Prototype Reactors

- Shippingport
- Dresden
- Fermi I
- Magnox

Generation II

Commercial Power Reactors



- PWR, BWR
- CANDU
- VVER, RBMK
- AGR

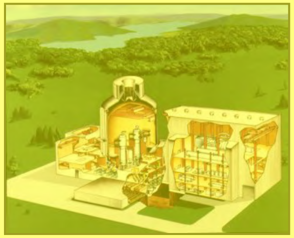
Generation III

Advanced LWRs

- ABWR
- EPR
- System 80+

Generation III+

Evolutionary Designs



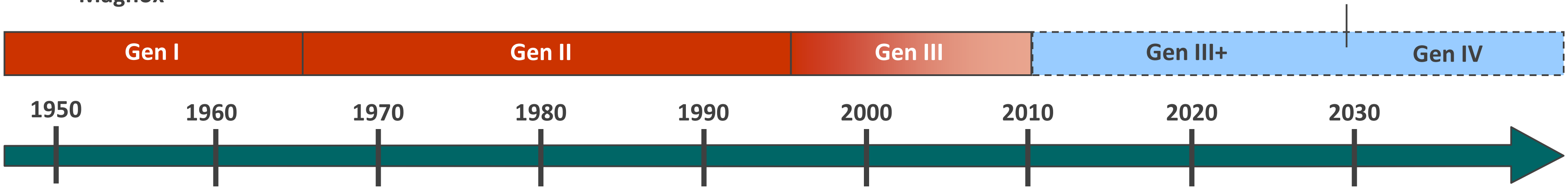
- ESBWR
- AP1000
- ACR

Generation IV

Future Generation Designs

Technology Goals

- Safe
- Sustainable
- Economical
- Proliferation Resistant
- Physically secure



Generation III/III$^+$ Reactors: Goals and Basic Approaches

- Improved economic competitiveness
  - Reduced capital cost via decreased commodities, simplification, standardization
  - Faster construction via standardization, modularization and improved planning & management
  - Increased reliability & service lifetime, including fuel, materials & components
  - Improved operability & maintainability
  - Better surveillance and diagnosis of operating conditions
- Further enhancement of safety
  - Increased reliability to minimize accident precursors
  - Greater use of passive means and natural phenomena to assure cooling
    - Gravity, heat capacity, thermal expansion, natural circulation, evaporation and condensation

    rather than
    - AC power supplies and motor-driven components
  - Enhanced diversity and redundancy of safety systems
  - Severe accident mitigation, should prevention measures fail

Generation III/III$^+$ Reactors: Goals and Basic Approaches

- Standardization embraced to allow more streamlined regulatory process
  - Design certification (DC)
  - Early site permit (ESP)
  - Combined construction and operating license (COL)

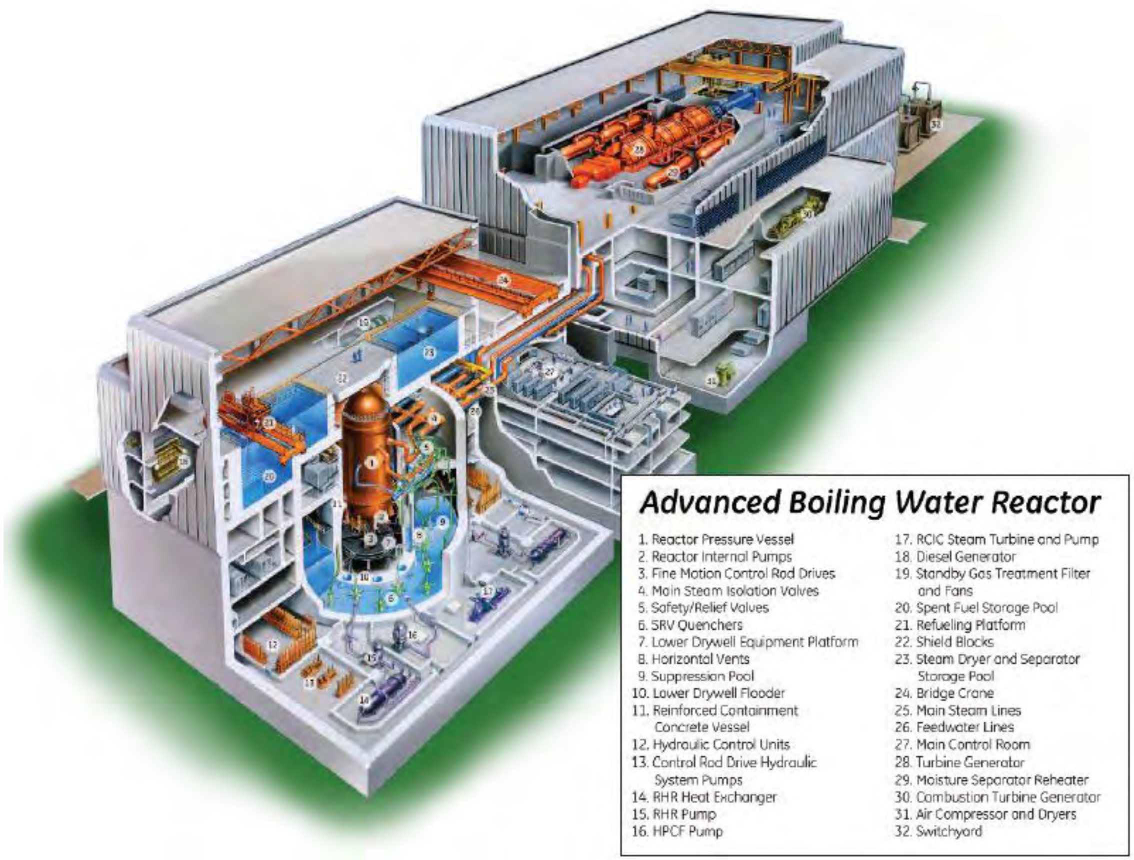
- Also key: better management and QA of processes for plant design, construction, licensing, operations & maintenance
  - Aided with vastly improved IT and PM tools

Evolutionary Nuclear Reactor Designs

ABWR

- ***1370 MWe***
- ***Built and operating in Japan***
- ***Reviewed and certified by NRC in 1996***
- ***Based on proven BWR features***
- ***Advances***
  - ***Increased modularization***
  - ***In-vessel recirculation system***
  - ***Fine-motion control rod drives***
  - ***State-of-art digital, multiplexed, fiber-optic I&C system***
  - ***High performance fuel***
  - ***Improved water chemistry***
  - ***Integrated containment & reactor building***
  - ***42 month construction***

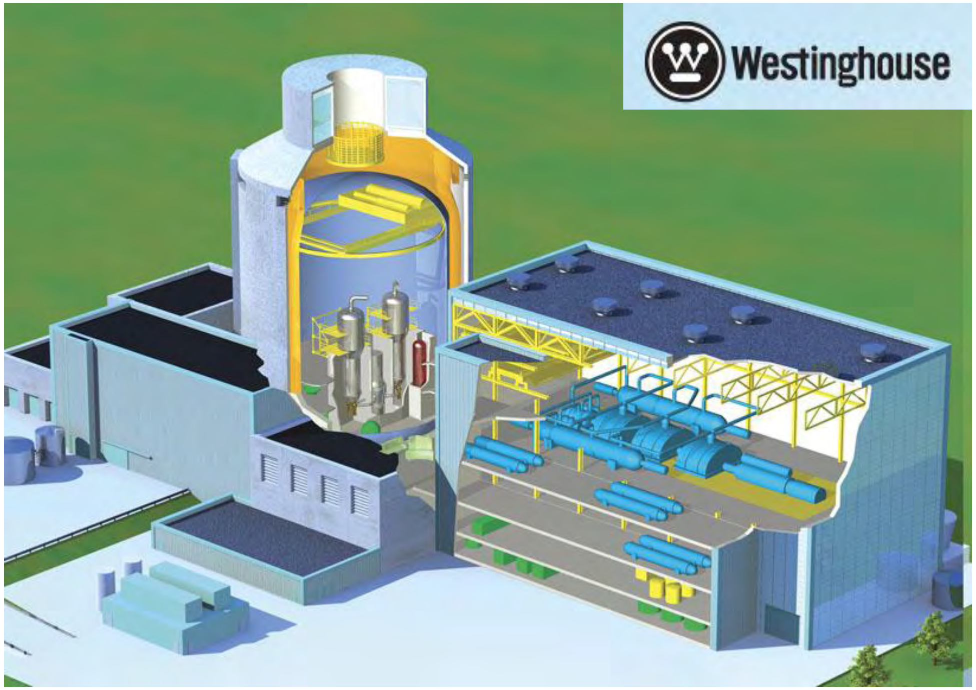
HITACHI



Evolutionary Nuclear Reactor Designs

AP 1000

- ***1110 MWe PWR design***
  - ***Certified by NRC early in 2006***
- ***Safety functions achieved with passive means***
  - ***Passive "safety injection"***
  - ***Residual heat removal***
  - ***Passive containment cooling***
- ***Design simplification examples***
  - ***60% fewer safety-related valves***
  - ***75% less piping***
  - ***80% less control cable***
  - ***35% fewer pumps***
  - ***50% less seismic building volume***
- ***Canned rotor primary pumps enhance reliability***
- ***Digital instrumentation and control systems***
- ***Targeted construction time is ~ 36 months***
  - ***Modular construction techniques***



Issues Related to the "Renaissance"

- Financing/Investors: Risk Management
  - Capital cost of nuclear power is large
    - $3000 / KW overnight
  - Construction duration can be long
    - Delays drive up cost
  - Cost of capital
  - Process has not been worked in some time
- DOE Loan Guarantee Program (www.lgprogram.energy.gov/)
  - Established in 2005
  - To qualified projects in the belief that accelerated commercial use of these new or improved technologies will help to sustain economic growth, yield environmental benefits, and produce a more stable and secure energy supply
  - Gives confidence to investors, reduced cost of capital
  - Not a payout
  - $8.3 billion for Southern Co., $2 billion for AREVA enrichment plant

- Biomass
- Hydrogen
- Solar
- Wind
- Hydropower
- Nuclear
- Advanced Fossil Energy Coal
- Carbon Sequestration practices and technologies
- Electricity Delivery and Energy Reliability
- Alternative Fuel Vehicles
- Industry Energy Efficiency Projects
- Pollution Control Equipment

Issues Related to the "Renaissance"

- Near Term Influences (Negative)
  - North American electricity will not recover to pre-recession levels until 2012 or so
  - Regional power markets likely to remain oversupplied for at least the next 5 years
  - Low natural gas prices likely to persist in the near term
  - May lead to significant expansion of gas capacity to back up renewables

Early successes needed to "Show the Way" and start the "Renaissance"

Expect uncertainties/risk and cost to decrease as plants are constructed

New Generating Capacity: 1995 - 2009, MW	
Coal	13,000
Gas	320,000
Nuclear	1,300
Oil	5,000
Renewables	37,000
Hydro	2,000

Source: "The Future of Nuclear Energy," presentation by Marvin Fertel (NEI) (www.nei.org/resourcesandstats/documentlibrary/newplants/presentations/sept-1-2010-presentation/)

Issues Related to the "Renaissance"

- Long-Term "Issues"
  - Uncertainty regarding "Carbon Policy"
    - Nuclear is the only energy generation source that has to "Pay for Its Waste Disposition"
    - Any carbon charges would increase nuclear "competitiveness" relative to fossil
  - Heavy industry
    - U.S. no longer has one to support nuclear – it is overseas (where reactors have been being built)
    - Could "choke" significant growth
  - Manpower: the Nuclear Workforce is aging
    - Universities eliminated Nuclear Engineering departments
    - Nuclear utilities did not hire
    - Efforts are underway to educate and train the next generation
  - Safety: One accident could delay or halt any "Renaissance"
    - Anywhere in the world, not just in the U.S.
    - Many reactors are being built (e.g., China) and plant crews and operators are young

Used Fuel Disposition

The New Plants Generate the Same Used Fuel

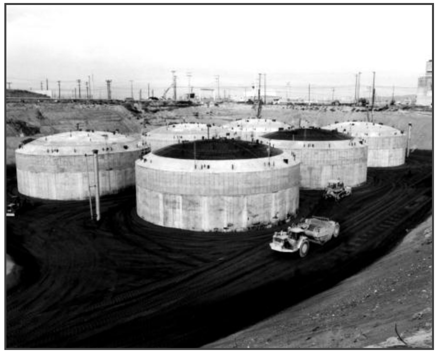
Federal Government Faces Multiple Obligations Regarding Nuclear Waste Management

Support Nuclear Navy Mission

Support Surplus Weapons Material Disposition

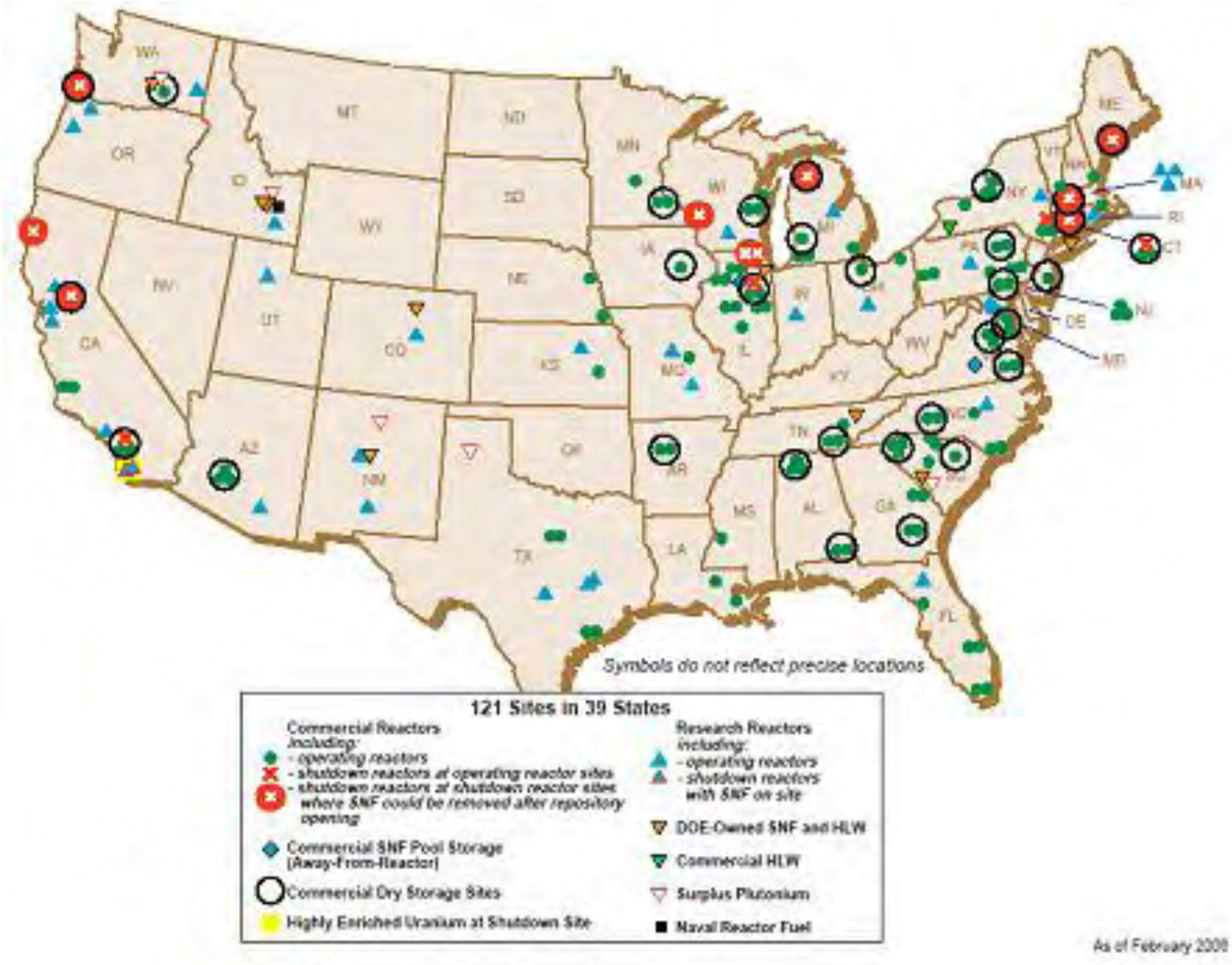
- **National Security**
  - Support continued operations of the Navy's principal combat vessels
- **Nuclear Non-Proliferation**
  - Ensure security of nuclear fuel and nuclear waste
- **Energy and Economic Security**
  - Maintain nuclear energy option that supplies 20% of our electricity needs to sustain present and future economic security
- **Homeland Security**
  - Accept nuclear materials now stored at sites within 75 miles of 162 million Americans
- **Environmental Protection**
  - Ensure environmentally sound disposition of our government defense and commercial wastes

Support Commercial Nuclear Energy Option



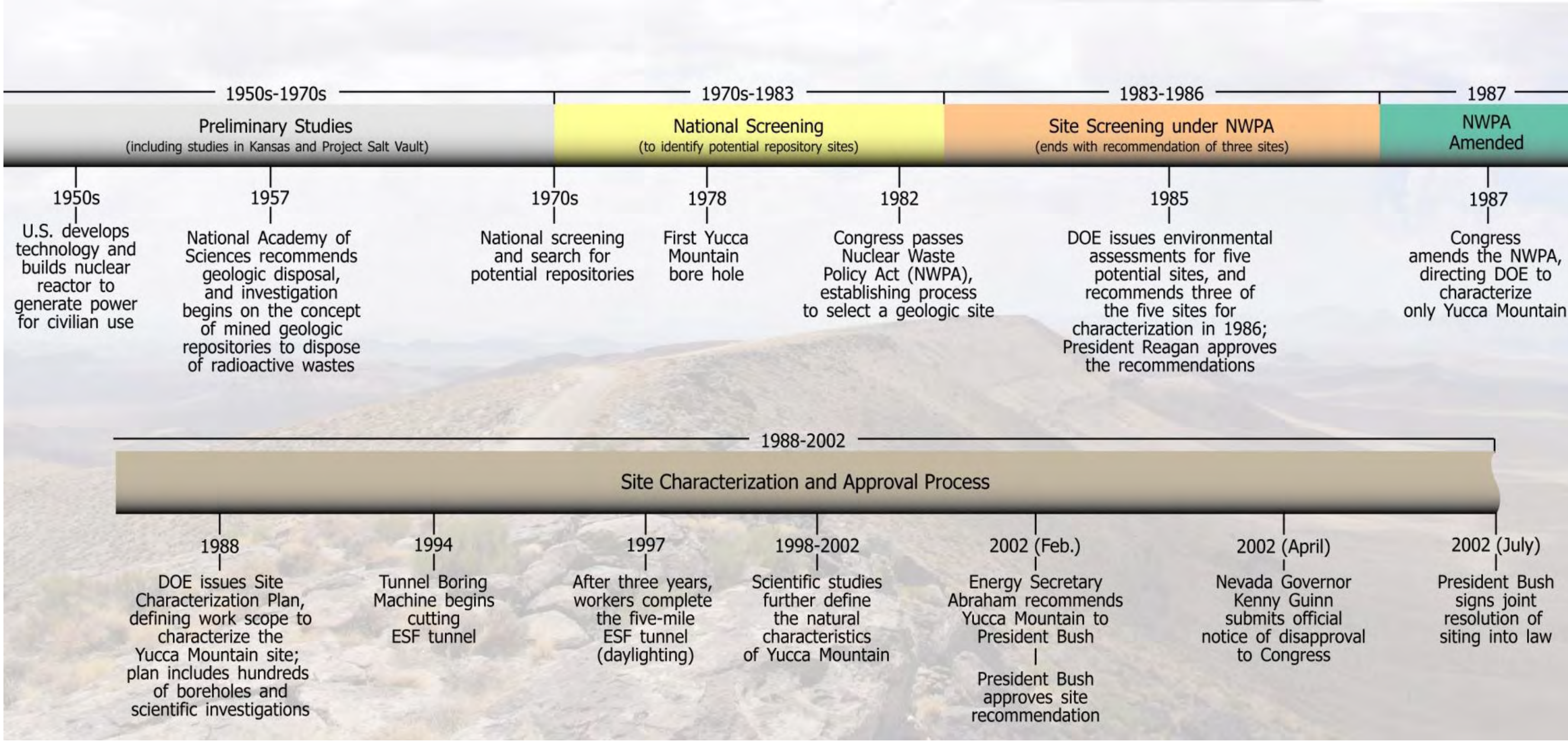
Support Defense Complex Clean-Up

Current Locations of Used Nuclear Fuel (UNF) and High-level Radioactive Waste (HLW)



121 sites in 39 states

U.S. Nuclear Waste Policy since 1950



- 2008: DOE submits License Application to NRC
- 2010: U.S. Secretary of Energy Steven Chu announced formation of Blue Ribbon Commission on America's Nuclear Future to make recommendations for safe, long-term solution to managing used nuclear fuel and nuclear waste

Used Fuel Disposition

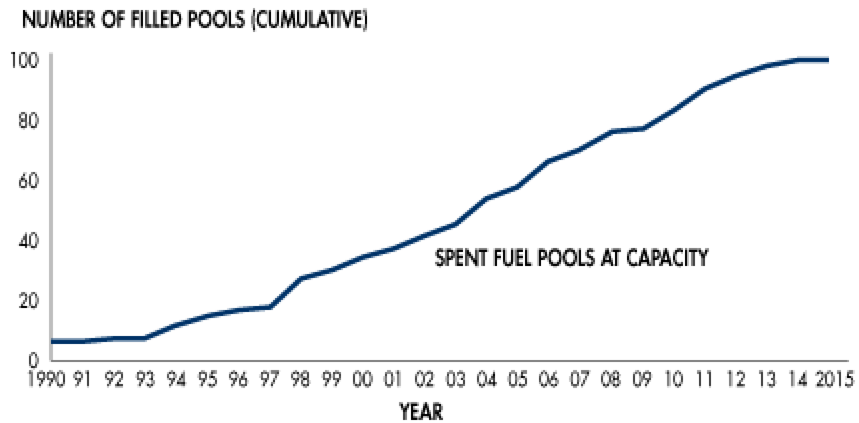
- U.S. Department of Energy was pursuing the disposal of used nuclear fuel in a deep geologic repository at Yucca Mountain, Nevada in accordance with the Nuclear Waste Policy Act of 1982, as amended
- License application for construction of the repository submitted to the NRC in June 2008
- In 2009 DOE announced intention to no longer pursue disposal at Yucca Mountain
- In March of 2010 DOE filed a motion with the NRC to withdraw the license application
  - Atomic Safety and Licensing Board (ASLB) must grant motion – denied in June 2010
  - Commissioners evaluating ASLB decision
  - Suits filed in District Court of DC claiming DOE is violating the NWPA
  - NRC review halted
    - August 23, 2010 NRC issues Safety Evaluation Report on Volume 1: General Information
    - NRC Chairman halted further work due to zero-out in Fiscal Year 2010 budget
  - DOE closed out" operations at Yucca Mountain
    - Contractor and National Laboratory Staff finished
    - Federal staff being re-assigned
  - Uncertain future

Used Fuel Disposition

- DOE established the Blue Ribbon Commission for America's Nuclear Future
  - Conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense used nuclear fuel, high-level waste, and materials derived from nuclear activities
  - Deliberations on-going
  - Draft report in January/February time-frame; Final in July
- Ultimately the Nuclear Waste Policy Act will have to be modified to implement a new used fuel management strategy
  - Technical feasibility does not appear to be in question
  - The process appears to be the challenge
- Overall strategy seems to be directed at continued storage of used nuclear fuel at reactor sites pending future decisions
  - Many decades → possibly approaching centuries
  - This is not without issues
- Future decisions
  - Advanced fuel cycles
  - Disposal systems, environments, and sites

Used Fuel Storage

- Utilities began to utilize dry storage in the 1980s when fuel pools began to fill and no disposition path was available
- Temporary solution until permanent disposal facility was made available
- The Administration's decision to cancel Yucca Mountain will mean that the nation will need to store used fuel for the foreseeable future (>100 years)
- NRC licenses are issued for 20 years, with possible renewals up to 60 yrs
- Issues associated with very long term storage
  - retrieval and transport of used fuel after long term storage
  - Limited U.S. experience with storage and transportation of high burnup fuel (>45 GWD/MTU)
  - "Orphaned" fuel



Note: All operating nuclear power reactors are storing used fuel under NRC license in spent fuel pools. Some operating nuclear reactors are using dry cask storage. Information is based on loss of full-core reserve in the spent fuel pools.

Source: Energy Resources International and DOE/RW-0431 – Revision 1

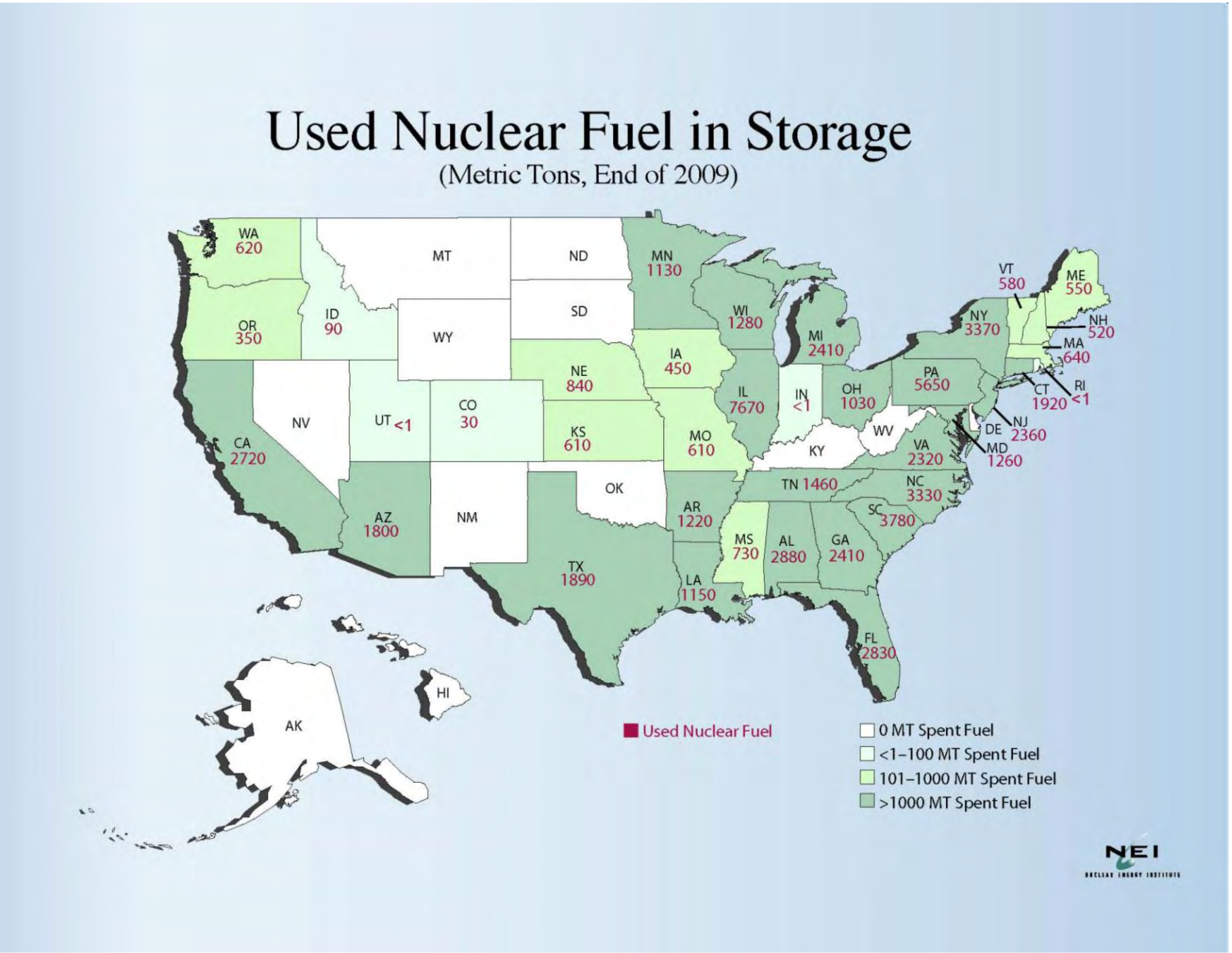
www.nrc.gov/waste/spent-fuel-storage/nuc-fuel-pool.html

Used Fuel Storage

- Technical bases need to be developed to justify licensing;
  - Used fuel storage beyond 60 years
  - Retrievability and transportation of used fuel after long-term storage
  - Transportation of high burn-up fuel
- DOE research and development program is underway, in collaboration with the NRC, the nuclear industry, and international participants
- Private Fuel Storage
  - Group of eight electric utility companies that have partnered with the Skull Valley Band of Goshute Indians
  - Develop a regional dry storage facility
  - Received NRC license in February 2006
    - 8 ½ year licensing process
  - In September 2006 DOI disapproved PFS-Goshute lease and use of public lands for an intermodal transfer facility
  - PFS filed suit in 2007
  - US District Court for the District of Utah overturned DOI decision, July 2010

INL Dry Storage Characterization (DSC) Project

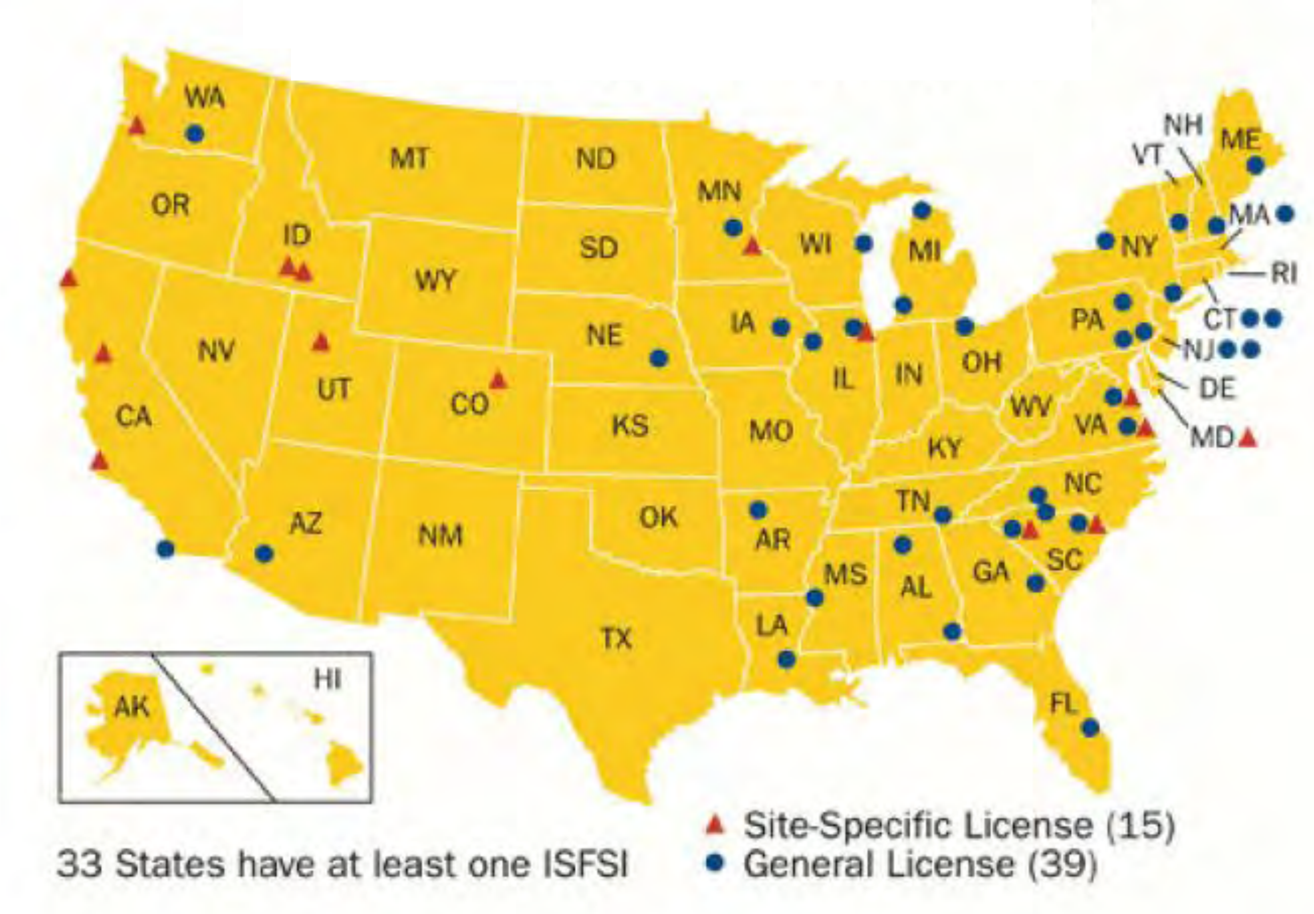
Used Fuel Storage



The amount of used nuclear fuel in storage will continue to grow until a disposition solution is found

Nuclear Energy Institute: www.nei.org/filefolder/Used_Nuclear_Fuel_in_Storage_Map.jpg

Used Fuel Storage



Nuclear Regulatory Commission
www.nrc.gov/waste/spent-fuel-storage/locations.html

The number of sites having and the amount of fuel stored in dry storage will continue to grow until a disposition solution is found

Geologic Disposal Research and Development

- We're not starting from scratch
  - There is an international consensus that deep geologic disposal is a robust and necessary solution for permanent isolation of high-level radioactive waste
  - WIPP was successfully developed and is in operation
  - DOE and many in the scientific community concluded that Yucca Mountain was ready to license
  - Internationally, mature safety assessments indicate that clay and granite sites are also suitable
- We have an opportunity to rethink disposal concepts: nearly all options are back on the table
- Goals of disposal R&D at this stage:
  - Provide a sound technical basis for the assertion that the US has multiple viable disposal options that will be available when national policy is ready
  - Identify and research the generic sources of uncertainty that will challenge the viability of disposal concepts
  - Increase confidence in the robustness of generic disposal concepts to reduce the impact of unavoidable site-specific complexity
  - Develop the science and engineering tools required to address the goals above, through collaborations within NE and DOE, and with industry and international programs

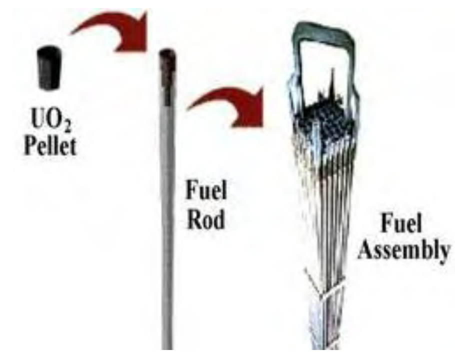
Other National Nuclear Waste Management Programs

Country	Material to be Disposed	Centralized Storage	Geologic Environments	URL	Site-Selection	Anticipated Start of Repository Operations
Finland	SNF		Granite, Gneiss, Grandiorite, Migmatite	ONKALO (Granite)	Site at Olkiluoto Selected	2020
Sweden	SNF	CLAB - Oskarshamn	Granite	Aspo (Granite)	Site at Osthammar Selected	2023
France	HLW and ILW		Argillite and Granite	Bure (Argillite)	Site near Bure Selected	2025
Belgium	HLW		Clay/Shale	Mol (clay)	Not Initiated	~2040
China	HLW		Granite		Preliminary Investigations Underway - Beishan in Gobi Desert	~2050
Switzerland	HLW	Wulenlingen (ZWILAG)	Clay and Granite	Mont Terri (Clay) Grimsel (Clay)	Initiated	No sooner than 2040
Japan	HLW		Granite and Sedimentary	Mizunami (Granite) Hornonobe (Sedimentary)	Initiated	No Decision Made
Canada	SNF		Granite and Sedimentary	Pinawa (Granite) - being decommissioned	Initiated	No Decision Made
United Kingdom	HLW and ILW		Undecided		Initiated	No Decision Made
Germany	HLW, SNF, heat generating ILW	Gorleben and Ahaus	Salt	Gorleben (Salt)	On Hold	No Decision Made
Republic of Korea	SNF	Envisioned	Granite	Korea Underground Research Tunnel (Granite, Shallow)	Not Initiated	No Decision Made
Spain	No Decision Made	Siting Process Initiated	Granite, Clay, Salt		Not Initiated	No Decision Made

Source: Nuclear Waste Technical Review Board, 2009. Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel

U.S. Nuclear Fuel Cycle

- The U.S. and many other countries are currently utilizing a "Once-Through Fuel Cycle
  - Uranium-based fuel is irradiated once
  - Stored pending future decisions (repository)

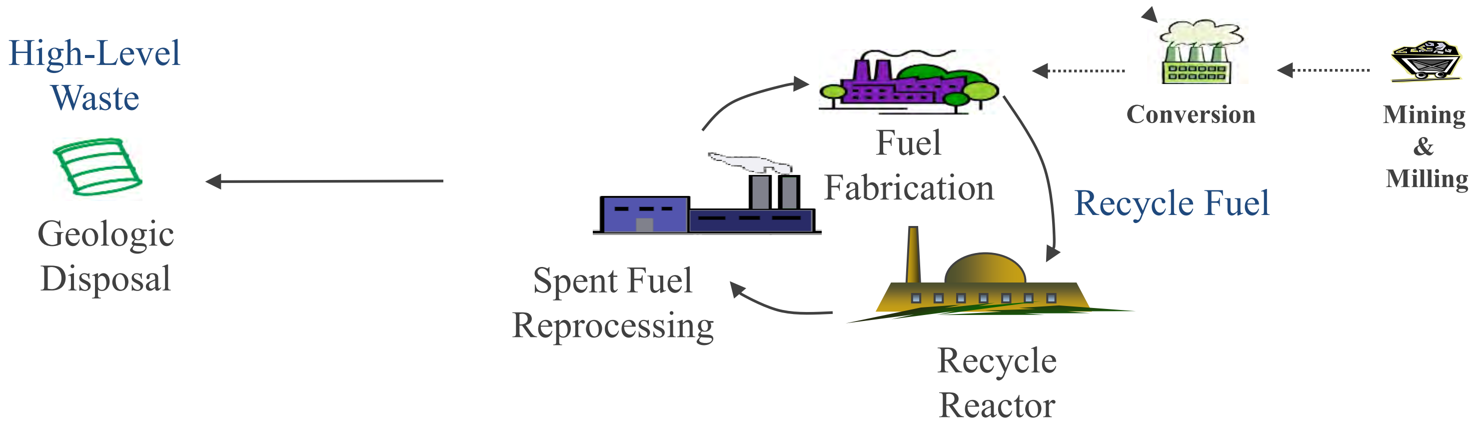


?

Advanced Fuel Cycles and Advanced Reactors

- Advanced fuel cycles and advanced reactor concepts may offer better solutions to the current once-through fuel cycle
  - Improved resource utilization
  - Improved reactor safety
  - Waste management benefits
- However, there are social-political and technical issues
- There are also research and development needs

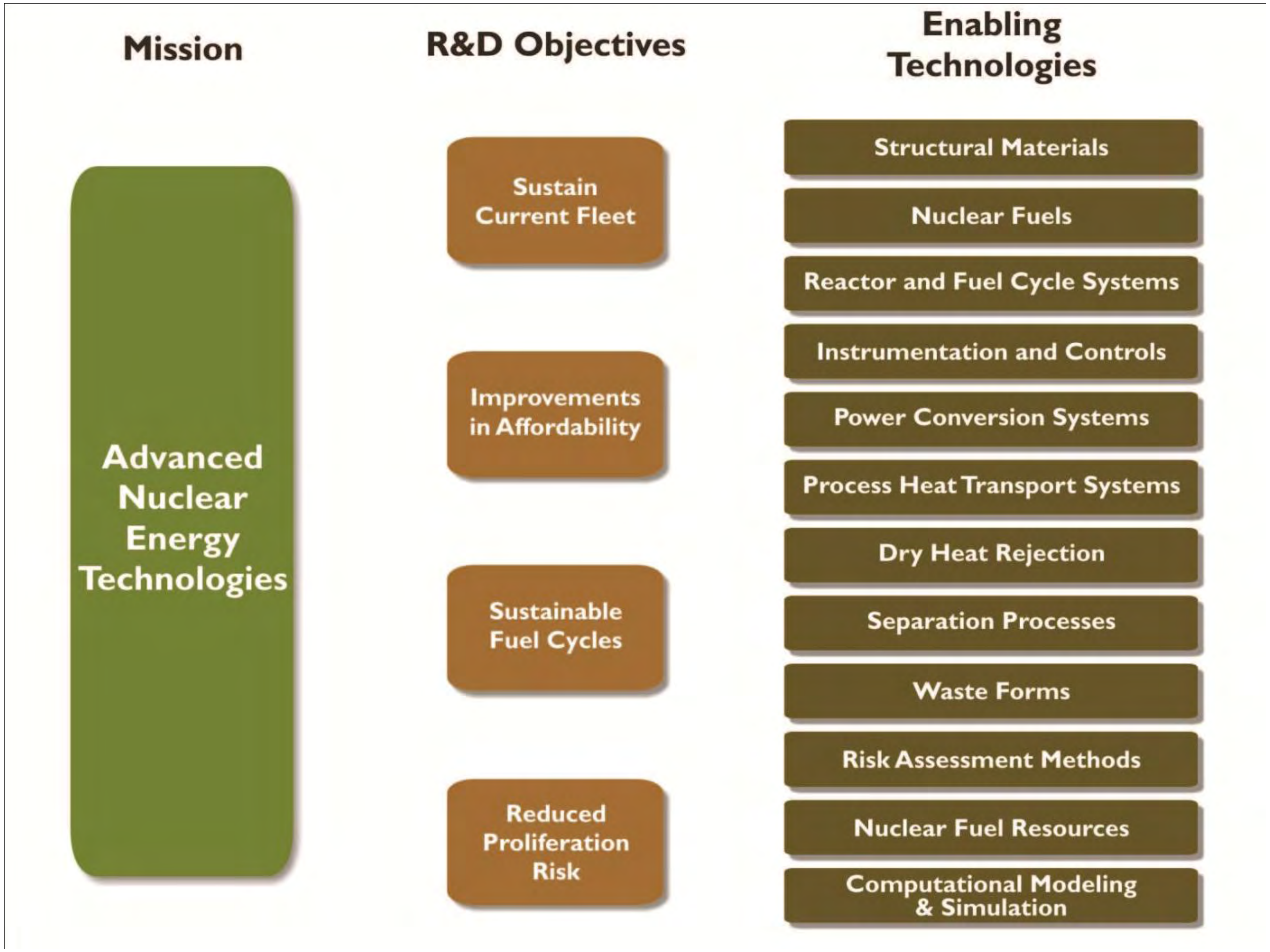
Closed Nuclear Fuel Cycle (or Reprocessing/Recycling)



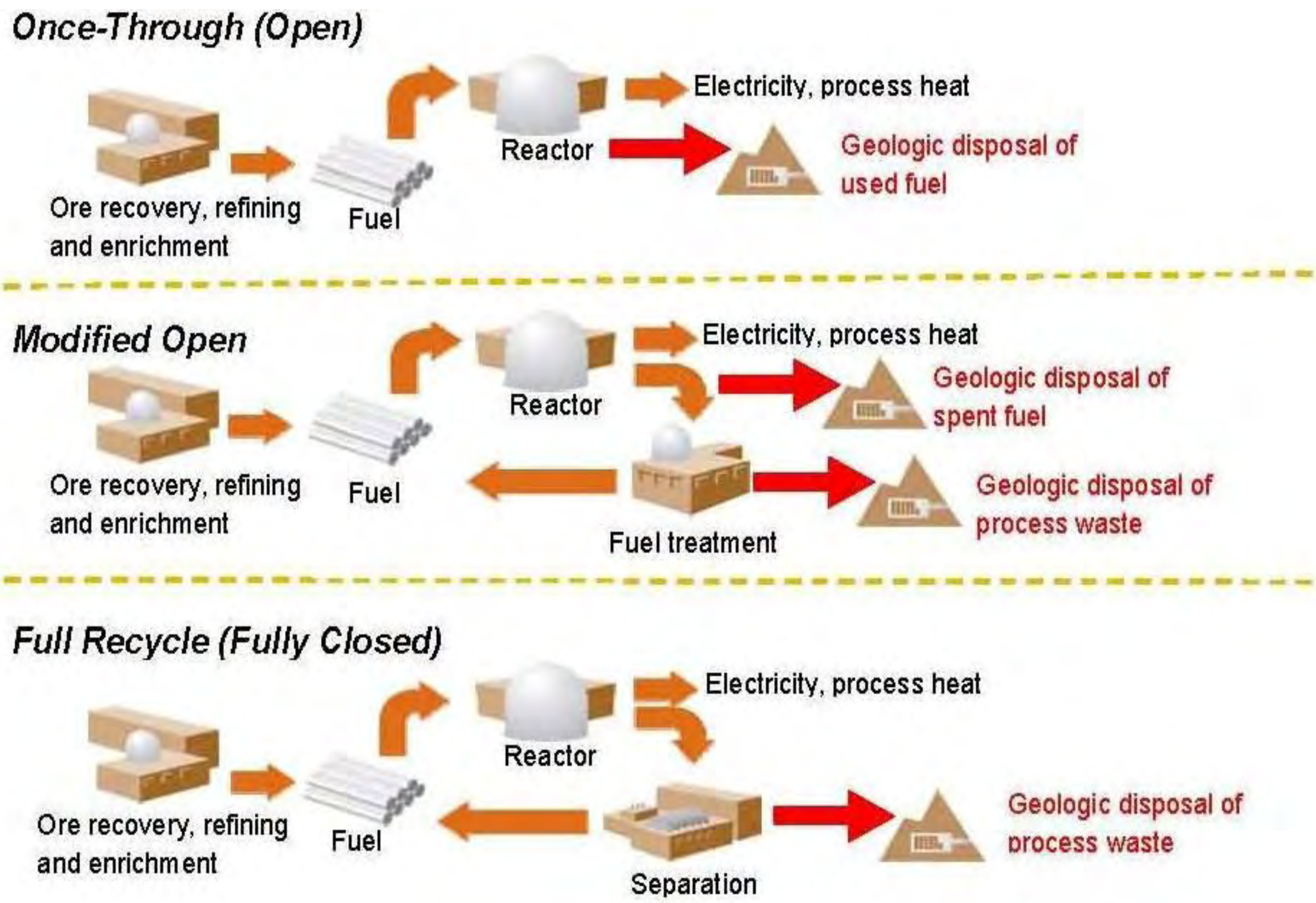
Advanced Fuel Cycles and Advanced Reactors

- The primary mission of DOE-NE is to advance nuclear power as a resource capable of making major contributions in meeting the nation's energy supply, environmental, and energy security needs by resolving technical, cost, safety, security and regulatory issues, through research, development, and demonstration (RD&D)
- DOE-NE is investigating a variety of advanced fuel cycles and advanced reactors
- More information can be found at the DOE-NE website: www.ne.doe.gov/
  - In particular the DOE-NE R&D roadmap at http://www.ne.doe.gov/pdfFiles/NuclearEnergy_Roadmap_Final.pdf
- Additional presentation material can be found at the Blue Ribbon Commission's website at:
  - www.brc.gov/Reactor_Fuel_Cycle_Technology_SC/RFCT_SC_07_12_10mtginfo.html

DOE Office of Nuclear Energy Programs

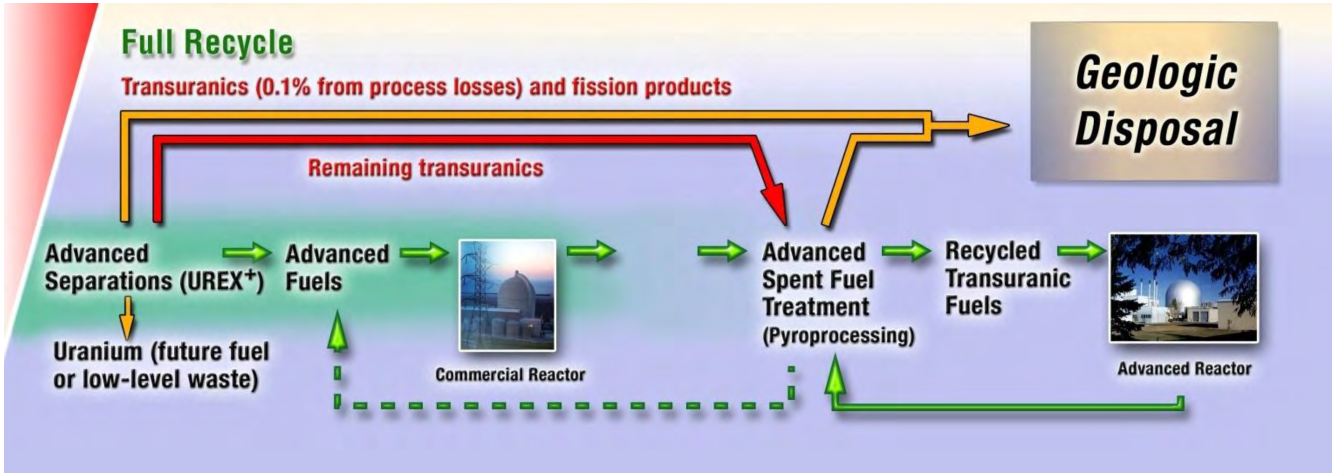


U.S. Fuel Cycles Being Considered



Closing the Nuclear Fuel Cycle: Technical Challenges

- Separations and Processing
  - Process losses, waste forms, safeguards, and cost reduction
- Advanced Reactors
  - Cost reduction
- Scale-up is needed to discover and solve industrial issues



Potential Benefits of Closed Fuel Cycle: Uranium Supply and Economics

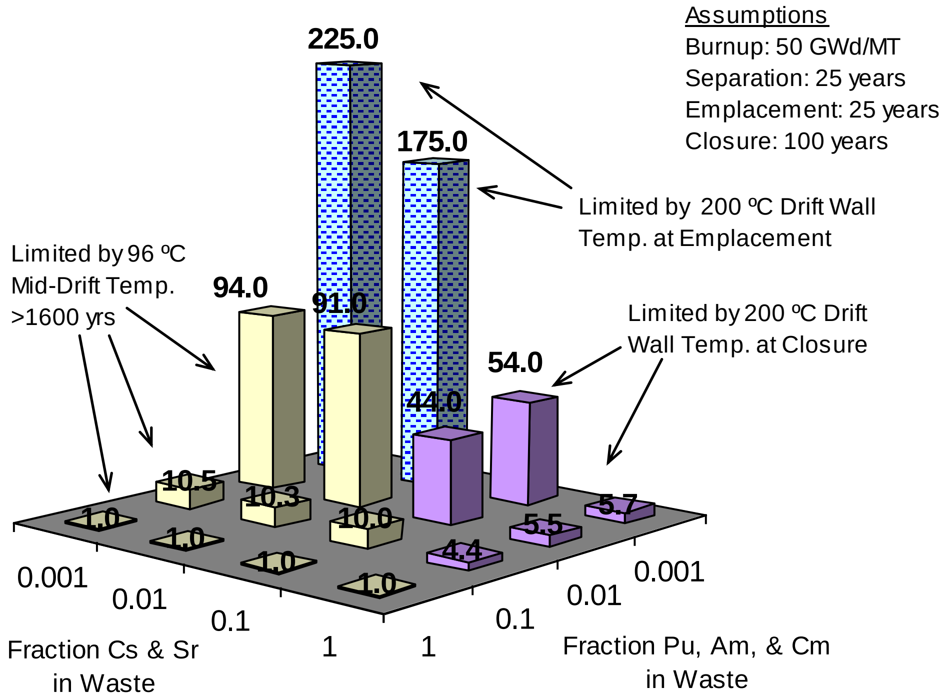
- Closed fuel cycle can effectively multiply uranium resources by factor of ~100
  - Costs much higher than current uranium fuel

- Current known uranium resources sufficient for nuclear energy production for several decades

- Considerations other than cost
  - Energy security – much of the uranium resources are non-U.S.
  - Given supply and demand, the "tipping point" on current vs. closed fuel cycle could be reached within century

Potential Benefits of Closed Fuel Cycle: Waste Management

- With processing of used PWR fuel to remove elements responsible for decay heat that causes temperature limits to be reached, large gains in utilization of repository space are possible
  - Only considers thermal performance, not dose rate
- Pu, Am, Cs, Sr, & Cm are dominant elements
  - Recovered elements must be treated
- Recycling of Pu, Am, & Cm for transmutation and/or fission
  - Irradiation in reactors
- Such metrics being considered in systematic evaluation of fuel cycle options



Conclusion

- Nuclear power currently represents ~20% of the U.S. electricity capacity
- The safety of nuclear power in the U.S. has been excellent – and is improving
- The licenses of the current fleet of operating reactors have been or will be extended for an additional 20 years – R&D is underway to determine if they can run beyond 60 years
- The nuclear "renaissance" may be beginning, but there are hurdles to overcome
- The disposition of used nuclear fuel continues to be a challenge, but long term storage allows for a clear policy to be developed and implemented
- Advanced fuel cycles and reactor concepts may offer better solutions – hurdles exist and R&D is underway