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Minnesota Department of Commerce

August 19, 2009

Planning for Minnesota's Energy Future:

Including Nuclear Power in Minnesota's Future Energy Mix

Minnesota Energy Policy

- Nuclear Ban: § 216B.243 Subd. 3b
  - Senate Votes to Overturn 42-24
  - House Fails to Overturn 62-70

- Coal Ban: § 216H.03 Subd. 3

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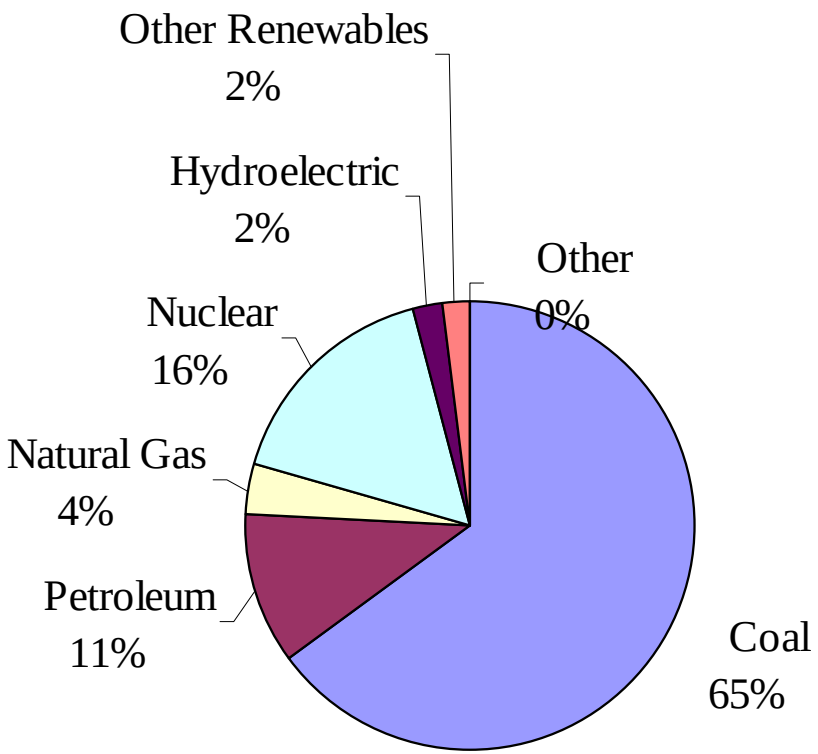
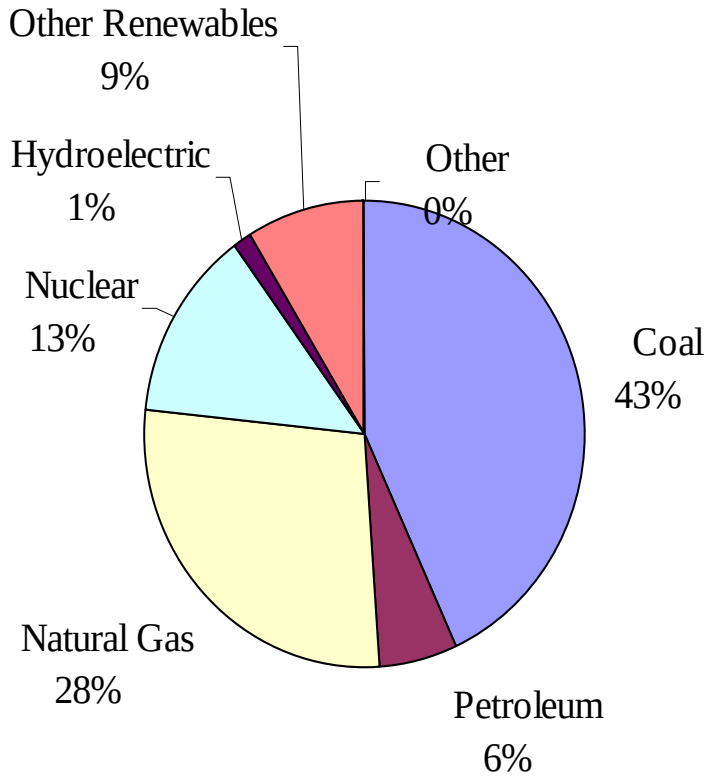
Minnesota Electric Capacity

Electric Capacity - 1990



Electric Capacity 2006



source: EIA

Electricity Production Subsidies

Table 35. Subsidies and Support to Electricity Production: Alternative Measures

Fuel/End Use	FY 2007 Net Generation (billion kilowatthours)	Alternative Measures of Subsidy and Support	
		Subsidy and Support Value 2007 (million dollars)	Subsidy and Support Per unit of Production (dollars/megawatthours)
Coal	1,946	854	0.44
Refined Coal	72	2,156	29.81
Natural Gas and Petroleum Liquids	919	227	0.25
Nuclear	794	1,267	1.59
Biomass (and Biofuels)	40	36	0.89
Geothermal	15	14	0.92
Hydroelectric	258	174	0.67
Solar[1]	1	14	24.34
Wind	31	724	23.37
Landfill Gas	6	8	1.37
Municipal Solid Waste	9	1	0.13
Unallocated Renewables	NM	37	NM
Renewables (subtotal)	360	1,008	2.80
Transmission and Distribution	NM	1,235	NM
Total	4,091	6,747	1.65

NOTES: Total may not equal sum of components due to independent rounding.

http://www.eia.doe.gov/oiaf/servicerpt/subsidy2/pdf/chap5.pdf

United States Nuclear Power Reactors

- 104 nuclear power reactors operating.
- 1 nuclear power reactor under construction (Watts Bar-2, Tennessee).
- In 2007, nuclear power provided about **20%** of the US electricity.

http://www.iaea.or.at/programmes/a2/

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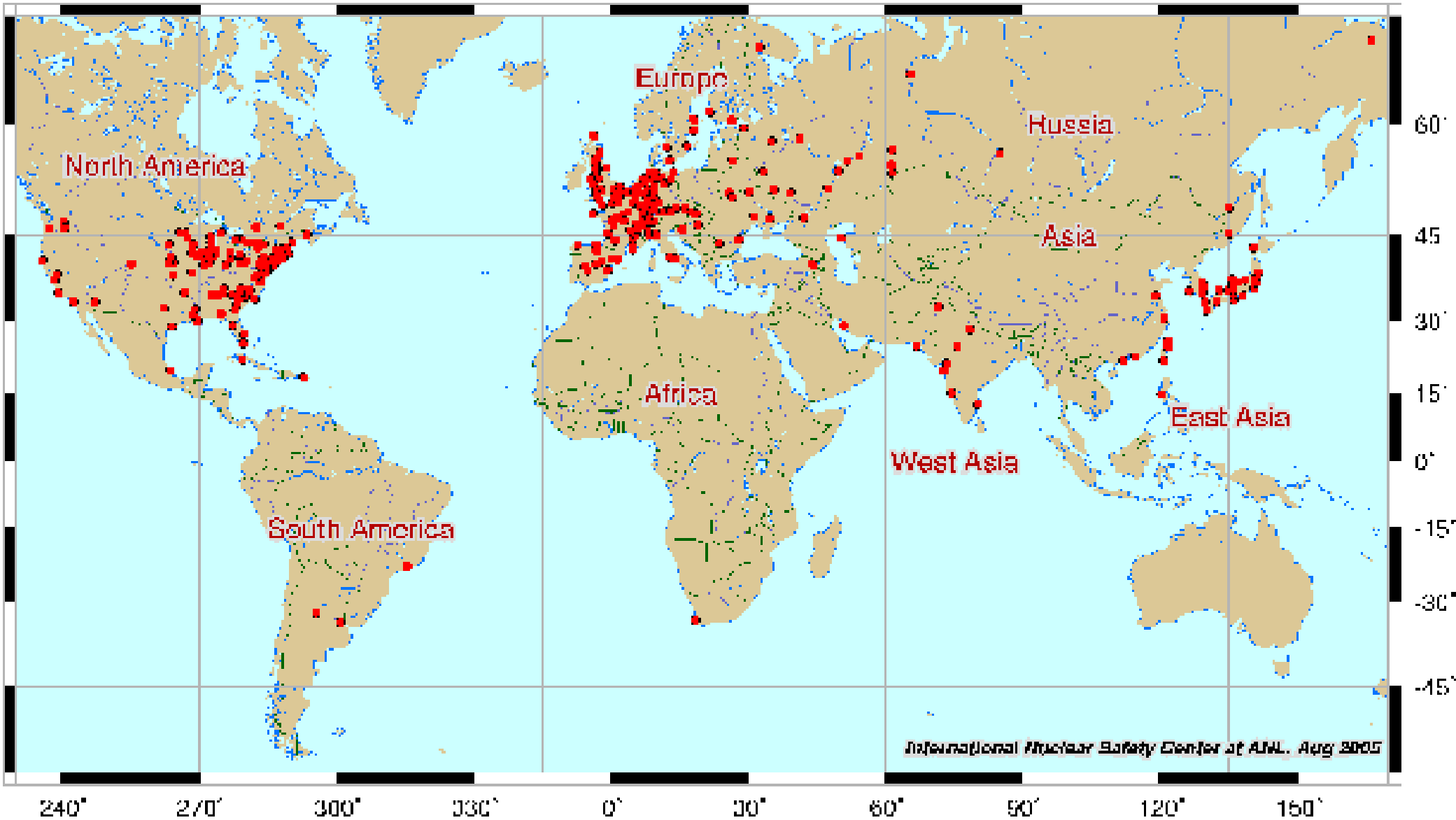
Worldwide Nuclear Power Use

- 436 nuclear power reactors operating in 30 countries.

- In 2007, nuclear power provided about 16% of the world's electricity.

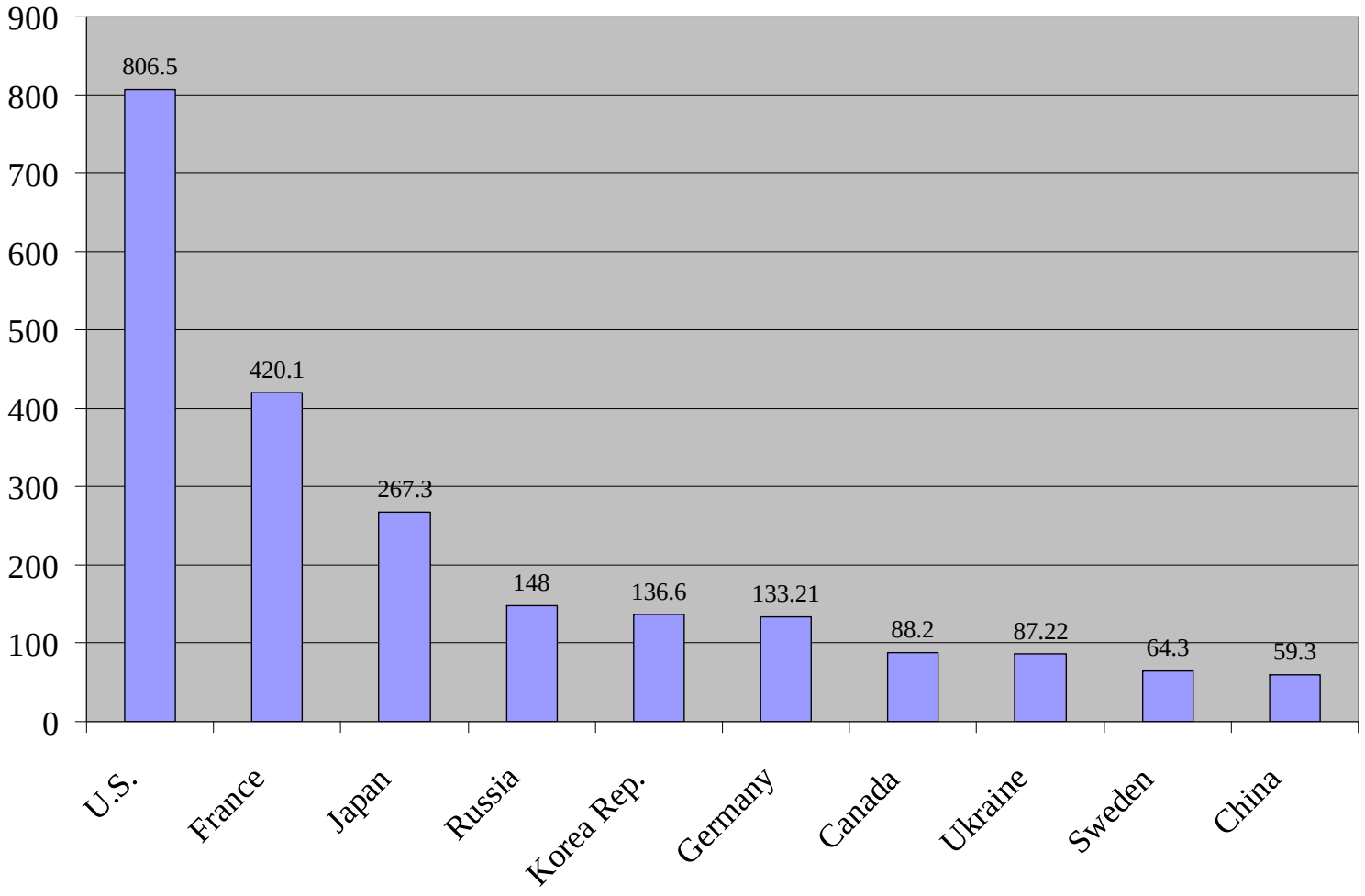
Worldwide Nuclear Power Use



http://www.insc.anl.gov/pwrmaps/map/world_map.tif

Top 10 Nuclear Generating Countries

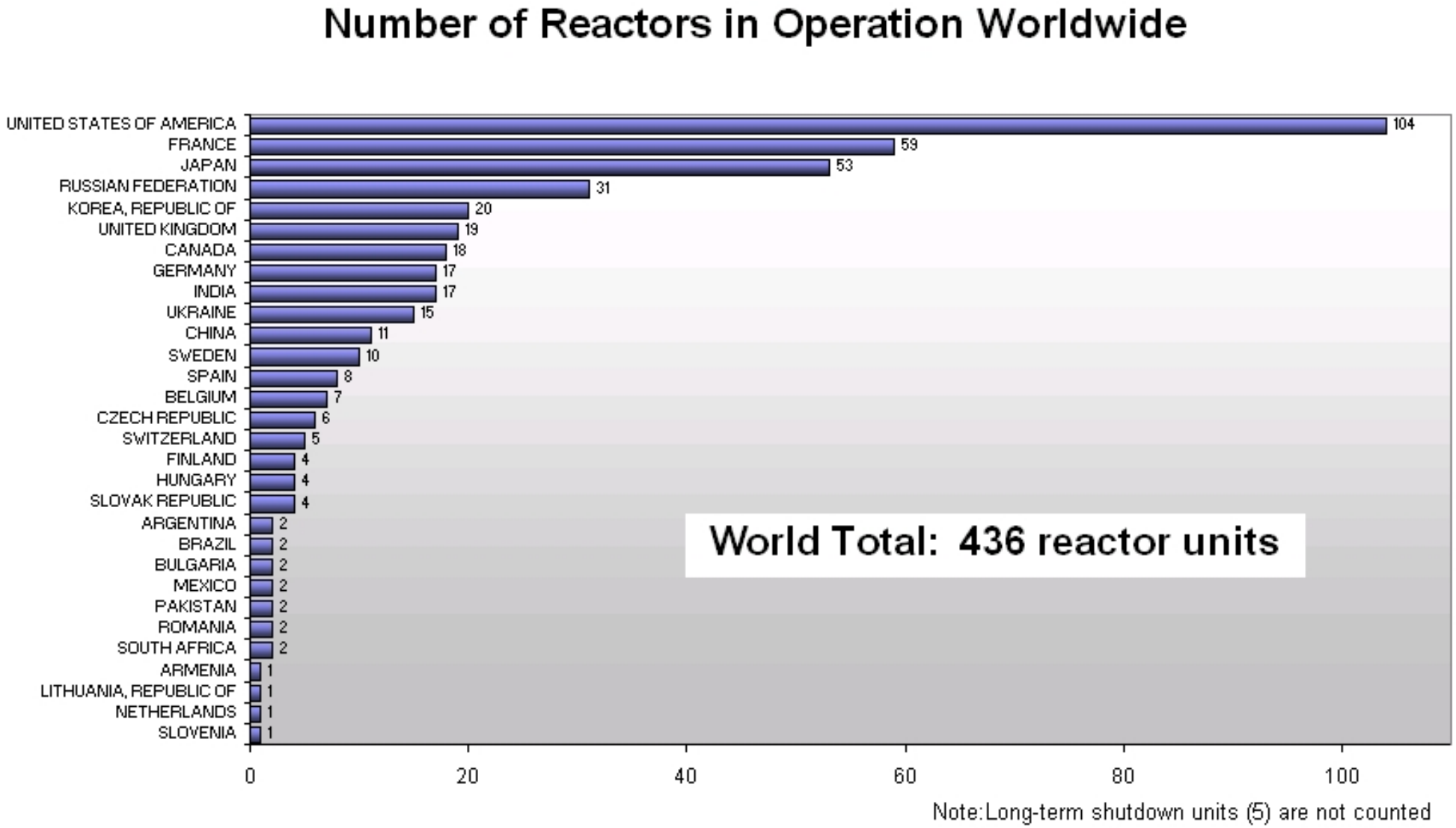
2007, Billion kWh



Source: International Atomic Energy Agency, U.S. is from Energy Information Administration

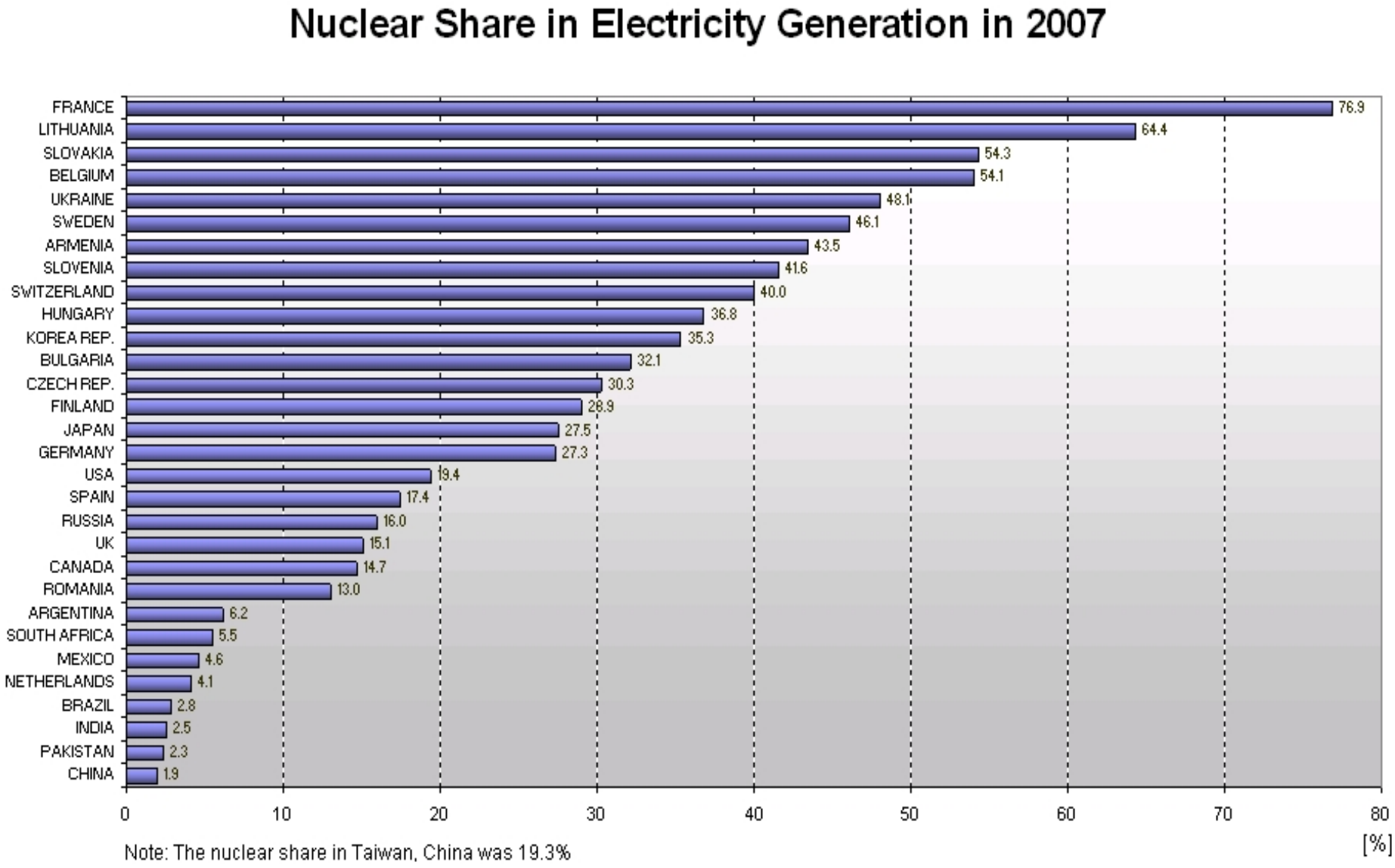
Updated: 9/08

Worldwide



Source: http://www.iaea.or.at/programmes/a2/

Worldwide



Source: http://www.iaea.or.at/programmes/a2/

Nuclear Units Under Construction Worldwide

Country	Reactor Name	Reactor Type	Total MWe	Estimated Start-up Year
Argentina (1)	Atucha 2	PHWR	692	2010
Bulgaria (2)	Belene 1	PWR	953	NA
	Belene 2	PWR	953	NA
China (11)	Fangjiashan 1	PWR	1,000	NA
	Fuqing 1	PWR	1,000	NA
	Fuqing 2	PWR	1,000	NA
	Hongyanhe 1	PWR	1,000	NA
	Lingao 3	PWR	1,000	2010
	Lingao 4	PWR	1,000	NA
	Ningde 1	PWR	1,000	NA
	Ningde 2	PWR	1,000	NA
	Qinshan 2-3	PWR	610	2010
	Qinshan 2-4	PWR	610	2011
	Yangjiang 1	PWR	900	NA
China, Taiwan (2)	Lungmen 1	ABWR	1,300	NA
	Lungmen 2	ABWR	1,300	NA
Finland (1)	Olkiluoto 3	PWR	1,600	NA
France (1)	Flamanville 3	PWR	1,600	2012
India (6)	Kaiga 4	PHWR	202	2009
	Kudankulam 1	PWR	917	2009
	Kudankulam 2	PWR	917	2010
	PFBR	FBR	470	NA
	Rajasthan 5	PHWR	202	2009
	Rajasthan 6	PHWR	202	2009
Iran (1)	Bushehr 1	PWR	915	2009
Japan (2)	Shimane 3	ABWR	1,325	NA
	Tomari 3	PWR	866	NA
Pakistan (1)	Chasnupp 2	PWR	300	2011
Russia (8)	Beloyarsky 4	FBR	750	NA
	Kalinin 4	PWR	950	NA
	Kursk 5	LWGR	925	NA
	Leningrad 2-1	PWR	1,085	NA
	Novovoronezh 2-1	FBR	1,085	NA
	Severodvinsk 1	PWR	32	NA
	Severodvinsk 2	PWR	32	NA
	Volgodonsk 2	PWR	950	NA
S. Korea (5)	Shin-Kori 1	PWR	960	2010
	Shin-Kori 2	PWR	960	2011
	Shin-Kori 3	PWR	1,340	NA
	Shin Wolsong 1	PWR	960	2011
	Shin Wolsong 2	PWR	960	2012
Ukraine (2)	Khmelnitski 3	PWR	950	2015
	Khmelnitski 4	PWR	950	2016
United States (1)	Watts Bar 2	PWR	1,165	NA
Total (44)			38,888	

Source: International Atomic Energy Agency PRIS database
http://www.iaea.org/programmes/a2/index.html
Updated: 2/09

ABWR - Advanced Boiling Light-Water-Cooled and Moderated Reactor
FBR - Fast Breeder Reactor
LWGR - Light-Water-Cooled, Graphite-Moderated Reactor
PHWR - Pressurized Heavy-Water-Moderated and Cooled Reactor
PWR - Pressurized Light-Water-Moderated and Cooled Reactor

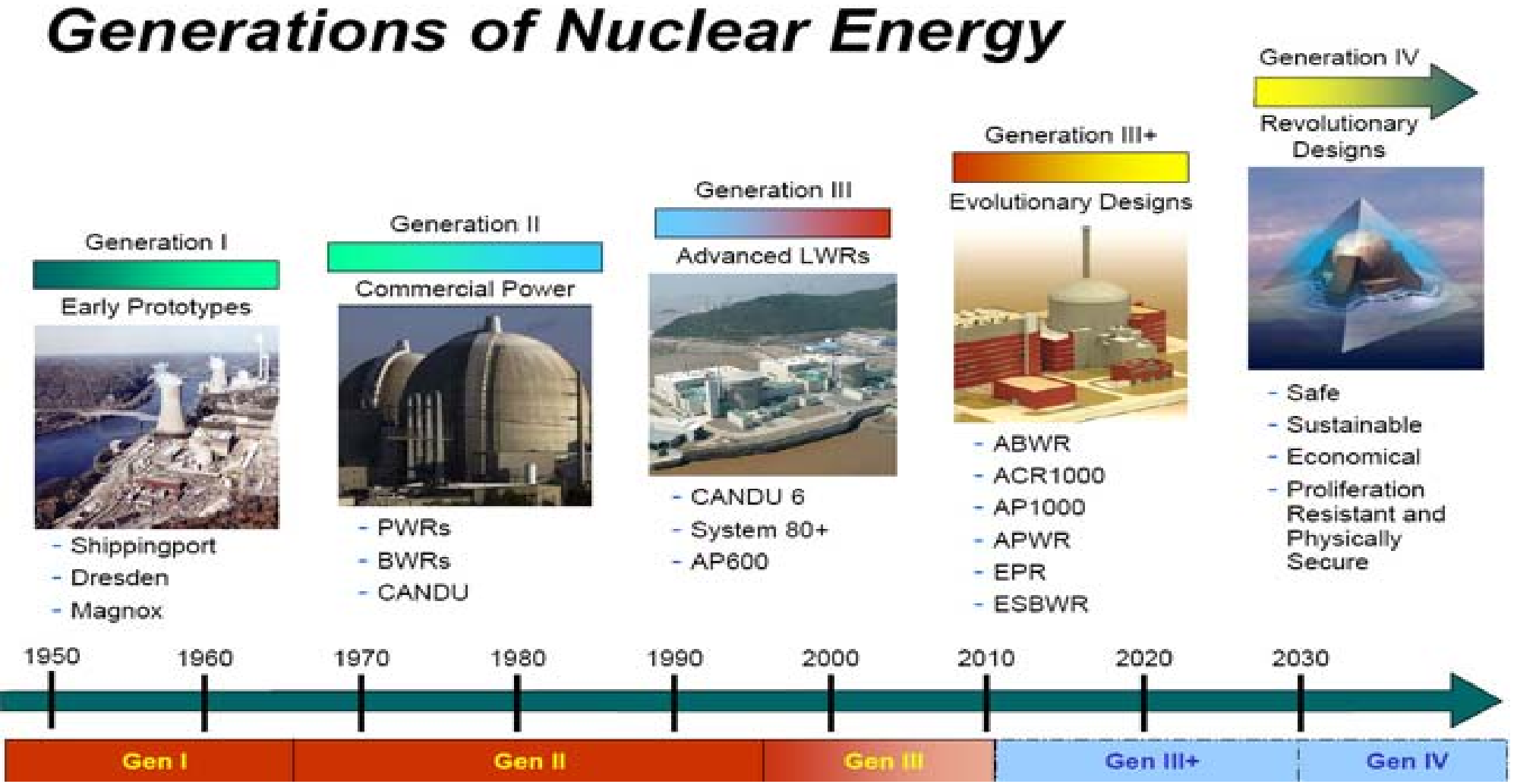
New Nuclear Power Life-Cycle Costs Comparison

Table 1. Cost of Electricity from Various Generating Technologies (Nuclear Energy Institute Financial Model)									
Technology	**Nuclear**		**SCPC**	**IGCC**		**Gas Combined Cycle**			
Project Structure	PF LG 80/20	RB CWIP 50/50	RB CWIP 50/50	RB CWIP 50/50	PF LG 80/20	PF 50/50	PF 50/50	PF 50/50	
EPC Cost ($/kWe)	$3,500 - 4,500		$2,250	$3,700		$1,000			
Total Cost ($/kWe)	$5,071 -6,378	$4,351 -5,473	$2,424	$4,164	$4,855	$1,195	$1,206	$1,218	
Fuel Cost (nuclear - $/MWh) (coal/gas - $/mmBtu)	$7.50		$1.50	$1.50		$6.00	$8.00	$10.00	
Capacity (MWe)	1,400		800	600		400			
First Year Busbar (2007 $/MWh)	**$64.4 - 75.8**	**$96.9 -118.8**	**$70.6**	**$112.3**	**$71.8**	**$70.4**	**$83.9**	**$98.4**	
Levelized Busbar (2007 $/MWh)	—	$73.60 -87.70	$55.2	$83.60	—	—	—	—	
Impact of $30/Ton C02 Price (2007 $/MWh)	—	—	+ $25.00	+ $25.0		+ $13.0			

Abbreviations: PF=project finance; LG=loan guarantee; RB=rate base; CWIP=construction work in progress.
Notes: The nuclear cases assume 48-month construction, 6-month start-up; owner's cost of $286/kWe and 10% contingency; 6.5% interest rate on commercial debt for unregulated entities, 6.0% interest rate on commercial debt for regulated entities, 4.5% interest rate on government-guaranteed debt; 15% return on equity; 5% loan guarantee cost in 80/20 loan guarantee case; 90% capacity factor; O&M cost of $9.50/MWh and fuel cost of $7.50/MWh. The capital cost estimates for supercritical pulverized coal (SCPC) and integrated gasification combined cycle (IGCC) are from recent regulatory filings for projects.

See Paper titled The Cost of New Generating Capacity in Perspective at http://www.nei.org/resourcesandstats/nuclear_statistics/costs

V. Designs of New Nuclear Power Reactors



http://www.gen-4.org/Technology/evolution.htm

ABWR: The U.S. Advanced Boiling Water Reactor

- Uses a single-cycle, forced circulation design with a rated power of 1,300 megawatts electric (MWe).
- The design incorporates features of the BWR designs in Europe, Japan, and the United States, and uses improved electronics, computer, turbine, and fuel technology.
- Improvements include the use of internal recirculation pumps, control rod drives that can be controlled by a screw mechanism rather than a step process, microprocessor-based digital control and logic systems, and digital safety systems.
- The design also includes safety enhancements such as protection against overpressurizing the containment, passive core debris flooding capability, an independent water makeup system, three emergency diesels, and a combustion turbine as an alternate power source.

http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html

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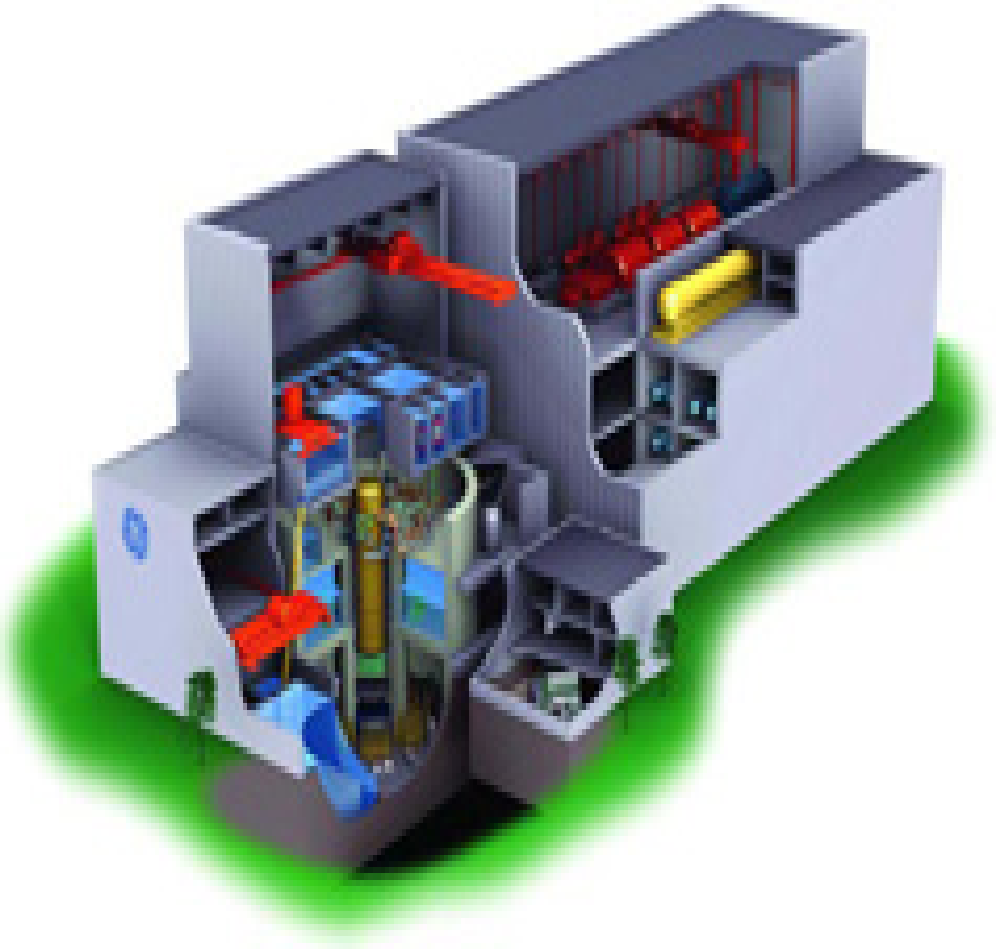
AP1000: The Advanced Passive 1000

- A larger version of the previously approved AP600 design.
- This 1,100 MWe advanced pressurized water reactor incorporates passive safety systems and simplified system designs.
- It is similar to the AP600 design but uses a longer reactor vessel to accommodate longer fuel, and also includes larger steam generators and a larger pressurizer.

http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html

ESBWR: The Economic and Simplified Boiling Water Reactor



- A 1,500 MWe, natural circulation boiling water reactor that incorporates passive safety features.
- This design is based on its predecessor, the 670 MWe Simplified BWR (SBWR) and also utilizes features of the certified ABWR.
- The ESBWR enhances natural circulation by using a taller vessel, a shorter core, and by reducing the flow restrictions.
- The design utilizes an isolation condenser system for high-pressure water level control and decay heat removal during isolated conditions.
- After the automatic depressurization system operates, a gravity-driven cooling system provides low-pressure water level control.
- Containment cooling is provided by a passive system.

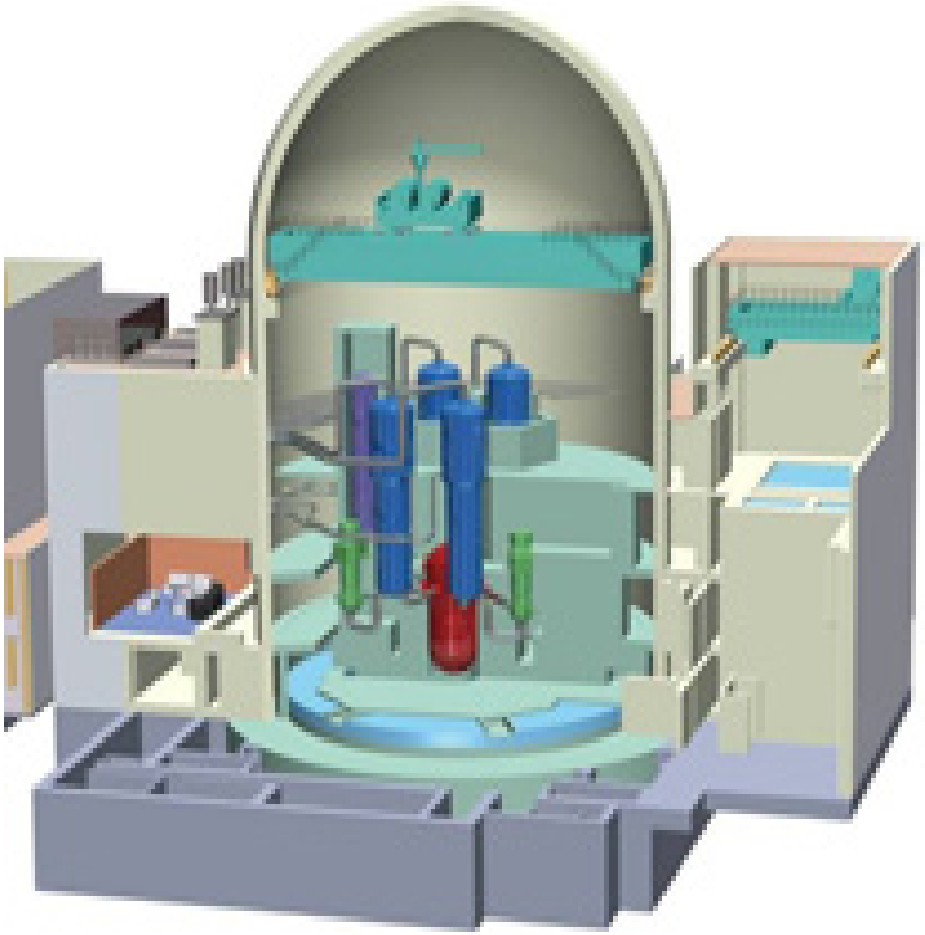
http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html

EPR: The Evolutionary Power Reactor

- 1,600 MWe pressurized water reactor of evolutionary design.
- Design features include four 100% capacity trains of engineered safety features, a double-walled containment, and a “core catcher” for containment and cooling of core materials for severe accidents resulting in reactor vessel failure.
- The design does not rely on passive safety features.
- The first EPR is under construction at the Olkiluoto site in Finland, with another planned for the Flammanville site in France.

http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html

APWR: Advanced Pressurized Water Reactor

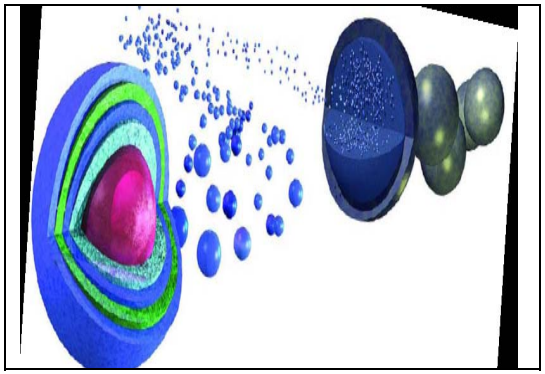


- An evolutionary 1,700 MWe pressurized water reactor currently being licensed and built in Japan.
- The design includes high-performance steam generators, a neutron reflector around the core to increase fuel economy, redundant core cooling systems and refueling water storage inside the containment building, and fully digital instrumentation and control systems.

http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html

Pebble Bed Modular Reactor (PBMR) in Pre-Application Review

- A modular high-temperature gas reactor that uses helium as its coolant.
- PBMR design consists of eight reactor modules, 165 MWe per module, with capacity to store 10 years of spent fuel in the plant).
- The PBMR core is based on German high-temperature gas-cooled reactor technology and uses spherical graphite elements containing ceramic-coated fuel particles.



The fuel consists of low-enriched uranium particles, measuring about 0.5 mm in diameter, contained in four coated layers of protective graphite sphere.

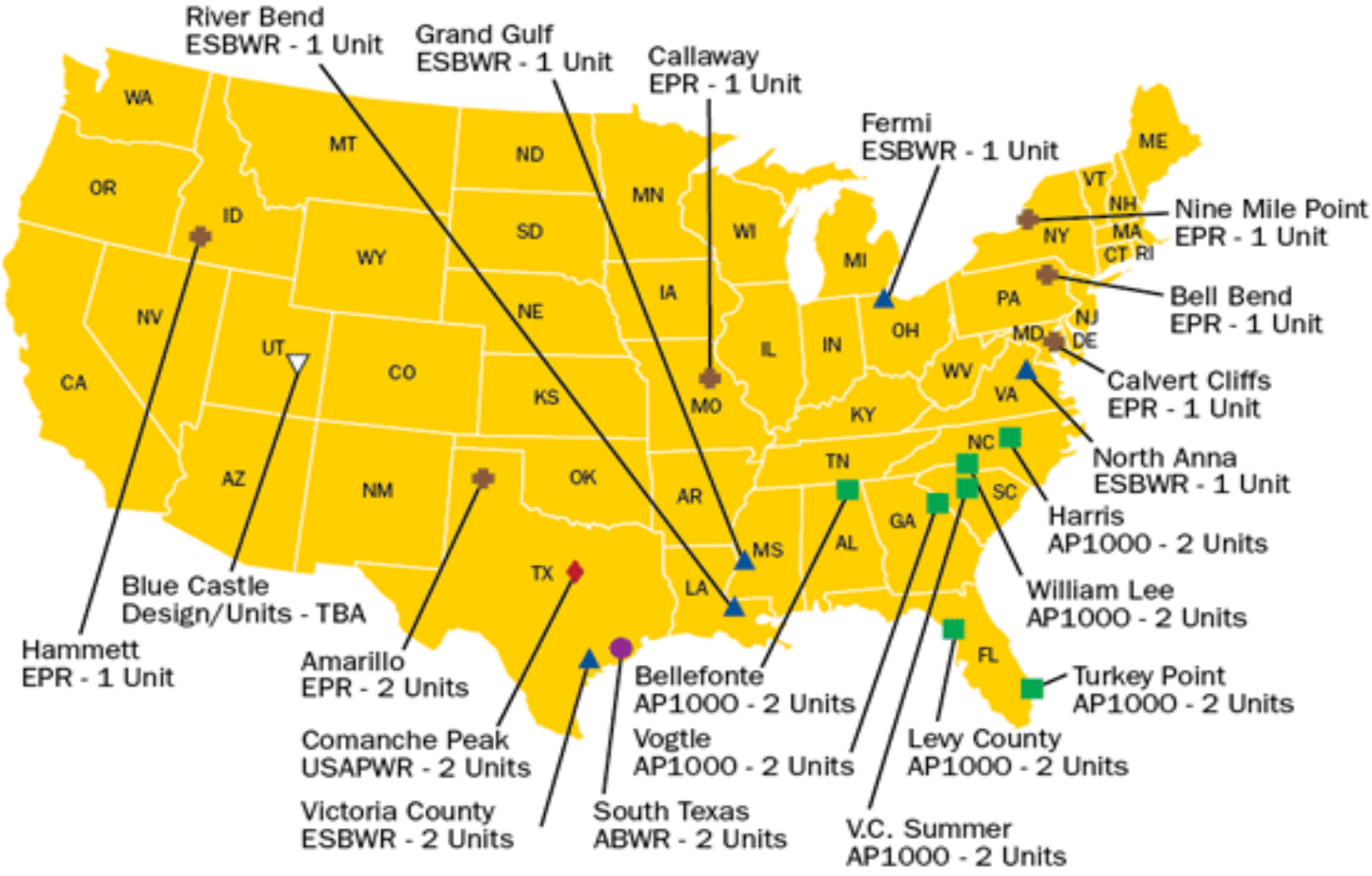
Fun figures - One pebble contains 9g of Uranium, with an enrichment level of 9.6%, burnt to 92 000MWdays/ton of heavy metal = 71.5GJ. Converted into electricity it is about 8MWh per pebble.
The converted electrical energy in one pebble is (8MWh):
Enough to power 132 500 light bulbs (60W) for 1 hour or
Enough to power one 60W light bulb for 30 years, 3 months, burning 12 hours/day.

http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.html

Differences between PBMR and current US light-water reactors

- Fuel design - Tennis ball-sized "pebbles" of ceramic graphite, impregnated with thousands of tiny, coated particles of low-enriched uranium, fuel the PBMR.
- Cooling mechanism - a PBMR site would not require large water supplies, because it uses helium (not water) to cool the reactor.
- Electricity output/Plant Size - The main PBMR building of an eight module (1320MWe) plant fit into two soccer fields (113m x 103m), allowing for a phase-in of new units as electricity demand grows.
- Construction process - The PBMR concept consists of pre-fabricated modules assembled at the plant site in just two years.
- Waste Management - Safe storage is ensured since the encapsulating graphic spheres provide corrosion protection and prevents environmental contamination by the release of fission products. products isolated from one another.
- Safety Features - The PBMR technology has a simple basis which requires no human intervention.

Location of Projected New Nuclear



http://www.nrc.gov/reactors/operating/map-power-reactors.html

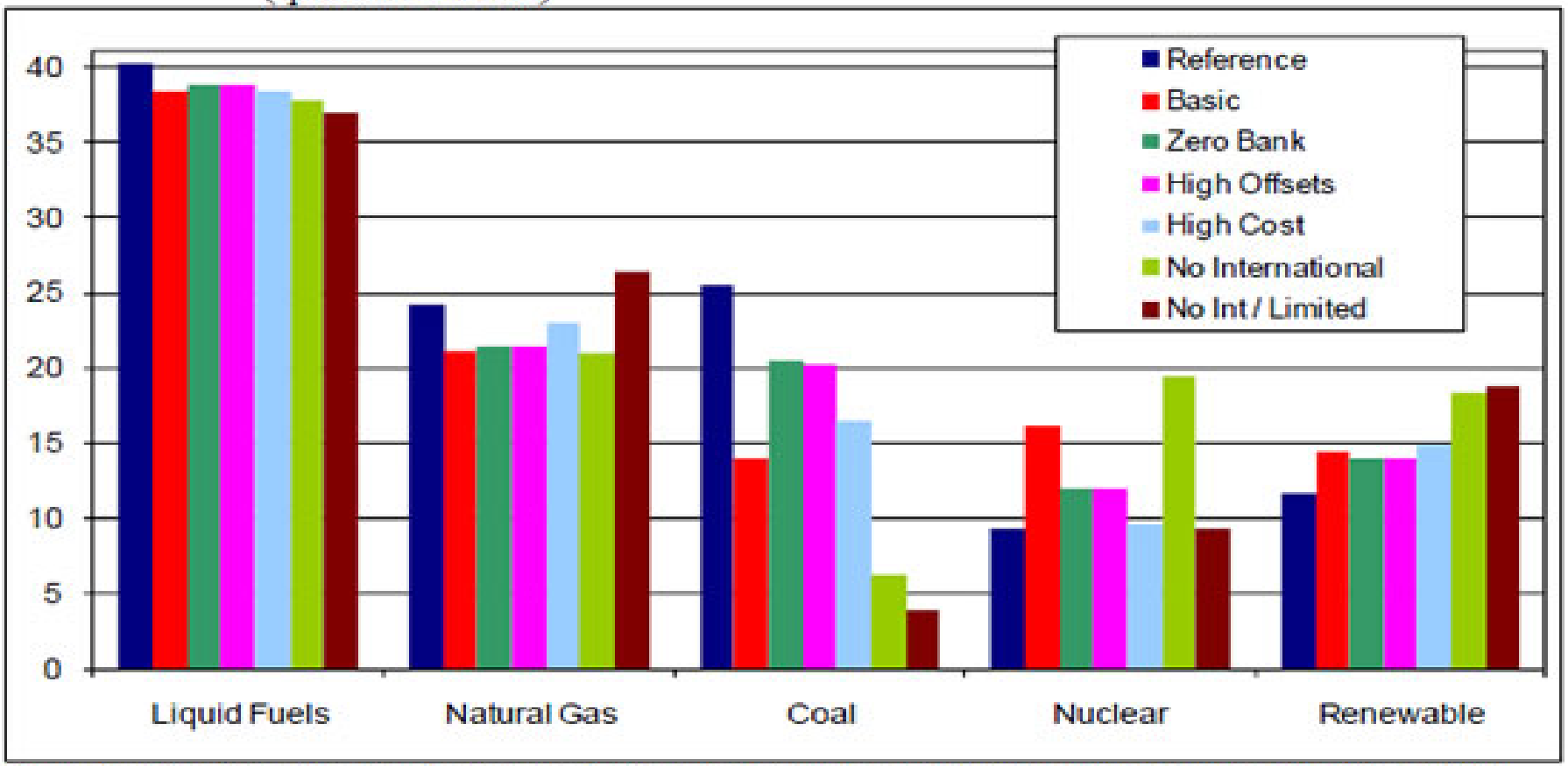
Waxman-Markey Bill H.R. 2454

- Energy Information Administration (U.S. DOE)
  - Less Electricity Generated Under H.R. 2454
  - "Basic Case": Nuclear to increase 74% by 2030
    (Table 1 of August 2009 Report)
  - "Basic Case": More Nuclear than Renewables
  - Nuclear to Increase in Any Scenario Under H.R. 2454

EIA's Analysis of ACESA

KF4. Emissions reductions from changes in fossil fuel use in the residential, commercial, industrial and transportation sectors are small relative to those in the electric power sector.

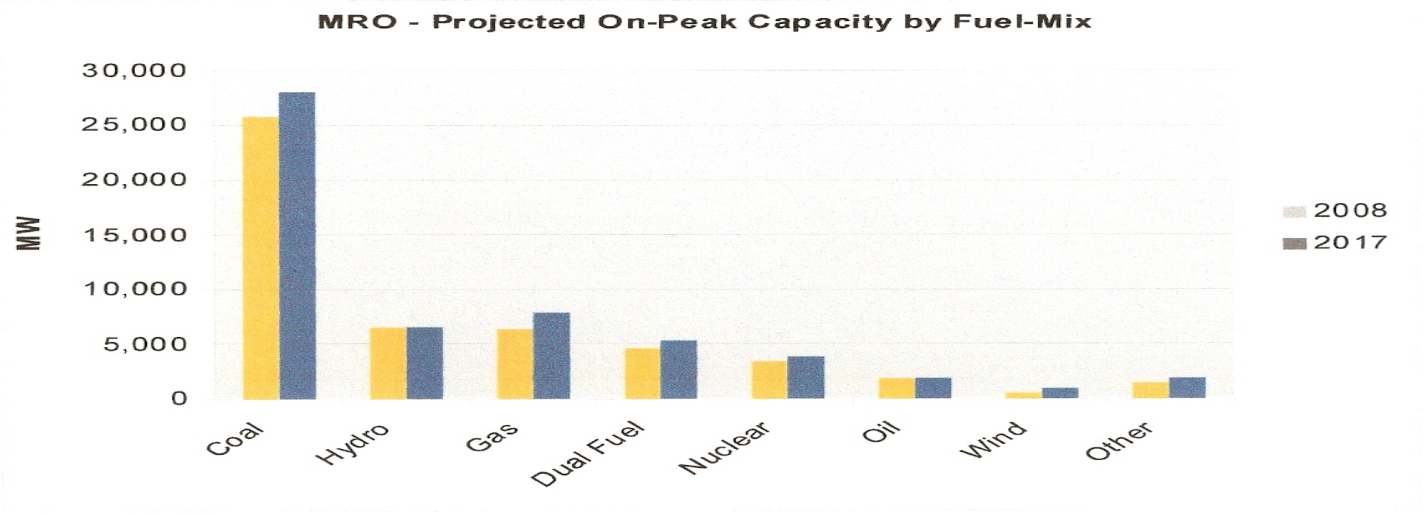
Figure ES-2. Primary Energy Consumption by Fuel in Main ACESA Cases, 2030
(quadrillion Btu)

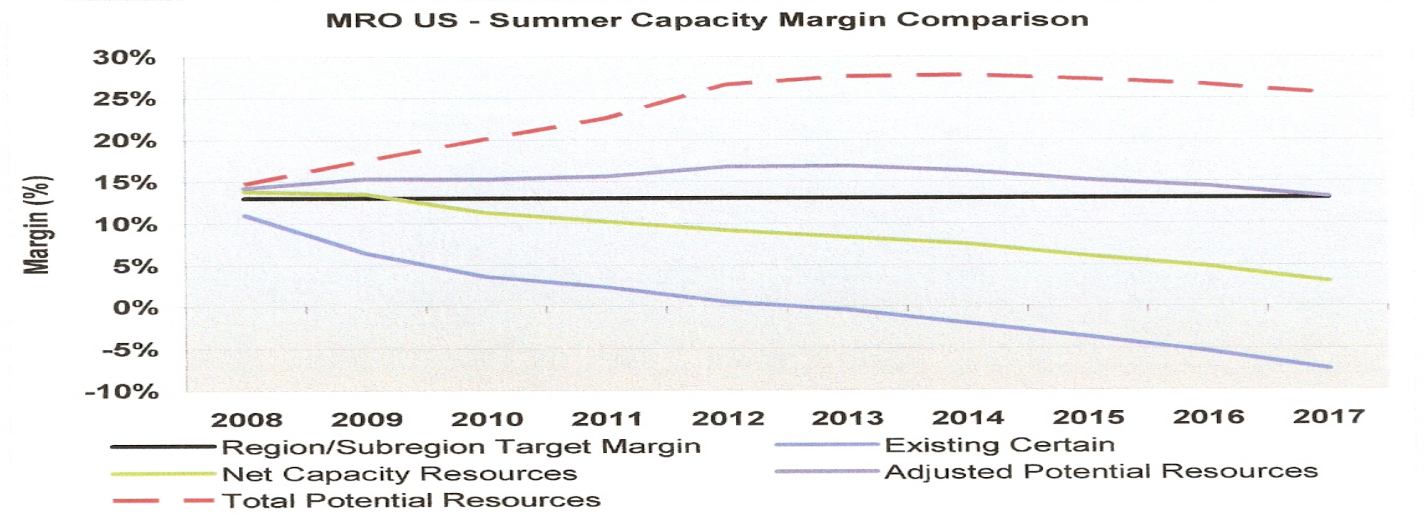


Source: National Energy Modeling System runs, STIMULUS.D041409A, HR2454CAP.D072909A, HR2454NOBNK.D072909A, HR2454HIOFF.D072909A, HR2454HC.D072909A, HR2454NOINT.D072909A, and HR2454NIBIV.D072909A.

Advocates of Nuclear Power

- Patrick Moore, Ph.D.
  - Early member of Greenpeace
- Stewart Brand
  - Creator *Whole Earth Catalog*
- James Lovelock
  - Proposed GAIA theory


MRO - Projected On-Peak Capacity by Fuel-Mix
MW
30,000
25,000
20,000
15,000
10,000
5,000
0
Coal
Hydro
Gas
Dual Fuel
Nuclear
Oil
Wind
Other
2008
2017


MRO US - Summer Capacity Margin Comparison
Margin (%)
30%
25%
20%
15%
10%
5%
0%
-5%
-10%
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Region/Subregion Target Margin
Existing Certain
Net Capacity Resources
Adjusted Potential Resources
Total Potential Resources

Minnesota's Electricity Future

- Minnesota's electric fuel generation is changing.
- Renewables and energy efficiency will not address our baseload energy needs.
- Energy planning for 2025 and beyond must start now.
  - Nuclear power is part of energy mix.
  - Contribution of nuclear power will remain constant with renewal of the three current units until operating expires in **2034**.
  - Coal power electric generation is the largest portion of Minnesota's energy mix. No new plants built since 1980's.