SNS COLLEGE OF TECHNOLOGY

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DEPARTMENT OF AGRICULTURAL ENGINEERING

19AGB401- SOLAR AND WIND ENERGY

RENEWABLE ENERGY

NUCLEAR ENERGY BASICS AND STATUS

- To Understand the Situation and Prospects of the Nuclear Power Enterprise Within the Overall Energy Context
  - Domestically
  - Internationally

NUCLEAR POWER TECHNOLOGIES

GOALS OF NUCLEAR POWER DISCUSSION: To Answer the Following Questions

- Who used nuclear power today?

Answer: Most industrialized countries.

- Who is likely to use nuclear power in the future?

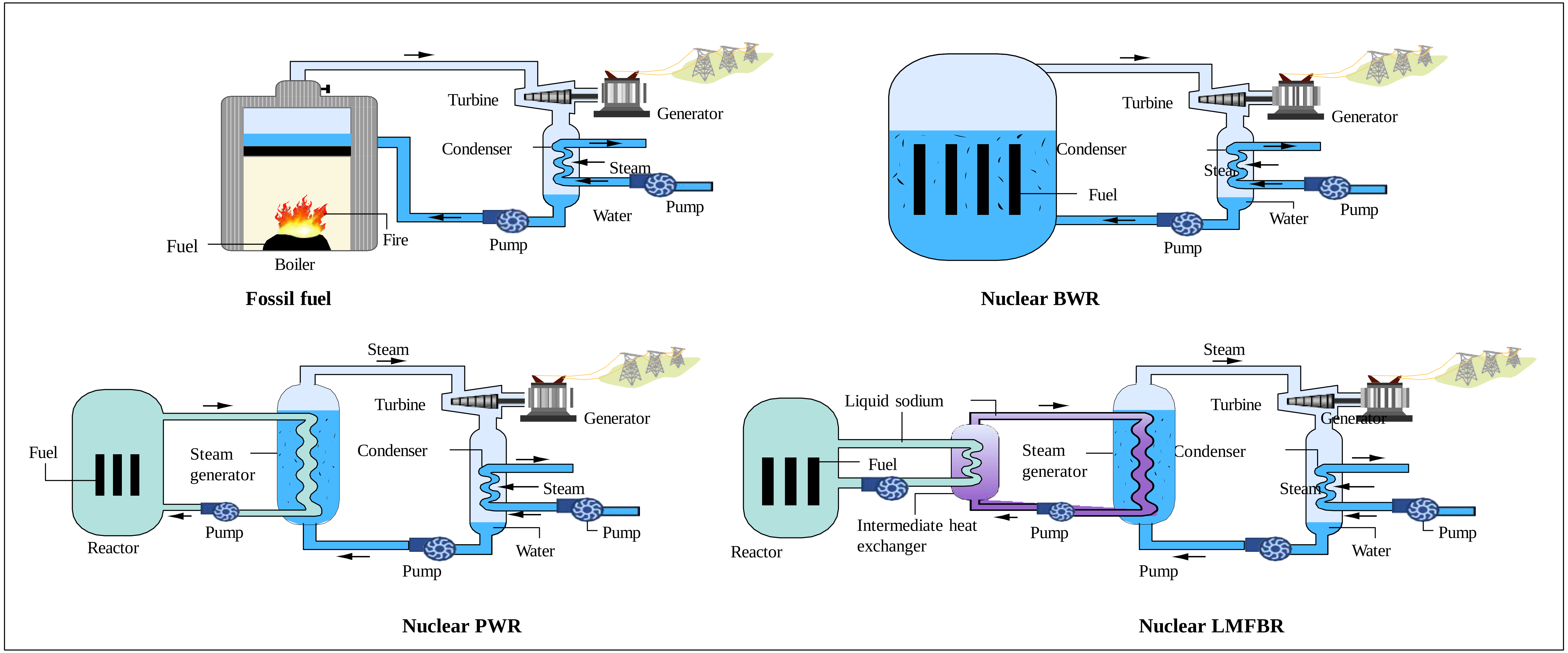
Answer: East Asian and developing countries, countries wanting energy supply diversity.

- What are the important nuclear power technologies
    - Today? Answer: LWRs – pressurized and boiling water reactors.
    - Future? Answer: Maybe LWRs near term, gas-cooled reactors medium term, breeder reactors long term.
- How could nuclear power relieve global warming?

Answer: Most likely with large-scale, high-temperature breeder reactors.

- What are the future prospects for nuclear power?

TYPES OF STEAM-ELECTRIC GENERATING PLANTS



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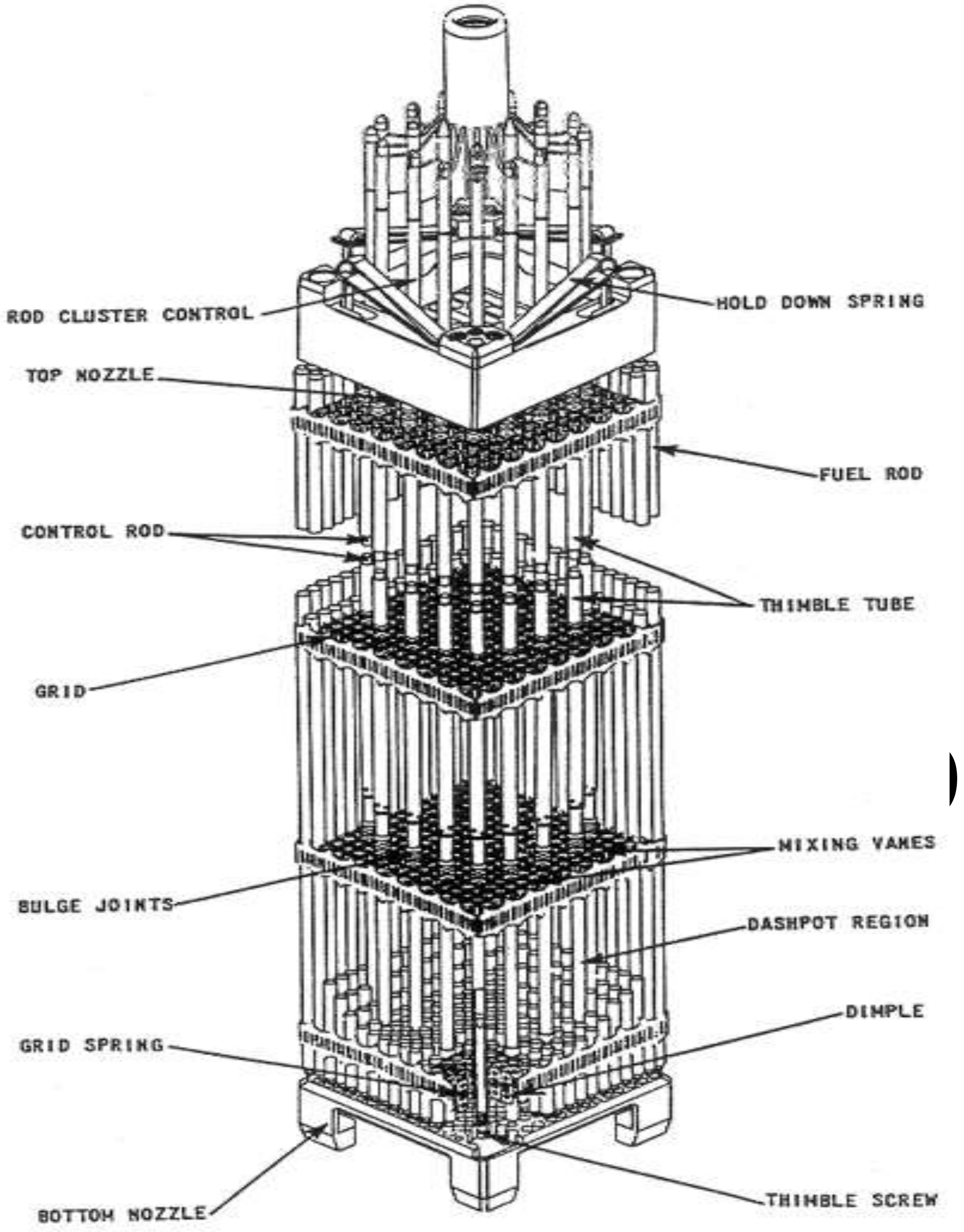
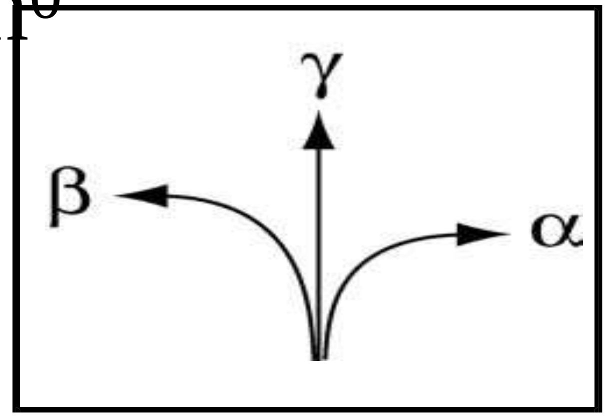


Reactor Fuel Assembly

RANGE OF RADIATION IN TISSUE

Particle Name	Range (m)	Particle Type and Charge
Fission Product	10^{-6}	Fragment of Nucleus
α	$10^{-4} – 10^{-5}$	Helium Nucleus^{++}, 2 protons, 2 neutrons
β	10^{-3}	Electron Photon^0
γ	0.1 – 10	
n	0.1 – 10	Neutron^0



TRANSMUTATION

Stable Isotope A^m + Neutron n → New Isotope A^{m+1}

FISSION

- $n + {}^{235}U \rightarrow {}^{236}U \rightarrow 2$ Fission Products
- + ν (≈2.5)n
- + 6 β
- + 10 γ
- + neutrinos
- + kinetic energy (≈ 200 MeV)

ENERGY BALANCE FOR AN AVERAGE FISSION

MeV

Kinetic energy of fission fragments (2 nuclei: A Å95, 165 ±5 A Å140)

γ γ

Beta decay of fragments (7 rays) β 8 ± 1.5

Neutrinos related to above 12 ± 2.5

Gamma rays related to above (7 rays) γ 6 ± 1

Kinetic energy of neutrons (2 to 3 neutrons) 5 ±

Prompt rays (5 rays) 6 ± 1

NEUTRONIC PROPERTIES OF NUCLEAR FUELS

Parameter	NEUTRON ENERGIES					
	THERMAL			MeV		
	U^{233}	U^{235}	Pu^{239}	U^{233}	U^{235}	Pu^{239}
α	0.123	0.2509	0.38	0.1	0.15	0.1
η	2.226	1.943	2.085	2.45	2.3	2.7
ν	2.50	2.43	2.91	2.7	2.65	3.0

$$\eta = \frac{\nu}{1+\alpha}, \frac{\text{n's produced}}{\text{absorption}}; \quad \alpha = \frac{\text{captures}}{\text{fissions}}; \quad \nu = \frac{\text{n's produced}}{\text{fission}}$$

<u>Conversion Reactions</u>:

$$U^{238} + n \rightarrow U^{239} + \gamma \rightarrow Np^{239} + \beta^- \rightarrow Pu^{239} + \beta^-$$

$$Th^{232} + n \rightarrow Th^{233} + \gamma \rightarrow Pa^{233} + \beta^- \rightarrow U^{233} + \beta^-$$

SELF-SUSTAINED CHAIN REACTION

$$1 \text{ neutron } + U^{235} \rightarrow \eta \text{ neutrons} \Rightarrow \begin{cases} 1 \text{ neutron for subsequent fission, and} \\ (\eta - 1) \text{ neutrons for leakage, parasitic absorption, and conversion} \end{cases}$$

Necessary Condition for Breeding: for each fissile nucleus consumed another is produced via conversion of fertile material, e.g., a U^{235} nuclear is consumed and replaced by production of a new Pu^{239} nucleus, via the reaction –

$$n + U^{238} \rightarrow U^{239} + \gamma$$
$$Np^{239} + \beta^{-} + \gamma$$
$$Pu^{239} + \beta^{-} + \gamma$$

Conversion Ratio ≡ Number of new fissile neuclei produced as a result of fission of a single nucleus

$$\text{Conversion Ratio : } \begin{cases} \geq 1 \text{ for breeding} \\ < \text{ for burning} \end{cases}$$

FUNDAMENTAL SOURCES OF ENERGY USED BY DIFFERENT ENERGY TECHNOLOGIES

Energy Source	Fundamental Nuclear Energy Source
Solar	Gravitationally confined solar fusion reactions transmitted via photons
Fossil Fuels	Gravitationally confined solar fusion reactions transmitted via photons and stored in biomass
Geothermal	Naturally-occurring radioactive decays of materials within the Earth and Gravitational Work
Tidal	Nuclear reactions following the Big Bang Sustaining Current Gravitational Work
Nuclear Fission	Neutron-induced fission reactions of heavy nuclei Nuclear fusion
Nuclear Fusion	reactions of light nuclei

ENVIRONMENTAL EFFECTS OF ENERGY SOURCES

FUEL / PHASE	Coal	Petroleum	Natural Gas	Nuclear	Hydro	Solar Terrestrial Photovoltaic	Solar Power Tower	Wind	Fusion	Geothermal
Extraction	Mining Accidents Lung Damage	Drilling-Spills (off-shore)	Drilling	Mining Accidents Lung Damage	Construction	Mining Accidents	- -	- -	He, H^2, Li Production	- -
Refining	Refuse Piles	Water Pollu tion	- -	Milling Tails	- -	- -	- -	- -	- -	- -
Transportation	Collision	Spills	Pipeline Explosion	- -	- -	- -	- -	- -	- -	- -
On-Site										
Thermal	High Efficiency	High Efficiency	High Efficiency	Low Efficiency	- -	Low Efficiency Ecosystem Change	Ecosystem Change	- -	- -	Low Efficiency H_2S
Air	Particulates SO_2, NO_x	SO_2, NO_x	NO_x	BWR Radia tion Releases	- -	- -	- -	- -	- -	Brine in Streams
Water	Water Treat ment Chemi cals	Water Treat ment Chemi cals	Water Treat ment Chemi cals	Water Treat ment Chemi cals	Destroys Prior Ecosystems	Water Treat ment Chemi cals	Water Treat ment Chemi cals	- -	Tritium in Cooling Water	Poor Large Area
Aesthetic	Large Plant Transmission Lines	Large Plant Transmission Lines	Large Plant Transmission Lines	Small Plant Transmission Lines	Small Plant Transmission Lines	Poor Large Area	Poor Large Area	Large Area Large Towers Noise?	Small Area	Cool Brine
Wastes	Ash, Slag	Ash	- -	Spent Fuel Transportation Reprocessing Waste Storage	- -	Spent Cells	- -	- -	Irradiated Struc tural Material	- -
Sprecial Problems	- -	- -	- -	- -	- -	Construction Accidents	- -	Bird, Human Injuries	Occupational Radiation Doses	- -
Major Accident	Mining	Oil Spill	Pipeline Explosion	Reactor Cooling	Dam Failure	Fire	- -	- -	Tritium Release	

PUBLIC MOOD MORE FAVORABLE TO NUCLEAR POWER

- Global Warming Concerns
  - Popular belief
  - IPCC reports and 2007 Nobel Peace Prize
- Fossil fuel costs/supply security
- Middle-East Wars
- Better Nuclear Power Technology – Mainly Concerning Safety
- Good Operational Record of Existing Nuclear Plants

WORLD ELECTRICITY GENERATION

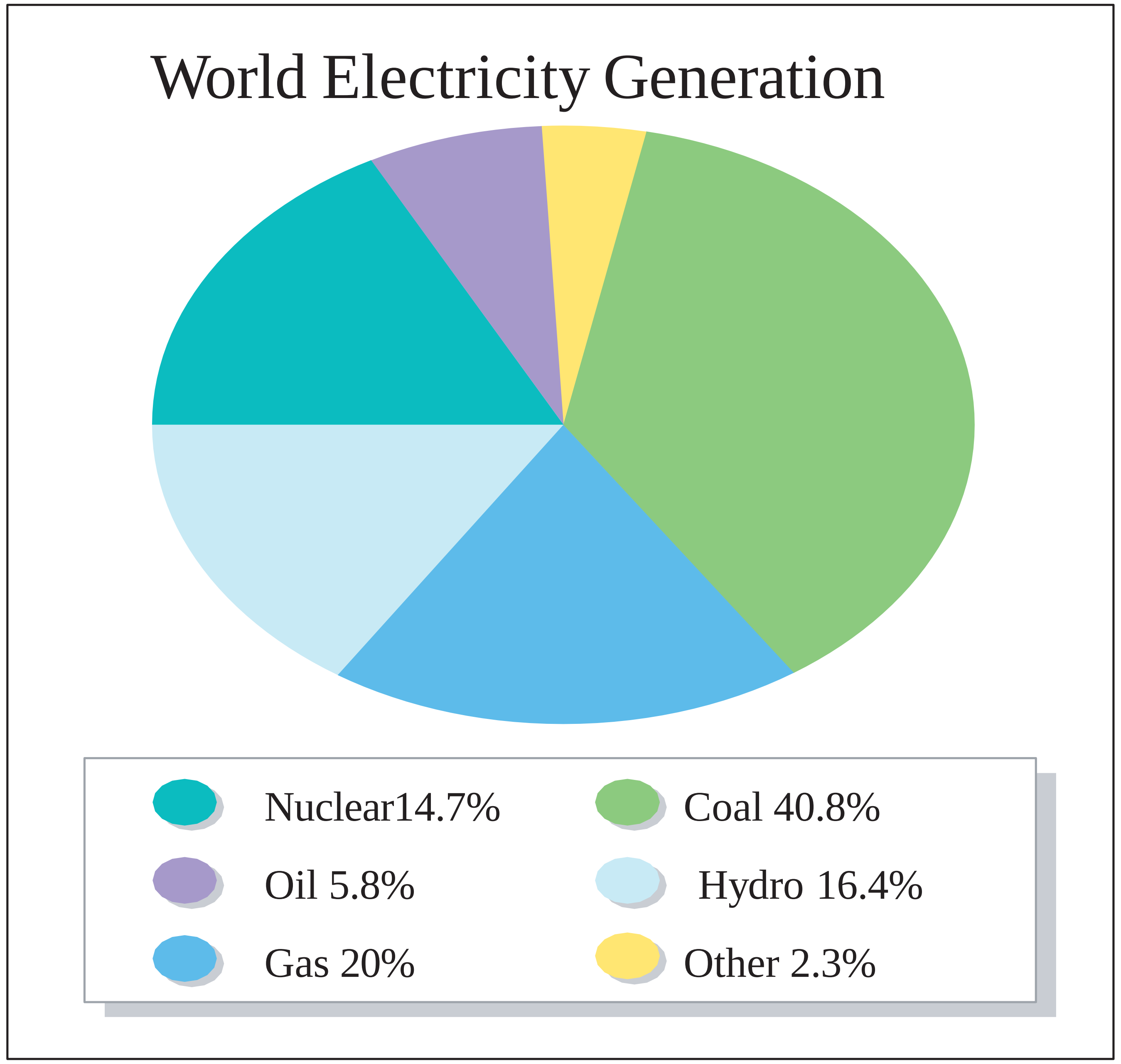


Image by MIT OpenCourseWare. Source: OECD/IEA 2006.

http://www.world-nuclear.org/info/inf01.html

- 441 Units Operating in 30 Countries, with 376,000 MWe of total capacity
- 7 New Units Expected to Start Up in 2010
- 60 New Units Under Construction, 11 Started in 2009 150 New Units Planned
- 340 New Units Proposed
- China Plans 50 Units Over Next 10 Years
- UK "White Paper" Encourages New Nuclear Power Plants (1/08)
- New Units in South Korea, China, Finland, France, India, Japan, Russia—most growth is in Asia

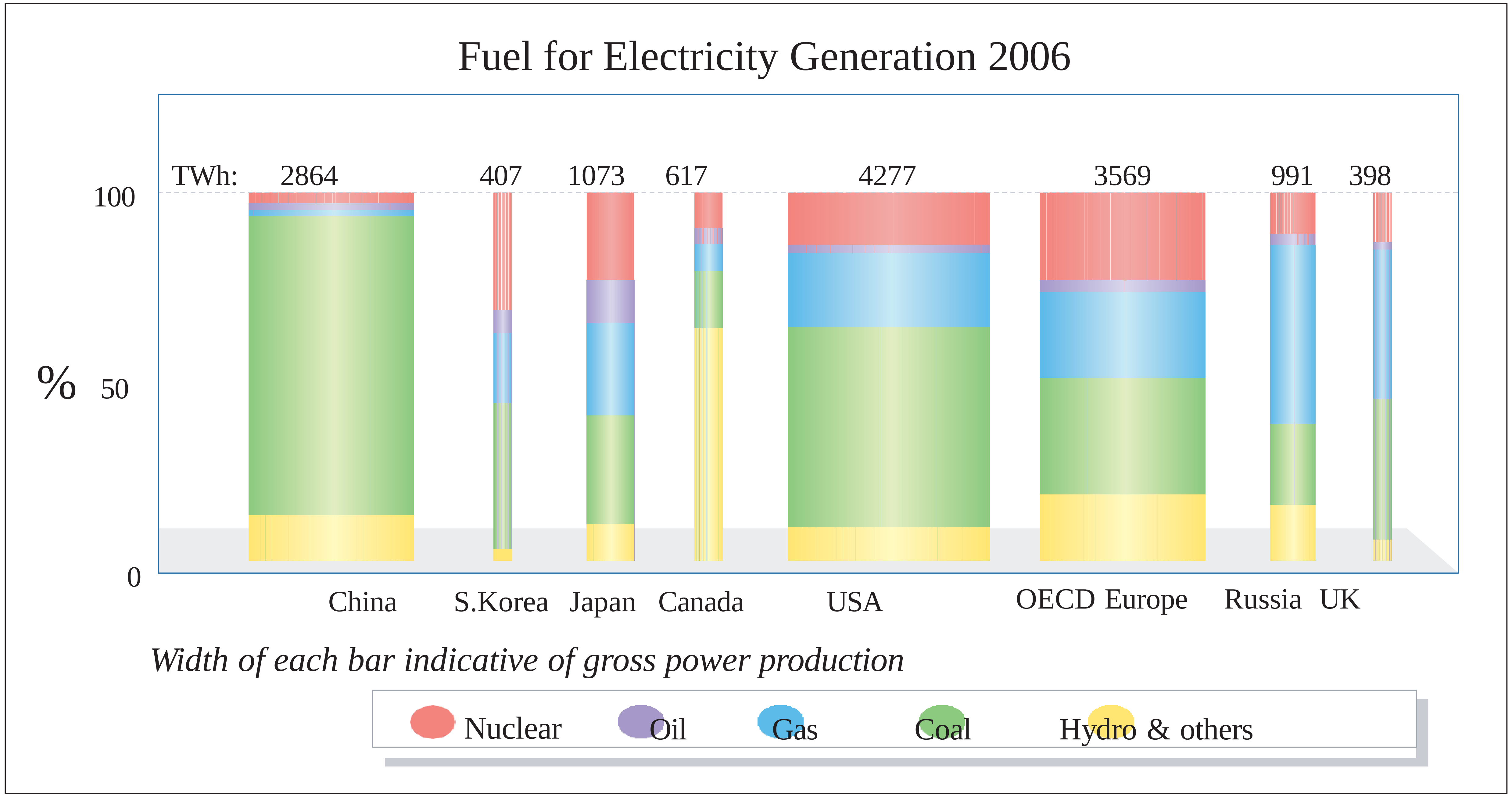


Image by MIT OpenCourseWare. Source: OECD/IEA Electricity Information 2007.

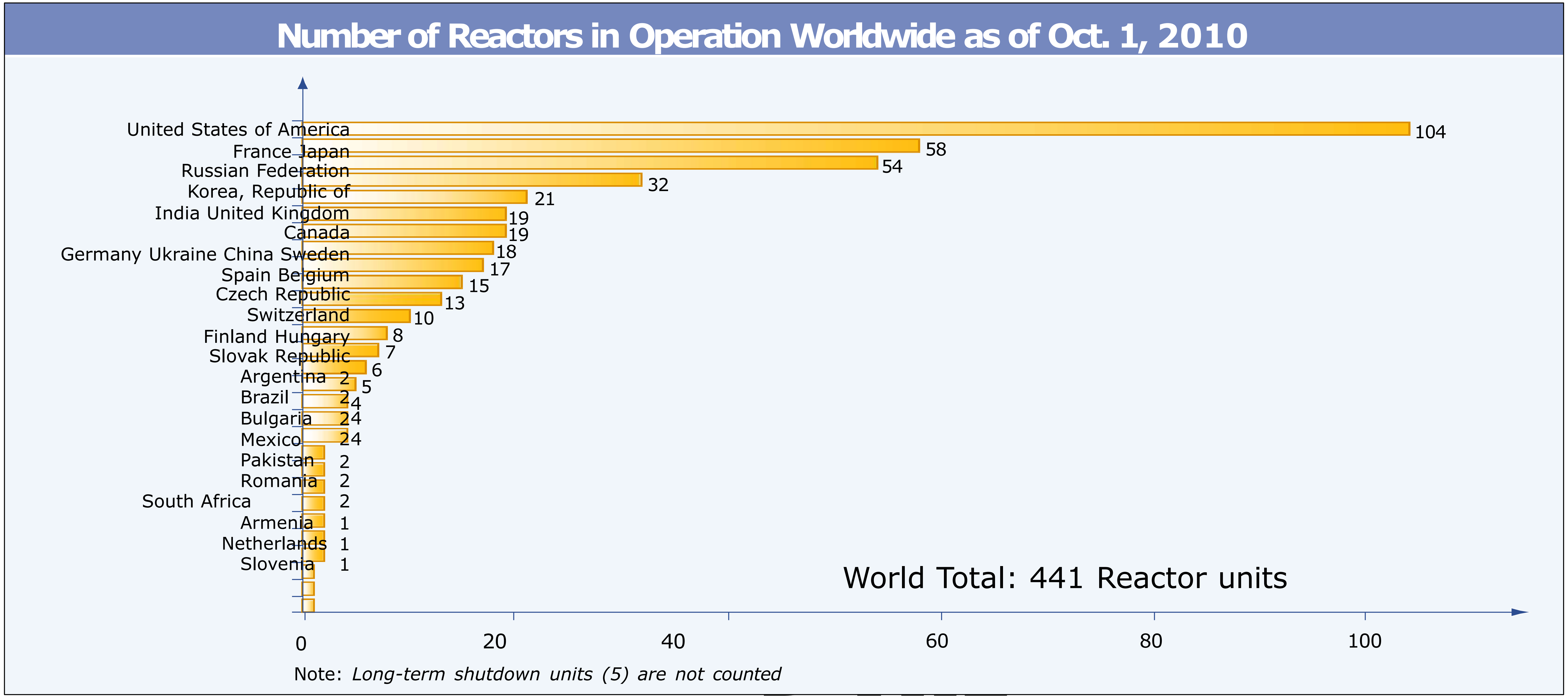


Image by MIT OpenCourseWare. Source: International Atomic Energy Agency.

WORLD

http://www.iaea.org/cgi-bin/db.page.pl/pris.oprconst.htm

NUCLEAR ELECTRICITY PRODUCTION AND SHARE OF TOTAL ELECTRICITY PRODUCTION

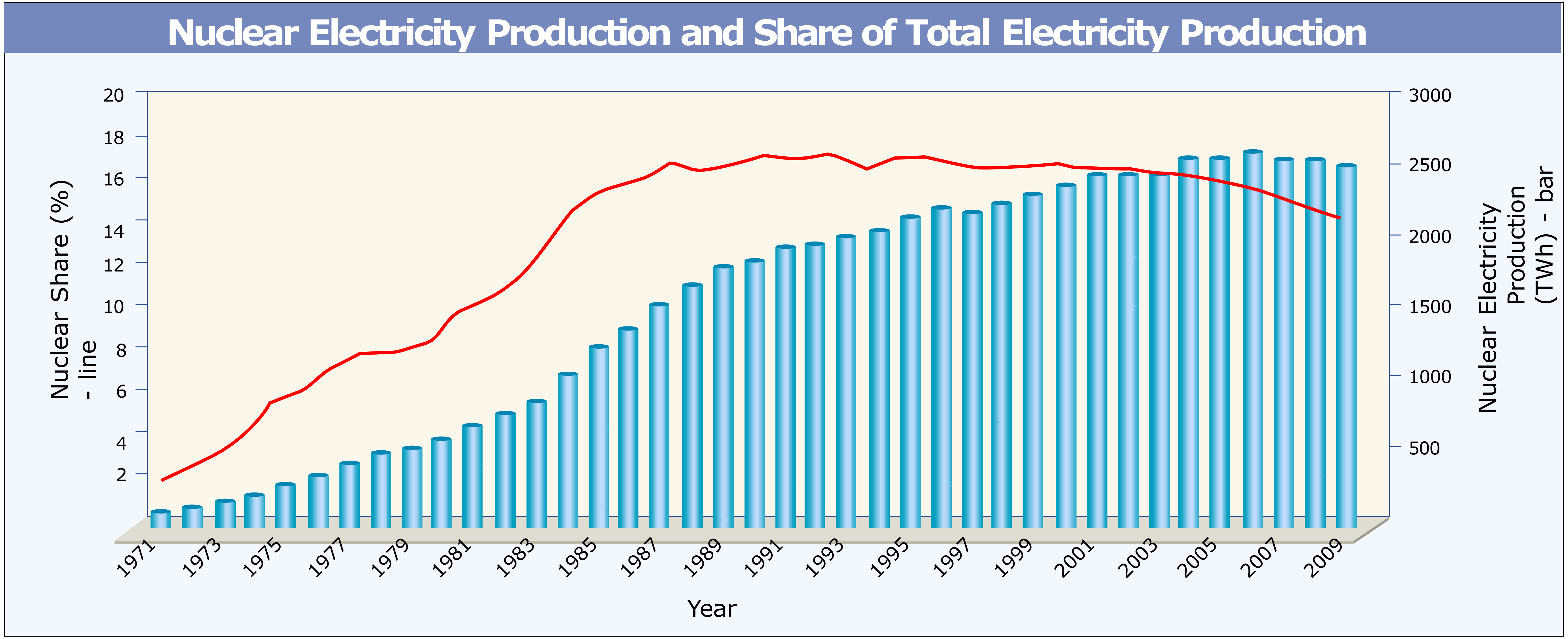
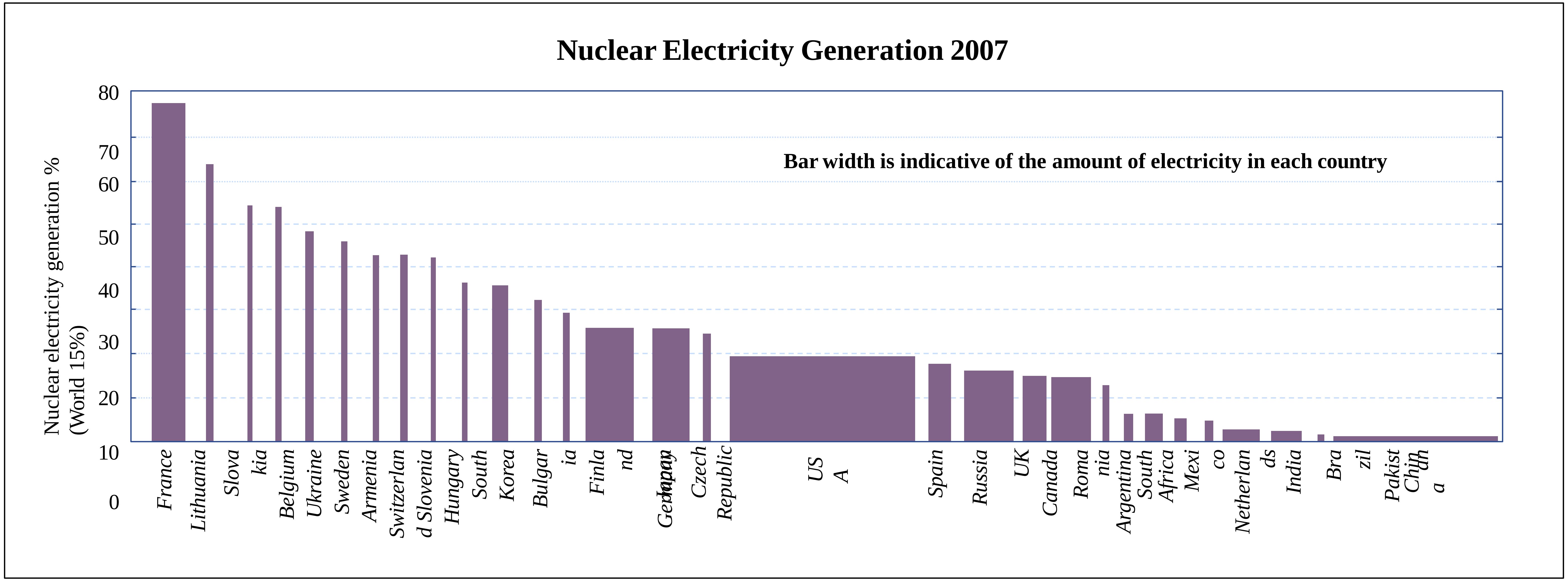


Image by MIT OpenCourseWare. Adapted from the World Nuclear Association.

http://www.world-nuclear.org/info/inf01.html

NUCLEAR ELECTRICITY GENERATION 2007



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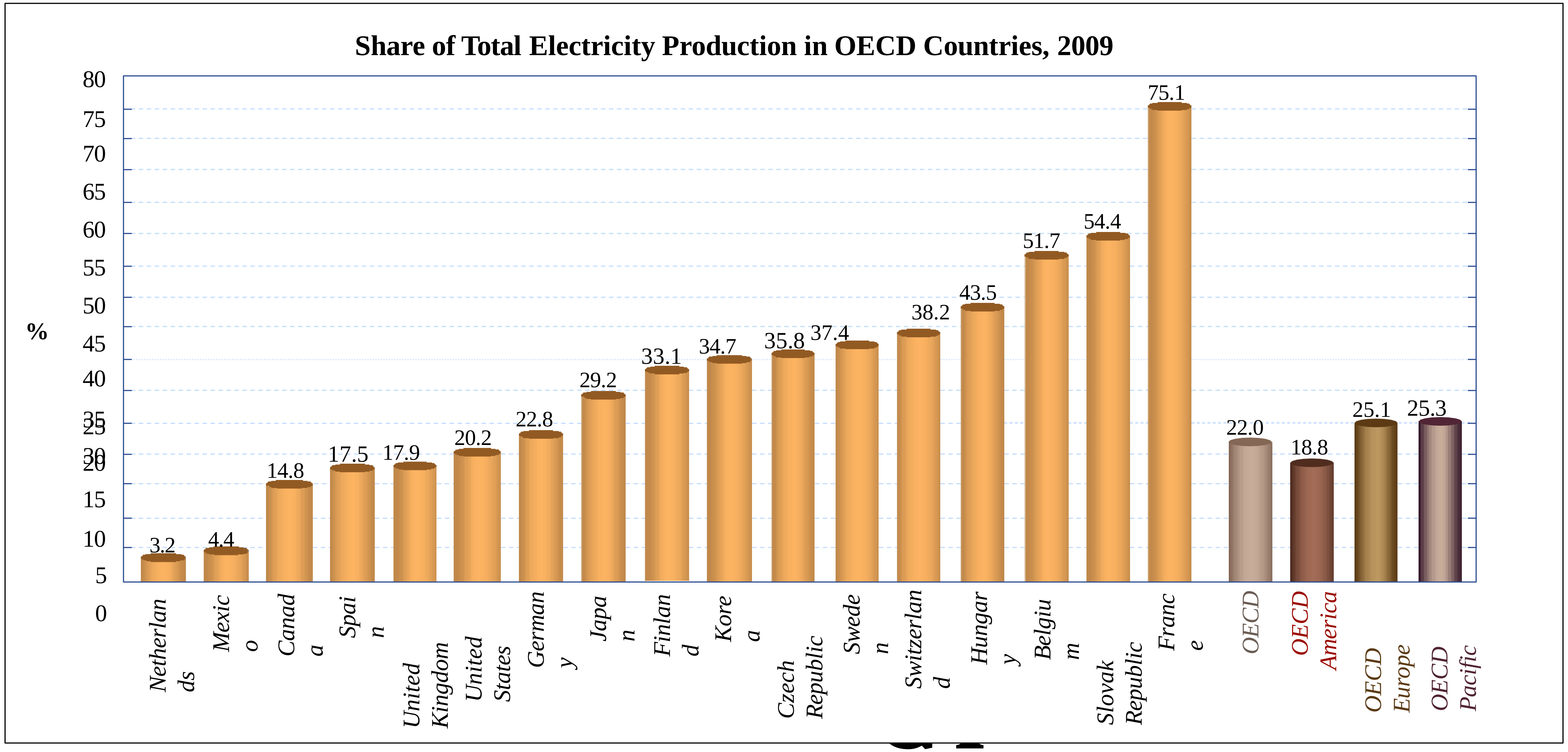


Image by MIT OpenCourseWare. Source: OECD.

Source: http://www.oecd.org, *Nuclear Energy Data*, 2010

EXISTING NUCLEAR POWER PLANTS (Approximately 441 Worldwide)

Country	Fraction of Electricity	Units Under Construction	Operating Units
France	75.2	1	59
Belgium	51.7	0	7
Bulgaria	35.9	0	2
S. Korea	34.8	6	21
Switzerland	39.5	0	5
Japan	28.9	2	55
UK	17.9	0	19
USA	20.2	1	104
Russia	17.8	10	32
S. Africa	4.8	0	2
Netherlands	3.7	0	1
China	1.9	23	13

Sources: world-nuclear.org & euronuclear.org, 10/10

INTERNATIONAL TRENDS

- Deregulation originated in the United Kingdom, went well until natural gas prices fell (≈ 2002); British Energy was near bankruptcy and depended upon government loans

- Deregulation is also being tried in United States, Canada, Chile, Japan, South Korea, Australia, and European Community

- Consolidation among nuclear equipment vendors is occurring: Areva, Siemens, British Nuclear Fuels Ltd/Toshiba, General Electric, Hitachi, Mitsubishi Heavy Industries

- New reactor manufacturers from S. Korea, Russia, perhaps China next, entering international competition

REGIONAL FACTORS

EUROPE

- Electricité de France is a big exporter and owner
- Nuclear power shutdowns have been mandated in Sweden, Germany and Belgium; now being revoked or reconsidered
- Fifth Finnish nuclear unit (EPR) plant is proceeding

AFRICA

- South Africa was developing the pebble bed modular reactor (PBMR), has shut down the project

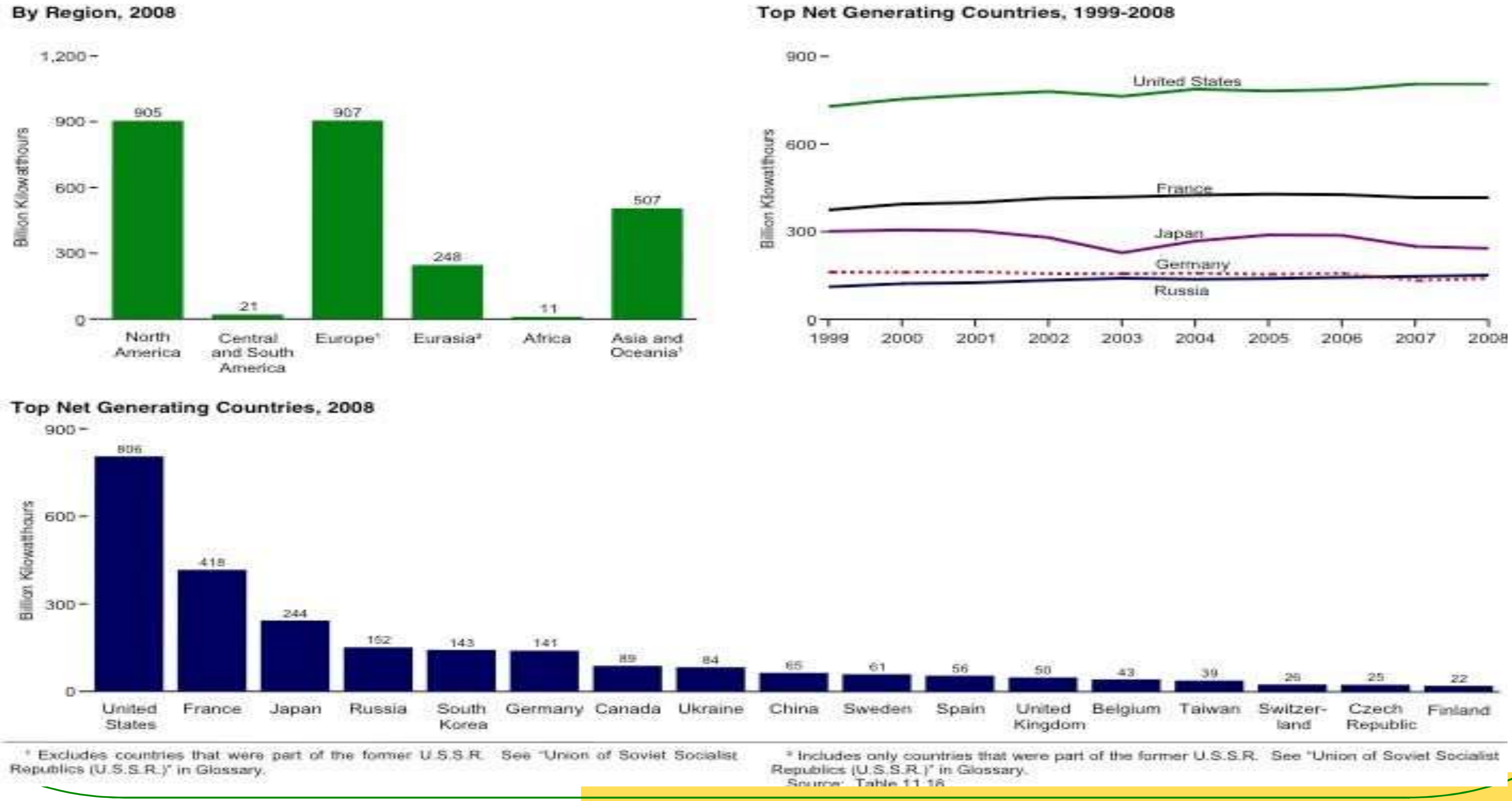
REGIONAL FACTORS, continued

ASIA

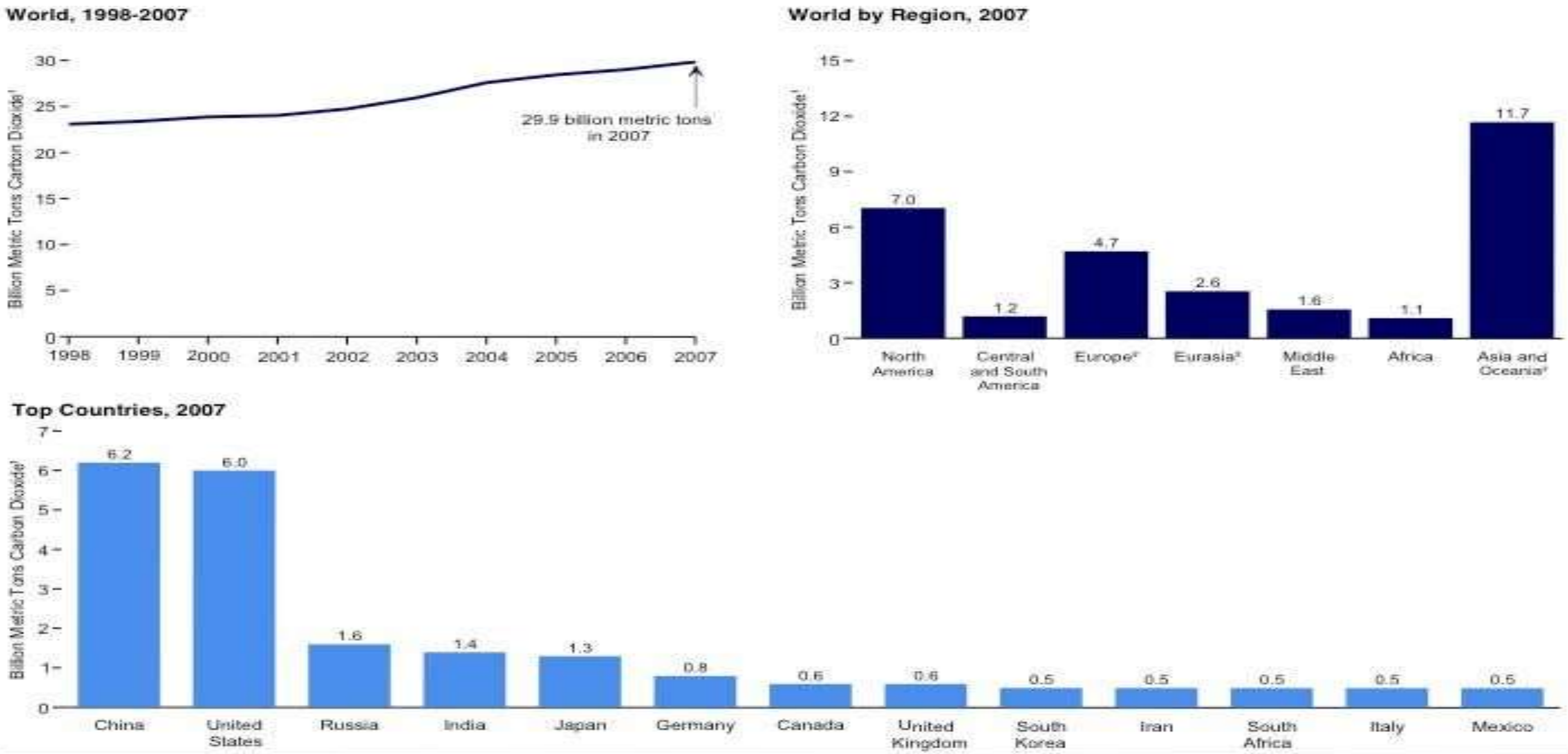
- China has 9 units under construction, 41 more planned
- Japan has 11 units planned and 2 units under construction; is in recovery from 7 units of TEPCO taken off-line following 2007 earthquake and are slowly returned to service
- South Korea has privatized KEPCO, is planning a new series of LWRs, has 6 units under construction and two planned
- Taiwan is completing 2 BWRs; nothing is planned beyond them

EMERGING NUCLEAR ENERGY COUNTRIES

- 45 Countries Considering New Nuclear Power Programs; some can be classified according to how far their plans have progressed
  - Iran: Power reactors under construction
  - UAE, Turkey: Contract signed, legal and regulatory infrastructure well- developed
  - Vietnam, Jordan, Italy: Committed plans, legal and regulatory infrastructure developing
  - Thailand, Indonesia, Egypt, Kazakhstan, Poland, Belarus, Lithuania: Well- developed plans but commitment pending
  - Saudi Arabia, Israel, Nigeria, Malaysia, Bangladesh, Morocco, Kuwait, Chile: Developing plans
  - Namibia, Kenya, Mongolia, Philippines, Singapore, Albania, Serbia, Estonia & Latvia, Libya, Algeria, Azerbaijan, Sri Lanka: Discussion as serious policy option
  - Australia, New Zealand, Portugal, Norway, Ireland: Officially not a policy option at present



Energy Information Administration / Annual Energy Review 2009;
http://www.eia.gov/emeu/aer/inter.html



[1] Metric tons of carbon dioxide can be converted to metric tons of carbon equivalent by multiplying by 12/44.
[2] Excludes countries that were part of the former U.S.S.R. See "Union of Soviet Socialist Republics (U.S.S.R.)" in Glossary.
[3] Includes countries that were part of the former U.S.S.R. See "Union of Soviet Socialist Republics (U.S.S.R.)" in Glossary.
Note: Data include carbon dioxide emissions from fossil-fuel energy consumption and natural gas venting and flaring.
Source: Table 11.19.

ON

Energy Information Administration / Annual Energy Review 2009;
http://www.eia.gov/emeu/aer/inter.html

PLAUSIBLE TRENDS IN REACTOR TECHNOLOGY EVOLUTION

CURRENT/SHORT TERM

Light Water Reactors (LWRs)

- Pressurized Water Reactor (PWR)
- Boiling Water Reactor (BWR) Heavy Water Reactor (PHWR)
- Pressurized Heavy Water Reactor (CANDU)

INTERMEDIATE TERM (>20 years)

Brayton Cycle Gas (He or CO_2) Cooled Reactor (GCR-GT)

LONG TERM (>50 years)

Fast Breeder ($^{238}U \Rightarrow {}^{239}Pu$-based) Thermal Breeder ($^{232}Th \Rightarrow {}^{233}U$-based)

MHTGR SIDE-BY-SIDE ARRANGEMENT WITH PRISMATIC FUEL

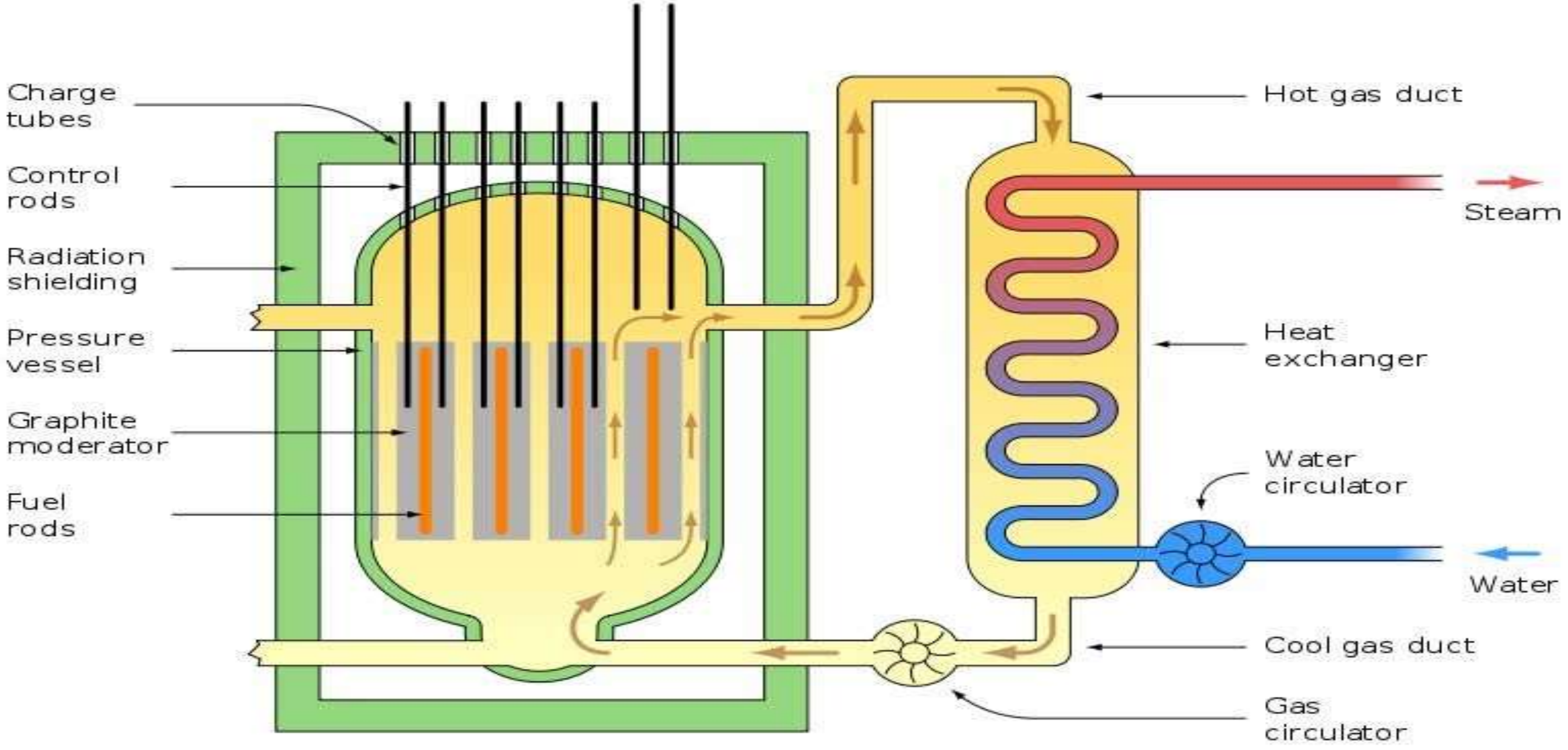


Image by Emoscopes on Wikimedia Commons.

FACTORS LIKELY TO AFFECT FUTURE USE OF NUCLEAR POWER

Operational Safety Record

Utility, Critical Elite, Public, Investor Attitudes End of Cold War

Degree of Nuclear Weapons Proliferation Nuclear Waste Disposal

Success

Global Warming and Air Pollution Worries

Ability of Nuclear Power to Produce More than Electricity