



Nuclear Power: (Scary?) Carbon-Free Electricity

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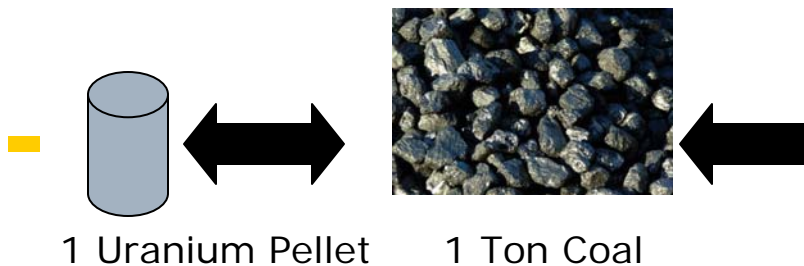
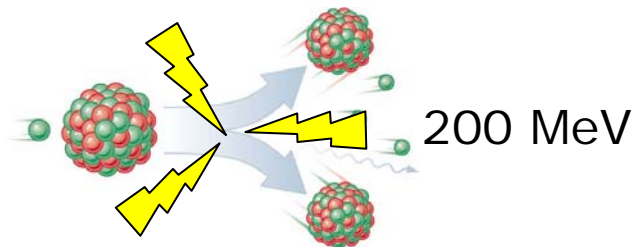
Basic Messages: Why nuclear?



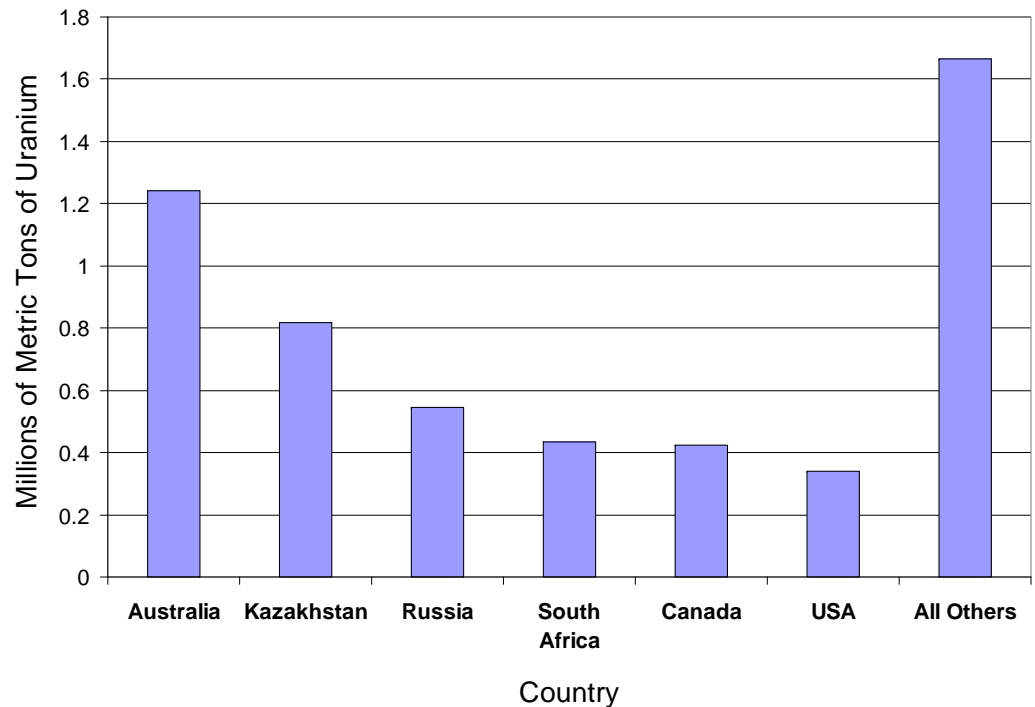
Image: Ohio Citizen



Image:



Known Uranium Resources at < \$130/kg



Basic Messages: Why not nuclear?



Proliferation

Safety



Image: U.S. Nuclear Regulatory Commission



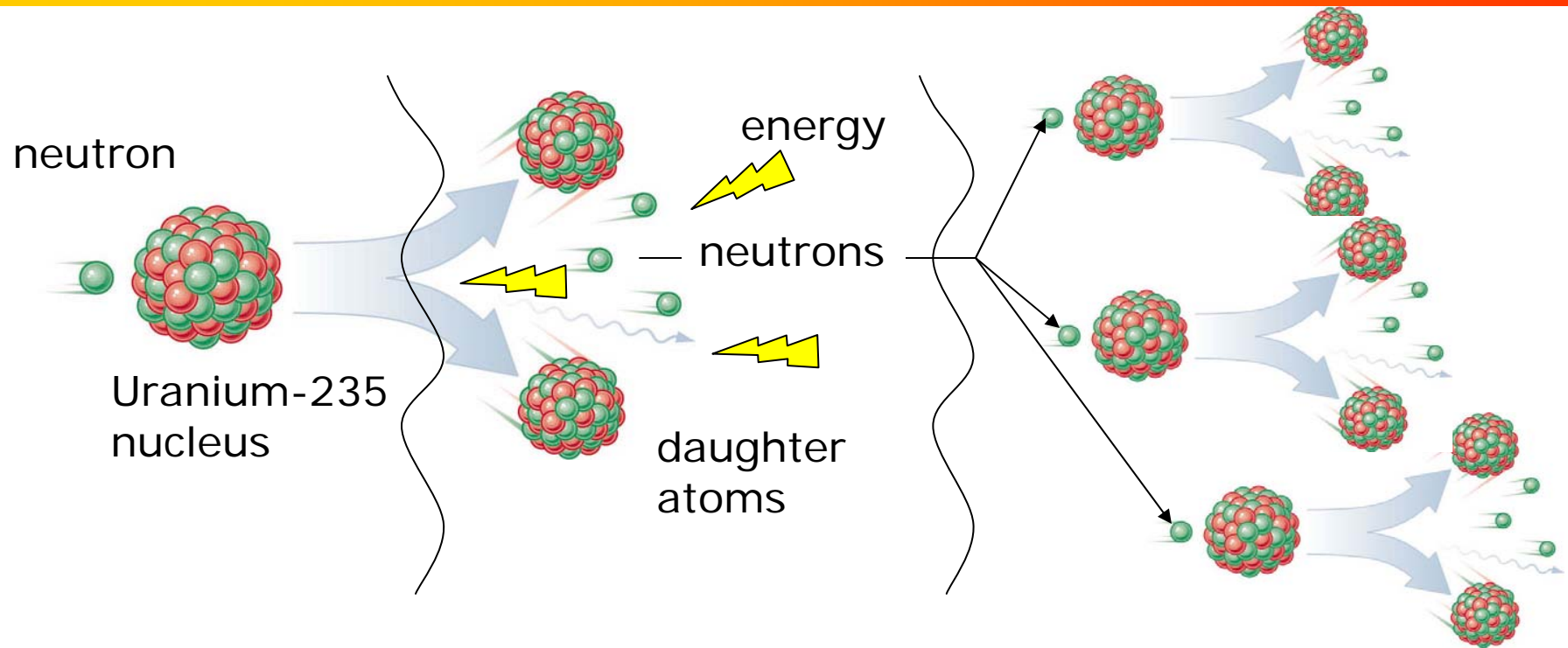
Image: World Nuclear Association

Waste

Overview

1. How Nuclear Power Works (Technology)
2. Nuclear History: how we got here and what the industry is today
3. Advanced Nuclear Power Tech
4. Challenges
5. Opportunities

HOW IT WORKS: fission



HOW IT WORKS: reactor core

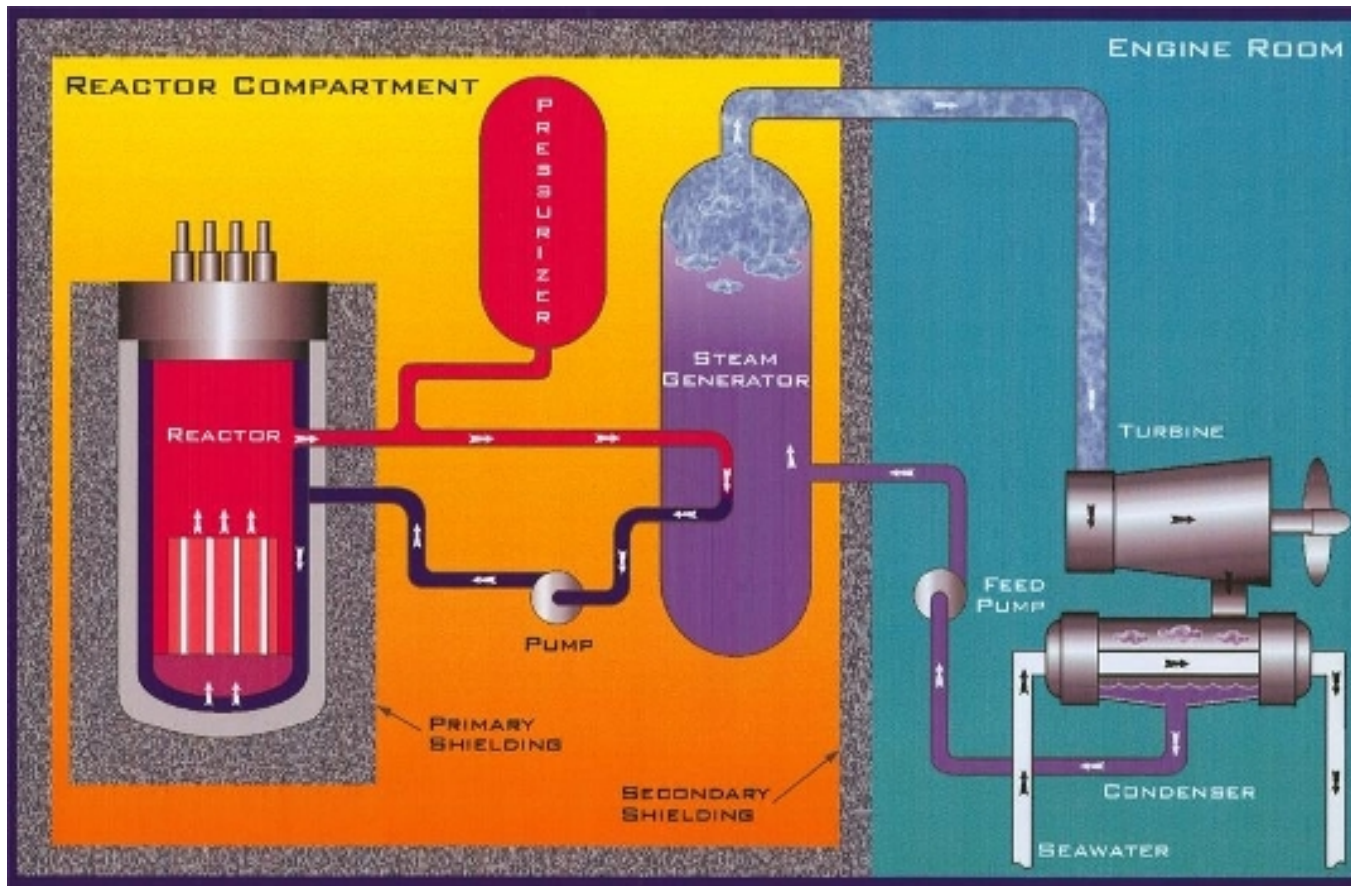


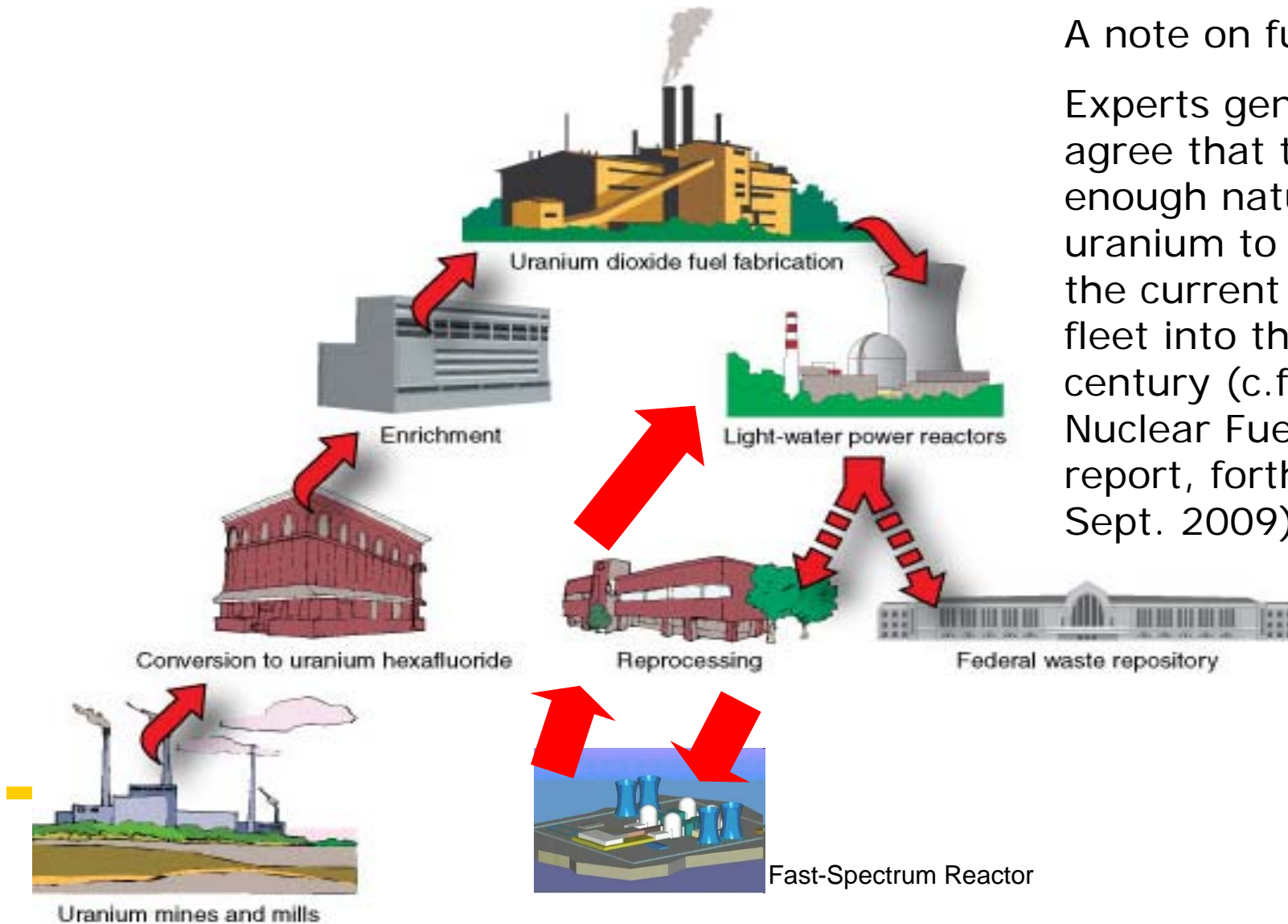
Image: National Nuclear Security Administration

2 reactor types in the U.S., both Light-Water Reactors (LWRs):

Boiling Water Reactor (BWR) – made by GE

Pressurized Water Reactor (PWR) – made by Westinghouse

HOW IT WORKS: the nuclear fuel cycle

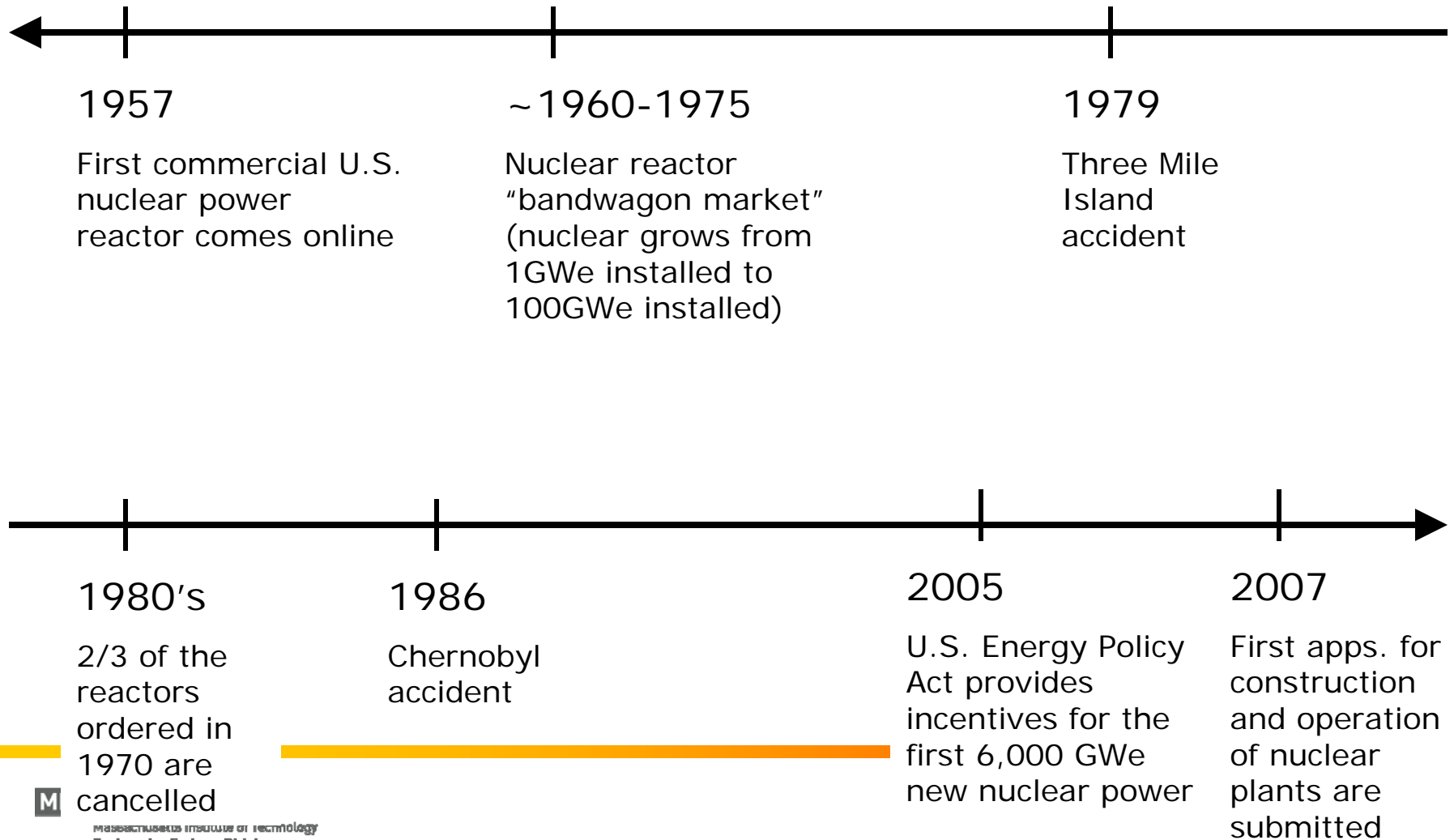


A note on fuel:

Experts generally agree that there is enough natural uranium to sustain the current worldwide fleet into the next century (c.f. MIT Nuclear Fuel Cycle report, forthcoming Sept. 2009)

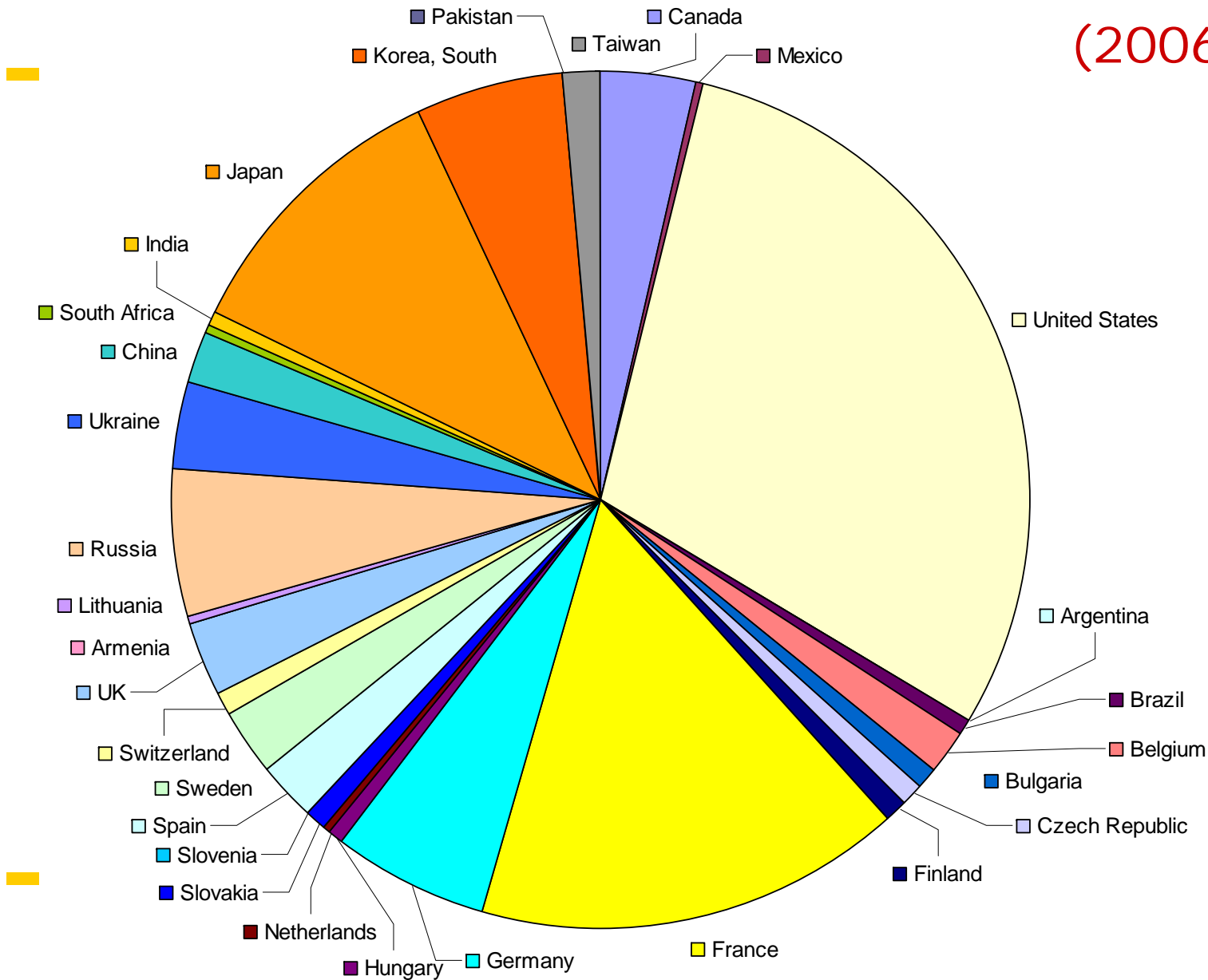
How Nuclear Power Grew, and Where We Are Today

U.S. Nuclear Timeline



Nuclear Power Generation by Country

(2006)

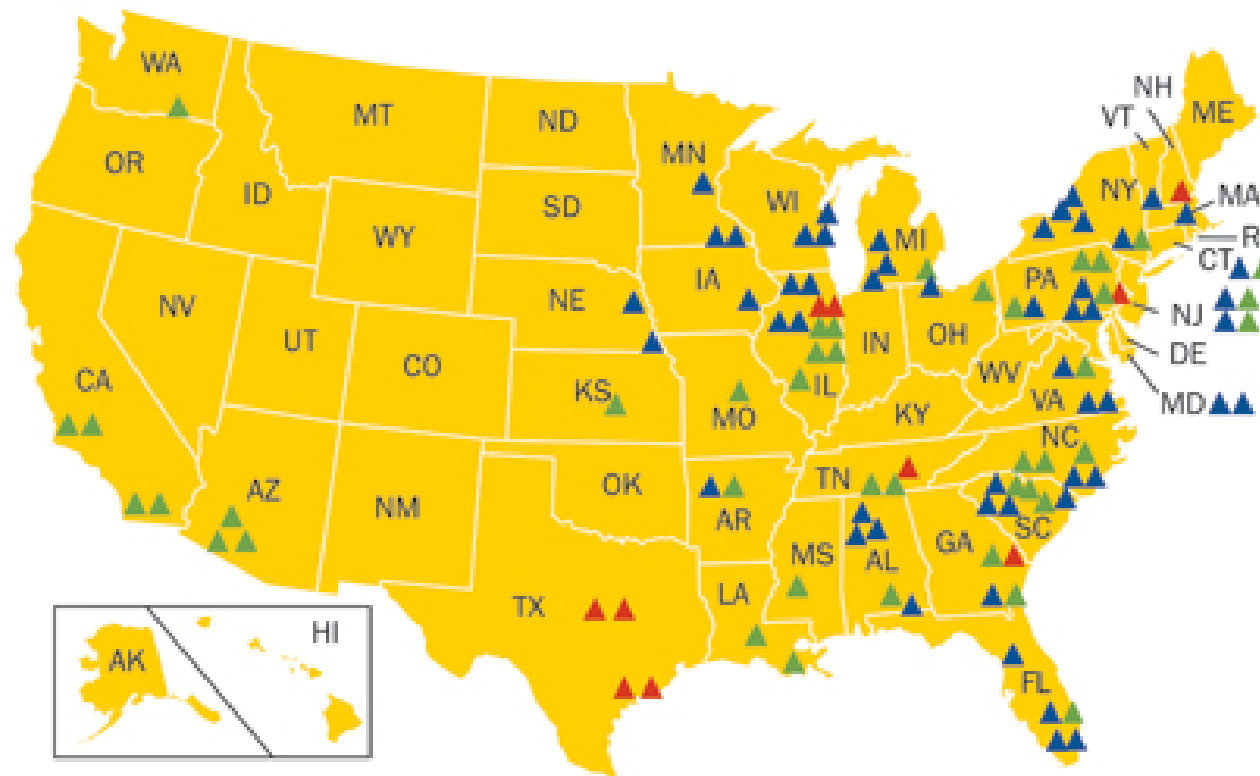


U.S. Nuclear Power Generation, 2009

- 104 operating nuclear reactors
- Nuclear power provided 19.6% of the KWh generated in the U.S. in 2008
- Capacity factors for nuclear plants hover above 90% (nuclear plants operate for 18 months, then shut down for refueling for 3-4 weeks); baseload coal 70-90%, PV ~15%, wind 20-40%

U.S. nuclear power reactors

U.S. Commercial Nuclear Power Reactors—Years of Operation



Years of Commercial Operation	Number of Reactors
△ 0-9	0
▲ 10-19	10
▲ 20-29	42
▲ 30-39	52

The Nuclear Industry Now

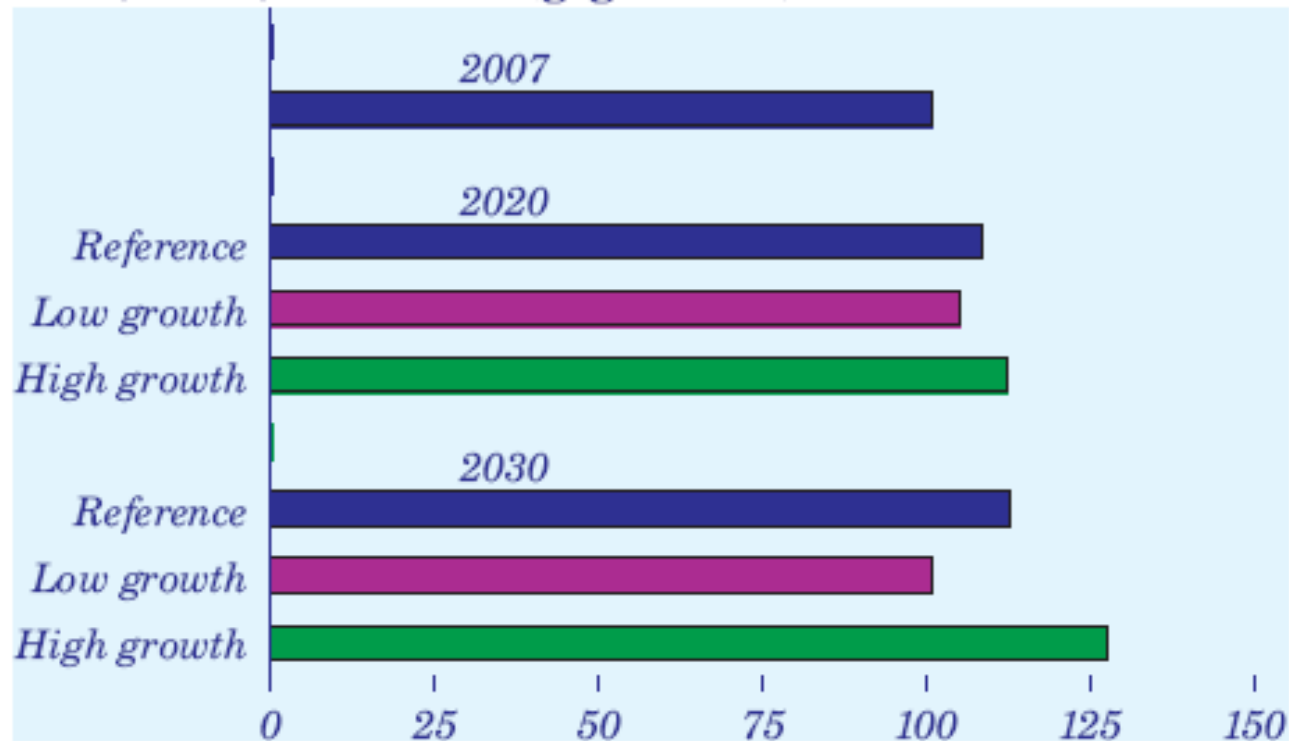
- ❑ 3 major reactor vendors: AREVA, Westinghouse (+ Toshiba), GE (+ Hitachi)
- ❑ The major vendors plus a few others (Mitsubishi, Babcock & Wilcox, etc.) are major suppliers of “nuclear services”
- ❑ Utilities buy and operate nuclear plants (Exelon is the largest U.S. nuclear utility)

What's next in the U.S.?

- The first “new” reactors could begin construction as early as 2012, and begin operation as early as 2016
- Unclear yet how effective the EPA Act 2005 incentives will be; will we build 6,000 GWe more nuclear power and stop, or will utilities keep building?

EIA Prediction of Nuclear Power Growth

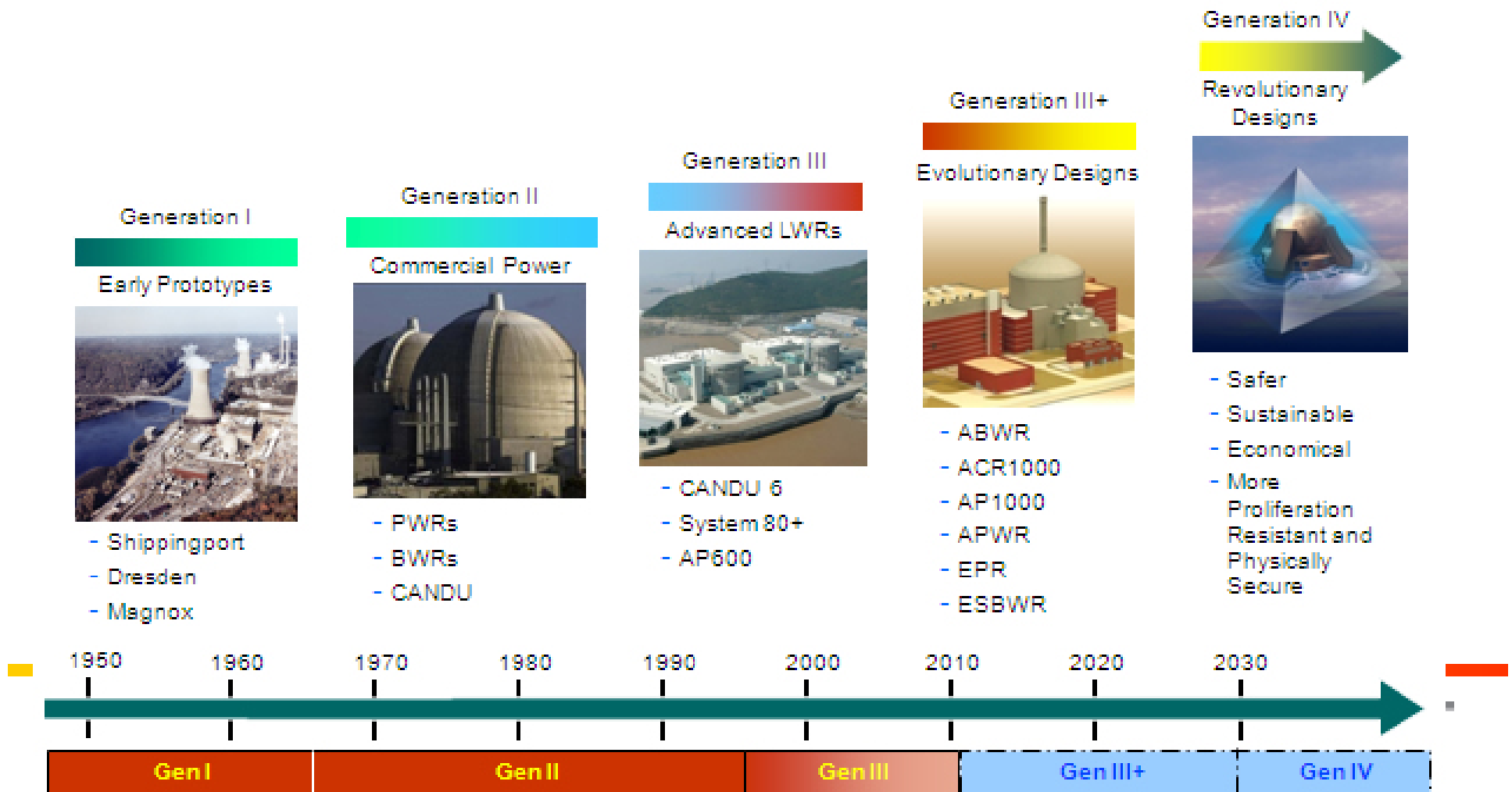
Figure 59. Electricity generating capacity at U.S. nuclear power plants in three cases, 2007, 2020, and 2030 (gigawatts)



New Reactor Technologies

Advanced Technologies

Evolution of Nuclear Power

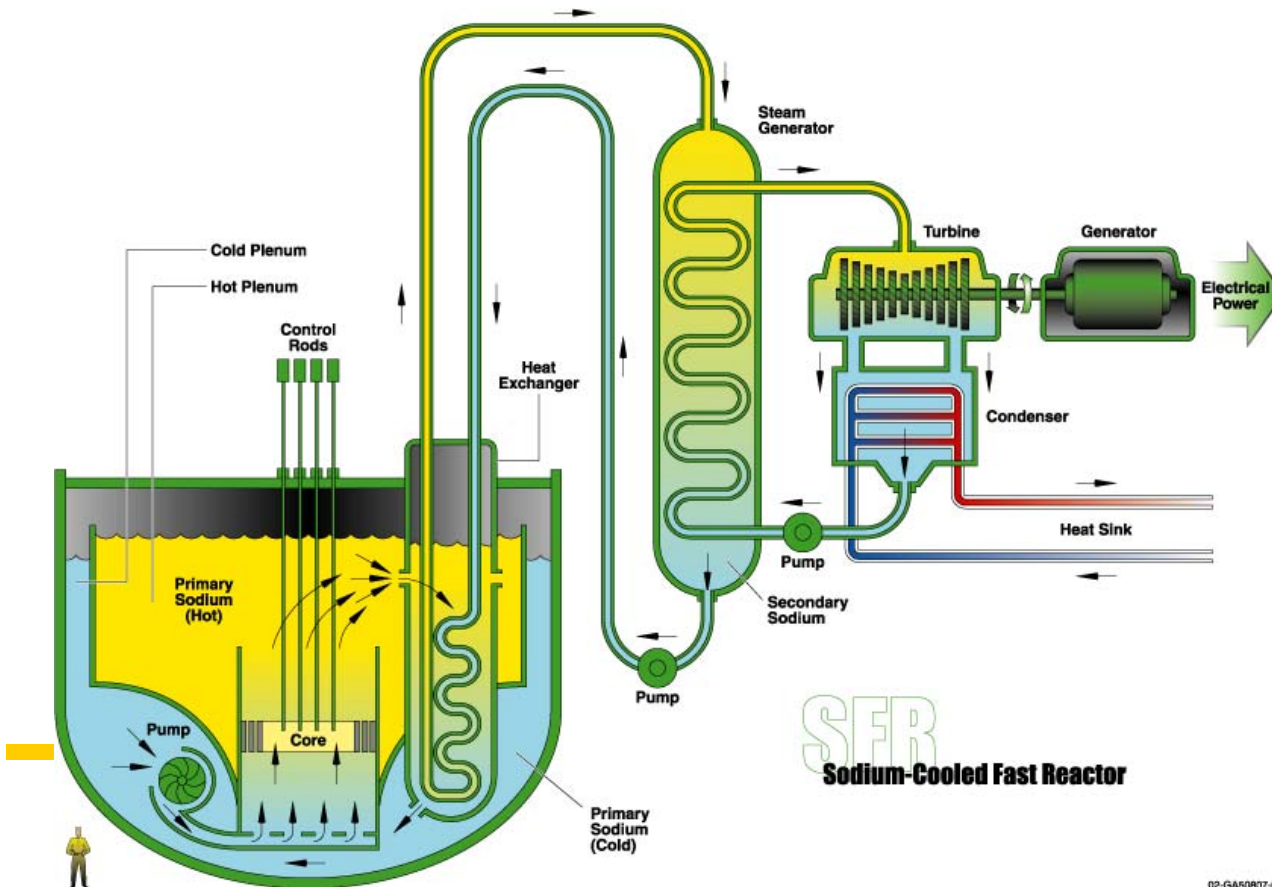


New Nuclear Plant Advances (mostly about safety) in Gen III+

- ❑ (More) redundant coolant systems
- ❑ “Core catchers”
- ❑ Digital Instrumentation and Controls
- ❑ “Passive Safety”

Advanced Technologies: Gen IV Reactors

- Research coordinated through the “Generation IV International Forum” on six technologies



SFR (left): lots of experience, advantages in waste management

GFR: gas-cooled, even better passive safety

VHTR: high-temp steam that could be used for industrial processes

LFR, MSR, SCWR

Advanced Technologies: “Grid-Appropriate” Modular Reactors

- ❑ 50-600 MWe reactors
- ❑ Intended to be completely standardized, with “assembly-line” manufacturing
- ❑ Cheaper (?)
- ❑ Can be put together in parks, or used for smaller communities or less-developed grids
- ❑ Includes so-called “battery reactors” that would last 1.5-3+ years without refueling, and could be sent (sealed) to sensitive countries

... but ...

- ❑ Nuclear Reactors typically exhibit strong economies of scale
- ❑ The U.S. Nuclear Regulatory Commission is focused heavily on more “traditional” reactor designs
- ❑ Do small communities necessarily want small nuclear plants?
- At least one company has abandoned smallness
- ❑ Many of these designs are very innovative... which means they are very HIGH RISK for licensing

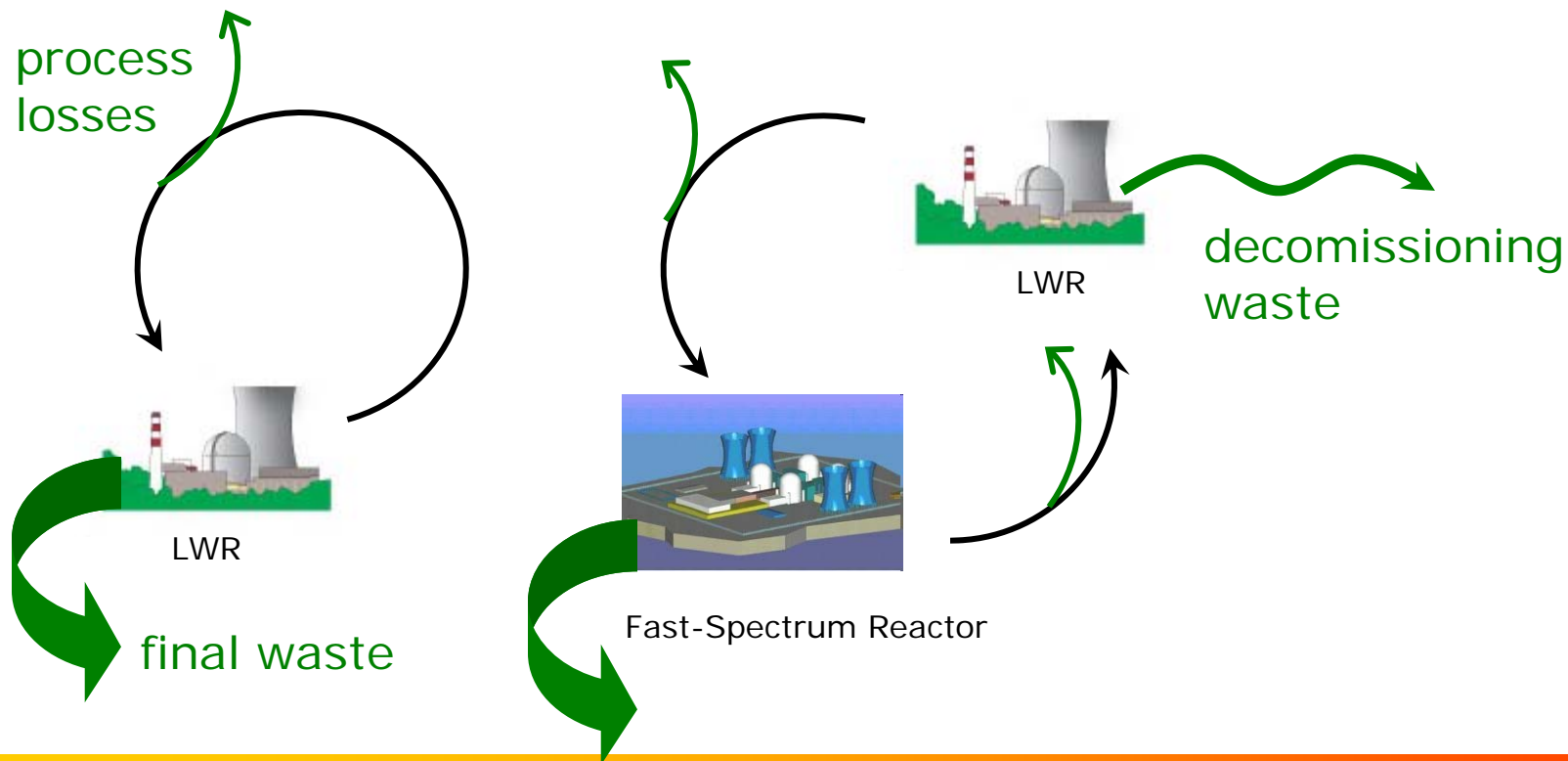
Challenges

ECONOMICS: it's about the reactor

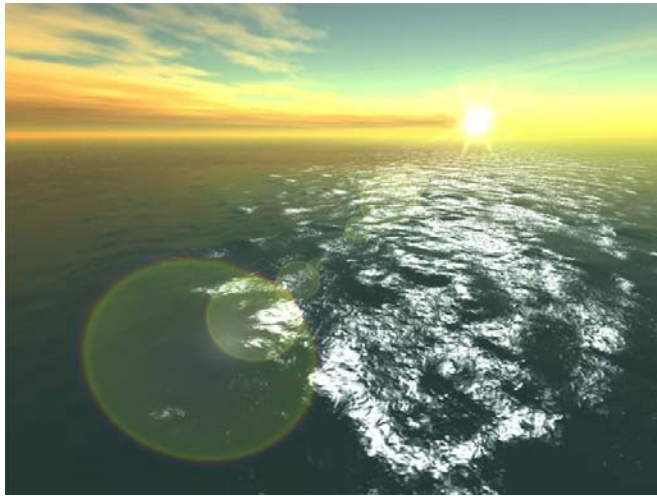
- ❑ Economics of nuclear electricity are tied to capital costs of the reactor (fuel costs are negligible)
- ❑ This means that “old” reactors are now cash cows for utilities
- ❑ Financing a new nuclear plant is difficult – especially in this economic climate
- ❑ Increasing commodity prices have also been problematic
- ❑ The true problem for reactors in the late 70's and 80's was the huge increase in costs; it remains to be seen whether new nuclear plants can meet cost targets

NUCLEAR WASTE MANAGEMENT

No matter what you do, you will always need a nuclear waste repository



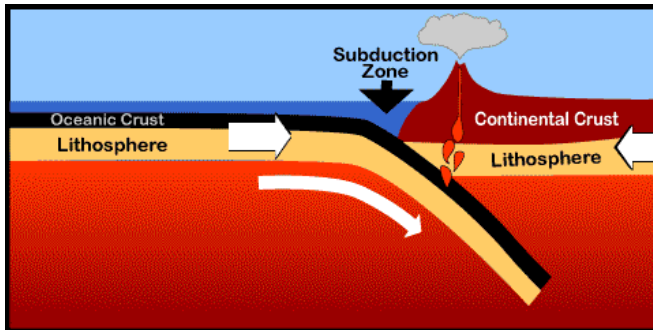
WASTE MANAGEMENT "OPTIONS"



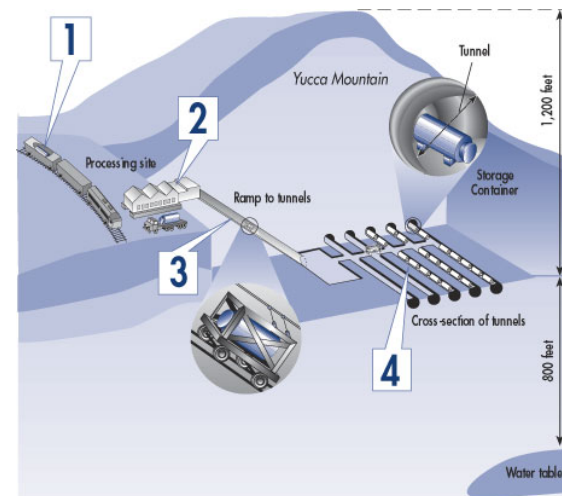
Sprinkle it in the ocean



Shoot it into space



Bury it deep in a subduction zone



**BURY IT IN
TUNNELS
UNDER-
GROUND!**

WASTE MANAGEMENT: why is yucca mountain so controversial?

- ❑ A political decision
- ❑ 1982 politics vs. 2010 politics
- ❑ Better places exist...
- ❑ Not enough attention to the social dimension (fighting not-in-my-backyard)
- ❑ RESULT: Obama administration has withdrawn the repository application and convened a committee to figure out what to do next

PROLIFERATION:

- ❑ Bombs are relatively easy to make, but bomb **material** is hard to come by
- ❑ 2 basic routes to a weapon from a civilian power reactor program: through fuel enrichment (cf. Iran) or through fuel reprocessing
- ❑ General strategies for preventing proliferation involve **safeguards** (keep a country from using its commercial program as a cover for a weapons program), or **physical protection** (keep terrorists, others from stealing material)

SAFETY: less of a problem now than it used to be

- ❑ World instances of radiation exposure have been dropping since 1998, fuel performance etc. has increased
- ❑ Almost zero radioactive release to the U.S. public in over 40 years of reactor operations
- ❑ Organizations like the Institute of Nuclear Power Operations (U.S.) and the World Association of Nuclear Operators (worldwide) do industry self-policing on safety matters
- ❑ 1995: Probabilistic Risk Assessment (PRA) incorporated into the Nuclear Regulatory Commission's safety analyses

Comparative Energy Fatalities

Fuel	Immediate fatalities 1970-92	Who?	Normalized to deaths per TWy* electricity
Coal	6400	workers	342
Natural gas	1200	workers & public	85
Hydro	4000	public	883
Nuclear	31	workers	8

* Basis: per million MWe operating for one year, not including plant construction, based on historic data which is unlikely to represent current safety levels in any of the industries concerned.

Source: Ball, Roberts & Simpson, Research Report #20, Centre for Environmental & Risk Management, University of East Anglia, 1994; Hirschberg et al, Paul Scherrer Institut, 1996; in: IAEA, *Sustainable Development and Nuclear Power*, 1997; *Severe Accidents in the Energy Sector*, Paul Scherrer Institut, 2001.

Opportunities

Is it time for the Nuclear Renaissance?

- ❑ Climate change is a problem
- ❑ Nuclear power provides carbon-free, baseload electricity, and **we know how to do it**
- ❑ Nuclear plants need some water for cooling, but are otherwise totally unrestricted by geography

Current Events

My list of 5 things in the news

1. Yucca Mountain is “dead”
2. Iran and the “nuclear nightmare”
3. Vermont Yankee license extension is rejected by the Vermont State Senate
4. Modular reactor fever
5. The U.A.E. just signed a contract with South Korea’s nuclear vendor for four nuclear power plants

Yucca Mountain... Dead?

- ❑ 1956: National Academy of Sciences recommends deep geologic disposal
- ❑ 1960: Atomic Energy Commission goofs on Lyons, Kansas site for repository
- ❑ 1982: Nuclear Waste Policy Act provides a screening process for sites
- ❑ 1983: 9 sites proposed
- ❑ 1987: Yucca Mountain downselected in amendment to NWPA
- ❑ 1998: DOE misses deadline to begin accepting spent fuel
- ❑ June 2008: DOE submits a license application to the Nuclear Regulatory Commission
- ❑ 2010: Obama organizes a blue ribbon commission on the future of U.S. nuclear power (Prof. Moniz is on the commission)

Rejection of License Renewal for Vermont Yankee

- ❑ The Nuclear Regulatory Commission was prepared to extend the license for 20 years beyond 2012, when the plant is scheduled to close
- ❑ The Vermont Senate voted to veto the license extension, forcing the plant to close in 2012 anyway
- ❑ Reasons cited include the collapse of a cooling tower in 2007, and leaks of tritium from underground pipes (detected recently, despite earlier testimony by the reactor operator that there WERE no pipes underground carrying radioactive substances)