Global Energy Needs: Defining a Role for a "Right Sized Reactor"

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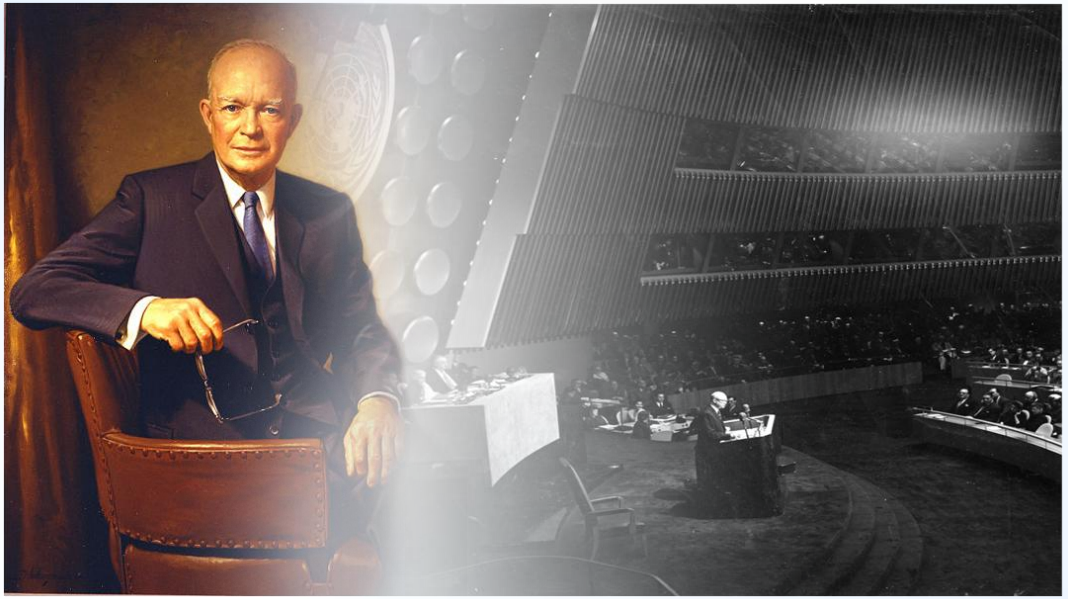
In 1953, President Eisenhower started the Atoms for Peace Program to promote U.S. national security interests:

- Increasing global competition over energy resources to fuel rebuilding Europe and Japan after WWII.
- The need to shift materials and technology into peaceful purposes.
- An opportunity for expanding strategic infrastructure and support nuclear navy expansion



- *The need to manage the likely spread of nuclear know-how and technology through the pre-eminence of the U.S. nuclear industry (and, DOD became the "Market Initiator").*

"Here we are today…"

Source: R.G. Hewlett and J.M. Holl, Atoms for Peace and War, 1953-1961: Eisenhower and the Atomic Energy Commission, University of California Press, Berkeley, CA, 1989.

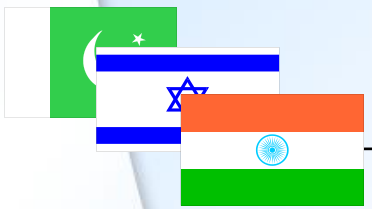
The Global Nuclear Picture is Complex and Changing Almost Daily

Source: Conference Chairman: Senator Sam Nunn, Global Nuclear Materials Management, A CSIS Conference Report, Energy and National Security Program, December 4, 1998.

Civilian nuclear energy as an arms reduction vehicle

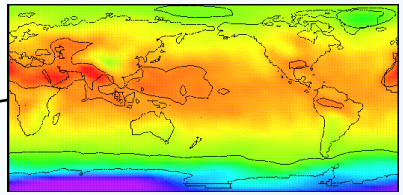
Reapplication of defense nuclear assets

Emerging nuclear suppliers and users



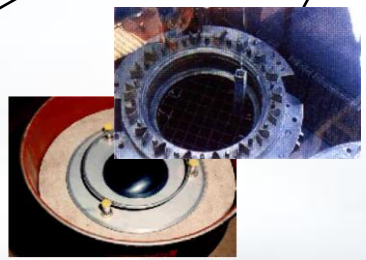
All but 3 countries have signed the nonproliferation treaty

Realities & Opportunities



World-wide pressures changing the energy cost/risk picture

Iran, North Korea, and Terrorism

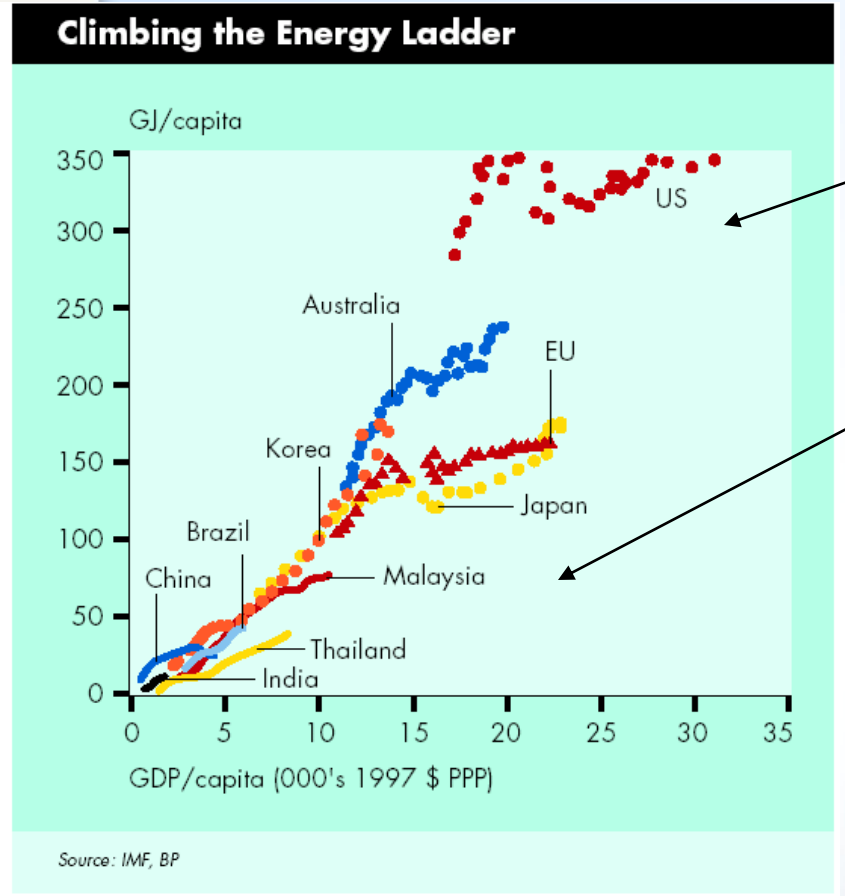


Excess material: liabilities or assets?

End of the Cold War and growth of the EU

Clandestine nuclear trade

Addressing our Energy Future is on the Critical Path to Global Peace & Prosperity



- *Energy availability is directly tied to national economic health and protecting energy supplies and deliveries drives the national security strategy of many countries.*

  - The U.S. must change its energy posture to sustain and grow our own prosperity

  - Other nations must climb the energy ladder to achieve prosperity and reduce the stresses that lead to despair

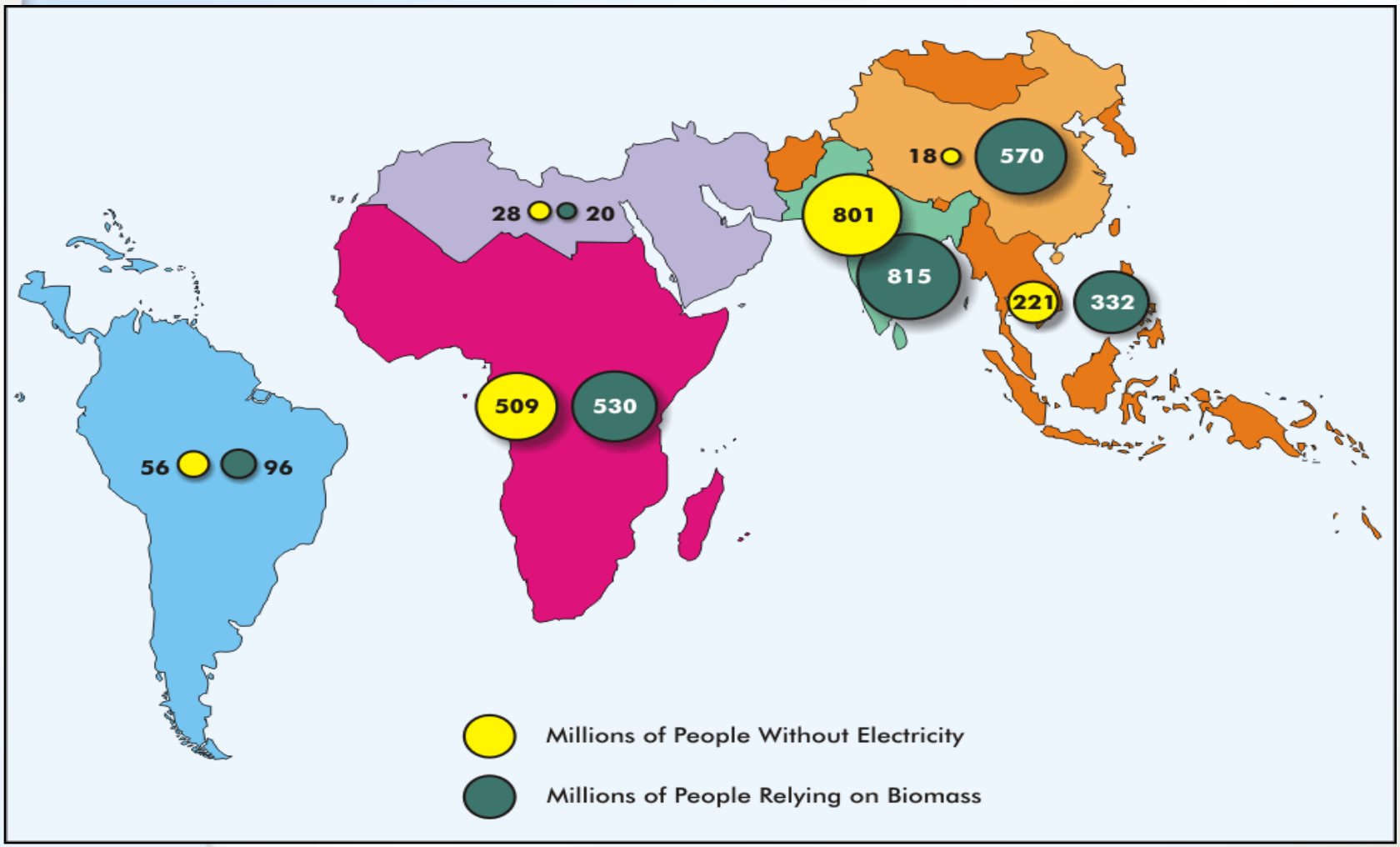
  - An order of magnitude increase in today's energy consumption would be needed to achieve a global minimum standard of living near that of Malaysia's by 2050

  - *Doing so could be key to achieving global peace and prosperity*

- *<u>However</u> there is a huge potential for conflict over access to conventional, finite energy resources and free energy markets are disappearing as more governments control the supply side.*

Source: Sam Nunn et al. The Geopolitics of Energy into the 21st Century, Volume 1: An Overview and Policy Considerations, A Report of the CSIS Strategic Energy Initiative, November 2000.

It has been Estimated that Within a Decade Nearly 80% of the World's Middle-income Consumers would live in Nations Outside the Currently Industrialized World

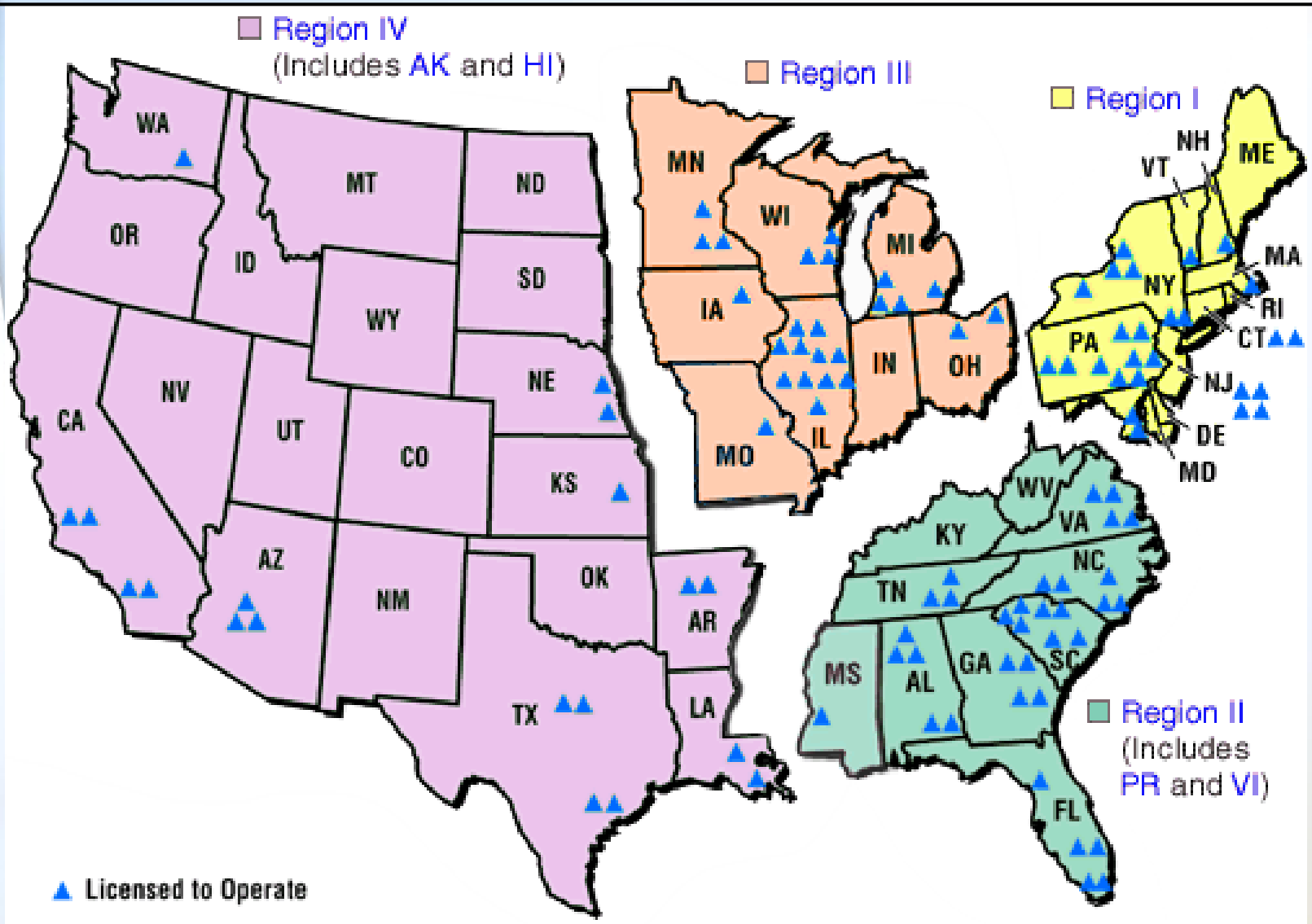


Source: Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future, Committee on Prospering in the Global Economy of the 21st Century, March 8, 2007.

The Good News: The US Nuclear Complex is Quietly Growing Stronger

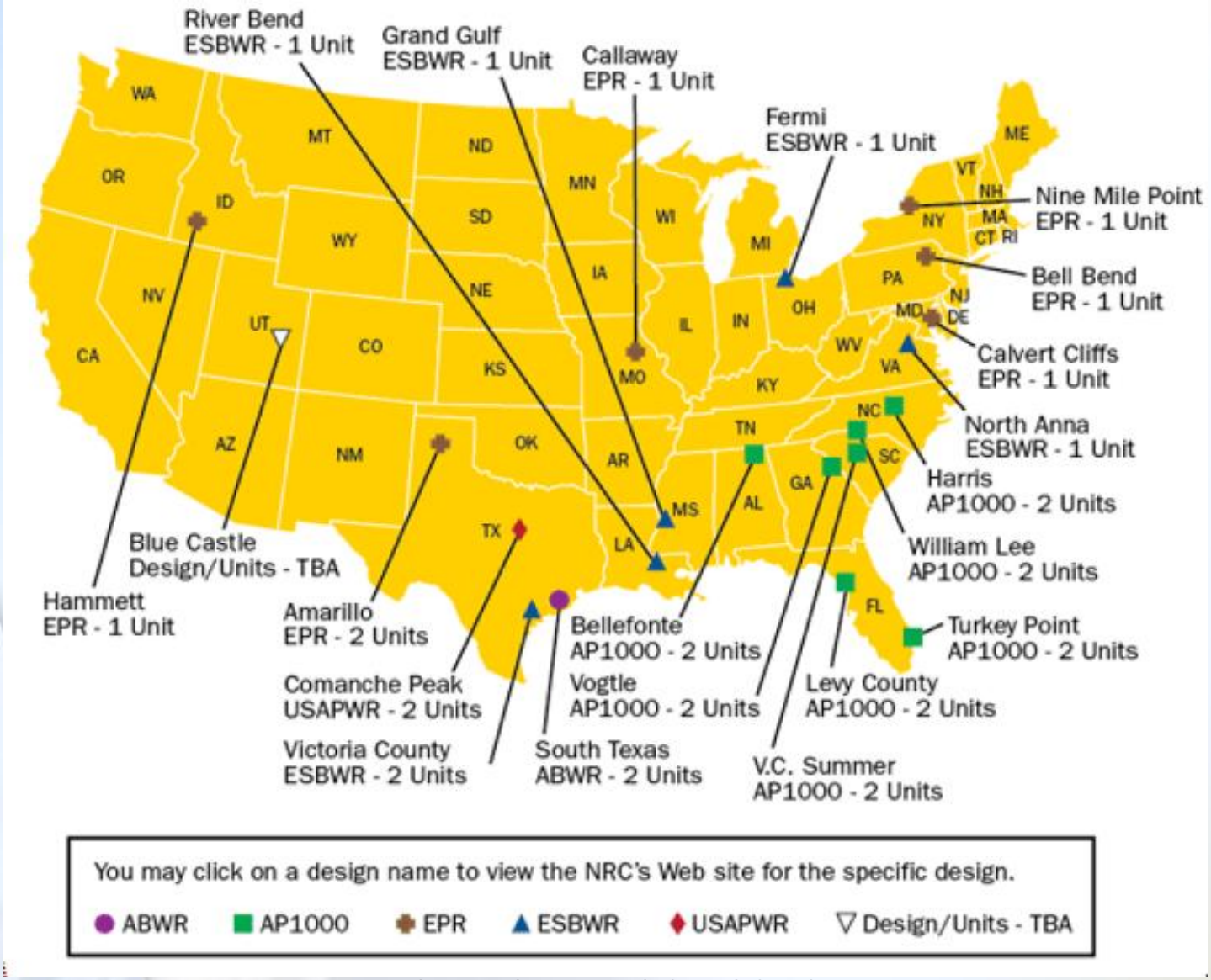
- The existing reactor fleet is operating at low cost, high capacity factor, and with a great safety record
- US utilities are seriously considering building new nuclear plants
- Nuclear Engineering programs across the country are growing in numbers and budget
- The Department of Energy has launched several successful nuclear programs in the past decade

Nuclear Power Plants are Providing 20% of US Electricity Today



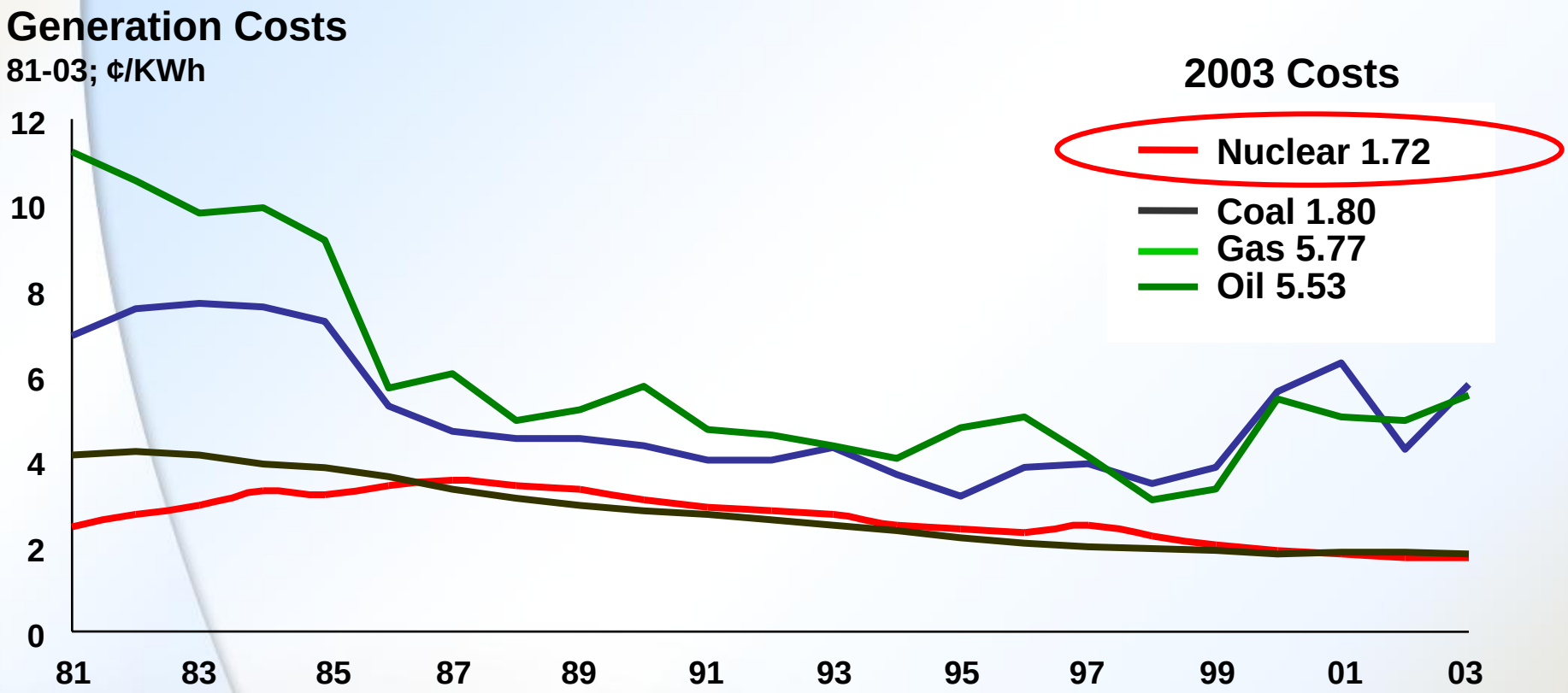
http://www.nrc.gov/reactors/power.html

Announced Potential New Nuclear Power Plants



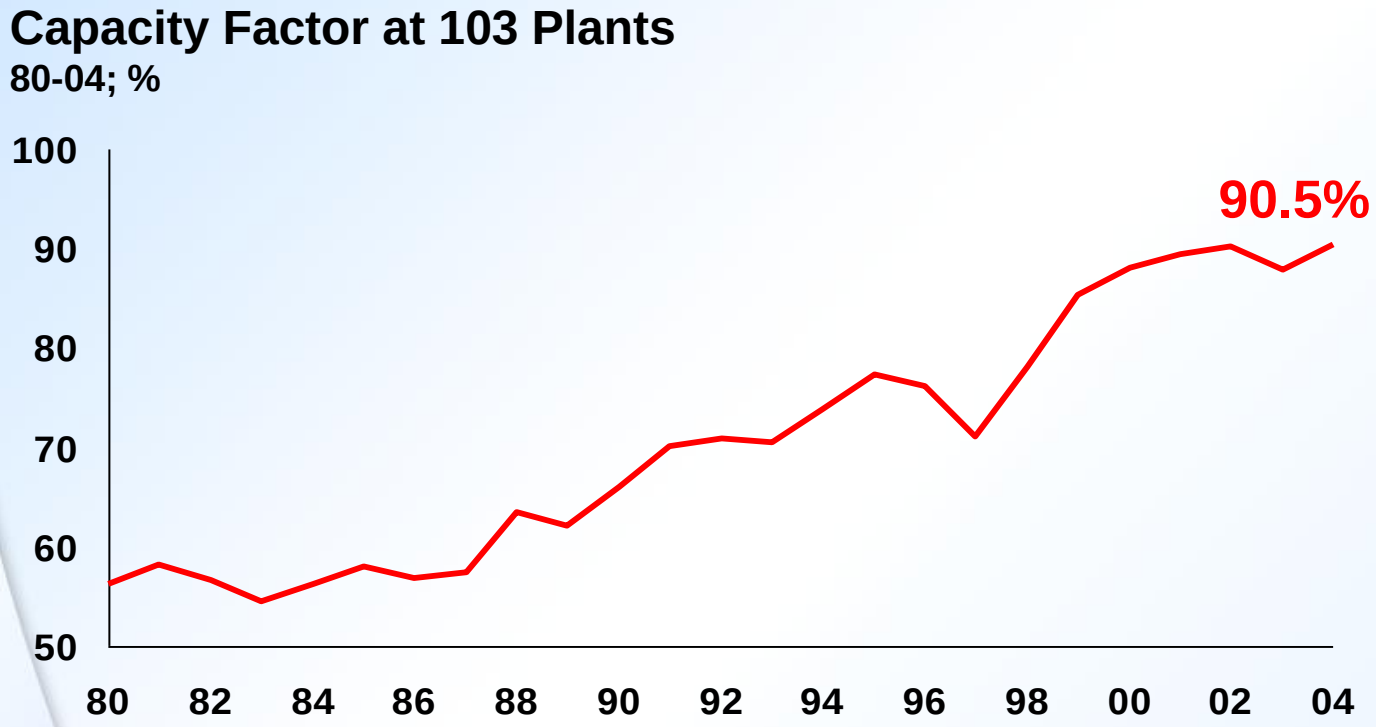
Source: Nuclear Regulatory Commission website, 3/09

Current Reactor Fleet is Lowering Operating Cost



Nuclear Energy Institute

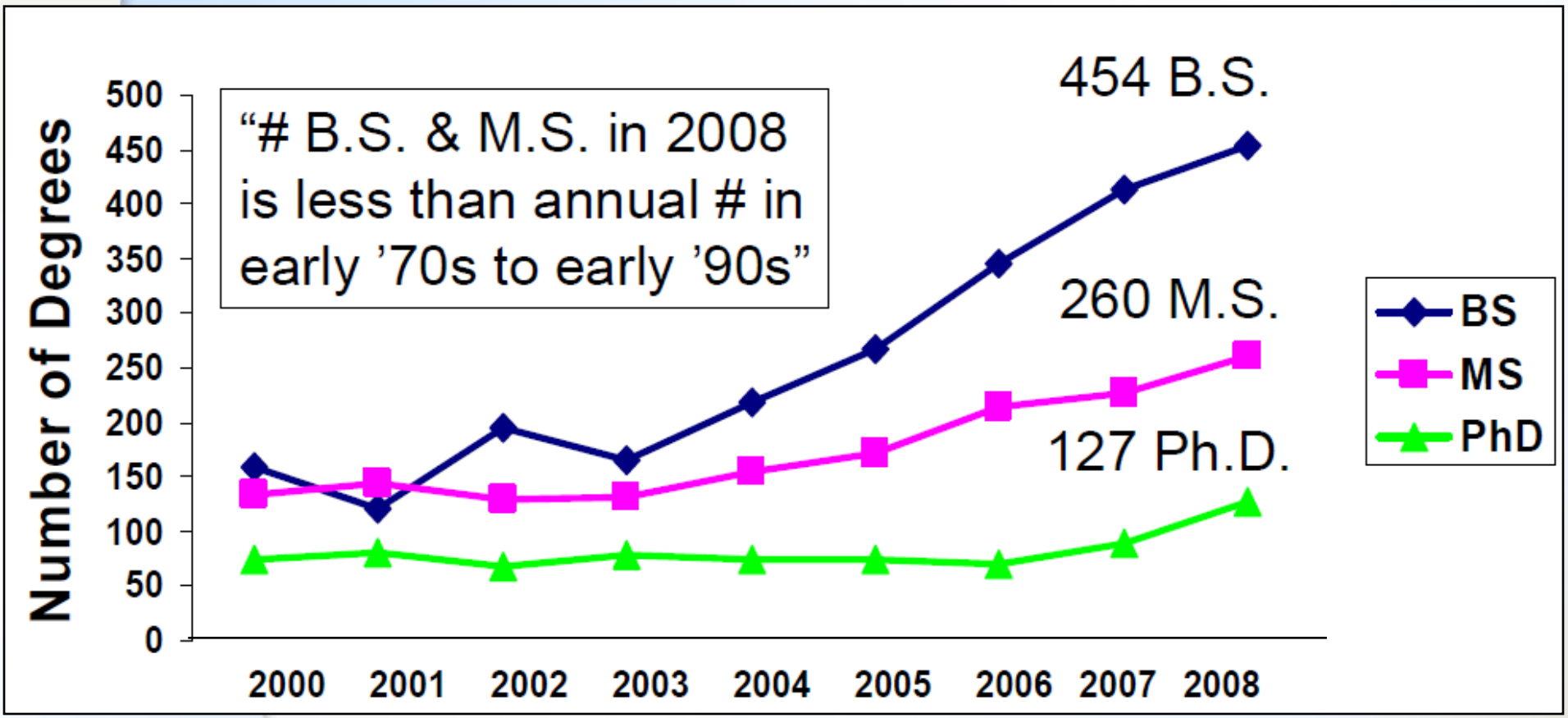
Current Fleet is Increasing Capacity Factors



Nuclear Energy Institute

Capacity factor increase at 103 plants in the last 15 years is equivalent to building 26 new 1,000 MW plants

Nuclear Engineering Graduation Numbers are Increasing



Source: "Nuclear Engineering Enrollments and Degrees Survey," 2008 Data, Oak Ridge Institute for Science and Education

DOE Labs Play a Vital Role in the Development and Sustainability of Nuclear Energy

- **Technology Transfer**
- **Severe Accident Analysis**
  - MELCOR is used by NRC for reactor licensing
- **Research and Development for current and new reactors**
  - GE can make a research request to DOE
  - DOE gives it to a lab to answer
  - GE and the other nuclear companies are provided info
- **Fire PRA development**
  - Sandia co-developed this with industry and it is now the NRC standard
- **Transportation Security**
  - RADTRAN is becoming an industry standard

Internationally, Some are Already "Getting it Done" in the US and Abroad

- **Many companies are pushing the nuclear interest and are developing infrastructure in the US**
  - AREVA is building enrichment and heavy component manufacturing in the US
  - Toshiba and Westinghouse are building fuel and reactor components
  - These companies train and employ thousands of US citizens
- **The Russians are advancing "supply and return" policies with multiple countries**

However, these multi-national countries are not developing US technology, and they do not empower the US government to dictate non-proliferation policy to other countries.

Recent DOE Nuclear Programs

- Generation IV Program (GenIV)
- Global Nuclear Energy Partnership (GNEP)
- Advanced Fuel Cycle Initiative (AFCI)
- Nuclear Power 2010
- LWR Sustainability Program
- Next Generation Nuclear Plant (NGNP)
- Nuclear Hydrogen Initiative (NHI)
- Nuclear Energy Research Initiative (NERI)
- Research Reactor Infrastructure (RRI)

Revolutionary Changes in U.S. Policy have Opened the Door for a Major Global Opportunity for the U.S. Nuclear Supply Industry

Bi-partisan interests have called for changes in the global nuclear enterprise:

- ***We will help developing countries meet their growing energy needs by providing them with small-scale reactors.***
- ***In exchange, these countries would agree to use nuclear power only for civilian purposes and forego uranium enrichment and reprocessing activities that can be used to develop nuclear weapons.***
- ***The "supply and return" concept addresses a major potential proliferation concern with expanded use of nuclear power.***
- ***But, do we really have anything to supply?***

Source: George W. Bush, President's Description of GNEP, Radio Address, February 18, 2006.

Excerpts from President Obama

- “We should build a new framework for civil nuclear cooperation, including an international fuel bank, so that countries can access peaceful power without increasing the risks of proliferation.”
- “We must harness the power of nuclear energy on behalf of our efforts to combat climate change, and to advance peace opportunity for all people.”
- “Because [the nuclear material trafficking] threat will be lasting, we should come together to turn efforts such as the Proliferation Security Initiative and the Global Initiative to Combat Nuclear Terrorism into durable international institutions. And we should start by having a Global Summit on Nuclear Security that the United States will host within the next year.”

President Barak Obama speaking in Prague, Czech Republic on April 6th 2009

- "But to create more of these clean energy jobs, we need more production, more efficiency, more incentives. And that means building a new generation of safe, clean nuclear power plants in this country.

President Barak Obama speaking at the State of the Union Address on January 27, 2010

Most of the Emerging Market Opportunity is for Smaller Reactors

Why "SMALL" Reactors?

Small Reactor: 0 – 300 MW(e)
Medium Sized Reactor: 300 – 700 MW(e)

In 2006:

- **Of 442 NPPs, 139 were small and medium sized reactors (SMRs)**
- **SMRs: 61.6 GW(e) or 16.7% of the world nuclear electricity production**
- **Of 31 newly constructed NPPs, 11 were SMRs**
- **More than 50 concepts and designs of innovative SMRs were developed in** *Argentina, Brazil, Canada, China, Croatia, France, India, Indonesia, Italy, Japan, the Republic of Korea, Lithuania, Morocco, Russian Federation, South Africa, Turkey, USA, and Vietnam*
- **Most of innovative SMRs provide for or do not exclude *non-electric applications***

Source: V. Kuznetsov, International Conference on Non-electric Applications of Nuclear Power, April 16-19, 2007, Oarai, Japan

Can U.S. Utilities Really Afford the Big Plants?

The Challenge of Scale

(Market values 10.4.2007)

Exelon	$51.43 billion
TXU	$31.70 billion
Dominion	$30.05 billion
Southern	$28.02 billion
FPL	$25.37 billion
Duke	$24.28 billion
Entergy	$22.02 billion
Constellation	$15.65 billion
Progress	$12.31 billion
Two-unit nuclear power station	$10-12 billion
NRG	$10.35 billion
DTE Energy	$8.34 billion
SCANA	$4.54 billion

(R. Myers, NEI)

The Right-Sized Concept Has Been Used for the Last Two Decades in the U.S.

The Last 15 Years: Investment in Electric Infrastructure Collapsed Except for Small Power Systems

- Living off of nuclear and coal investments made during 1960s, 1970s, 1980s.
- Since 1992, almost 290 gigawatts of right-sized natural gas capacity has been added in 100-300 MW "chunks."

(R. Myers, NEI)

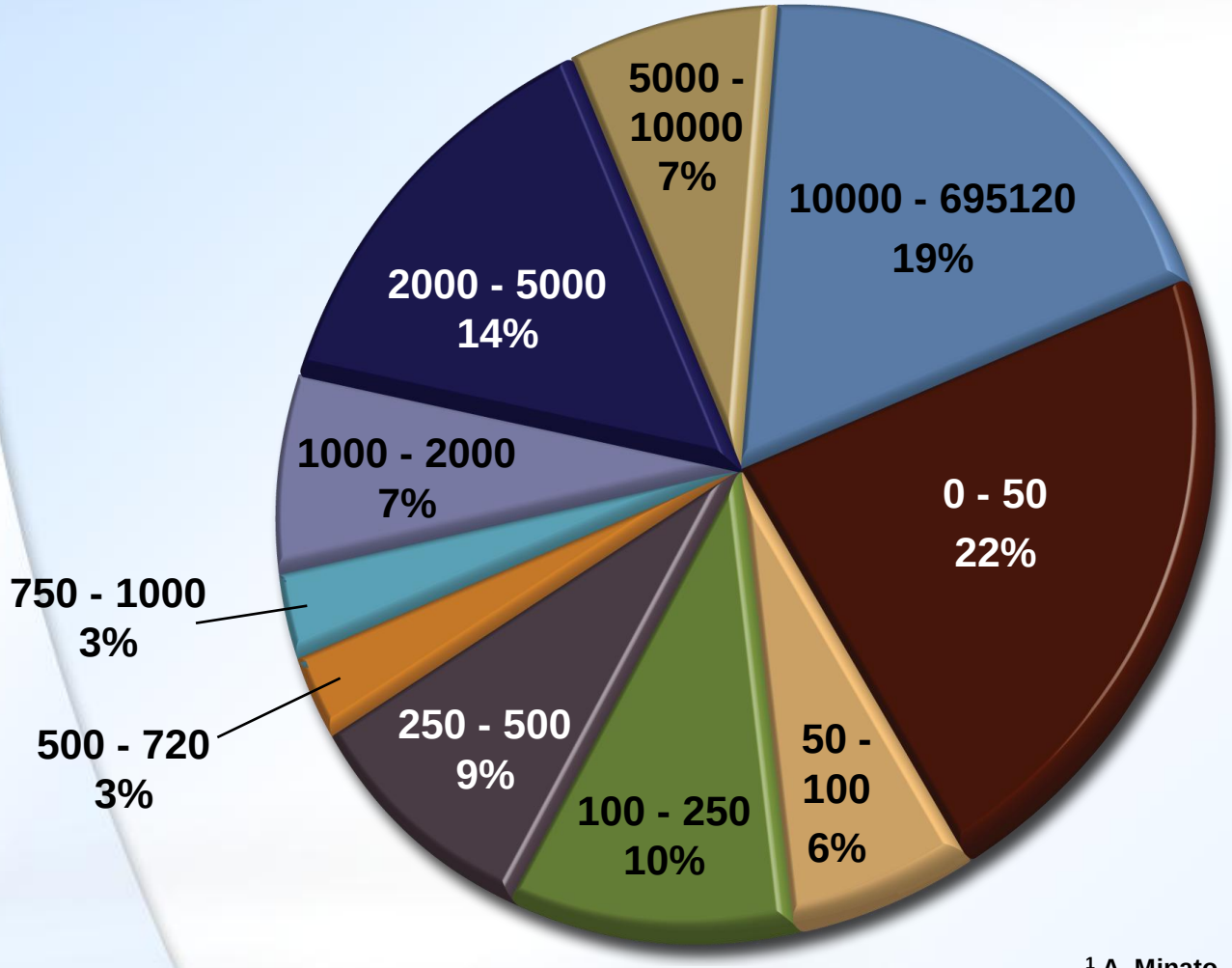
New Generating Capacity: 1992-2005	
Gas	**288,576 MW**
Renewables	9,983 MW
Coal	8,044 MW
Oil	4,933 MW
Hydro	2,629 MW
Nuclear	2,485 MW
Other	223 MW

Source: Energy Information Administration

Note: New nuclear from existing plant up-rates

Most of the Emerging Export Market Opportunity is for Small to Medium Reactors (SMRs)

(1) Total Capacity of Electrical Generation in 226 Countries (MWe)



[1] A. Minato, CRIEPI

Right sized reactors take advantage of emerging nuclear and energy system trends.

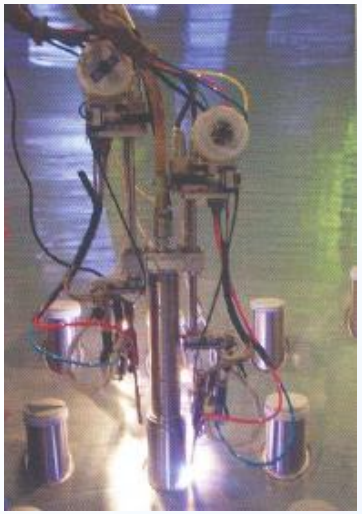
Nation States Now Own Most of U.S. Origin Manufacturing Capability

- Combustion Engineering (PWRs)
  - Sold to Swiss-Swedish group Asea Brown Boveri in late 1980s
  - Later sold to Westinghouse (BNFL)
- Gulf General Atomic (gas-cooled reactors)
  - Lost market with dismal performance at Fort St. Vrain in Colorado
- Babcock and Wilcox (PWR)
  - Sold to Areva (France) in 1996; French Government 90% owner
- Westinghouse (PWR maker)
  - Sold to British Nuclear Fuels Ltd (BNFL) in 1998
  - BNFL sells it to Toshiba LLC in 2006
  - Toshiba sells 10% of Westinghouse to Kazatomprom (Kazakhstan)
  - Will be exported from China within 15 years
- General Electric (BWR)
  - Now multinational; 60% owned by Japan's Hitachi

Almost All Components for Large U.S. Plants Will Be Imported from Countries Like Japan

Kobe Shipyard & Machinery Works

Mitsubishi 600-1200MWe PWR



J-Groove Welding Equipment
for Reactor Vessel Head

Super Miller

NC Horizontal Boring Machine

Dome Cladding Equipment

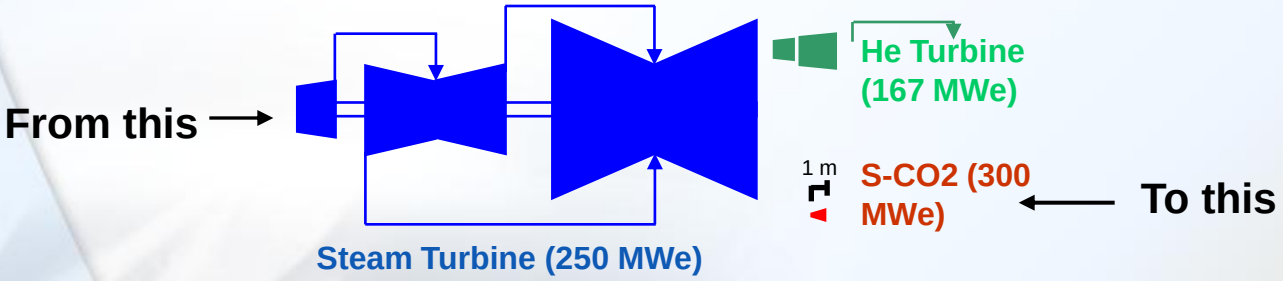
Source: Mitsubishi Heavy Industries, Ltd., Kobe Shipyard & Machinery Works, 2007

Several Other "Emerging Nuclear Nations" Could Become Globally Competitive Nuclear Suppliers

- Example: Argentina
  - Has Bilateral Nuclear Cooperation Agreements with Algeria, Brazil, Peru, Romania, Turkey, Yugoslavia (Serbia), India, Italy, Iran, Israel, Pakistan, Libya, the Czech Republic, and Germany
  - Is developing a small, standardized reactor for export to developing nations
    - Has developed indigenous capabilities in uranium enrichment, reprocessing, reactor design, fuel design, and waste management
- Other emerging supplier nations with indigenously developed capabilities—China, South Korea, Japan, Kazakhstan, Ukraine, 'Russia', South Africa, India, Brazil

"Right-Sizing" Addresses Cost, Waste, Proliferation, and Perceived Safety Issues

- **Factory produced, fueled, sealed**
- **Long fuel lifetime** *(up to 30 years, no need for on-site fueling)*
- **Inherently safe**
- **High efficiency**
- **Transportable** *(components shipped to site for assembly)*
- **Remotely monitored**
- **Capacity - 100 to 300 MW_E**



Right Sized Reactors Can Be Based on Any of the Current Reactor Technologies

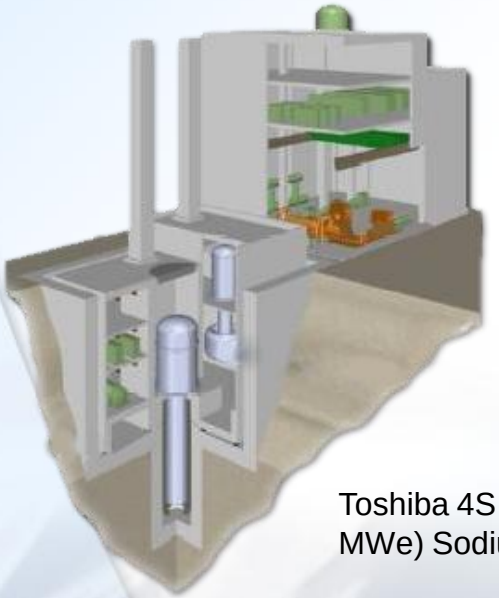
- Water Cooled (LWR)
  - **Generally based on light water systems**
    - **Pros** – very large experience base
    - **Cons** – low temperatures, high pressures, refueling frequency
    - Examples: KLT-40/Russia, IRIS-50/Westinghouse
- Gas Cooled (He)
  - **Based on prismatic, or pebble bed designs**
    - **Pros** – passive safety, high temperature output
    - **Cons** – fuel has been demonstrated but capabilities need to be reestablished, high pressure, large components per unit power, costs expected to be higher than LWR
    - Examples: PBMR/S Africa, GTMHR/General Atomics, VHTR/DOE-Gen IV

KLT-40 Russian Icebreaker Reactor (PWR,35 MWe, basic design for floating nuclear power plant)

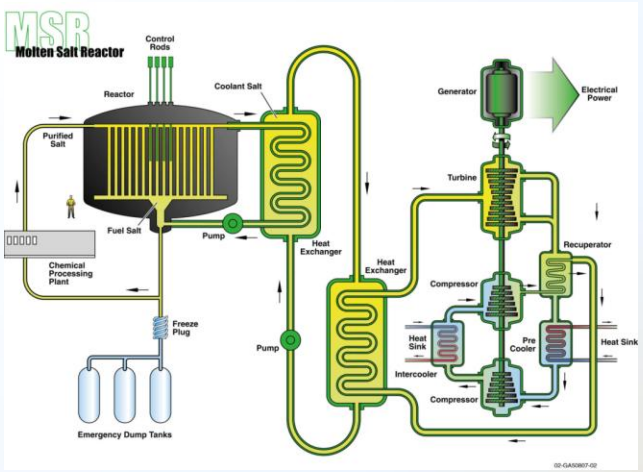
PBMR (pebble bed, (165 MWe) S. Africa

Right Sized Reactors Can Be Based on Any of the Current Reactor Technologies (cont'd)

- Liquid Metal Cooled (Na, NaK, Pb, Pb-Bi)
  - **Generally based on fast reactor systems**
    - **Pros** – *significant experience base,* long times between refueling, low pressures, compact,
    - **Cons** – proliferation and safety concerns, Na coolant complications
    - **Examples:** RSR Reactor, PRISM/GE, STAR/US DOE, 4S/Toshiba, SVBR/Russia
- Molten Salt Reactor
  - **Existing concepts could be modified to embrace "right-sized" approach**



Toshiba 4S (10 to 50 MWe) Sodium cooled



Where Can We Reduce RSR Costs?

- Comparison of Cost Categories using
  - Toshiba 4S (sum of parts)
  - GE PRISM (scaled down)
  - Experience from Palo Verde Nuclear Station

Not Optimal

Capital cost is too high by ~2x

Major Capital Cost Elements	Total Costs ($)
Land & Rights	$5,405,000
Buildings	$20,261,027
Nuclear Steam Supply System	$43,123,093
NSSS Field Costs	$1,866,642
Turbine Generator	$24,339,104
Electric Plant	$10,244,668
Miscellaneous	$2,008,200
Main Condenser & Heat Rejection	$3,973,581
Indirect Costs	$50,106,262
Contingency	$26,625,969
Interest During Construction	$29,355,215
	$217,308,761

- Reduce Costs by Design
  - Far smaller containment building
  - Generating SCCO2 far more compact than steam
  - SCCO2 far smaller than steam turbine
  - Contingency % of total
- Reduce Costs by Advanced Manufacturing
  - Re-occurring costs spread over multiple units
  - Contingency % of total and more predictable
  - Faster construction reduces interest
  - Other components may be lower cost in volume
- Goal is $1,500/kW

The Right-Sized Reactor is a "Disruptive" or Game Changing Technology Whose Time Has Come

National Security Benefits

- Eliminates the desire of customers with nuclear systems to have enrichment and reprocessing capabilities.
- Reduces potential for future conflict over access to energy resources and to the economic potential that energy enables.
- Dramatically reduces proliferation tensions.

Energy Security Benefits

- Results in minimal nuclear waste and assured sustainability of nuclear resources at home.
- Provides affordable domestic alternative to natural gas generation of electricity.

Economic Competitiveness Benefits

- Revitalizes manufacturing capability for high value systems with the generation of thousands of sustainable high-tech jobs.
- Enables US penetration of a growing market worth several trillion dollars.
- Results in a truly renewable and affordable energy resource.

Questions?