Global Energy Needs: Defining a Role for a “Right Sized Reactor”

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President

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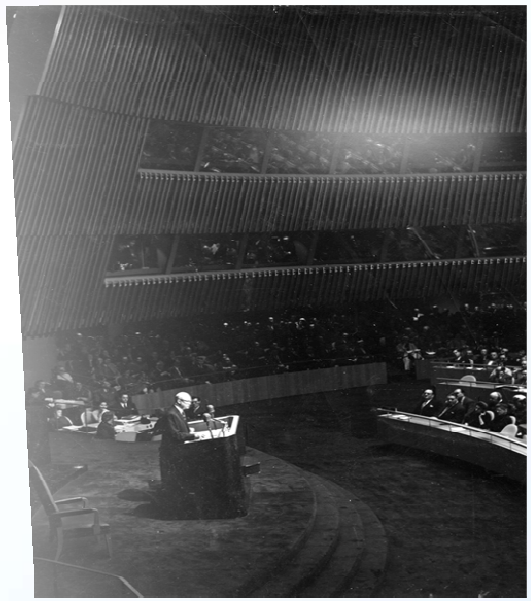
In 1953, President Eisenhower started the Atoms for Peace Program to promote U.S. national security interests:

- 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

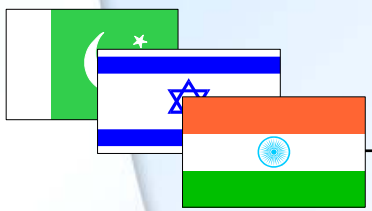
Source: Conference Chairman: Senator Sam Nunn, Global Nuclear Materials Management, A CSIS Conference Report, Energy and National Security Program, December 4, 1998.

Realities & Opportunities

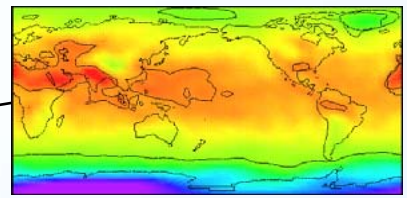
Civilian nuclear energy as an arms reduction vehicle

Reapplication of defense nuclear assets

Emerging nuclear suppliers and users

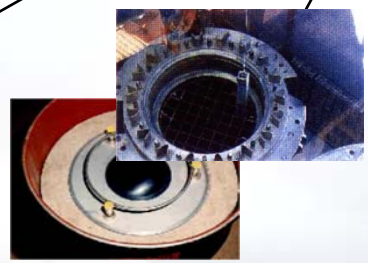


All but 3 countries have signed the nonproliferation treaty

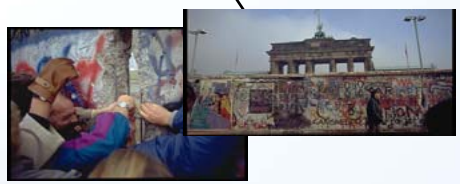


World-wide pressures changing the energy cost/risk picture

Iran, North Korea, and Terrorism



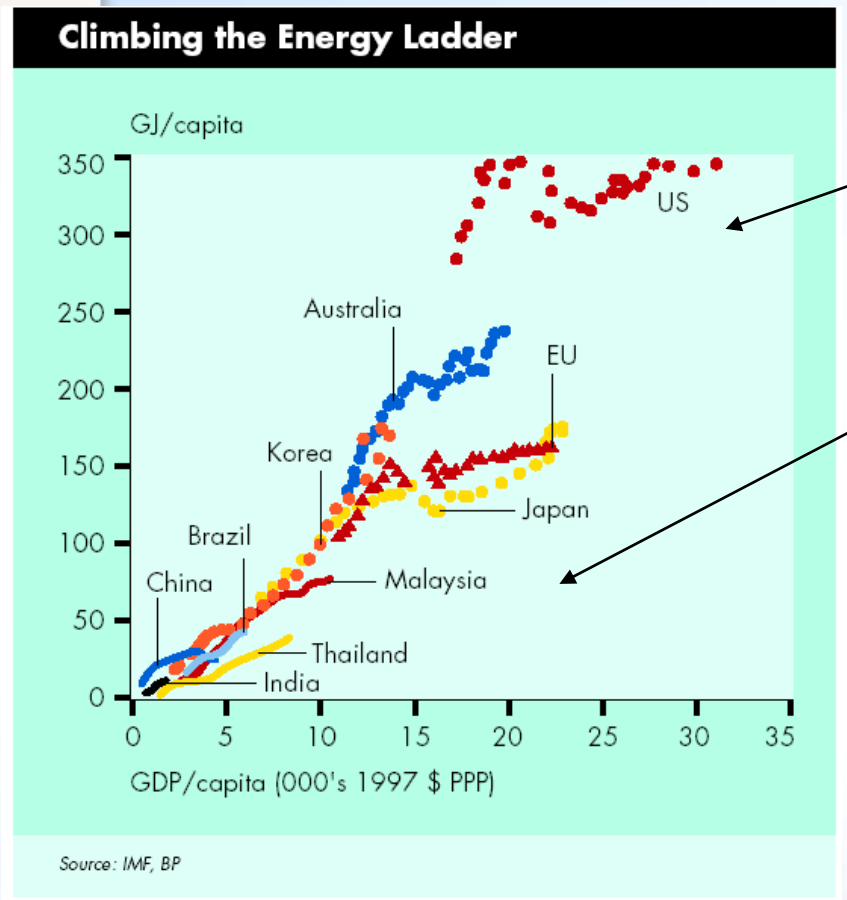
Excess material: liabilities or assets?



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



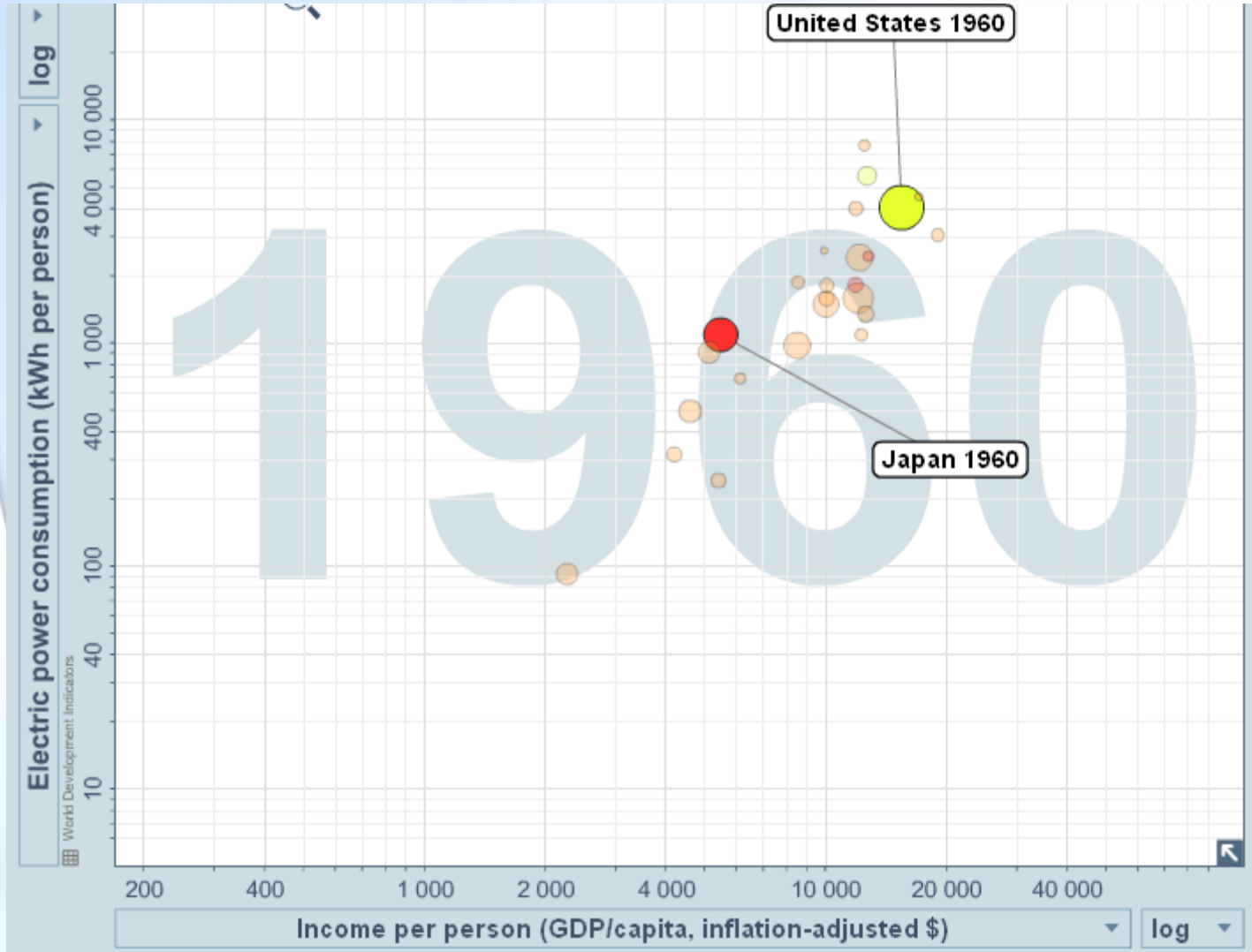
- *Energy availability is directly tied to national economic health and protecting energy supplies and deliveries drives the national security strategy of many countries.*

  - 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.

Dynamic View of Power Consumption vs. Income



http://graphs.gapminder.org

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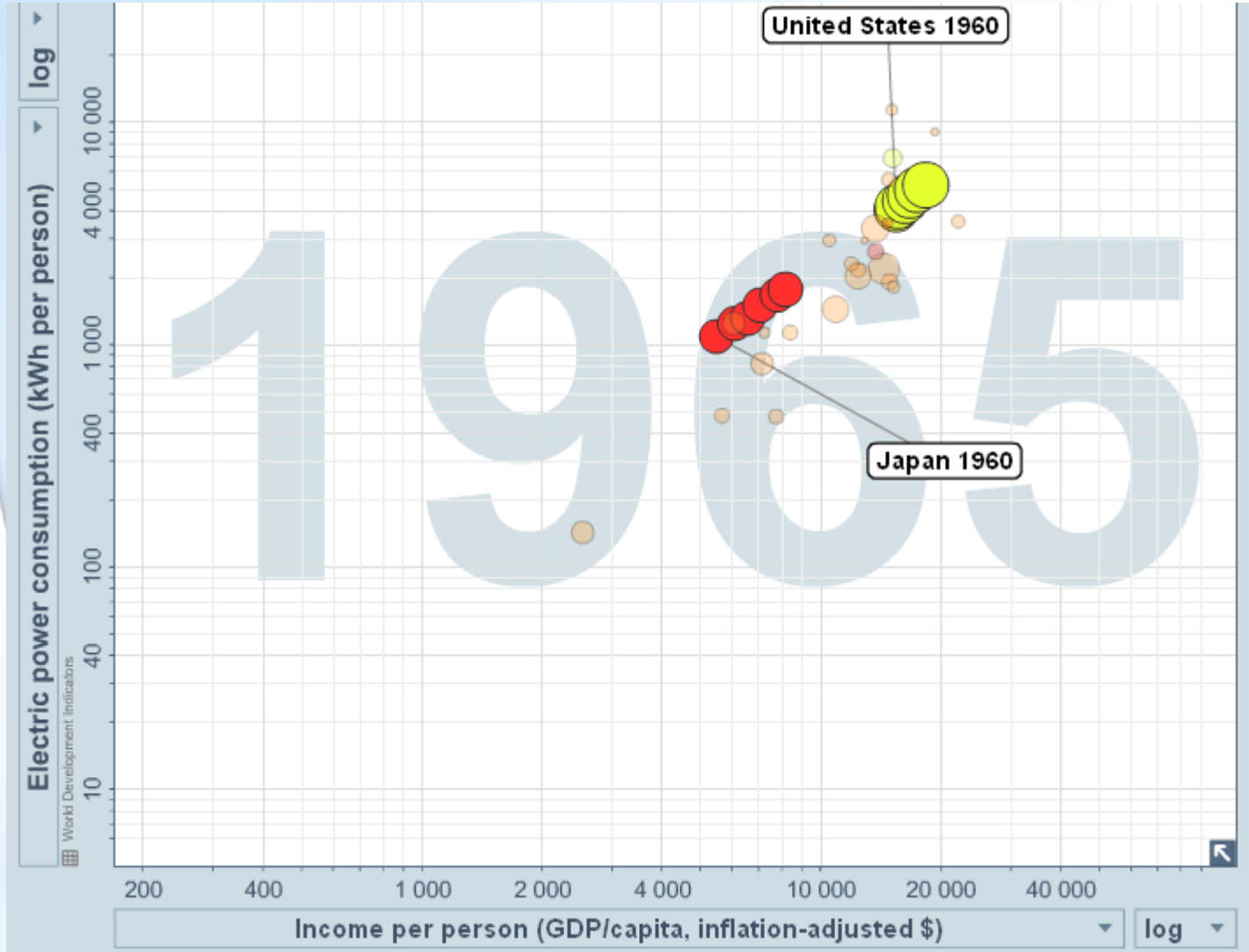

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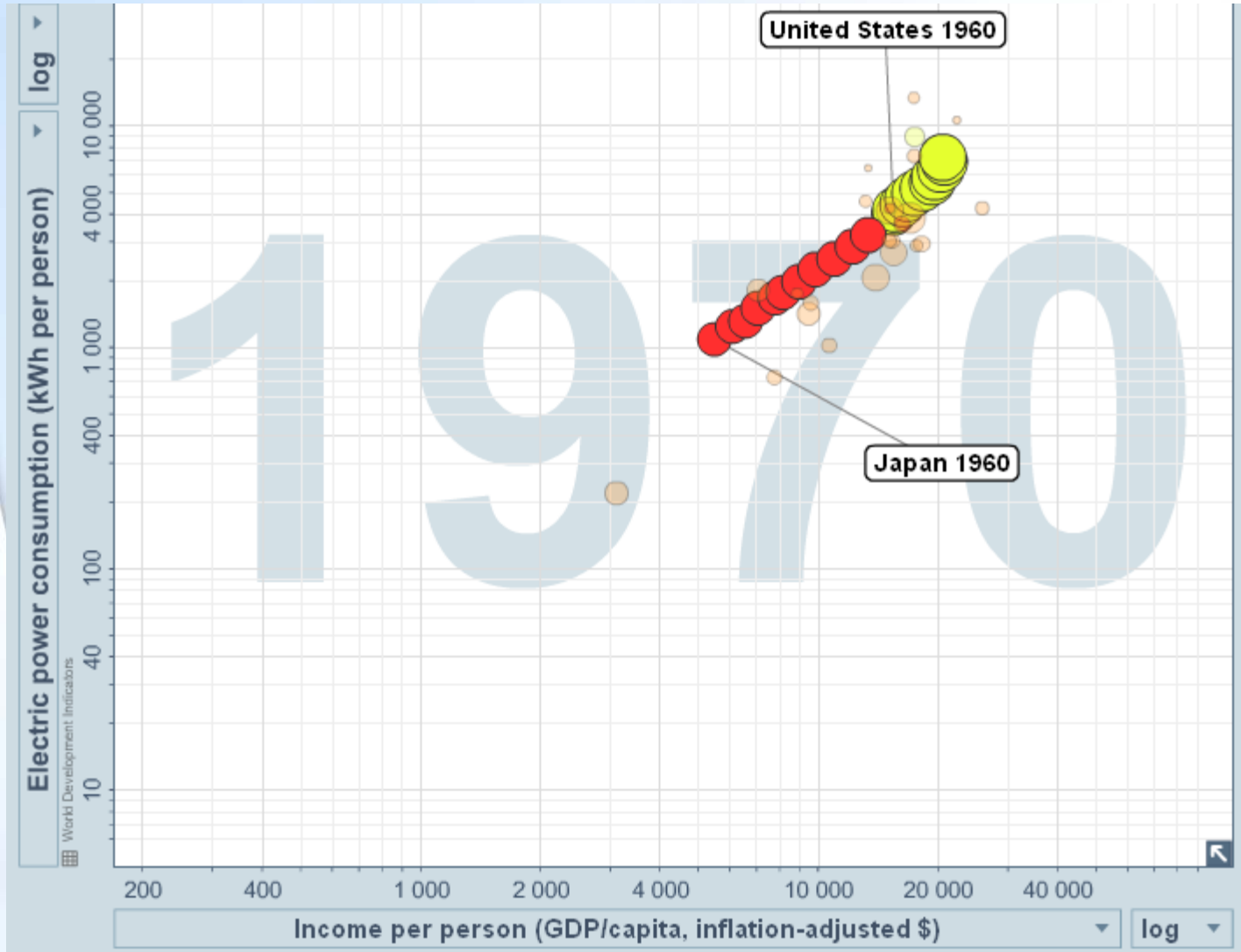

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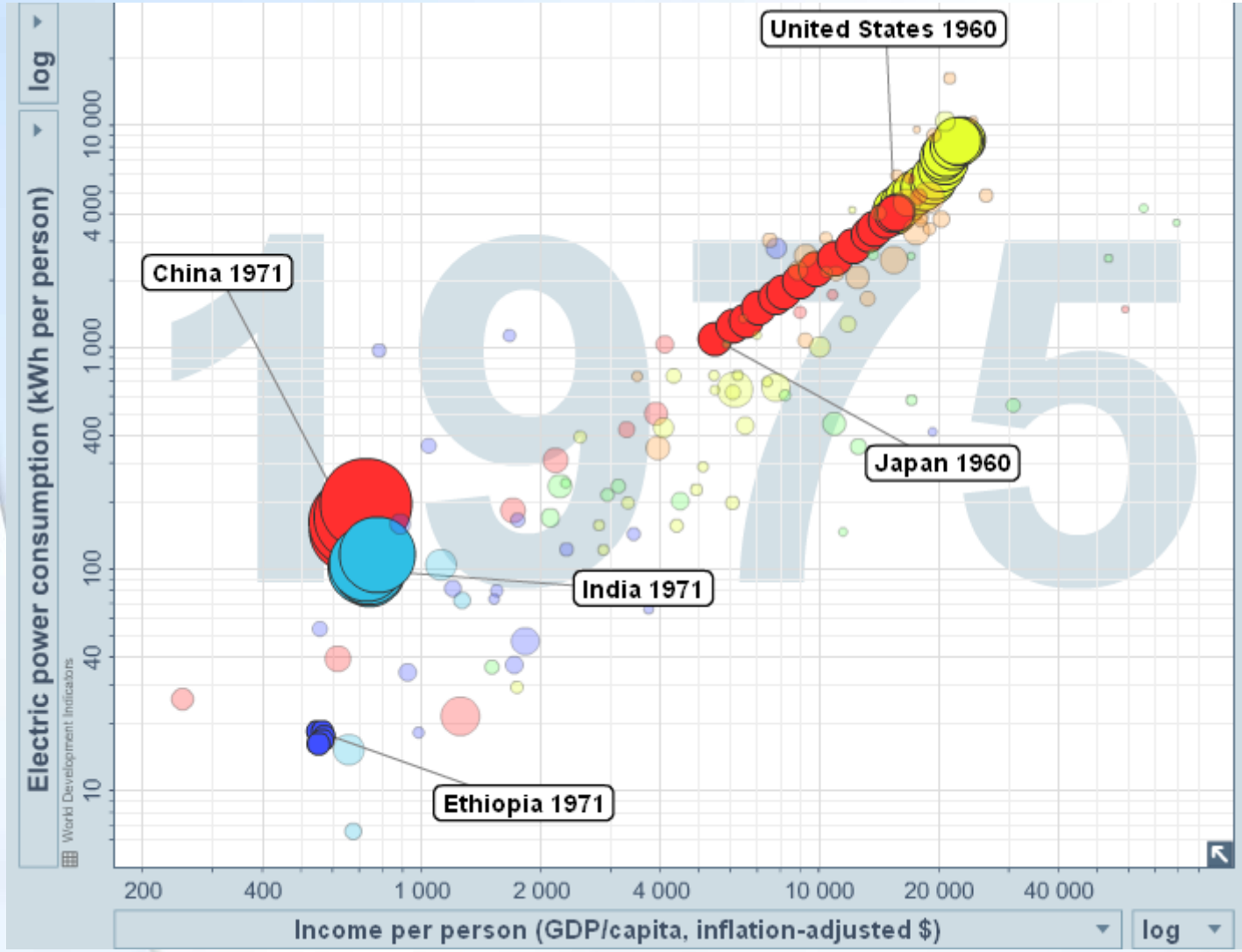

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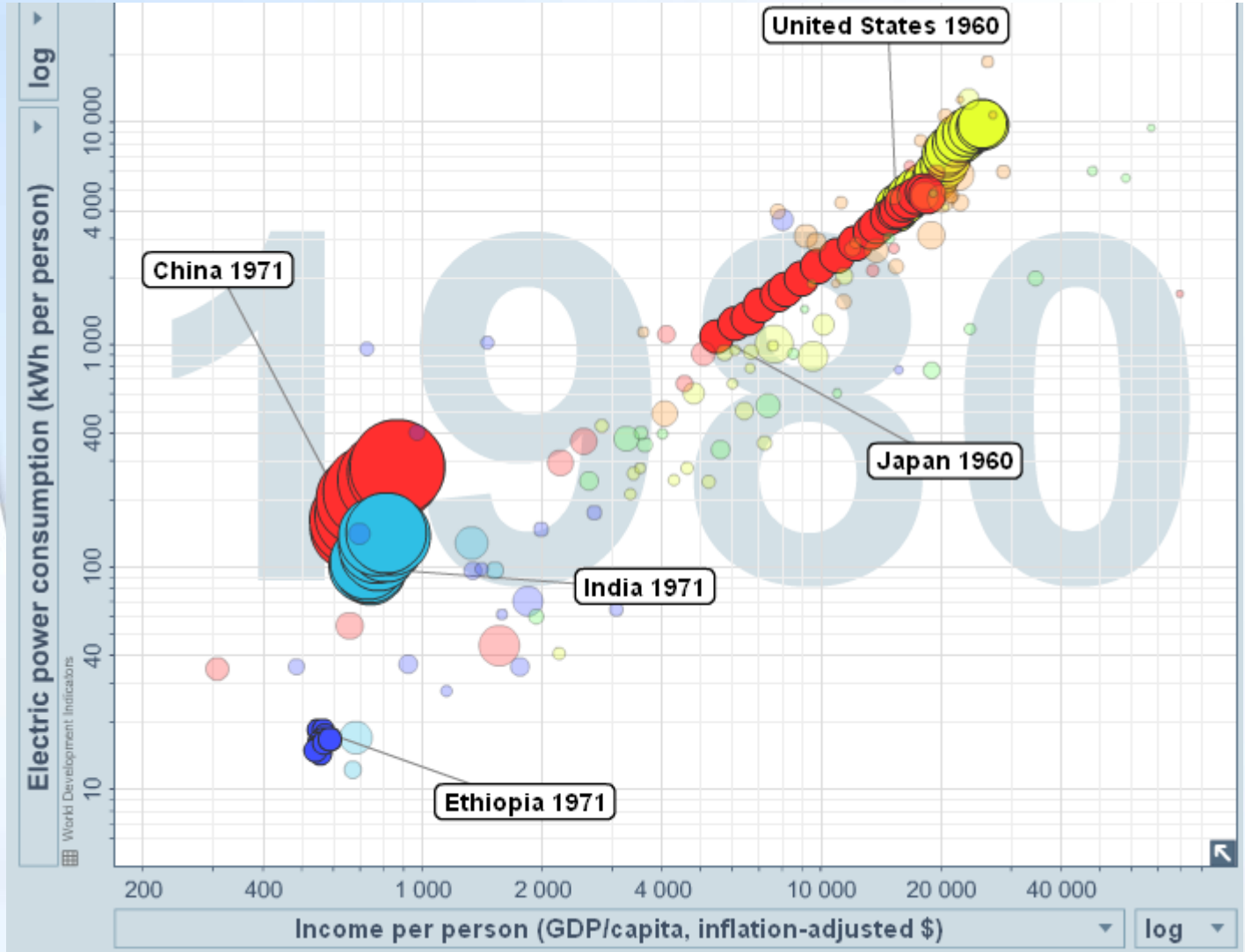

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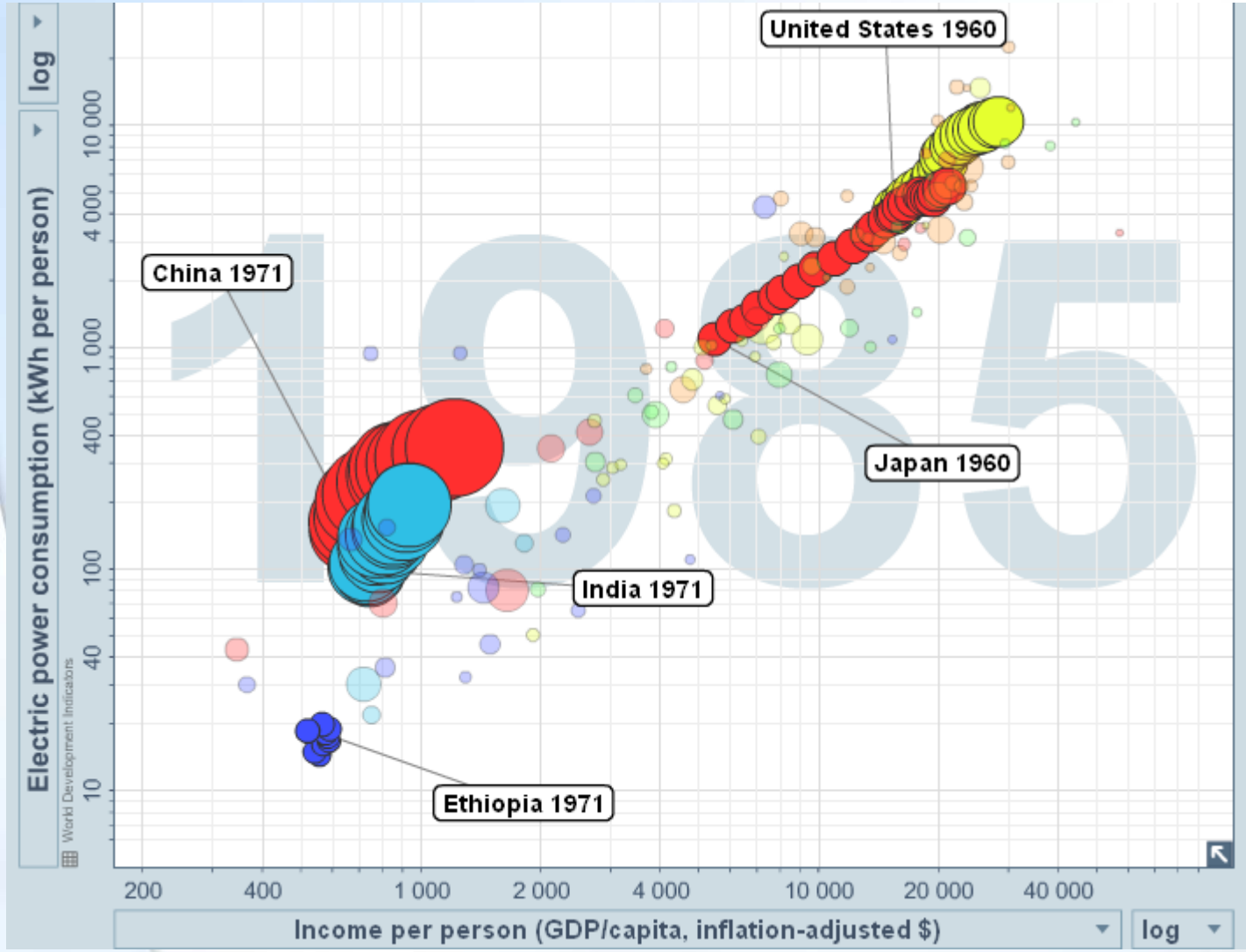

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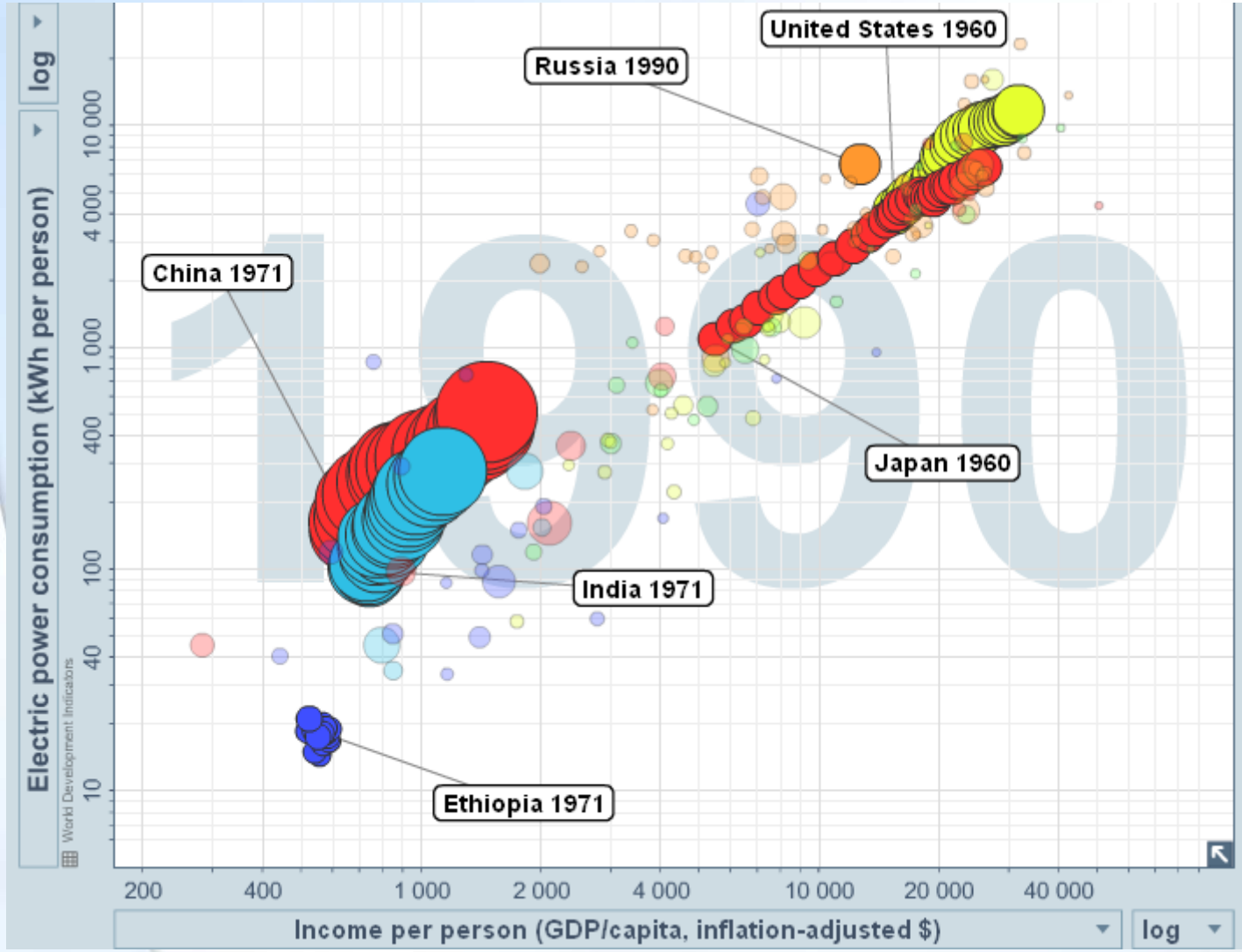

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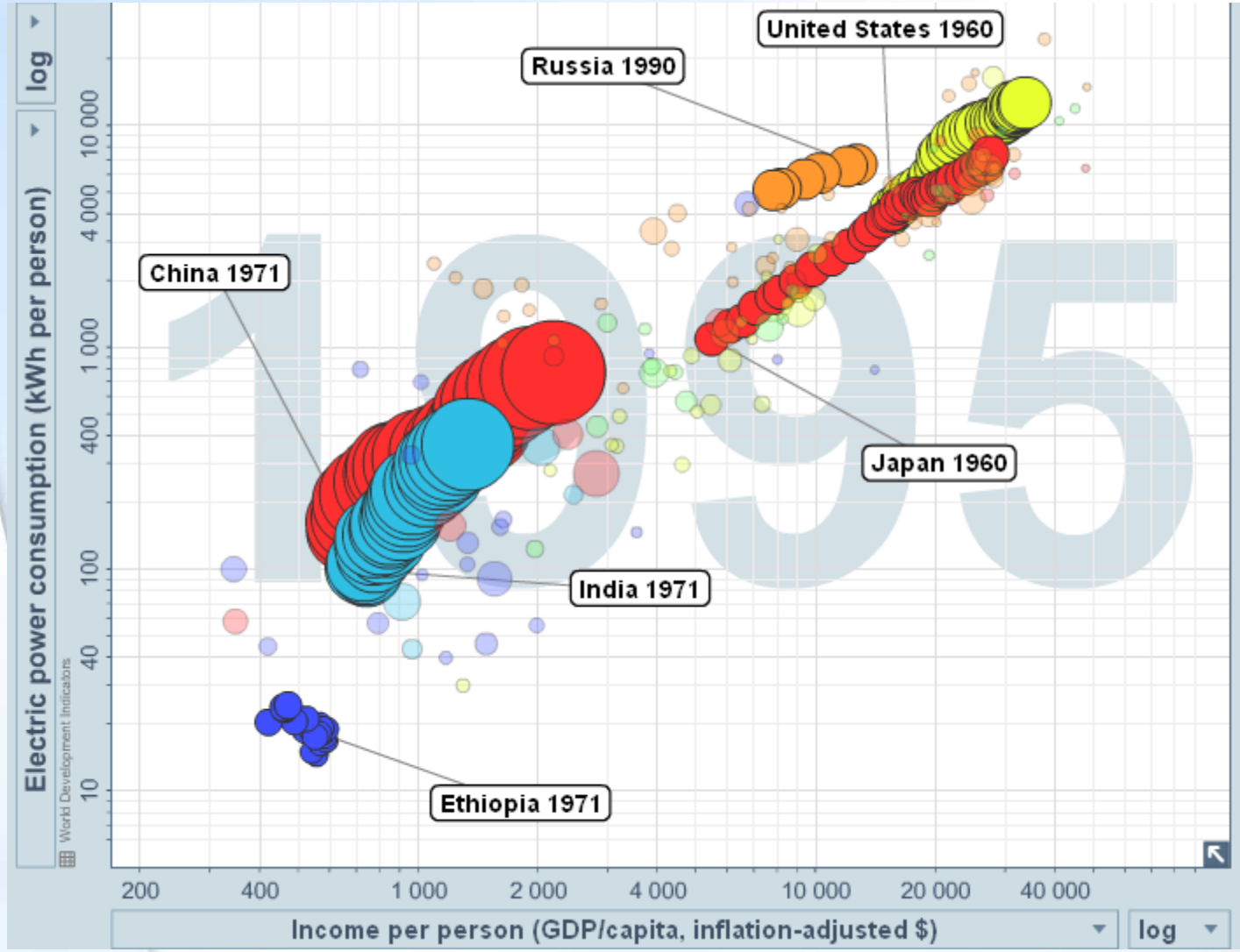

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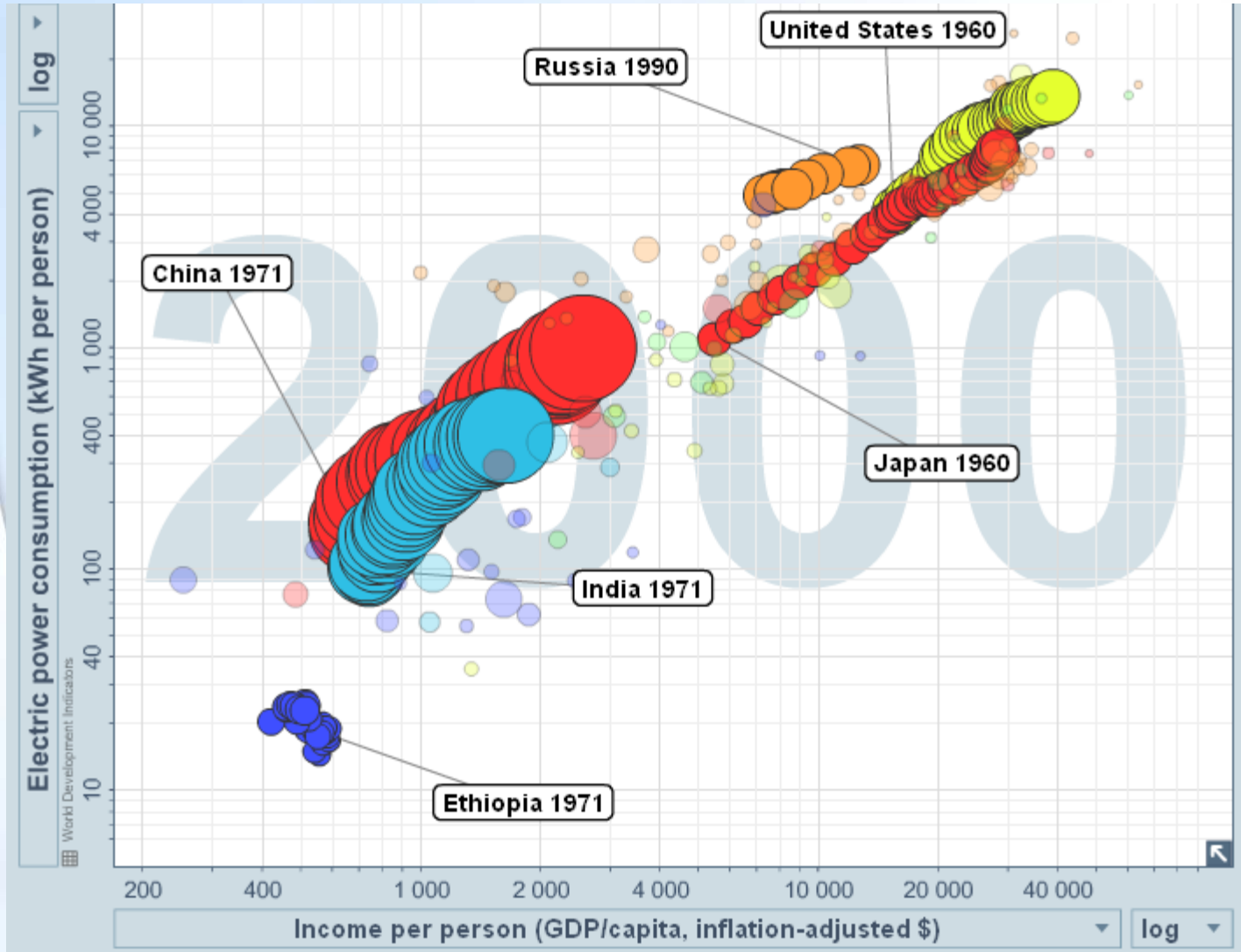

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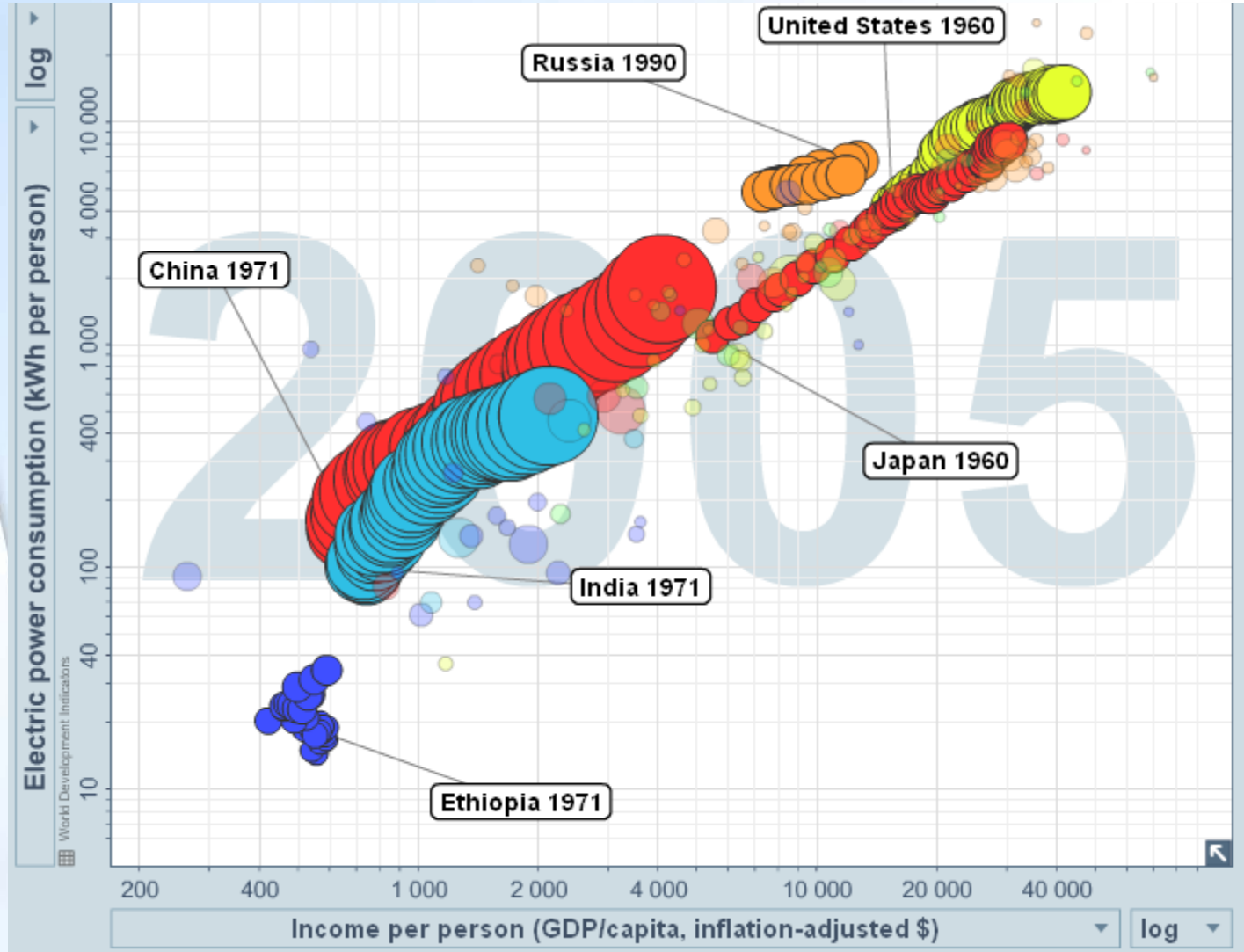

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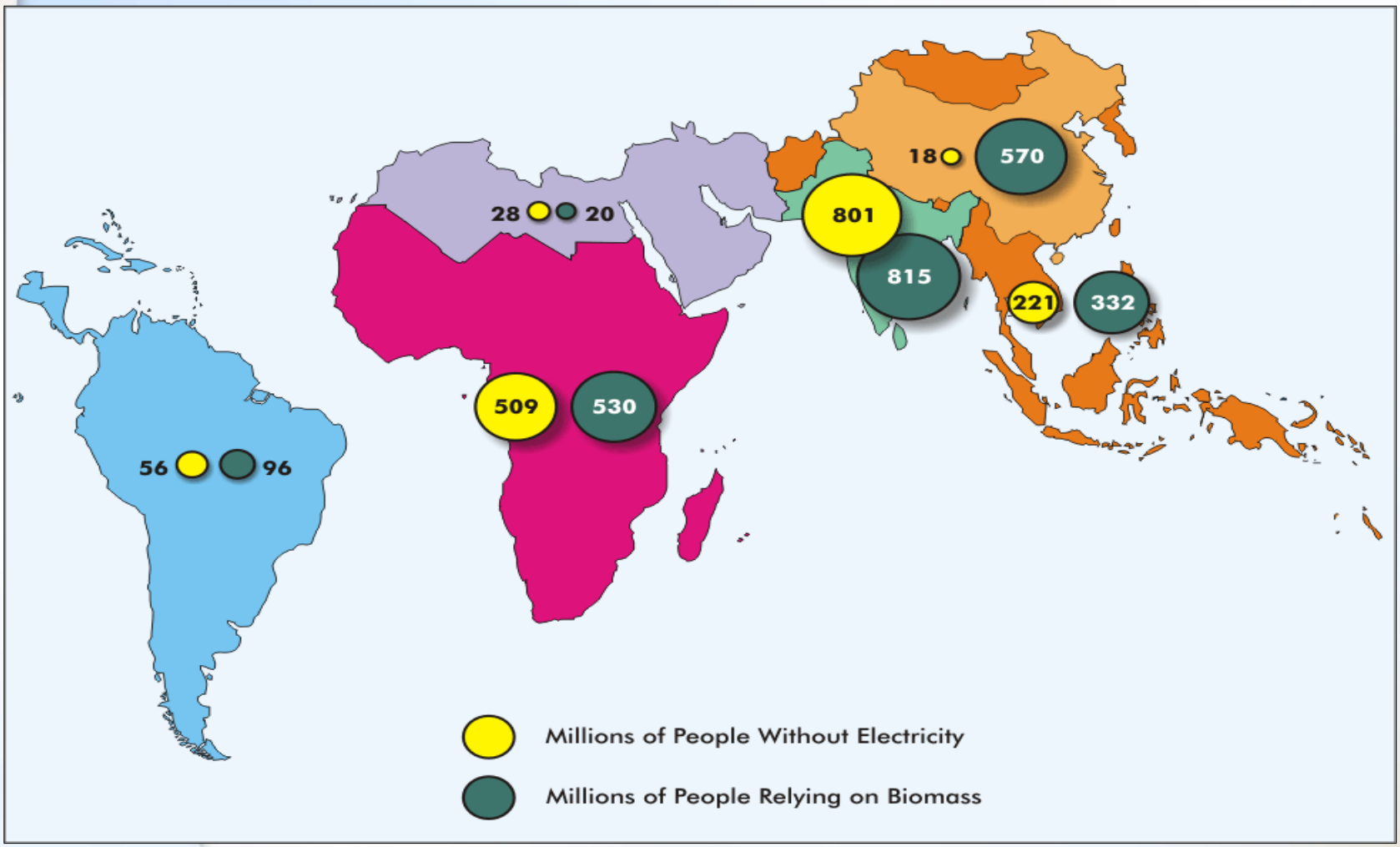
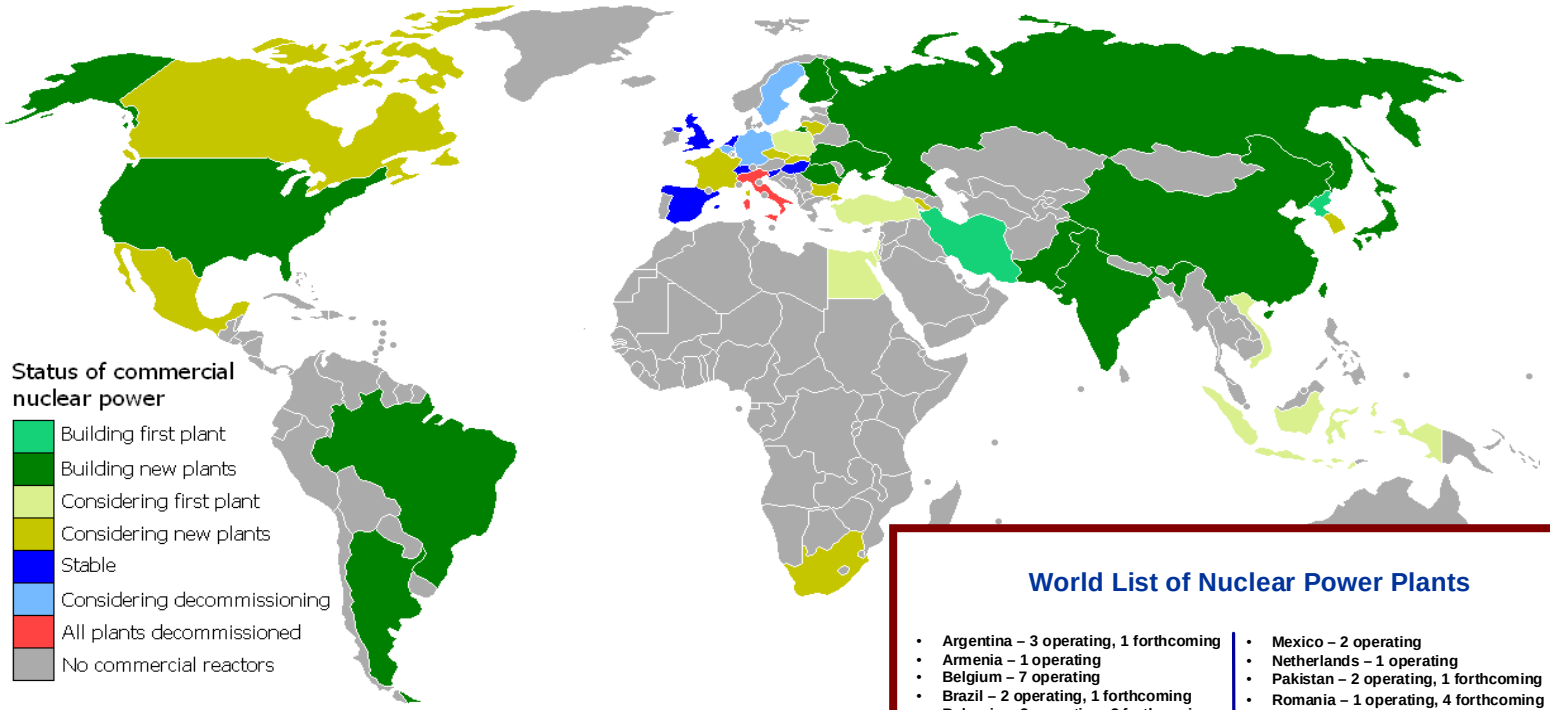
It has been Estimated that Within a Decade Nearly 80% of the World's Middle-income Consumers would live in Nations Outside the Currently Industrialized World



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.

Significant Nuclear Power Growth Beyond Traditional Users Has Begun



World List of Nuclear Power Plants

- Argentina – 3 operating, 1 forthcoming
- Armenia – 1 operating
- Belgium – 7 operating
- Brazil – 2 operating, 1 forthcoming
- Bulgaria – 2 operating, 2 forthcoming
- Canada – 22 operating
- China – 9 operating, 10 forthcoming
- China (Taiwan) – 6 operating, 2 forthcoming
- Czech Republic – 6 operating
- Finland – 4 operating, 1 forthcoming
- France – 59 operating, 1 forthcoming
- Germany – 17 operating
- Hungary – 4 operating
- India – 16 operating, 7 forthcoming
- Iran – 1 forthcoming
- Japan – 55 operating, 3 forthcoming
- Lithuania – 1 operating
- Mexico – 2 operating
- Netherlands – 1 operating
- Pakistan – 2 operating, 1 forthcoming
- Romania – 1 operating, 4 forthcoming
- Russia – 31 operating, 6 forthcoming
- Slovakia – 5 operating, 2 forthcoming
- Slovenia – 1 operating
- South Africa – 2 operating
- South Korea – 20 operating, 6 forthcoming
- Spain – 8 operating
- Sweden – 10 operating
- Switzerland – 5 operating
- Ukraine – 15 operating, 3 forthcoming
- United Kingdom – 19 operating
- USA – 104 operating, 1 forthcoming

Source: World List of Nuclear Power Plants, Nuclear News 10th Annual Reference Issue, March 2008.

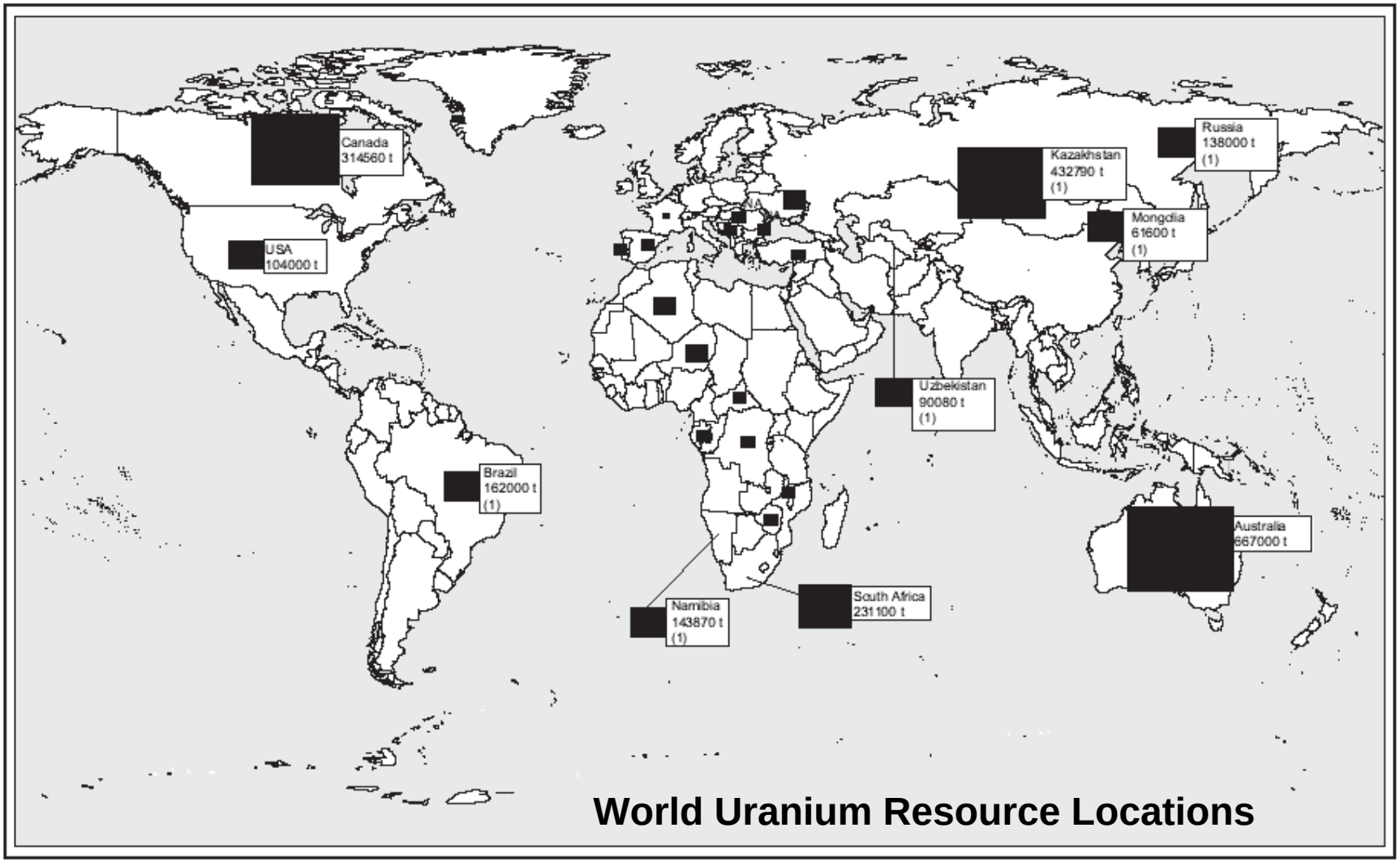
Several of These Other "Emerging Nuclear Nations" Could Become Globally Competitive Nuclear Suppliers

- **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**

Source: William C. Potter, International Nuclear Trade and Nonproliferation, The Challenge of the Emerging Suppliers, Lexington Books, 1990.

More than One Half of the World's Uranium Resources are in the "Developing World"

Source: British Nuclear Energy Society, September 2005

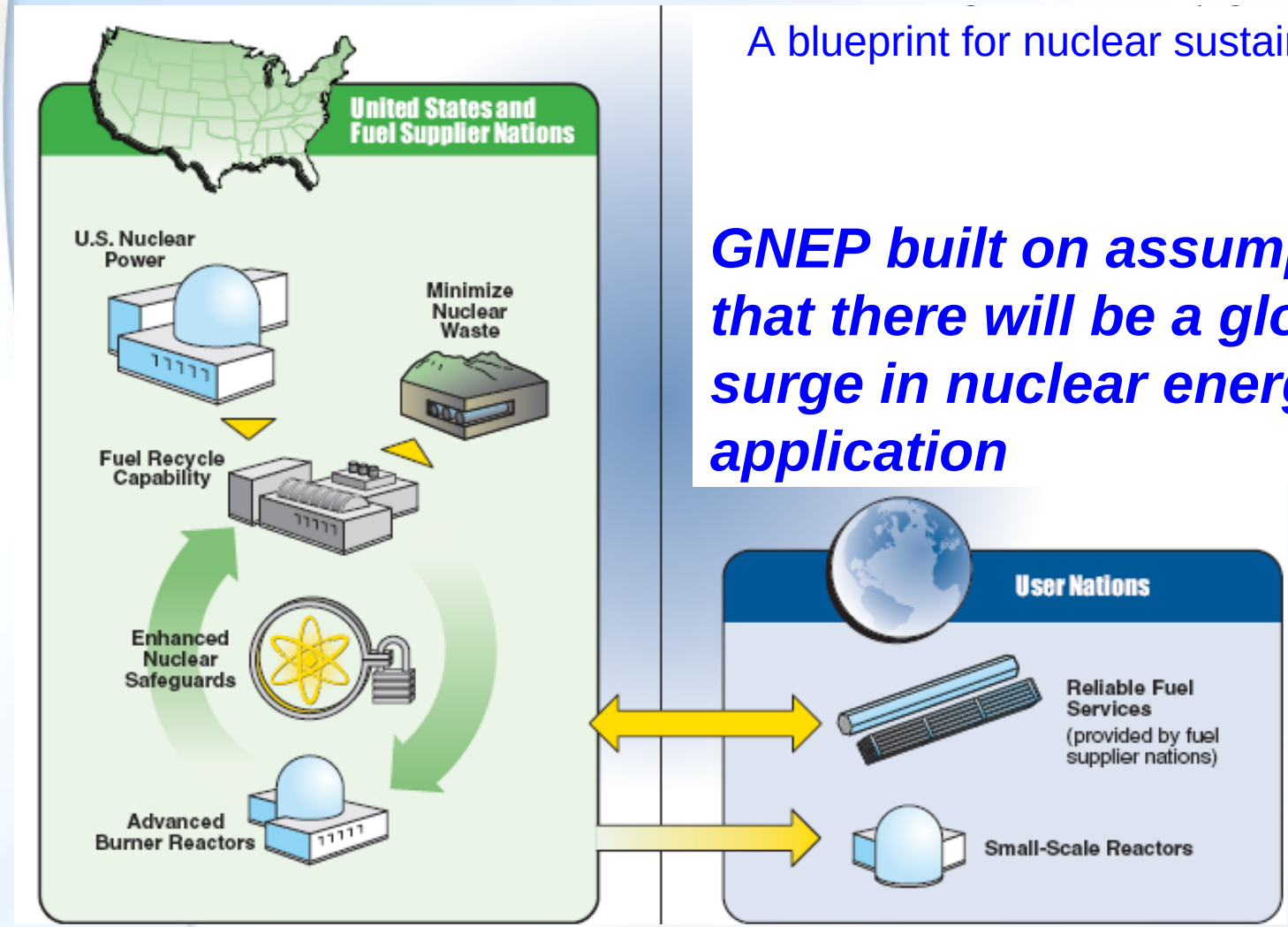


Excerpts from President Obama

- “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

Global Nuclear Energy Partnership (GNEP)



A blueprint for nuclear sustainability

GNEP built on assumption that there will be a global surge in nuclear energy application

Source: www.gnep.energy.gov

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 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)

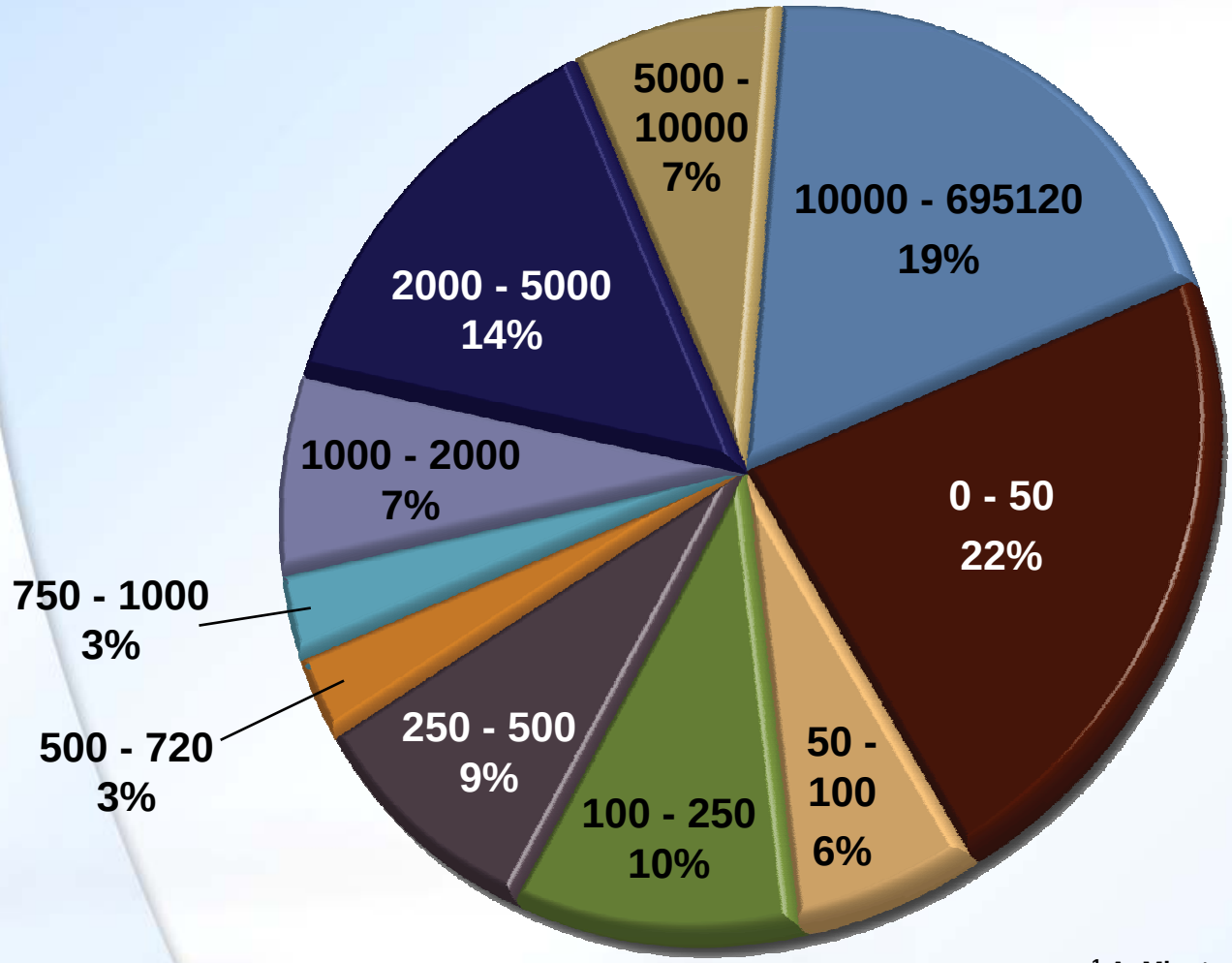
New Generating Capacity: 1992-2005	
Gas	**288,576 MW**
Renewables	9,983 MW
Coal	8,044 MW
Oil	4,933 MW
Hydro	2,629 MW
Nuclear	2,485 MW
Other	223 MW

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)



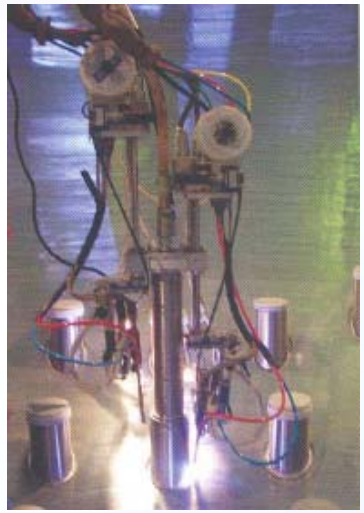
[1] A. Minato, CRIEPI

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

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

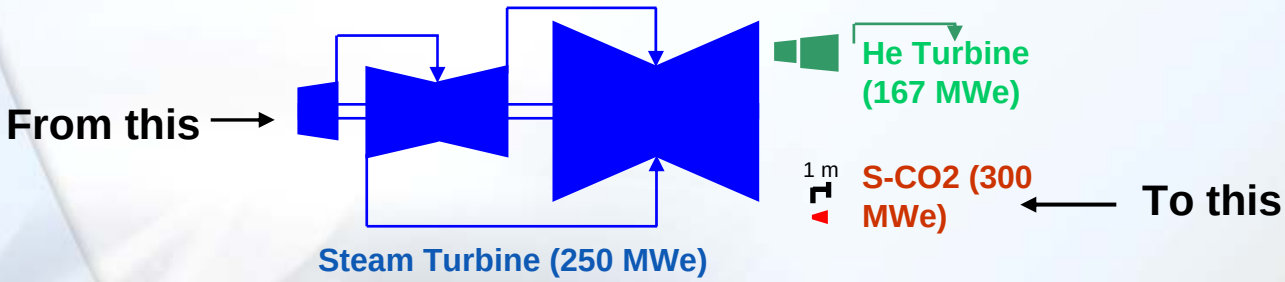
NC Horizontal Boring Machine

Dome Cladding Equipment

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

"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

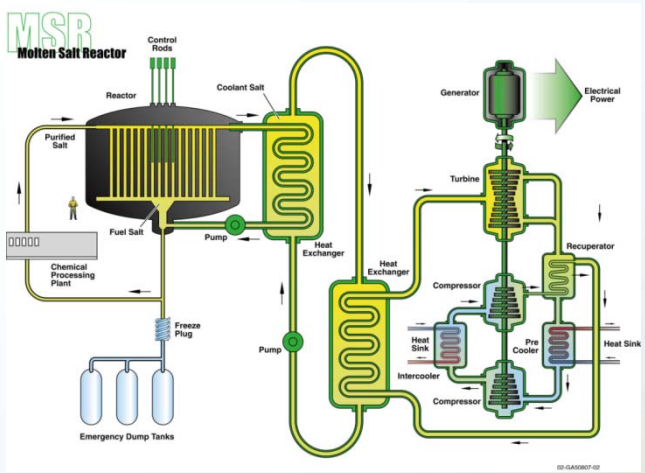
KLT-40 Russian Icebreaker Reactor (PWR,35 MWe, basic design for floating nuclear power plant)

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



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.
- Results in a truly renewable and affordable energy resource.

Building a Global Nuclear Future
"Global Challenges – National Needs"

- Enable the emerging world to access clean, reliable energy supplies to fuel their economies
- Create a global nuclear services supply system that provides the benefits of nuclear energy to nations while discouraging materials production of nuclear proliferation concern
- Create partnerships among nuclear power states to establish a new paradigm for incorporating advanced manufacturing and infrastructure technologies to improve safety, reliability and security of fuel cycle systems
- Provide a longer term foundation for creating nuclear systems that are twice as efficient, create 90% less waste and enable the cradle to grave export of small long-lived reactors to developing markets in the world
- Pursue a multi-national repository that provides significant safety, security, economic and non-proliferation advantages

Conclusions

- Energy is a key driver of world economic prosperity
  - Demand for energy and electricity will grow substantially over the coming years, especially in the developing world
- Nuclear power will be an important part of the global energy and electricity mix and a key asset in reducing global carbon emissions
- Science and technology supported by domestic and international policy cooperation, will enable nuclear power success

Questions?