The Promise of Small Modular Reactors

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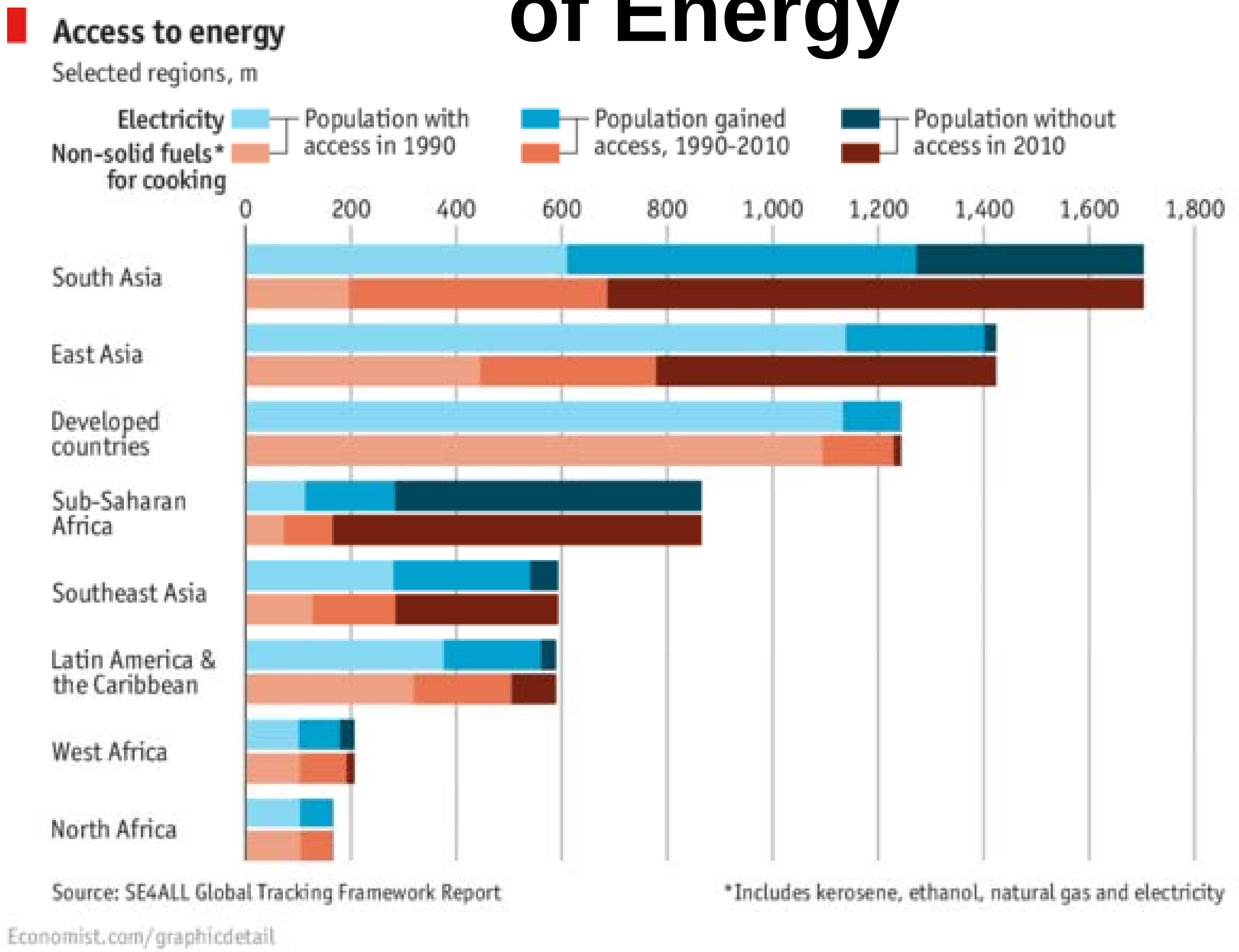
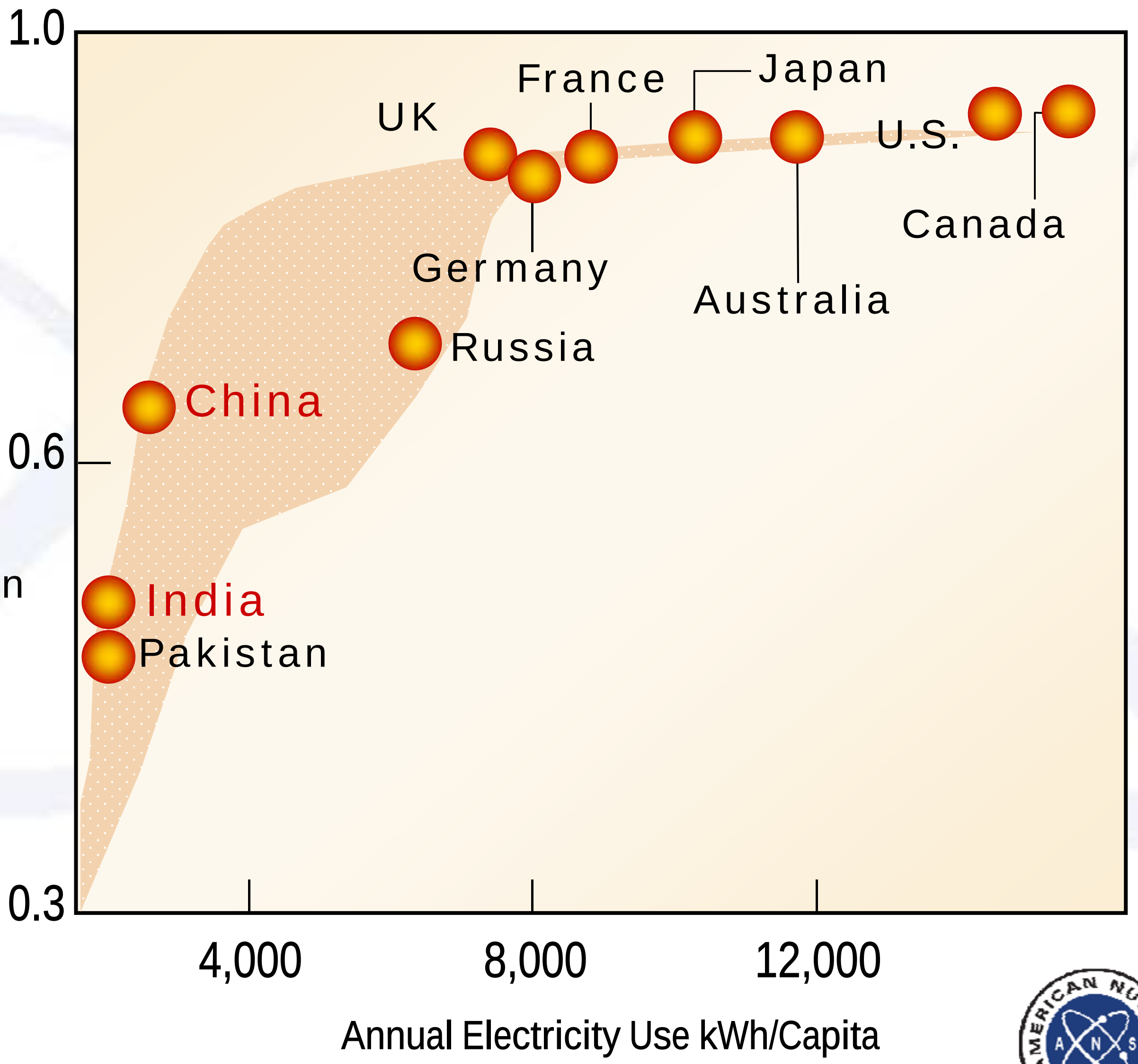
Clean, Reliable and Secure Source of Energy



Access to energy = quality of life



80% of the world's population is below 0.8 on the UN's Human Development Index (HDI)

Advantages of SMRs

- Have lower capital cost with reduced debt profile;
- Require shorter construction time;
- Are deployable in markets that cannot accommodate or afford large reactors;
- Meet some mission requirements for non-power applications;
- Provide electricity to remote populated areas.

SMRs can be used for specific low-carbon applications

- Scalable electricity generation;
- Scalable industrial applications, such as:
  - Electricity production for transportation,
  - Synthetic fuel production for transportation (high-temperature reactor designs),
  - Extraction of oil from tar sands (high-temperature reactor designs), and
  - Production of fresh water by desalination

“SMR technology incorporates the passively safe features so essential for new commercial nuclear”

“…will improve proliferation resistance and simplify the fuel cycle and waste management process.”

Testimony by Donald R. Hoffman as President, American Nuclear Society House Appropriations Subcommittee on Energy and Water Development On the FY 2015 Energy and Water Development Appropriations Bill April 11, 2014

“plug and play”

SMRs provide simplicity of design, enhanced safety features, the economics and quality afforded by factory production, and more flexibility (financing, siting, sizing, and end-use applications) compared to larger nuclear power plants.

Passive Safety - LWR Designs

- Low core linear power
  - – low fuel and clad temperatures during accidents
  - – lower flow velocities that minimize flow induced vibration effects
- Large coolant volume to core power ratio
  - – more time for safety system response during accidents
- No large pipes connected to RPV
  - – LB-LOCA eliminated by design

Passive Safety Features (cont'd)

- Small penetrations at high elevation
  - increased amount of coolant left in the RPV after a SB-LOCA
- Small penetrations
  - reduced rate of energy release to containment resulting in lower containment pressures
- Automatic Depressurization Valves
  - fast depressurization of the RPV to start
  - low-pressure injection

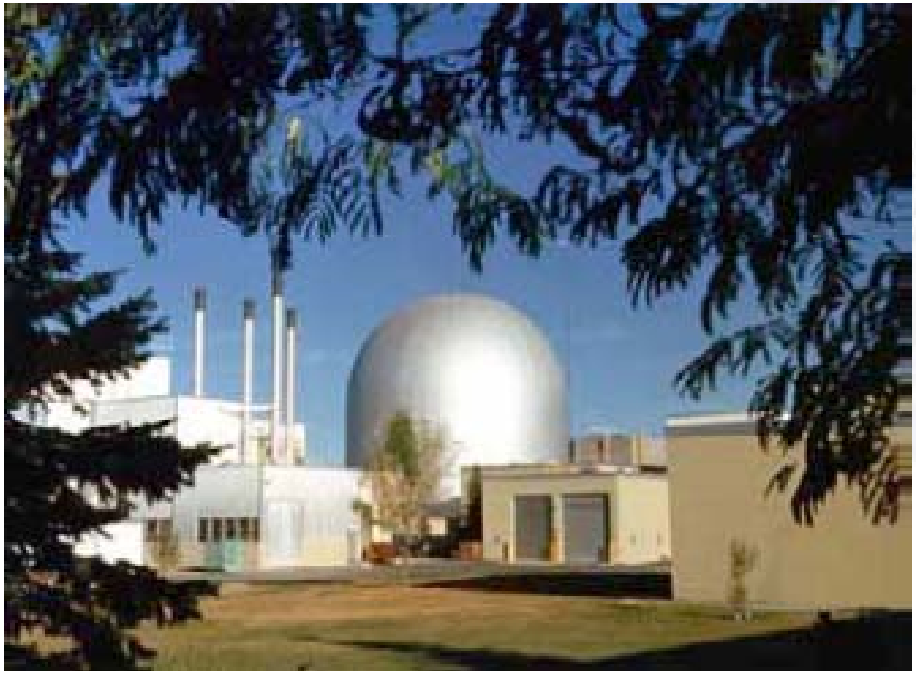
Safety and Nonproliferation

- Most SMRs will be built below grade for safety and security enhancements.
- Some SMRs will be designed to operate for decades without refueling.
- These SMRs would be fabricated and fueled in a factory, sealed and transported to sites for power generation or process heat, and then returned to the factory for defueling at the end of the life cycle.

US History with SMRs

- The United States has built small reactors since the 1950s with many land-based and sea-based platforms. These efforts have advanced the safety and security of light water–cooled, gas-cooled, and liquid metal–cooled SMR technologies

EBR-II
1964 — 1994



- Loss of Flow without SCRAM
- Loss of Heat Sink without SCRAM

LATIN AMERICAN SECTION * AMERICAN NUCLEAR SOCIETY *

AMERICAN NUCLEAR SOCIETY ANS

Early Naval Reactors

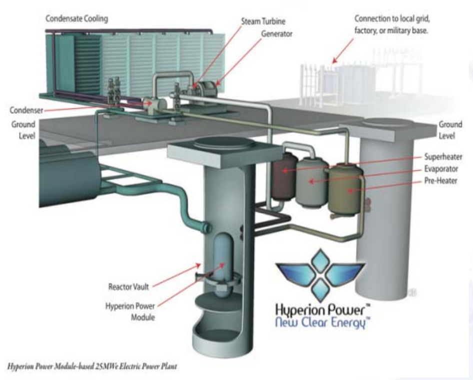
- The USS NAUTILUS (SSN-571), the world's first nuclear powered ship – a submarine – with her pressurized water reactor.
- The world's second nuclear powered submarine, the USS SEAWOLF (SSN-575), with the world's first operational sodium-cooled reactor.

Variety of SMRs under Development Today

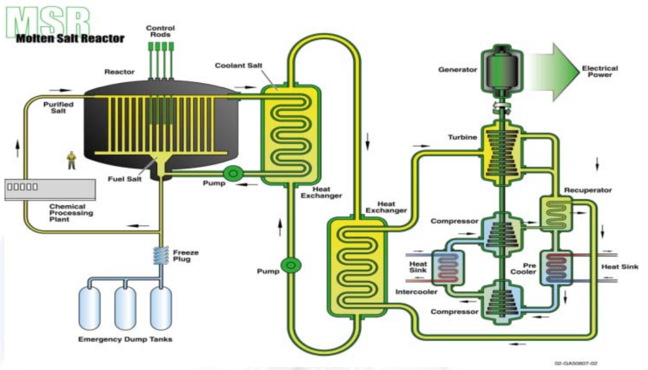
SMR – small and medium-sized reactors are generally 10 – 300 MWe

- Small light water reactors
- Sodium or lead cooled fast reactors
- High-temperature gas reactors
- Exotic designs - e.g. Traveling Wave

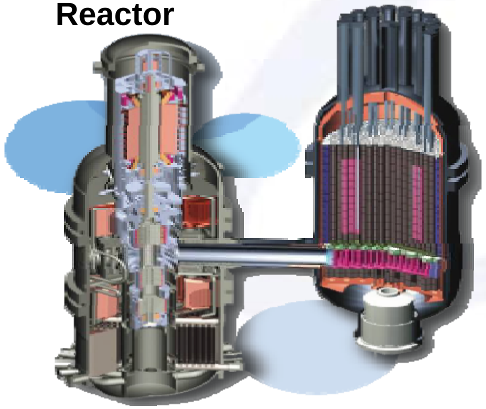
SMR Technologies in Use and in Development



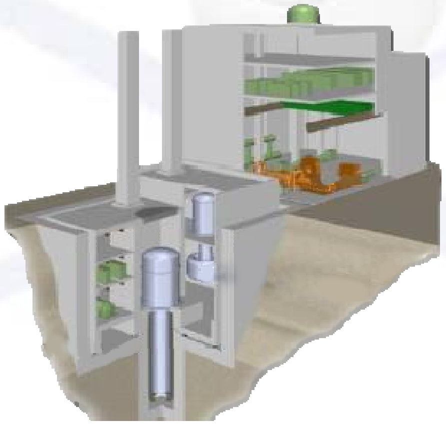
Hyperion Reactor



KLT-40 Icebreaker Reactor (35 MWe floating nuclear power plant)



General Atomics MHR



Toshiba 4S (10 to 50 MWe) Sodium cooled

PBMR (165 MWe)

“develop nuclear power systems that are suited for the global marketplace. More than 60 countries are actively seeking or have expressed interest in developing new nuclear energy generation capacity. At the same time, over 80% of the world’s power grids are not large enough to absorb a 1 GW class nuclear plant. That is where SMRs come into the picture.”

TESTIMONY OF Thomas L. Sanders

President American Nuclear Society

BEFORE THE HOUSE SCIENCE ANF TECHNOLOGY COMMITTEE

May 19, 2009

Sodium or lead cooled fast reactors

Small pool type reactors that operate at low pressures. Their fast neutron spectrum could allow for extended refueling intervals of up to 20-30 years. They have desirable safety characteristics, and when combined with advancements in turbine technology, can be operated in an extremely safe manner for long periods of time.

High Temperature Gas Reactors

"These proposed designs are generally optimized for process heat applications such as hydrogen production, water desalination, shale oil recovery. They could be located in industrial parks to offset the use of fossil fuels for process heat generation."

Exotic Designs

“While these innovative concepts will require longer-term research and development efforts, their simplicity of operation could provide "walk away safe" power to remote communities here in the US and around the world.”

ANS Leadership Role

- Established the ANS President's Special Committee on SMR Generic Licensing Issues (SMR Special Committee) in 2010.
- The importance of SMR development cited:
  - Job creation,
  - Potential opportunities to export SMRs as well as supporting technologies and services, and
  - Opportunities to incorporate proliferation-resistant features into SMR designs and manufacturing.

Areas of Concern Cited

ANS worked with experts in the U.S. nuclear industry, universities, national laboratories, and government agencies to identify key regulatory impediments in the areas of licensing, risk informed regulation, physical security, staffing requirements, which could hinder timely deployment of a new generation of SMRs, and offered consensus solutions to address them.

- Victoria K. Anderson, *Nuclear Energy Institute*
- Mike Anness, *Westinghouse Electric Company*
- Stephen Atherton, *General Electric Hitachi Nuclear Energy*
- Richard Barrett, *Advanced Systems Technology*
- *and Management*
- Edward Blandford, *University of California Berkeley*
- John Bolin, *General Atomics*
- Mark S. Campagna, *Hyperion Power*
- Han Kwon Choi, *URS, Washington Group*
- Michael Corradini, *University of Wisconsin*
- Richard Denning, *The Ohio State University*
- Thomas Fanning, *Argonne National Laboratory*
- Paul Farrell, *Radix*
- John Ferrara, *Babcock & Wilcox*
- Vince Gilbert, *Excel*
- Eddie Grant, *Excel*
- Tony Grenci, *Westinghouse Electric Company*
- Budd Haemer, *Pillsbury*
- Jeff Halfinger, *Babcock & Wilcox*
- Charles Hess, *The Shaw Group*
- Dan Ingersoll, *Oak Ridge National Laboratory*
- Andy Kadak, *Massachusetts Institute of Technology*
- Sergey Katsenelenbogen, *Advanced Systems Technology and Management*
- John Kelly, *Sandia National Laboratories*

- T. J. Kim, *Babcock & Wilcox Modular Nuclear Energy*
- Jim Kinsey, *Idaho National Laboratory*
- David E. Leaver, *Worley Parsons Polestar*
- Eric P. Loewen, *General Electric-Hitachi*
- Gary Mays, *Oak Ridge National Laboratory*
- S. Michael Modro, *International Atomic Energy Agency*
- Philip Moor, *High Bridge Associates*
- Tom Mulford, *Electric Power Research Institute*
- Robert Neibecker, *Bechtel*
- Scott Newberry, *Advanced Systems Technology and Management*
- Jim Powell, *Radix*
- Ted Quinn, *Longenecker and Associates*
- Ross Radel, *Sandia National Laboratories*
- William Reckley, *Nuclear Regulatory Commission*
- Jose Reyes, *NuScale*
- Roger Reynolds, *Terrapower*
- Doug Rosinski, *Ogletree Deakins*
- Steve Routh, *Bechtel*
- Walter Sawruk, *ABS Consulting*
- Finis Southworth, *Areva*
- Jon Thompson, *Nuclear Regulatory Commission*
- Ed Wallace, *NuScale Power*
- Ruth F. Weiner, *Sandia National Laboratories*
- Joe Williams, *Nuclear Regulatory Commission*

“SMRs have great potential to contribute to U.S. energy, economic and national security.”

TESTIMONY OF Joe Colvin, President American Nuclear Society BEFORE THE COMMITTEE ON ENERGY AND NATURAL RESOURCES, UNITED STATES SENATE June 7, 2011

they provide great operational flexibility. SMRs can be deployed in arid regions to produce large quantities of fresh water through desalination. They can be used as a heat source for industrial processes, including hydrogen production, fertilizers, production of synthetic fuels and biofuels. They can be deployed in remote areas to produce energy for towns and military installations as well as heat for mining operations and unconventional oil recovery.

SMRs could be an attractive alternative for smaller U.S utilities, especially in the Midwest, who seek to replace their old, coal-fired generating stations because of environmental considerations. These facilities would already have the necessary water, rail and transmission facilities and the necessary infrastructure, thereby simplifying the installation process.

ANS Position Statement 25

June 2011

- Expedite research on issues which must be addressed prior to commercial deployment of SMRs for flexible and scalable electricity generation applications
- Assisting in the identification and resolution of generic SMR licensing issues by establishing the most efficient and effective licensing approaches through interactions with all stakeholders and the NRC

Recommendations ANS PS25

- Encourage the development and deployment of multiple SMR designs as part of a balanced energy mix and expand their use beyond electricity generation,
- Participate in programs that demonstrate the feasibility of multiple SMR designs and approaches to reduce the time to market, and

Recommendations ANS PS25

- Encourage increased manufacturing/export technology capability in the United States for both domestic deployment and worldwide export within the “123 Agreement Framework”3 in order to increase the use of nuclear energy as part of a balanced energy mix.

Advantages and Opportunities

- Many of the SMR designs offer passive safety, resilience, flexibility and nonproliferation attributes.
- SMRs support a significantly reduced GHG emission energy production– clean energy.
- Fuel can be supplied by the existing fuel fabrication supply chain with long refueling cycles.

Challenges

- Licensing of the reactors, in spite of similarities to currently operating LWR reactors, must be successfully and swiftly accomplished.
- Some open supply chain issues need to be resolved.
- First of a kind costs are expected to be high, deployment of Nth of a kind (NOAK) reactors is key to the overall business case.

Symposium Topics

- National and International Programs
- Power Production
- Naval Propulsion
- Fuel Cycle
- Licensing Aspects
- Modular Construction

Path Forward for SMRs

- Ensure licensing and deployment
- Consider innovative financing and investment mechanisms.
- Examine new models that match an emerging new electricity marketplace
- Examine the benefits of continued and robust public-private partnerships.
- Inform and educate about the benefits to the economy and society.

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