NUCLEAR ENERGY
Issues Associated with its Future Utilization

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January 2016
Issues Associated with the Future of Nuclear Power

- Public Understanding of the Importance of Limiting Carbon Emissions and the Vital Role of Nuclear Power
- Public Trust and Appreciation of Safety
- Nuclear Waste Management
- Competitiveness of Nuclear Power in Deregulated Electric Markets
Correlation Between Human Development Index and Per Capita Electricity Consumption, 2009

Per Capita Electricity Consumption (kWh) - Key World Energy Statistics, International Energy Agency (2009 data)
1.6 billion people have no access to electricity, 80% of them in South Asia and sub-Saharan Africa.

2.4 billion people burn wood and manure as their main energy source.

3 billion more people will be born by 2040.
Each New Decade is the Warmest
(from Somerville, November ANS Meeting)

- 2001-2012 even warmer. Every year warmer than 1990s average.
- 1990s even warmer. Every year warmer than 1980s average.
- 1980s warmest decade on record at the time.
Arctic Sea Ice Declined Dramatically
(from Somervile, November ANS meeting)
Percent who think Global Climate Change is Happening, 2014. Average 63%.
(Yale Project on Climate change Communication; Nov., 2015)
Percent who think climate change will harm future generations, 2014. Average: 61%
(Yale Project on Climate change Communication; Nov., 2015)
Adults who believe most scientists think global warming is happening, 2014
Average 41% vs 98% actual!
(Yale Project on Climate change Communication; Nov., 2015)
ENERGY IN THE U.S.

Estimated U.S. Energy Use in 2013: ~97.4 Quads

Source: LLNL. 2014. Data is based on DOE/EIA-0335(2014)-03, March 2016. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, and/or whose auspices this work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU equivalent values by assuming a typical fossil-fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-419527
CARBON EMISSIONS IN THE U.S.
Nuclear Energy

Plays an Important Role in US Energy Supply

• Nuclear power is a clean, reliable base load energy source
  – Provides 19% of U.S. electricity generation mix
  – Provides 61% of U.S. emission-free electricity
  – Avoids about 700 MMTCO₂ each year
  – Helps reduces overall NOx and SOx levels

• U.S. electricity demand projected to increase ~28% by 2040 from 2011 levels

• 100 GWe nuclear capacity - 99 operating plants
  – Fleet maintaining close to 90% average capacity factors
  – Most expected to apply for license renewal for 60 years of operation.

Source: Energy Information Administration
Quotes from recent James Hansen article

• Published in The Guardian, Dec 3, 2015
• “Nuclear will make the difference between the world missing crucial climate targets or achieving them.”
• “Policy must be based on facts and not on prejudice...Climate systems cares about greenhouse gas emissions – not about whether energy comes from renewable power or abundant nuclear power.”
• “Some argue that it is feasible to meet all our energy needs with renewables. ...[These] scenarios downplay or ignore the intermittency issue by making unrealistic technical assumptions and can contain high levels of biomass and hydro .. at the expense of true sustainability.”
• “Large amounts of nuclear power would make it much easier for solar and wind to close the energy gap.”
Integration of Renewable and Nuclear Power
Enables Carbon Reduction across the Energy Spectrum
(Under study in Japan, U.S., China)

• Hybrid Energy Systems
  – Focus on recognition that only Renewables, Nuclear and Hydro are clean energy sources available today.
  – Hydro can not expand significantly in the U.S. or Japan (?)
  – Emphasize integration of assets on a grid level
  – Recognize that a national grid must exhibit supply diversity and high levels of reliability

• Key Attribute
  – Designed to optimize contribution of both nuclear and renewable assets
  – Cleanly produce all needed electricity PLUS another asset in the industrial or transportation sector
Price Distribution in Current/Future Scenarios
(from Charles Forsberg, MIT, at ICAPP, 2016)
Schematic of a Hybrid Energy System
Clean Production of Hydrogen with Hybrid Energy Systems

Zero Emissions Heat Suppliers
- Nuclear & Clean Coal

Thermal Energy
- Thermal Energy Storage Buffer

Hydrogen & Oxygen Production
- \(O_2\)

Rankine & Brayton Power Cycles

Electricity Grid

Renewable Power Generation

Batteries

Petroleum & Biofuels Refineries

Industrial Hydrogen Users

Fuel Cell Vehicles
Public Trust and Understanding of Safety

• Public recognition of an independent regulator
• Open data sources on performance indicators
• Public discussion of the rationale used for relocations after Fukushima and the uncertainties in that action
• A strong INPO-like organization (JANSI?)
U.S. poll: Favorable to Nuclear Energy
(from Bisconti Research)
Aftermath of TMI

- Public support gradually increased
- INPO creation
  - JANSI in Japan??
- NRC role validated
  - Vastly strengthened safety regulations
Example of Publicly Available Performance Indicators

This indicator shows the total number of unplanned manual and automatic scrams at year-end.
PASSIVE SAFETY
Important to discuss in Japan???

• ACTIVE SAFETY
  - All LWRS in the world utilize active safety today
  - Reactors require prompt operator actions in an upset condition
    Correct actions typically needed in less than an hour
    Frequent drills with U.S. NRC to assure operator readiness to respond
    Additional equipment procured to address Station Blackout (U.S. and Japan)
    Failure to take prompt actions was a MAJOR contributor to Fukushima disaster

• PASSIVE SAFETY
  - Designed to avoid the need for prompt operator actions
  - Typically large quantities of stored coolant moved by gravity or convection
  - Some advanced reactors have inherent safety, no meltdown possible.
  - Passive safety can extend time for actions from hours to indefinite
  - Toshiba-Westinghouse AP1000 was first passively safe reactor certified
    No operator actions needed for 3 days.
Passive SMR Technologies
Should there be Interest in Japan??

Working definition of SMRs: reactor units with a nominal output of 300 MWe or less and able to have very large components or the entire reactor fabricated remotely and transported to the site for minimal assembly and timely operation.

Safety Benefits

- Very long coping times
  - NuScale passive safety yields unlimited coping times
- Passive decay heat removal by natural circulation
- Smaller source term inventory
- Simplified design eliminates/mitigates several postulated accidents
- Below grade reactor siting
- Potential for reduction in Emergency Planning Zone
- Inland siting to avoid all tsunami concerns
In 2012, DOE initiated a 6-year/$452M program to provide financial assistance for design engineering, testing, certification and licensing of promising SMR technologies with high likelihood of being deployed at domestic sites in the mid-2020’s.

Commercial SMR development is being accelerated through public/private arrangements with 50% cost share provided by U.S. industry partners.

Site permitting and licensing activities are in progress:

- U.S. Government Interagency Agreement for the Tennessee Valley Authority’s Clinch River Site -- Developing Early Site Permit (ESP), expected mid-2019; Cost-shared 50/50
- Second NuScale Cooperative Agreement -- NuScale to partner with a utility to explore siting SMR on or near Idaho National Laboratory; Site-related activities needed to develop license application; Cost-shared 50/50
National Path Forward on Nuclear Waste

• Yucca Mountain required by Nuclear Waste Policy Act Amendments of 1987
  – Not chosen through a scientific or consent process
  – Opposed in Nevada and effectively blocked

• Obama Administration recognized need for alternative approaches
  – Blue Ribbon Commission formed
  – Impasse continues
Blue Ribbon Commission Report
(issued January 2012)


2. A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.

3. Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.

4. Prompt efforts to develop one or more geologic disposal facilities.

5. Prompt efforts to develop one or more consolidated storage facilities.

6. Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available.

7. Support for continued U.S. innovation in nuclear energy technology and for workforce development.

8. Active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns.
Key Elements of Administration’s Used Nuclear Fuel and High Level Waste Strategy

- System Design
  - Pilot interim storage facility
  - Consolidated interim storage facility
  - Geologic repository
  - Transportation system designed, regulated, and executed for safe and secure interstate shipping

- Consent-based Facilities Siting
  - Agreement at multiple jurisdictional levels
  - Open and transparent communication of benefits and risks
  - Mutually agreed upon off-ramps

- Governance & Funding
  - A new organization, empowered with the authority to succeed
  - Timely access to sufficient funding
  - Fees collected; applied to their intended purpose
Choice of Open vs. Closed Fuel Cycle

• Open Cycle chosen for U.S. in near term
  – Many sites suitable for geologic repository in U.S.
  – Strong U.S. research program in reprocessing
  – U.S. could revisit their choice, but after a repository is operational (in my view)

• Closed cycle chosen for Japan
  – “Complex” history for Rokkasho
  – Very large quantities of separated plutonium
  – Ongoing search for possible repository sites

• Decision Drivers
  – Different Countries may make different choices
  – Economics may drive decision
    • Economics of repositories, fuel resources, and reprocessing.
Regulated vs De-regulated Markets

• Regulated Markets
  – Public Utility Commissions control price and supply
  – PUCs can take a long term view of grid reliability and cost of electricity.

• De-regulated Markets
  – In theory, increase competition and lower prices
  – Consumers can choose their providers
  – Consumers and shareholders focus on short term costs and profits
Deregulation in Texas

• Cost benefits have not been realized
  – In general, all electricity prices have decreased.
  – In 10 years pre-deregulation, Texans paid 6% below the national average.
  – In 10 years post-deregulation, Texans paid 8.5% above the national average

• Areas of deregulation have paid more
  – Comparing Texans in deregulated vs regulated areas, a typical household lost $4500 since 2002.

Source: Texas Coalition for Affordable Power
Status of U.S. Deregulation
Investment Considerations in Regulated vs De-Regulated Markets

• In a regulated environment, long term system planning drives investments
  – System expansion is viewed from a long term cost and reliability perspective
  – Utilities can be confident of Return on Investment as long as they control costs of the construction of new assets.

• In a de-regulated environment, electricity spot prices drive investment.
  – Impossible to accurately predict long term spot prices.
  – Utilities emphasize quick, cheap construction of generation assets to satisfy shareholders.
Externalities of Nuclear Power not valued in Deregulated Markets

• Zero carbon generation
• Very high reliability
• Fuel Diversity
• Non-proliferation benefits
Challenges to Nuclear Power in U.S.

• Declining power demand in many regions
• Renewable mandates in many states
  – Very few states include nuclear in the mandate
• Federal renewable production tax credits
• Very low natural gas prices and easy construction
• De-regulated markets only value spot pricing.
• Very high capital costs with long construction times.
Challenges and Changes to U.S. Nuclear Fleet

“Nuclear plants are under increasing economic pressure to close as a result of record low capacity prices.......... Losing these plants has long-term implications both to the reliability of the system and on the nation’s emission profile.“
Federal Energy Regulatory Commissioner Moeller, April 2015

• Discussions continue on how to value the benefits of nuclear energy in electricity markets. Some market failures have led to plant closings.
  – Vermont Yankee permanently shut down December 2014
  – Fifth reactor closed since January 1, 2013

• OECD/NEA study (2012): Introduction of additional renewables will impact nuclear by reducing load factors and electricity prices.
  – 10% market penetration for wind results in ~24% reduction in nuclear profitability
Action to Address Market Issues

• State policies
  – Illinois legislature considering low carbon portfolio standard to recognize nuclear attribute
  – New York completed a power purchase agreement to allow Ginna plant to continue operation

• Market changes
  – PJM redefined capacity market to value fuel availability

• EPA Clean Power Plan
  – Will require states to meet GHG emissions reductions
  – Policies to do this should value nuclear
Cost of U.S. Electricity Production Operations, Maintenance and Fuel Only

U.S. Electricity Production Costs
1995-2014, In 2014 cents per kilowatt-hour

Production Cost = Operations and Maintenance Costs + Fuel Costs.
Production costs are based on FERC filings submitted by regulated utilities and do not include some costs such as capital and indirect costs. Production costs are modeled for utilities that are not regulated.

Source: ABB Velocity Suite
Updated: 5/15

NEI Nuclear Energy Institute
# 2002-2014 Trends in U.S. Nuclear Plant Costs

(2014 $ per MWh)

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<th>Year</th>
<th>Fuel</th>
<th>Capital</th>
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<th>Total</th>
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<td>7.17</td>
<td>8.18</td>
<td>20.92</td>
<td>36.27</td>
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<tr>
<td>2002-2014 Increase</td>
<td>25%</td>
<td>109%</td>
<td>13%</td>
<td>28%</td>
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<td>2009-2014 Increase</td>
<td>21%</td>
<td>-8%</td>
<td>2%</td>
<td>3%</td>
</tr>
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</table>

*Source: Electric Utility Cost Group (EUCG)*
Drivers of Nuclear Electricity Cost Increases

- Capital expenditure on upgrades for license extension
- Capital expenditure on uprates
- Capital expenditure on safety-related upgrades (past: vessel-head replacement; future: hardened/filtered vents)
- Security-related upgrades
Global Demand for Nuclear Energy Continues

Sanmen Source: SNPTC
Summer Source: SCE&G
Vogtle Source: Georgia Power Co.

• Key Drivers:
  • Long-term energy supply/energy security
  • Clean, base-load source of energy
  • Significant source of jobs and economic benefit
Thanks for your Attention

• My contact Information
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• One of my prime sources and colleagues is Ed Kee
  – Ed is owner of Nuclear Economics Consulting Group
  – Ed has written many commentaries on economic issues of nuclear energy including deregulation
  – Ed’s commentaries are translated into Japanese by JAIF.
  – Ed’s commentaries are at http://www.jaif.or.jp/necg-commentary-series/#nucleareconomics