The 21st Century Commercial Case for GEN IV: A Utility-Informed Perspective on Advanced Nuclear Generation

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12th INPRO Dialogue Forum
Vienna, Austria
April 15, 2016
EPRI...Born in a Blackout

- Independent, nonprofit center for collaborative public interest energy and environmental research
- International membership funds ~25% of EPRI research (40% for nuclear sector)
- EPRI programs engage ~80% of nuclear operators worldwide
- EPRI members generate more than 90% of the electricity in the U.S. (100% of nuclear)
EPRI Perspective on the 21st Century Role for GEN IV

- Maintaining nuclear role in 21st century will be challenging in terms of scale and timing for meeting:
  - generation capacity needs
  - emission targets
- GEN IV can/should complement GEN III/III+
  - no Generation IV without healthy Generation II/III/III+
  - GEN II/III will continue to provide nuclear generation backbone through 2100
- Sustained future role for nuclear energy will require more compelling business case(s) derived from GEN IV attributes:
  - enhanced passive safety from inherent physical properties of design
  - natural resource amplification via high conversion or breeding
  - asset flexibility: deployment, operations and products

Compelling commercial drivers and owner-operator requirements have not been clearly articulated.
Robust International Market for New Nuclear

- ~67 GWe under construction, including non-LWRs
- Operation of new plants will span the 21st century
- BUT...challenging market, regulatory and policy environments are placing nuclear at risk in some places...

### REACTORS UNDER CONSTRUCTION BY COUNTRY

<table>
<thead>
<tr>
<th>Country</th>
<th>Capacity (MWe)</th>
<th>Reactors</th>
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</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>25</td>
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<td>Belarus</td>
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<tr>
<td>United States</td>
<td>5633</td>
<td>5</td>
</tr>
</tbody>
</table>

**Total = 68**

### REACTORS UNDER CONSTRUCTION BY TYPE

- PWR, 57
- PHWR, 4
- HTGR, 1
- FBR, 2
- BWR, 4

Source: IAEA PRIS Database. Updated 29 Sept 2015
Global Energy Demand

Source: IEA, Energy Technology Perspectives 2015.
Global Energy Demand: Looking Ahead to 2050

Globally: 18% increase in energy use and shift to decarbonization – 8% decrease for developed countries – 41% increase for developing countries.

Source: IEA, Energy Technology Perspectives 2015. 2050 Projection Assumes +2C Scenario, 662,863 PJs Total Energy Demand.
Global Electricity: A Look to 2050

Globally: 76% increase in electricity and shift to decarbonization – 17% increase for developed countries – 128% increase for developing countries.

Source: IEA, Energy Technology Perspectives 2015. 2050 Assume +2C Scenario.
The Commercial Environment for Nuclear is Changing

- Developed energy markets must adapt large, aging infrastructures to maintain adequate energy and capacity.
- Developing energy markets face challenge and opportunity of “clean slates” and new choices.
- New paradigms for operating, maintaining power system:
  - flexibility
  - resilience
  - connectivity
- Uncertainty is only certainty:
  - price of natural gas?
  - price of carbon emissions?
  - new technology (or lack thereof)?
One Size Does NOT Fit All…

- Energy policy, market conditions, energy needs vary by country, region
- Business case for advanced reactors and other technology will vary accordingly
- What makes sense for France, UK, South Korea may not translate to U.S.
- What works for the southeastern U.S. may not work for the Northeast

Basis for retail electricity prices varies by U.S. region

EPRI REGEN Model, 2012
Market Environment for Nuclear in U.S. is Challenging

- Recent closures (-5)
  - Crystal River, FL
  - Kewaunee, WI
  - San Onofre, CA (2)
  - Vermont Yankee, VT

- Announced Closures (-3)
  - FitzPatrick, NY
  - Oyster Creek, NJ
  - Pilgrim, MA

- Additional At Risk (-11)*
  *Per Inside Climate News, 2015

- New Plants (+5)
  - Vogtle, GA (2)
  - V.C. Summer, SC (2)
  - Watts Bar, TN (1)

The Math: \(104 - 5 - 3 - 11 + 5 = 90\) operating units?
Uncertainty from Disruptive Competition, Distributed Generation, and Regulation

Green = Good
Red = Bad
Blue = Extreme

Contributing Factors
- Early retirement of fossil plants
- Renewable portfolio standards take effect in 2025 to 2030
- Modest growth in demand
- Continued lowering cost of renewables as technology improves

Program on Technology: Fossil Fleet Transition with Fuel Changes and Large Scale Variable Renewable Integration.
Utilities want and need future options for intensive low carbon energy
Many plans and projections assume 80% of existing LWRs operate to 80 years

$2 trillion in coal and nuclear generation at risk in the United States.
Meeting U.S. Emission Goals Gets Harder Without Nuclear

Note: US-REGEN. Does not include CPP but does reflect other recent EPA regulations.
Growing Need for Flexible Operation of Current Nuclear Fleet with Increasing Renewable Penetration

- In the US, pre-planned and agreed upon power ramping:
  - Seasonal
  - Time-of-day
  - Time-of-week

- Extensive experience in France and Germany:
  - Primary and secondary frequency response
  - 2-5% rated power/min within a limited band

*Courtesy of E.ON Kernkraft*
GEN IV Fundamental Properties Drive New Opportunities for Economics, Flexibility and Safety

Data were assembled from various public sources.
Is Flexibility the Missing Link between Advanced Nuclear Developers and Customers?

- **Operational Flexibility**: operation under a wide range of external conditions:
  - maneuverability
  - fuel use
  - cogeneration
  - island operation

- **Deployment Flexibility**: deployment under a wide range of external conditions:
  - scaling
  - siting
  - construction

- **Product Flexibility**: diversification of revenue generating products:
  - electricity
  - process heat
  - radioisotopes
Cogeneration is Not New to Nuclear, Even in the U.S.

Diablo Canyon’s Desalination Facility to Help Fight California Drought

• PG&E enters five-year agreement with county
• Desalinated water to fight wildfires; other uses under study
• Integrated nuclear and desal facilities used in Japan, India and Kazakhstan

June 18, 2015—As California suffers through its fourth straight year of drought, increasingly severe shortages of water are raising alarms. The state has issued stringent water conservation measures for cities and towns as well as in the state’s vast agriculture industry.

San Luis Obispo County, on California’s Central Coast, has found an innovative way to supplement its rationed supply of fresh water. The Diablo Canyon Nuclear Power Plant has an on-site desalination facility that it uses to generate fresh water from seawater, both to cool the plant and for its employees’ drinking water needs.

NEI SmartBrief, June 18, 2015.

The Midland Nuclear Power Plant, abandoned at 85%, was converted to a combined-cycle, natural-gas-fired co-gen facility.

Storable Commodities and New Markets as Future Disruptive Opportunities for Advanced Nuclear

- Transportation accounted for 28% of US energy use in 2014, > 95% supplied by fossil fuel
- Hydrogen as new dominant energy carrier for transportation would:
  - displaced petroleum
  - avoid reliance on battery technology and side step electrification

Potable water as the “oil” of the 21st century
- 50% of world’s population within 200 km of coast
- fresh water comprises only 2.5% of earth’s water; of this only 1% is readily accessible for use
- trading of water as a commodity has begun

“Toyota sees great potential in hydrogen and fuel cell vehicles.”

http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/
Current Landscape and Notable Developments

- International progress: demos and prototypes
- In the United States:
  - Increasing private sector interest and investment (> $1 billion)
  - Attention and interest from environmental NGOs et al.
  - DOE / NRC joint project for non-LWR general design criteria development
  - Jan ‘16: Two DOE awards to industry-led advanced reactor design teams (5-year, up to $50 million, 80/20 cost share each)
- Need for options for replacement & new generation drives growing electric utility interest:
  - Mar ‘15 Nuclear Energy Institute launch of a utility-championed Advanced Reactor Working Group
  - Jan ‘16 launch of EPRI GEN IV strategic program

Unique opportunity exists to leverage public and private interest.
EPRI Has Established a Formal GEN IV RD&D Program

- Four-year commitment within a broader EPRI strategic focus on flexible, resilient and integrated energy infrastructures
- Vision: EPRI will play a leading role to enable commercialization of advanced nuclear generation in time and at scale to make a difference
- Key activities:
  - scout global development of GEN IV systems and enabling technologies
  - articulate owner-operator requirements
  - identify roles and opportunities for GEN IV as part of larger power and energy infrastructures
  - identify viable RD&D pathways to commercialization
  - provide independent, credible technology assessment methods, tools and analyses
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Compelling commercial drivers and owner-operator requirements need to be articulated.
First Task: Feasibility and Framework Development for a GEN IV Owner-Operator Requirements Document (ORD)

- Phase I: High-level review of the existing requirements for LWRs and other reactor technologies to determine applicability for a GEN IV ORD
  - Map high-level EPRI ALWR URD policies and requirements to a technology neutral framework (mostly Tiers 0 and 1)
  - Identify gaps due to technology neutral approach
  - Seek input on owner-operator expectations; technology attributes and requirements; and information needed by developers, vendors, constructors

- Value Proposition for a GEN IV ORD:
  - Provides extensive owner-operator input
  - Establishes early owner-operator buy-in
  - Stabilizes definitions for key attributes and requirements

- Initial emphasis on standardization and clarification of terms, attributes and requirements rather than prescribing them
  - Then design classes and variants (HTGR, MSR, SFR)
    - Eventually…specific designs
Together…Shaping the Future of Electricity