Advances in Nuclear Power Technology

STUDY BRIEFING

December 9, 2011
Study Committee

- **Michael F. Ahern** Vice President, Utility Services, Northeast Utilities
- **Donald W. Downes**, Chairman, DPUC (ret.)
- **A. George Foyt, ScD (Academy Member)**, Manager of Electronics Research, United Technologies Research Center (ret.)
- **Gale Hoffnagle**, CCM, QEP (Academy Member) Senior Vice President and Technical Director, TRC Environmental Corporation
- **Hanchen Huang, PhD**, School of Engineering Named Professor in Sustainable Energy, Department of Mechanical Engineering, University of Connecticut
- **Charles L. Kling, PhD (Academy Member)**, Consulting Engineer, Westinghouse Electric Company, LLC
- **Lee S. Langston, PhD**, Study Committee Chairman (Academy Member), Emeritus Professor of Mechanical Engineering, University of Connecticut
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- **Harris Marcus, PhD (Academy Member)**, Director, Institute of Materials Science, University of Connecticut
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- **Kevin McCarthy**, CT Dept. of Environmental Protection (ret.)
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- **Sara Rockwell, PhD (Academy Member)**, Professor of Therapeutic Radiology and Pharmacology Associate Dean for Scientific Affairs, Yale School of Medicine
- **John (Jack) M. Tuohy Jr., PE**, Executive Director, Nuclear, Hitachi Power Systems America, Ltd.
- **Edward L. Wilds, Jr., PhD**, Director, Division of Radiation, Bureau of Air Management, Department of Environmental Protection
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- **Study Management Team**
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  - Tom Filburn, PhD, Professor of Mechanical and Biomedical Engineering, University of Hartford

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  - Terri Clark, Associate Director
  - Ann Bertini, Assistant Director for Programs
Peter Cable, PhD, Applied Physical Sciences Corporation
John Cagnetta, PhD, Northeast Utilities (ret.)
Sten Casperssson, Westinghouse Electric Company
Study Background

- CEAB requested that CASE perform a study on advances in nuclear power technologies to inform and assist the state’s leadership in making decisions that are in the best interest of Connecticut citizens with regard to the use of nuclear power in the 21st century and beyond.

- Study Scope based on work items identified by the CEAB including items in the CEAB 2010 Integrated Resource Plan (IRP) - Nuclear Power Section:
  - Current Status of Nuclear Energy in Connecticut
  - Fuel Security
  - Safety Concerns
  - Environmental Issues
  - Nuclear Proliferation
  - Financing & Schedule Risks of Planning & Constructing a Nuclear Plant
Two sub-studies were conducted as part of the larger study

- Detailed *Economic Impact Analysis* by the Department of Economic & Community Development with support from CERC. Provided an assessment of the economic and fiscal impacts of replacing or adding baseload generation in Connecticut
  - Replacing existing nuclear unit(s) at Millstone with a 1,000 MWe nuclear or CCGT plant
  - Adding a 1,000 MWe nuclear or CCGT plant at Millstone or CT Yankee sites

- *Benchmark Survey* by the Connecticut Economic Resource Center (CERC) of 600 Connecticut residents on their attitudes about nuclear power
Video Recordings of Presentations

- **The Uncertain Future of Nuclear energy after Fukushima**: Professor Frank von Hippel; May 10, 2011
- **About mPower Reactor Technologies**: Jeff Halfinger, Babcock and Wilcox Company; February 4, 2011
- **An Industry Perspective on Closing the Nuclear Fuel Cycle**: Mr. Paul Murray, AREVA; February 4, 2011
- **Nuclear Power in the United States**: Dr. Pete Lyons, Acting Assistant Secretary for Nuclear Energy, U.S. Department of Energy; January 18, 2011
- **Advances in Nuclear Power Technologies Study Committee Meeting**: October 18, 2010
  - **Dry Spent Fuel Storage**: Bernie White, Technical Assistant, Division of Spent Fuel Storage and Transportation, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission
  - **New Reactors: NRC Plans, Process & Progress**: Joe Colaccino, Chief, EPR Projects Branch, Office of New Reactors, Nuclear Regulatory Commission
  - **Atlantic Compact Commission: Update on Activities from 2000 through 2010**: Max Batavia, Executive Director, The Atlantic Interstate Low-Level Radioactive Waste Compact
  - **Low Level Radioactive Waste Disposal**: Kevin McCarthy (*Study Committee Member*) Atlantic Compact Commissioner for Connecticut

Video Recordings Provided by: Office of Research and Materials, Connecticut Department of Transportation
Recordings will remain accessible on ConnDOT Website as part of the official record of this study
Overview of Nuclear Power
Advances in Nuclear Power Technology
Economic Impact Analysis
Survey Results
Findings and Recommendations
Primary Conclusion

- Nuclear power currently provides approximately 50% of Connecticut’s electricity and has been the primary source of emission-free electricity generation since 1970.

- Operating licenses of the two existing nuclear power plant units in Connecticut—Millstone Unit 2 and Unit 3—have been extended to 2035 and 2045, respectively.

- Many years of planning and approvals would be required for their replacements.
Benefits of new or replacement nuclear power generating units in Connecticut are:

- Lower-cost baseload generation by replacing marginal cost electricity generators
- Emission-free electricity generation
- Fuel diversity in the ISO-New England Region
- Creation of new jobs by expanding the highly trained workforce required to safely operate nuclear power plant units
To achieve these benefits

- **Nuclear industry must successfully demonstrate that:**
  - Nuclear power plants can be constructed and delivered on budget and on schedule using advanced construction and modular manufacturing techniques
  - New and current nuclear plants can be operated at a high level of safety and security

- **State’s leadership needs to:**
  - Aggressively demand that the federal government meet its legal obligations regarding spent nuclear fuel by expeditiously providing storage, geological disposal, and funding of nuclear waste management
Types of Reactors Operating, Being Built, or Under Development

- **Light Water Reactors (operating)**
  - Generation II
    - Boiling Water Reactors
    - Pressurized Water Reactors

- **Generation III and III+ Reactors (being built)**
  - Active Safety Systems
  - Passive Safety Systems

- **Small Modular Reactors (under development)**

- **Generation IV Reactors (potentially ready >2030)**

Source: Babcock and Wilcox mPower SMR
World Status of Nuclear Power Plants

- 443 nuclear reactors operating worldwide in 29 countries (~16% of electricity generated) *** Note: stats prior to Fukushima incident

- 104 nuclear reactors operating in U.S. in 31 states (19.6% of electricity generated)

- 64 new nuclear reactors under construction in 15 countries

- 5 new nuclear reactors under construction in U.S.
  - Watts Bar 2 (TVA)
  - Vogtle 3&4 (Southern Nuclear)
  - V.C. Summer 2&3 (SCANA)

- U.S. lifetime extensions (20 years)
  - 66 approved by US NRC
  - 16 filed for approval
  - 20 more expected to file
U.S. Power Reactors in Operation (104 mostly in Eastern States)

Source: U.S. Nuclear Regulatory Commission (NRC)
Coal 74%
Gas CC 42%
Wind 25%
Solar 17%

Source: Energy Information Agency (EIA), U.S. DOE
EIA definition of Capacity Factor: The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period.
Comparison of Production Costs in U.S. by Fuel Type

U.S. Electricity Production Costs
1995-2009, In 2009 cents per kilowatt-hour

- 2009
  - Coal - 2.97
  - Gas - 5.00
  - Nuclear - 2.03
  - Petroleum - 12.37

Source: Nuclear Energy Institute (NEI); Ventyx Velocity Suite, Update: 5/10
U.S. Nuclear Capacity Additions by Power Upgrades

Cumulative Capacity Additions at U.S. Nuclear Facilities
1977-2015

- Under Review and Expected: 3,384 MWe by 2015
- Approved: 5,842 MWe

Source: NRC
Significant Events at U.S. Nuclear Plants:
Annual Industry Average, Fiscal Year 1988-2009

Significant Events are those events that the NRC staff identifies for the Performance Indicator Program as meeting one or more of the following criteria:

- A Yellow or Red Reactor Oversight Process (ROP) finding or performance indicator
- An event with a Conditional Core Damage Probability (CCDP) or increase in core damage probability (ΔCDP) of $1 \times 10^{-5}$ or higher
- An Abnormal Occurrence as defined by Management Directive 8.1, "Abnormal Occurrence Reporting Procedure"
- An event rated two or higher on the International Nuclear Event Scale

Source: NRC Information Digest (1988 is earliest year data is available)
Where U.S. Gets Emission Free Electricity Today

Sources of Emission-Free Electricity 2010

- Solar, Wind, & Geothermal: 9.5%
- Hydro: 21.6%
- Nuclear: 68.9%

Source: NEI
Equivalent Land Area to Produce Same Power

Green Energy Footprints

To produce 1000 MWe, you would need...

Nuclear: 0.8 sq. miles
Solar: 19 sq. miles
Wind: 78 sq. miles
CO₂ Emissions per kWh Electricity Delivered to Household Customer

Source: Vattenfall CO₂ Life-Cycle Analysis
Advances in Nuclear Power Technology
New Reactor Designs with Active Safety Systems

• Rely on AC electrical power to power safety functions

• Utilize active pumps, valves, and support systems
  – Cooling water systems
  – HVAC systems

• Typically have 4 trains of mechanical safety systems
  – May have 2 or 4 trains of emergency electrical systems

• Core decay heat removal is provided by:
  – Steam Generators (via Emergency Feedwater System)
  – Residual Heat Removal System
  – Safety Injection System
  – Accumulators

• Containment heat removal is provided by Containment Spray System
New Reactor Designs with Passive Safety Systems

- Do not rely on AC electrical power to provide safety functions
  - Use natural forces of heat transfer, gravity, evaporation, etc.

- Use systems and water already inside the plant, e.g., inside containment, for core cooling and inventory control of reactor/fuel

- Containment heat removal by gravity feed, evaporation and/or air cooling

- Maintains safety functions for at least 72 hours without any operator actions
Comparison of Active & Passive PWR Safety Systems

Standard PWR (only 2 trains shown)

AP1000
Passive Safety – How it Works

- All water is already inside containment
- Motive forces are gravity, compressed air, DC batteries, & convective heat transfer
- Automatically actuates without the need of operator action
- Simple alignment of a few valves which fail in a safe position

AP1000 Reactor
Core Cooling & Inventory Makeup
Small Modular Reactors
Starting the Development Cycle

- Must overcome the economies of scale
- Must be water cooled for mid-term deployment
- Must be highly standardized and factory built to control cost and achieve quality
- Must have short construction schedule
- Must be rail shippable to be broadly accessible
- Must use passive safety systems
- Must have certain prescriptive regulations revised
- Must have smaller Emergency Planning Zone to site near load centers
Locations of Proposed New Reactors in U.S.

Source: NRC
Status of New Plant Licensing

New Reactor Licensing Applications
Schedules By Calendar Year

Source: NRC: UPDATED 10/11/11
Construction Projects Today
(Example: Westinghouse AP1000)

Vogtle Units 3 & 4 (Georgia)
Early Stage Construction
Vogtle Project Status

*Project is Meeting Schedule and is Under Budget*

- Contract signed with Westinghouse team in April 2008
- Received Early Site Permit and Limited Work Authorization in August 2009
- Commenced Site Excavation in August 2009; completed Unit 3 in February 2010 and Unit 4 in April 2010
- Construction of Containment Vessel Assembly Building and Concrete Batch Plant Underway
- Nuclear component manufacture well underway
- NRC construction and operating license approval expected in January 2012
- Commercial Operations scheduled for 2016 and 2017

Vogtle Units 3 & 4 located in Georgia near Augusta and Waynesboro
V.C. Summer Project Status

> 1 million project hours before 1st lost time accident

- Contract signed with Westinghouse team in May 2008
- Installed over 400 sections of circulating water system piping
- Erected administration buildings, warehouses, & engineering/project support buildings
- Erected concrete batch plant #1
- Started excavation of power block area in March 2010
- Nuclear component manufacturing underway
- NRC construction and operating license approval expected in January 2012
- Commercial Operations scheduled for 2016 and 2018

V.C. Summer plant located in Columbia, South Carolina
Construction Projects Today
(Example: Westinghouse AP1000: 4 Units in Construction in China)
Sanmen Nuclear Power Station: Unit #1
Sanmen County, Zhejiang Province, China

- Containment Vessel Ring #1 (3/18/10)
- CA01 Module Placement (3/27/10)
- Reactor Vessel On Site (7/11)
- Containment Vessel Ring #4 (12/10)
What Is Different Today?

• Deployment of only standard plant designs
• Modern designs that utilize passive safety systems
• Designs that are complete before construction begins
• Incorporation of the lessons learned from past 3 decades
• Pre-licensed designs by NRC
• Government support for first movers (loan guarantees, standby support for regulatory delays not caused by the project, production tax credits because emission-free)
• Contracting structure where majority of risk is on suppliers
• Parallel module fabrication and site assembly/erection
• Modern construction techniques with advanced computer tools
Module Manufacturing & Site Assembly

Modular construction:
1. Parallel activities on site and in fabrication areas
2. Safer and higher-quality work in shops
3. Improved site productivity by lowering number of workers “in the site construction hole”

4. Onsite Assembly
   Building allows construction in all weather conditions

5. Vertical assembly
   minimizes complex lifts

Parallel Path
Activities
Example of Module Design & Construction

*Westinghouse AP1000*

*Generation III+ Nuclear Power Plant*

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Number</th>
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<tr>
<td>Structural</td>
<td>122</td>
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<tr>
<td>Piping</td>
<td>154</td>
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<tr>
<td>Mechanical Equipment</td>
<td>55</td>
</tr>
<tr>
<td>Electrical Equipment</td>
<td>11</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>342</strong></td>
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Modules Designed into AP1000
Large Structural Modules
Location in AP1000 Plant

- Auxiliary Building
- Containment Shield Building
- CA20
- CA01
CA20 comprised of 72 Sub-Modules:

Size (N x E x Height):
44’-0” x 68’-9” x 68’-0”

Dry Weight:
1,700,454 lbs.

Classification:
Seismic Category I

Installation of CA20 Module
CA01 Module Assembly
Steam Generator and Refueling Canal Module

CA01 comprised of 47 Sub-Modules:
Size (N x E x Height):
92'-0” x 96'-0” x 76'-0”
Dry Weight:
1,600,000 lbs. [725 Mg]

Installation of CA01 Module
THE GREAT EAST JAPAN EARTHQUAKE
Fukushima Incident: What Happened?

Fukushima Plant Before Earthquake/Tsunami
THE GREAT EAST JAPAN EARTHQUAKE
Fukushima Incident: What Happened?

Fukushima Plant After Earthquake/Tsunami
GENERAL PERSPECTIVE ON SCOPE OF DAMAGE FROM EARTHQUAKE/Tsunami in Japan – Not Related to Fukushima Incident

- ~25,000 people died
- 200 square miles destroyed (500,000 homes destroyed)

PERSPECTIVES ON FUKUSHIMA INCIDENT AS A RESULT OF THE EARTHQUAKE/Tsunami

- Fukushima reactors are all BWRs (BWRs not in use in Connecticut — Millstone reactors are PWRs)
- 9.0 magnitude earthquake followed by >14 m Tsunami (~50 minutes later) — both beyond design basis for nuclear power plants
- All reactors automatically shut down upon earthquake; all safety systems actuated properly
- Tsunami “knocked out” all off-site and on-site AC power – disabling safety systems
- DC batteries dissipated in ~8 hours
- Reactor heated up and water pressure relieved to suppression pool, reducing inventory in core
- Fuel cladding oxidized, lost integrity and generated H₂ by exothermic reaction with water
- Hydrogen explosions in spent fuel area caused most of structural damage (vent path from primary containment)
- Radioactivity released through vents and breach of 1 unit’s containment
- Over 70,000 people evacuated from area rapidly
- Land contamination in surrounding area
**THE GREAT EAST JAPAN EARTHQUAKE**

Potential Implications of the Fukushima Incident

- Displacement of local residences for extended period within evacuation zone
- Loss of existing nuclear capacity in Japan, Germany, and maybe elsewhere
- Financial disaster to TEPCO (Japanese utility)
- Reduced number of new reactors in future plans, including Japan
- Vulnerability analyses – exceeding design bases throughout the nuclear industry
- Potential backfits to operating reactors, e.g., incremental seismic supports, seaside retaining walls, water tight doors, etc.
- Quicker transfer of spent fuel from on-site pools to dry storage
- Revised siting criteria for new plants
- Design enhancements to new plants to make them more robust, e.g., against loss of all AC power, flooding protection beyond design bases

![Dry Cask Storage of 25 Years of Nuclear Waste](image-url)
The Economic Impact of Nuclear Power Generation in Connecticut

By
Connecticut Department of Economic and Community Development
With the Connecticut Economic Resource Center

Stanley McMillen, Ph.D., Managing Economist
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Assessing Connecticut Residents’ Opinions of Nuclear Power

Phone Survey Results - December 2010

By

Connecticut Economic Resource Center
Alissa DeJonge, Director of Research
Study Issues

- Connecticut Electric Rates
- Need for Additional or Replacement Baseload Generation and Impact on Electric Rates
- Comparison of Baseload Alternatives
  - Nuclear Power & Natural Gas
- Advances in Nuclear Power
- Advantages of Nuclear Power
- Issues Facing Expansion of Nuclear Power in Connecticut
  - Disposal & Storage of Spent Nuclear Fuel
  - Financing of a 1000 MW Nuclear Power Plant
- Other Considerations
  - Nuclear Safety and Security
  - Nuclear Fuel Reprocessing
  - Siting
  - Energy Education & Public Acceptance
• State’s electricity rates have been the second highest in the country, after Hawaii, since 2007

• High energy costs were the most important issue mentioned in the study’s survey

• State’s high electricity rates must be dealt with at a regional level because wholesale market is administered by ISO-New England
Connecticut Electric Rates - *Findings*

- High electricity rates are likely caused by several factors
  - State does not have any indigenous energy resources
  - Connecticut legislation deregulated electricity industry requiring electric companies to sell their power plants and buy power on the wholesale market
  - Region’s dependence on natural gas results in these plants setting the price of electricity about 90% of the time
  - Connecticut does not have any natural gas resources — so it must be transported by pipeline from other parts of the United States & Canada — which adds cost to purchase of natural gas for generating electricity
  - Congestion of the electrical grid adds to the price of electricity, especially in the southwestern third of the state
  - Environmental regulations
  - State is relatively high-cost in terms of salary, taxes, & land
Connecticut Electric Rates Recommendation

- Changes are needed in the “deregulated” market so that replacement of inefficient electricity generating facilities or the addition of new in-state low-cost generation more fully translates into lower electricity prices that makes Connecticut more competitive in attracting businesses and creating jobs.
No clear indicators for the direction in long-term baseload demand in Connecticut or New England (i.e., need for new baseload generation)
ISO-NE analysis found that the replacement of marginal units with new low-cost plant will reduce electric rates

— Addition of 1000 MW of supply would save New England consumers $600 million a year (2005 $) and reduce wholesale electricity rates by 5.7% (ISO-NE, *Electricity Costs White Paper, June 2006*)
Need for **Replacement Baselload Generation - Findings**

- Status of existing New England electric nuclear capacity
  - Millstone Units 2 and 3 operating licenses extended from 40 to 60 years
    - Millstone 2 – 2035
    - Millstone 3 – 2045
  - Seabrook and Pilgrim are awaiting NRC action on requested 20-year operating license extensions
  - Vermont Yankee received a 20-year operating license extension but Vermont lawmakers are trying to shut down the plant
Other Factors Affecting Future Baseload Capacity - *Findings*

- Importation of new baseload generation from other regions or Canada
  - Need for more transmission capacity

- Distributed generation
  - Improved economics and reduced vulnerability could prompt a move toward distributed generation

- Two natural gas/low sulfur facilities of ~540 MW each are already in the permitting process and could be favorably positioned to respond to Connecticut RFP on new generation
Connecticut should be proactive in developing in-state electricity generating facilities

Potential benefits are:
- Lower electricity rates through lower generation and congestion charges
- Potential job creation from becoming exporter of electricity
Comparison of Baseload Alternatives - *Findings*

- **Nuclear Power – YES, if...**
  - Federal government meets its obligation for disposal/storage of spent nuclear waste

- **Natural Gas - YES**
  - Primary fuel for nearly all new generating capacity built in Connecticut and New England since electricity market deregulation

- **Coal - NO**
  - In general lower cost fuel option than natural gas
  - Primary fuel for generation in many regions of the U.S
  - Not considered a likely alternative because of stringent air pollution standards in Connecticut
Comparison of Baseload Alternatives - *Findings*

- **Solar and Wind - NO**
  - Not considered baseload sources because they generate electricity on an intermittent basis

- **Biomass (Solid Waste) - NO**
  - Six solid waste burning facilities in the state that generate about 160 MWe
  - Not enough solid waste to generate an additional 1000 MWe

- **Hydroelectric - NO**
  - Hydroelectric power generates 1.6% of state’s electricity
  - Future hydroelectric power will likely be small-scale run-of-the-river facilities because of environmental requirements
Comparison of Baseload Alternatives
Recommendation

➢ Nuclear Power versus Natural Gas

— Fuel diversity should be promoted by the state as both a strategy to stabilize electricity prices and a regional policy
Advances in Nuclear Power - Findings

- Passive safety systems that operate without auxiliary AC power (either off-site or on-site)
- Deployment of only standard plant designs that are pre-licensed by the NRC
- Combined NRC construction and operating license that streamlines the licensing process
- Contracting structure where the majority of risk is on suppliers
- Parallel module fabrication and site assembly / erection
- Modern construction techniques with advanced computer tools that reduce construction schedule
Advances in Nuclear Power - *Findings*

- Improvements in construction techniques must be demonstrated in US
  - Four Generation III+ nuclear plants are currently under construction in the US

- Delivering first projects on schedule and within budget and continuing to maintain safe & reliable operation of existing nuclear plant fleet will help establish market confidence
  - Reduce or eliminate “nuclear premium” for financing of nuclear projects thus reducing levelized cost of electricity
  - Incorporate lessons learned from Fukushima accident in both NRC regulatory process and plant designs - additional costs may result from new safety requirements
First-build construction of Generation III+ nuclear facilities in US should be monitored by CEAB, DEEP and other state leaders to verify advances in construction techniques have achieved anticipated benefits of lower construction costs and shorter construction time frames.
Advantages of Nuclear Power Compared to Natural Gas CCGT - Findings

Estimated Job Creation

— For Plant Construction Periods:
  - Nuclear Facility: 15,600 jobs/year for 5 years
  - Natural Gas CCGT Facility: 8,500 jobs/year for 2 years

— For Plant Operation and Maintenance
  - Nuclear Facility: 450 additional jobs at an additional nuclear unit at Millstone (*if at different site* - 700 jobs, *plus approximately 80 security staff*)
  - Natural Gas CCGT Facility: 25 jobs
Advantages of Nuclear Power Compared to Natural Gas CCGT - *Findings*

- Diversification of fuel supply
- Fuel supply security
  - Known global supplies of uranium for at least 80 years at recovery costs below $130/kg U with major suppliers being Canada and Australia
  - Appears to be significant reserves of natural gas in the US, but transmission line constraints may limit availability during periods of high demand
- Nuclear power generates 69% of the emission-free electricity in the US
- High reliability with US nuclear power plant capacity factors averaging about 90% over the last ten years
Advantages of Nuclear Power Compared to Natural Gas CCGT Recommendation

- Nuclear power should be considered for baseload generation to balance the reliance on natural gas — once the federal government has developed a permanent repository or regional centralized interim storage facility for spent nuclear fuel.
To enable consideration of building a new nuclear power plant in Connecticut, it is necessary to resolve the issue of disposal and storage of spent nuclear fuel in accordance with Sec. 22a-136 of the Connecticut General Statues: Moratorium on Construction of Nuclear Power Facilities.
Issues Facing the Expansion of Nuclear Power in CT
Disposal and Storage of Spent Nuclear Fuel - *Findings*

- US does not have a nuclear spent fuel disposal and storage program
  - Obama Administration has decided that the proposed Yucca Mountain repository is not an option
  - Financial consequences of federal inaction are that utilities have successfully sued DOE with a potential cost to taxpayers that could exceed $11 billion
Issues Facing the Expansion of Nuclear Power in CT Disposal and Storage of Spent Nuclear Fuel - *Findings*

- Federal Blue Ribbon Commission established to provide recommendations for developing a safe, long-term solution to managing the nation’s used nuclear fuel and nuclear waste. Preliminary recommendations and conclusions include:
  - US should proceed expeditiously to develop one or more permanent deep geological facilities
  - Prompt efforts to develop one or more consolidated interim storage facilities as part of an integrated, comprehensive plan for managing the back end of the nuclear fuel cycle
  - Access to funds that nuclear utility ratepayers are providing for the purpose of nuclear waste management
  - New single-purpose organization to develop and implement a focused, integrated program for the transportation, storage, and disposal of nuclear waste
Cumulative U.S. Commercial Spent Nuclear Fuel Inventories – 2010 to 2060 (assumes no nuclear expansion, 60-year life)

- 2010: 65,000 MTU discharged
- 2025: 96,000 MTU discharged
- 2050: 133,000 MTU discharged
- Dry storage at >70 sites by 2030
How Much Spent Nuclear Fuel is in the U.S. Today and Projected for the Future & Where is it Located?

• Spent Fuel Pools
  – 104 operating reactors *(plus all SNF from operation of Millstone 1 [shutdown] remains in its spent fuel pool)*
  – SNF must remain in these pools 5-10 years to cool adequately
  – Most pools use high density SNF storage racks and are near full (retaining full core off-load capability)

• Dry Cask Storage Facilities (ISFSIs)
  – 57 currently in operation
  – EPRI estimates that all operating power reactors will have ISFSIs in operation by 2025
Connecticut Yankee – Dry Cask Storage Facility
Study committee agrees with the recommendations made by the Blue Ribbon Commission that there is an urgent need to expeditiously develop one or more geological disposal and interim storage facilities for spent nuclear fuel.

State of Connecticut should join other affected states and aggressively demand that the federal government meet its legal obligation regarding management of spent fuel and high-level nuclear waste.
Issues Facing the Expansion of Nuclear Power in CT
Financing of a 1000 MW Nuclear Power Plant - Findings

- Overnight cost and financing are the most significant factors impacting the levelized cost of electricity (LCOE)
- Elimination of nuclear financing premium makes the LCOE of nuclear power very competitive with that of a CCGT power plant, BUT
- Unlikely that merchant owner will decide that the financial risk is worth the potential benefits and/or be able to obtain financing at an acceptable rate for construction of a nuclear power plant is estimated to have an overnight cost of $4-5 billion
Issues Facing the Expansion of Nuclear Power in CT
Financing of a 1000 MW Nuclear Power Plant
Recommendation

➢ State policies that reduce financial risk and provide confidence to allow for private investment are needed

— Loan guarantees beyond the first-build reactors
— Long-term contracts for the electricity generated
— Economic incentives for fuel diversification
— Economic incentives for emission-free electricity generation
— Appropriate public / private business models that balance risk
Other Considerations: Nuclear Safety - *Findings*

- Institute of Nuclear Power Operations (INPO) was formed to continually improve and address operational procedures as a result of 1979 Three Mile Island accident
  - Safety record has improved dramatically since the late 1980s when data was first collected *(See Slide 18)*
Other Considerations: Nuclear Security - Findings

- Security includes physical security of the site, fuel supply, and cybersecurity
  - “Hardened” facilities with substantial protection from natural and man-made external threats because of their robust reinforced concrete structures
    - Potential area of vulnerability is wet storage of spent fuel
  - Large visible security system as well as other not-so-visible measures to deter and stop a terrorist attack
  - Cybersecurity is an issue facing electricity generation and transmission facilities that rely on large centralized power plants
    - Nuclear regulations do not allow for remote operation of a facility thus reducing the opportunity for a terrorist to take computer control of an operating facility
Other Considerations: Nuclear Safety & Security Recommendation

- Safety cannot be taken for granted
- Imperative that state and federal government continue to monitor and assess the safety record of the nuclear industry
- Continued on-site inspections, simulated terrorist attacks, and incorporation of the latest safety technologies are needed to increase the trust and confidence of the public in nuclear technology
Reprocessing of spent nuclear fuel enables separation of the useful fuel remaining and potential reduction of the volume and toxicity of the waste.
Other Considerations
Nuclear Fuel Reprocessing - *Findings*

- US decided in the 1970s to follow a once-through fuel cycle to reduce the potential of nuclear proliferation
- Blue Ribbon Commission could not reach consensus on the desirability of closing the nuclear fuel cycle
- Research, development, and deployment should continue on a range of fuel cycle technologies that have the potential to deliver societal benefits
Other Considerations
Nuclear Fuel Reprocessing - Recommendations

- The state should monitor federal activities with regard to development and implementation of a nuclear fuel cycle.
- Advances in this area have the potential to reduce the volume of high-level radioactive waste and increase the amount of energy that can be obtained from uranium reserves.
- Study Committee concurs with the Blue Ribbon Commission regarding the urgent need to site and license a permanent repository for spent nuclear fuel regardless of decisions regarding the nuclear fuel cycle.
Siting of electricity generating facilities in Connecticut and New England is a difficult process.

Study’s survey indicated that residents are more accepting of renewable energy — but reality has shown that these facilities (e.g., wind farms) are as difficult to site as a fossil fuel plant.
Siting of a new nuclear facility should be located at the Millstone Power Station in Waterford or Connecticut Yankee in Haddam Neck

- Millstone has the infrastructure already available & the Connecticut Yankee site still has some transmission infrastructure
- Expected that there would be local support because the communities surrounding these facilities are familiar with nuclear power
Study’s survey of Connecticut residents indicated that respondents are misinformed about many energy issues

- 48% of the respondents indicated that there weren’t any nuclear power plants operating in Connecticut or were not sure if any nuclear power plants were operating in Connecticut
- 84% of the respondents had never looked for information about electric energy issues
Other Considerations: Public Acceptance - *Findings*

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<thead>
<tr>
<th>Electricity Generation Technology</th>
<th>Very or Extremely Favorable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear Power</td>
<td>22%</td>
</tr>
<tr>
<td>Fossil Fuels</td>
<td>25%</td>
</tr>
<tr>
<td>Renewable and Green-Based Energy</td>
<td>84%*</td>
</tr>
</tbody>
</table>

*Siting of wind farms, trash-to-energy plants, and dam-supplied hydroelectric facilities generally has had a high level of public opposition which contradicts the high level of support indicated by the survey.

- Electricity generation industry *(all energy sources)* appears to want to keep a low profile, but the lack of public engagement detracts from their ability to generate public support for new projects.
Other Considerations
Energy Education and Public Acceptance
Recommendation

- Energy education is needed so that the public can be informed about the state’s energy future in regard to nuclear power, fossil fuels, renewable energy, and conservation
  - K-12 curriculum
  - Seminars at state’s colleges and universities
  - Public service announcements
Political leadership and long-term, stable energy policies are needed so Connecticut’s residents and businesses can benefit from low-cost, reliable, safe, sustainable, diverse, and environmentally friendly sources of electricity, and from energy efficiency and peak demand reduction programs.

Uncertainty and changing future regulations and policy (e.g., carbon tax, incentives, and tax policy) will limit future investment in new electricity generation, continuing to put Connecticut at a competitive disadvantage because of high electricity rates.
Contact for Additional Information:

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