ADVANCES IN NUCLEAR POWER TECHNOLOGY

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A REPORT BY

THE CONNECTICUT ACADEMY OF SCIENCE AND ENGINEERING

FOR

THE

CONNECTICUT ENERGY ADVISORY BOARD

Advances in Nuclear Power Technology

A Report By

The Connecticut Academy of Science and Engineering

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*Raw data from phone survey are available at the CASE website at www.ctcase.org/reports/nuclear/surveydata

LIST OF ACRONYMS

B&W	Babcock & Wilcox
BWR	Boiling Water Reactors
CASE	Connecticut Academy of Science and Engineering
CEAB	Connecticut Energy Advisory Board
CERC	Connecticut Economic Resource Center
CCGT	Combined Cycle Gas Turbine
CL&P	Connecticut Light & Power
COEX	Co-Extraction
COL	Combined Operating License
CR	Control Room
DBT	Design Basis Threat
DCD	Design Control Document
DOE	Department of Energy
DPUC	Department of Public Utility Control
EIA	Energy Information Administration
EIS	Environmental Impact Statement
EM	Electromagnetic
EMP	Electromagnetic Pulse
EPR	Evolutionary Power Reactor
ESBWR	Economic Simplified Boiling Water Reactor
ESP	Early Site Permit
FCG	Flux Compression Generator
FERC	Federal Energy Regulatory Commission
FMCC	Federally-Mandated Congestion Charges
GIF	Generation IV International Forum
GFR	Gas-Cooled Fast Reactor
HIP	High Pressure Injection
INPO	Institute of Nuclear Power Operations
IAEA	International Atomic Energy Agency
IPC	Inter-Process Communication
IRP	Integrated Resource Plan
ISFSI	Independent Spent Fuel Storage Installation
ISO-NE	Independent System Operator - New England
ITAAC	Inspections, Tests, Analyses and Acceptance Criteria
kWe	Kilowatt Electric
kWh	Kilowatt-Hour
LCOE	Levelized Cost of Electricity
LFR	Lead-Cooled Fast Reactor
LLW	Low-Level Waste
LOCA	Loss of Coolant Accident
LWA	Limited Work Authorization
LWR	Light Water Reactor
MMBtu	Million British Thermal Units

MOX	Mixed Oxide
MW	Megawatt
MWh	Megawatt Hour
MWt	Megawatt Thermal
MSR	Molten Salt Reactor
NGNP	Next Generation Nuclear Plant
NGO	Non-Governmental Organizations
NPT	Non-Proliferation Treaty
NRC	Nuclear Regulatory Commission
OTSG	Once-Through Steam Generators
PAG	Protective Action Guide
PBMR	Pebble Bed Modular Reactor
PORV	Pilot-Operated Relief Valve
PRISM	Power Reactor Innovative Small Module
PWR	Pressurized Water Reactor
RGGI	Regional Greenhouse Gas Initiative
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RPS	Renewable Portfolio Standards
SCADA	Supervisory Control and Data Acquisition
SCWR	Supercritical Watercooled Reactor
SER	Safety Evaluation Report
SFR	Sodium-Cooled Fast Reactor
SMR	Small Modular Reactors
SNM	Special Nuclear Materials
STPNOC	South Texas Project Nuclear Operating Company
SWU	Separative Work Units
TMI	Three Mile Island
TSA	Transportation Security Administration
UI	United Illuminating
USEC	United States Enrichment Corporation
VHTR	Very High Temperature Gas Reactor
WNA	World Nuclear Association

EXECUTIVE SUMMARY

THE PURPOSE OF THIS STUDY

Nuclear power currently provides half of Connecticut's electricity. It is the preeminent source of emission-free electrical power. Fuel price fluctuations, so significant in fossil fuel electrical generation, have a minor impact on nuclear generation.

However, if nuclear power is to be continued as a significant source of electricity generation in Connecticut, there are issues to be considered. These include safety concerns, disposal of spent nuclear fuel, nuclear proliferation, financing, new plant project budget and schedule risks, and the public's conception and misconceptions of nuclear power.

It is necessary to understand and evaluate these issues in order to make decisions with respect to Connecticut's future use of nuclear power generation. These yet-to-be made decisions will impact both the state's economic development and consumers' electricity costs over the next 40 to 60 years, well into this century.

BRIEF STATEMENT AND OVERVIEW OF PRIMARY CONCLUSIONS

Brief Statement of Primary Conclusion

Nuclear power has been the primary source of emission-free electricity generation in Connecticut since 1970. The 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. While retirement of these units is well into the future, it will require many years for planning and approvals for their replacements. The state's energy plans and policies should address the role that nuclear power will play in the state's energy future. Construction of a new or replacement nuclear power generating unit in Connecticut would provide many benefits, including:

- Lower-cost baseload generation by replacing marginal cost electricity generators with nuclear power
- Emission-free electricity generation
- Fuel diversity to reduce the New England region's reliance on natural gas and fossil fuels for electricity generation
- Creation of new jobs by expanding the highly trained workforce required to safely operate nuclear power plant units

To achieve these benefits, the nuclear industry must successfully demonstrate that advanced construction and modular manufacturing techniques will ensure that nuclear power plants can be constructed and delivered on budget and on schedule, and that new and current nuclear plants can be operated at a high level of safety and security. Four advanced nuclear plants are currently under construction in Georgia and South Carolina.

Furthermore, the state's leadership must aggressively demand that the federal government meet its legal obligations regarding spent nuclear fuel by expeditiously providing for the storage, geologic disposal, and funding of nuclear waste management.

Overview

Until recently, construction of new nuclear power plants in the United States had been dormant for many years. Evolutionary improvements in design have provided technological and safety advancements for the plants that have been in operation for many years in the United States and other countries. Modular construction methodology and standardization of plant design offer the potential to shorten construction schedules and provide on-budget project delivery. In the future, commercialization of emerging small modular nuclear reactor designs may provide other opportunities for nuclear power deployment if pilot projects are successful and regulatory issues are resolved so as to ensure the safe and economical operation of these units.

Nuclear power has provided and continues to provide a significant percentage of emission-free baseload electricity generation in Connecticut and the New England region. Adding or replacing baseload electricity generation for the state and the New England region involves many considerations. Decisions made by the leadership of the state and the region should be based on achieving regional goals that include a variety of factors such as cost of electricity, air quality goals, Regional Greenhouse Gas Initiative (RGGI) and Renewable Portfolio Standards (RPS) goals, fuel diversity, and reliability. All options to achieve these goals should be considered, including nuclear power for either additional or replacement baseload generation, both for the short- and long-term, along with a continued commitment and effort to maximize energy efficiency and to reduce peak demand. Lead times for securing approval for and constructing new nuclear power plants, or any electricity generating facilities, are significant. Therefore, it is necessary to look well into the future to consider options for replacing existing generation and for providing additional generation.

The recent earthquake and tsunami that caused the incident at the Japan Fukushima Daiichi nuclear power plant facility in March 2011 has raised public concern over the use of nuclear power in many countries, including the United States. This tragic event provides an opportunity for reflection and action by industry, as well as federal and state government leadership, to restore public trust and confidence in the nuclear industry. US involvement in international nuclear energy leadership will be important to assure that safety standards for nuclear power plant operations are maintained globally.

A Blue Ribbon Commission on America's Nuclear Future was established under the authority of the US Department of Energy (DOE) in accordance with provisions of the Federal Advisory Committee Act to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle and to recommend a new plan. The Commission's draft report to the Secretary of Energy was completed in July 2011 (http://brc.gov/sites/default/files/documents/brc_draft_report_29jul2011_0.pdf). The report provides advice, evaluates alternatives, and makes recommendations on reactor and fuel cycle technology and on the transportation, disposal and permanent storage of spent nuclear fuel.

In Connecticut, legislation prohibits the construction of a new nuclear power plant until such time as the federal government provides for the disposal and permanent storage of spent nuclear fuel that is currently being stored at Connecticut's two nuclear power plant sites—Connecticut Yankee in Haddam Neck and the Millstone Power Station in Waterford. Therefore, the Study Committee supports the Blue Ribbon Commission's findings that recommend "*prompt efforts to develop, as expeditiously as possible, one or more permanent deep geological facilities for the safe disposal of spent fuel and high-level nuclear waste; and prompt efforts to develop, as expeditiously as possible, one or more consolidated interim storage facilities as part of an integrated, comprehensive plan for managing the back end of the nuclear fuel cycle*" and recommends that the state and regional leadership use their resources to encourage the federal government to act on these findings and provide a long-term and sustainable solution for the disposal and storage of spent nuclear fuel.

The significant financial commitment necessary to construct a nuclear power plant in a deregulated electricity market is another major challenge that needs to be addressed in order for nuclear power to be considered as a viable baseload alternative. Stable policies that reduce financial risk and provide confidence to allow for private investment are needed. Examples include providing long-term contracts for the electricity generated and economic incentives for emission-free electricity generation.

STUDY DESCRIPTION

The report includes the following elements:

- Overview of nuclear power
- Evolution of nuclear power technology, including recent advances in nuclear technology and small modular reactors
- Nuclear power operation, including the power plant licensing process, security and safety, and the nuclear fuel cycle
- Comparison of nuclear power to alternative energy sources
- Considerations for nuclear power plant development in Connecticut, including an economic impact analysis, siting, local acceptance and education

STUDY COMMITTEE CONSIDERATIONS

The Study Committee considered the operational experience of the nuclear power industry including its demonstrated reliability, safety, and waste disposal practices; advances incorporated in today's nuclear power plant designs; and future improvements being developed for the next generation of nuclear power plants. The Committee also reviewed lessons learned from the nuclear incident at Three Mile Island and the events triggered by the earthquake and tsunami at Fukushima Daiichi, Japan, as well as from the terrorist attack of September 11, 2001. In addition, the committee conducted a survey of Connecticut citizens to better ascertain public acceptance of nuclear power and knowledge on a broad range of energy issues.

The Committee also considered issues such as levelized cost of electricity and economic impacts. This led to a review of the market mechanisms that set the cost of electricity in Connecticut so it could evaluate how alternative sources of baseload generation would affect rate payers.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

To provide an overall framework for the considerations that will influence decisions pertaining to potential construction of a large centralized power plant in Connecticut, this report first presents findings and recommendations regarding the Connecticut and New England electric markets, including an analysis of the need for additional or replacement baseload electricity generation.

First, nuclear power is compared to natural gas as a means of meeting future baseload needs for generation of electric power. Next, advances in design, permitting, and construction practices for nuclear power plants are presented. This is followed by an evaluation of the advantages and safety and security risks of nuclear power to identify the issues that must be addressed before the state can consider nuclear power as a viable alternative for meeting future electricity generation needs for the region. Finally, a review of this study's survey on public acceptance of nuclear power and overall understanding of energy issues provides the basis for the Study Committee's recommendations stressing the need for the general public to become more knowledgeable about energy issues.

Several factors to be considered include:

- Fuel diversity is critical to stabilizing electricity generation costs in Connecticut and throughout New England. Almost all new electric generating facilities built in the New England region over the past ten years utilize natural gas as their primary fuel. Independent System Operator New England (ISO-NE) estimates that even adding 5,400 MW of new capacity from a non-gas-fired technology or resource will not have significant impact on the region's dependence on natural gas (ISO-NE, 2007). Because the cost to generate electricity from a natural gas combined-cycle gas turbine (CCGT) power plant is very sensitive to the price of natural gas, increasing the region's reliance on natural gas would further expose New England to potentially high electricity prices. In contrast, the cost to generate electricity from nuclear power plants is not sensitive to the cost of fuel. Therefore, the state and the region should consider adopting policies and practices to assure that decisions on building electricity generating facilities in the future consider the need for fuel diversity.
- Nuclear power provides zero-carbon-emission baseload generation that contributes to meeting state and regional environmental goals including those established by the RGGI. Therefore the environmental consequences of replacing nuclear power generation with anything other than a zero-emission-based generation would have negative air emissions impacts.
- Construction and operation of a nuclear power plant have increased job creation compared to natural gas facilities where cost of fuel is the largest expense.
- However, the Study Committee supports the state's legislatively mandated moratorium on constructing new nuclear power plants in Connecticut until the federal government

provides a regional interim storage facility or a geological disposal facility in accordance with the Nuclear Waste Policy Act of 1982. Specifically:

  - Spent nuclear fuel storage is a valid concern.
  - The State of Connecticut should join other affected states to aggressively demand that the federal government meet its legal obligations regarding spent fuel disposal and storage by expeditiously implementing the Blue Ribbon Commission on America's Nuclear Future's recommendations on interim storage, geologic disposal, and funding of nuclear waste management.
  - Until the federal government acts in full, the State of Connecticut should interface with the Nuclear Regulatory Commission (NRC), Dominion and Connecticut Yankee to obtain assurance that spent fuel stored in Connecticut is safe under all conditions.

- Financing of nuclear power plants in a deregulated market will be a challenge. The high overnight cost and financing premium for nuclear power plants will likely make the financial risk to a merchant owner outweigh the potential benefits. Implementation of stable policies to address this issue is needed to make nuclear power a viable alternative for new electricity generation in Connecticut. Examples include providing long-term contracts for the electricity generated and economic incentives for emission-free electricity generation. The situation might change significantly if the nuclear industry establishes good performance on the early new plant construction projects now underway in other states and/or if significant carbon emissions penalties are implemented on generating facilities. Elimination of the financing premium for nuclear power plants provides a levelized cost of electricity (LCOE) that is very competitive to a CCGT power plant.

Even with the addition of low-cost baseload electricity generation, the Study Committee is concerned that Connecticut electricity ratepayers will not see the full savings from this investment. The realities of deregulation limit the benefit to only the reduction in the market-clearing price and do not provide ratepayers with the difference between the market-clearing price of the marginal generator and the price of the new low-cost electricity generator. The state should implement a policy whereby ratepayers see a greater share of the benefits of low cost electricity generation.

Connecticut and New England Electric Rates

FINDINGS

Connecticut's electricity rates have been the second highest in the country, after Hawaii's, since 2007. As of February 2011, the average rate was \$0.164 per kilowatt-hour (kWh) or 69% higher than the national average of \$0.097 per kWh (EIA, February 2011). Not surprisingly, high energy costs were the most important issue mentioned in this study's survey of 600 Connecticut residents in October 2010.

Connecticut's high electrical rates cannot be addressed solely as a state issue, but must be dealt with on a regional level because the electrical wholesale market is administered by the ISO-NE under rules approved by the Federal Energy Regulatory Commission (FERC). Electrical rates throughout New England are also relatively high, with an average rate of $0.146 per kWh that is 51% higher than the national average (EIA, February 2011).

Connecticut and the region's high electricity rates are likely caused by several factors including:

- The state does not have any indigenous energy resources.
- Connecticut legislation that deregulated the electricity industry required electric companies to sell their power plants and buy power on the wholesale market. Vermont did not deregulate and had an average rate of $0.138 per kWh in February 2011, which is 16% less than Connecticut. New Hampshire allowed electric utilities to own power plants and had an average rate of $0.150 per kWh, which is 9% less than Connecticut.
- As a result of the region's dependence on power plants that use natural gas as their primary fuel, these plants set the price of electricity about 90% of the time. Power plants that use lower cost fuels such as nuclear, coal, or hydroelectric power, rarely set the cost of power in the region. Coal is used to generate 45% of the electricity in the United States compared to only 12% in New England (EIA, 2010). Hydroelectric power is used to generate 37% of the electricity for the Pacific Northwest states (Washington, Oregon, and California) compared to 7% in New England (Edison Electronic Institute).
- Congestion of the electrical grid adds to the price of electricity, especially in the southwestern third of the state. For example, in order to maintain system reliability, less efficient plants operate more often than they would if congestion were not a problem. Congestion decreased following the completion of the Bethel-Norwalk and Norwalk-Middletown transmission lines in October 2006 and December 2008, respectively. This decreased federally-mandated congestion charges (FMCC) to 0.85 cents per kWh for Connecticut Light & Power (CL&P) and made them negligible for United Illuminating (UI) customers. However, transmission rates increased by 1.07 cents per kWh for CL&P customers and by 0.93 cents per kWh for UI customers from 2000 to 2009 according to the Department of Public Utility Control ([DPUC]; Effective July 1, 2011, DPUC was renamed the Public Utilities Regulatory Authority within the Department of Energy and Environmental Protection).
- Environmental regulations play a role in higher rates. It was estimated by DPUC that state legislation (PA 98-28) requiring electric companies to purchase renewable resources adds about 0.45 cents per kWh, plus an additional charge of 0.10 cents per kWh for funding renewable energy programs. Additionally, a 0.30 cents per kWh charge for conservation programs has the potential of reducing electricity rates more than the cost of the program, if the program is successful at reducing the growth of peak demand and increasing electricity efficiency. Finally, Connecticut's stringent air pollution standards and RGGI cause coal, a less expensive fuel than natural gas, to be utilized sparingly in Connecticut.
- Connecticut is a relatively high-cost state in terms of salary, taxes, and land.

These factors do not work alone but rather in combination, resulting in high electricity rates. For example, Connecticut does not have any natural gas resources so gas must be transported by pipeline from other parts of the United States and Canada. The transmission cost adds about $1 per 100 ft^3 of gas or about 1 cent per kWh to the cost of fuel for natural gas generating facilities in Connecticut. Because of the way the deregulated market works in Connecticut, the price of natural gas sets the market price of electricity about 90% of the time. Therefore, Connecticut residents pay a natural gas transportation "penalty" on all electricity generated even if the power is generated by power plants that use fuels other than natural gas.

RECOMMENDATION

The current structure of the New England regional and Connecticut electricity markets is not conducive to adding new or replacement low-cost baseload electricity generation and having the full cost savings realized in lower electricity prices. Changes are needed in the "deregulated" market so that replacement of inefficient electricity generating facilities or the addition of new low-cost generation more fully translates into lower electricity prices that will make Connecticut more competitive in attracting businesses and creating jobs. Connecticut should develop a plan that allows lower costs of generation from baseload plants to be passed on to consumers.

Need for Additional or Replacement Baseload Generation and Impact on Electric Rates

FINDINGS

There are no clear indicators for the direction in baseload demand in Connecticut or New England. An increase in electric demand through upward growth of the state/regional economy, population, and/or number of electric cars may necessitate the need for additional baseload. A decrease in demand through conservation, manufacturing moving out of state/region/country, or a decrease in population would likely mean that current baseload capacity would be sufficient. However, an ISO-NE analysis found that the replacement of marginal units with a new low-cost plant will reduce electric rates. For example, the addition of 1000 MW of supply would save New England consumers $600 million a year (2005 $) and reduce wholesale electricity prices by 5.7% (ISO-NE, Electricity Costs White Paper, June 2006).

Retirement of existing electricity capacity is also an important driver for new generation capacity. Millstone units 2 and 3 have had their operating licenses extended from 40 to 60 years and will now expire in 2035 and 2045, respectively. Seabrook and Pilgrim are awaiting NRC action on their 20-year license extensions. Vermont Yankee received a 20-year license extension from the NRC, but some Vermont lawmakers are trying to shut down the plant despite the license extension. This case is currently being litigated.

Also, it may be determined that it is more cost effective for the existing baseload fossil fuel generating facilities to be retrofitted or refurbished instead of being retired and replaced.

Other factors that need to be accounted for include:

- the potential importation of new baseload generation from other regions or Canada with the associated requirement of likely needing more transmission capacity;
- improved economics and reduced vulnerability that could prompt a move toward distributed generation instead of continued reliance on large centralized power plants; and
- uncertainty due to the fact that two natural gas/low sulfur oil facilities (NRG Energy's Meriden Project and GE owned Oxford/Towantic) of about 540 MW each that are

already in the permitting process could be favorably positioned to respond to a Connecticut RFP for new generation.

RECOMMENDATION

Connecticut should be proactive in developing in-state electricity generating facilities to meet the state's demand and consider potential benefits such as lower electricity prices through lower generation costs and electricity congestion charges, and potential job creation from becoming exporter of electricity.

Comparison of Baseload Alternatives: Nuclear Power and Natural Gas

FINDINGS

Because of the time required to site, design, license, and construct new generating facilities, it is important to understand the advantages and disadvantages of nuclear power, other potential baseload sources, and effectiveness of energy efficiency programs to help guide sound policy decisions that will have significant implications for Connecticut and the New England region for the next 40 to 60 years. Potential fuel sources to be considered are nuclear power, natural gas, coal and renewable energy options such as wind, solar, hydroelectric, and biomass. Natural gas is a viable alternative that has been used as the primary fuel for nearly all of the new generating capacity built in Connecticut and New England in the past ten years. Coal, which is in general a lower cost fuel than natural gas, and is used as the primary fuel for generation in many regions of the United States, is not considered a likely alternative because of the stringent air pollution standards in Connecticut. Solar and wind power are not considered baseload sources of power in Connecticut because they generate electricity on an intermittent basis. Biomass—specifically solid waste—is used as a baseload source of electricity in Connecticut. There are six solid waste burning facilities in the state that generate a total of about 160 MW of electricity. However, there is not enough solid waste disposed of in the state to generate an additional 1000 MW of electricity. Hydroelectric power does produce 1.6 % of the electricity in Connecticut (EIA, 2009), but future hydroelectric power will likely be small-scale run-of-the-river type of facilities because of the environmental standards required for securing siting approval for constructing large dams for electricity generation.

In 2009 (EIA), 53% of the state's electricity generation was supplied by nuclear power. In New England, nuclear power accounted for 30% of the generated electricity between 2007 and 2009 (ISO-NE). Nuclear power has been a very reliable source of electricity with availability and capacity factors between 89% and 92% from 2007 to 2009 (ISO-NE). However, Connecticut and New England's system-wide capacity is heavily dependent on natural gas, particularly during peak electricity usage. For example, natural gas fired power plants accounted for 41% of New England's total capacity in 2010 (ISO-NE, 2011; New England 2011 Regional Profile" (see http://www.iso-ne.com/nwsiss/grid_mkts/key_facts/ne_01-2011_profile.pdf). This dependence is further compounded because natural gas is also used for space and process heating and accounts for 23% of the total energy consumed (electricity, transportation, and space and process heating) in New England compared to 11% for nuclear power (EIA, 2008).

In conclusion, provided the federal government begins to meet its nuclear spent fuel disposal obligations, natural gas and nuclear power are the most viable alternatives for a 1000 MW centralized power plant in Connecticut. The findings from a comparison of large-scale nuclear power to natural gas electricity generation are summarized in Appendix ES-1.

RECOMMENDATION

Fuel diversity should be promoted by the state as both a strategy to stabilize electricity prices and a regional policy. Since deregulation of the electricity market, essentially all new electricity generation has used natural gas as its primary fuel. Overreliance on natural gas may lead to price instability and potential gas pipeline transmission constraints, especially during cold weather periods when there is increased demand for natural gas for space heating.

Advances in Nuclear Power

FINDINGS

The nuclear industry has made advances in nuclear technology that increase safety and reliability while reducing construction costs and schedule. These include:

- Passive safety systems that operate without auxiliary AC power (either off-site or on-site)
- Deployment of only standard plant designs that are complete before construction begins and are pre-licensed by the NRC
- Combined NRC construction and operating license that streamlines the licensing process while providing a consolidated process and opportunity for public review before construction of the plant begins
- 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

With new construction techniques, nuclear power has the potential to be a low-cost source of baseload power. However, these improvements must first be demonstrated in the United States. Currently, there are five nuclear power plant units under construction. They are Watts Bar 2 (Tennessee Valley Authority), Vogtle 3 & 4 (Southern Nuclear), and V.C. Summer 2 & 3 (SCANA). Successfully delivering the first projects on schedule and within budget and continuing to maintain safe and reliable operation of the existing nuclear plant fleet will help establish financial market confidence for follow-on projects. This will likely reduce or eliminate the “nuclear premium” for the financing of nuclear projects, thus reducing the levelized cost of electricity. However, additional costs may result from new safety requirements and regulations that arise from findings from studies of the events at the Fukushima Daichii power plant. In Connecticut, with marginal natural gas facilities setting the cost of electricity, the benefit will likely be to make the construction and operation of a nuclear power plant more attractive for investors, but it is uncertain if this will result in a decrease in the price of electricity.

RECOMMENDATION

The first-build construction of four Generation III+ nuclear facilities in the United States should be monitored by the Connecticut Energy Advisory Board (CEAB), the Department of Energy and Environmental Protection and other state leaders to verify that advances in construction techniques have achieved the anticipated benefits of lower construction costs and shorter construction time frames, with the new plants being delivered on schedule and on budget.

Advantages of Nuclear Power

FINDINGS

The primary advantages of generating electricity from a nuclear power plant compared to a natural gas CCGT power plant are:

- Construction, operation, and maintenance are the most significant lifetime costs of a nuclear power plant. Approximately 15,600 jobs per year (in 2010, 0.9% of the state's 1,723,900 total employment) would be created during the five-year construction phase (78,000 total job years), with about 450 jobs created to operate and maintain an additional unit at Millstone. The number of security-related jobs that would be created to guard the additional unit is uncertain. If the nuclear power plant were at a different site, a staff of approximately 700 would be required to operate and maintain the facility (http://nextbigfuture.com/2007/11/staffing-expanding-nuclear-industry.html, 2007). Security of the site would require about 80 officers based on approximately 8,000 officers that currently protect the 104 nuclear power plants in the United States (http://www.nei.org/keyissues/safetyandsecurity/plantsecurity). In contrast, approximately 8,500 jobs per year would be created during the two-year construction phase of a combined-cycle natural gas power plant (17,000 total job years), with 25 jobs created to operate and maintain the facility. The most significant lifetime cost for a combined-cycle natural gas plant is fuel. Since Connecticut does not have indigenous natural gas resources, the majority of the cost of operating natural gas generating electric facilities flows out of the state.
- Diversification of fuel supply helps to stabilize electricity prices. The state's dependence on natural gas has been increasing since almost all new electricity generating facilities in the last ten years use natural gas as their primary fuel source.
- There are sufficient known global supplies of uranium for at least 80 years at uranium recovery costs below $130/kg U with major suppliers being Canada (1st) and Australia (3rd). Because cost of raw uranium only accounts for about 2.5% of the cost of electricity generated, any supply constraints or increase in global demand will not have a large impact on electricity prices. There also appear to be significant reserves of natural gas in the United States, but transmission pipeline constraints may limit availability during periods of high demand such as during cold periods when natural gas for generating electricity competes with space heating needs. The New England region's reliance on natural gas could increase vulnerability of sufficient supply, thus increasing the volatility of electricity prices.
- Nuclear power generates 69% of the emission-free electricity in the United States with hydroelectric power accounting for 22% and solar/wind/geothermal accounting for 9% in 2010 (http://www.nei.org/filefolder/Infographic_-_Emission_Free_Sources_2010.jpg).

While natural gas has lower greenhouse gas emissions compared to coal, there is concern that the extraction of natural gas from shale deposits releases methane, which is a much more potent greenhouse gas than carbon dioxide (MIT Technology Review, Just How Green is Natural Gas?, 2011). Also, combustion of natural gas produces nitrogen oxides, which can be removed by ammonia injection, and very low levels of sulfur oxides.

- High reliability with US nuclear power plant capacity factors averaging about 90% over the last ten years (http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/usnuclearindustrycapacityfactors/)

RECOMMENDATION

Nuclear power should be considered for baseload generation to balance the reliance on natural gas once the federal government has developed a permanent federal repository or a regional centralized interim storage facility for spent nuclear fuel. Benefits of developing a new nuclear power plant unit in Connecticut include the potential for higher in-state job creation during both construction and operation, and emission-free electricity generation. In contrast, the major expense of a CCGT power plant is the cost of natural gas which must be imported into the state.

Issues Facing the Expansion of Nuclear Power in Connecticut

1. Disposal and Storage of Spent Nuclear Fuel

FINDINGS

For Connecticut to consider building a new nuclear power plant in the state it is necessary to satisfactorily resolve the issue of the 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 that states, "No construction shall commence on a fifth nuclear power facility until the Commissioner of Environmental Protection finds that the United States Government, through its authorized agency, has identified and approved a demonstrable technology or means for the disposal of high level nuclear waste. As used in this section, 'high level nuclear waste' means those aqueous wastes resulting from the operation of the first cycle of the solvent extraction system or equivalent and the concentrated wastes of the subsequent extraction cycles or equivalent in a facility for reprocessing irradiated reactor fuel and shall include spent fuel assemblies prior to fuel reprocessing."

At the present time, the United States does not have a nuclear spent fuel disposal and storage program. The Obama Administration has decided that the proposed Yucca Mountain repository facility is not an option and DOE has withdrawn its NRC license application, which was filed in June 2008. Congress needs to act on this issue because Public Law 107-200 that was passed in July 2002 contradicts this decision by stating "Approving the site of Yucca Mountain, Nevada for the development of a repository for the disposal of high-level radioactive waste and spent nuclear fuel, pursuant to the Nuclear Waste Policy Act of 1982."

The financial consequence of federal inaction is that 66 utilities have successfully sued DOE for breach of contract by not accepting spent nuclear fuel from nuclear power plants. Congress has started paying utilities for contract default with a potential cost to taxpayers that could exceed $11 billion.

The Blue Ribbon Commission provided recommendations for developing a safe, long-term solution to managing the nation's used nuclear fuel and nuclear waste. Preliminary conclusions and recommendations included:

- The United States should proceed expeditiously to develop one or more permanent deep geological facilities for the safe disposal of high-level nuclear waste. Geologic disposal in a mined repository is the most promising and technically acceptable option available for safely isolating high-level nuclear wastes for very long periods of time.
- 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 the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management (Nuclear Waste Fund).
- A new, single-purpose organization to develop and implement a focused, integrated program for the transportation, storage, and disposal of nuclear waste.
- A new approach that is consent-based, transparent, phased-in, adaptive, and science-based to site and develop nuclear waste management and disposal facilities.

RECOMMENDATION

The 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. This issue must be resolved before nuclear power can be considered a viable alternative to natural gas as a baseload source of electricity in Connecticut. To achieve this, the State of Connecticut should join other affected states and aggressively demand that the federal government meets its legal obligation regarding management of spent fuel and high-level nuclear waste.

2. Financing of a 1000 MW Nuclear Power Plant

FINDINGS

The overnight cost and financing are the most significant factors impacting the levelized cost of electricity from a nuclear power plant. Elimination of the nuclear financing premium makes the LCOE of nuclear power very competitive with that of a CCGT power plant. However, in a deregulated market, it is unlikely that a 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 the construction of a nuclear power plant that is estimated to have an overnight capital cost of approximately $4-5 billion. (The Economic Impact Analysis [Attachment 1] assumed an overnight cost of $4 billion [2007 dollars] for a 1000 MWe reactor plant. It is noted that an 1100 MWe AP1000 reactor plant has an estimated nominal overnight cost of $5 billion [2011 dollars]). This will likely be the case even if:

- the first-build nuclear power plants are completed on budget and on schedule
- the contracting structure for project construction assigns the majority of the financial risk associated with on-budget and on-schedule project delivery to suppliers and not the merchant owner.

RECOMMENDATION

Stable policies that reduce financial risk and provide confidence to allow for private investment are needed. Examples include:

- loan guarantees beyond the first-build reactors
- long-term contracts for the electricity generated
- economic incentive for fuel diversification
- economic incentives for emission-free electricity generation, e.g., product tax credits
- appropriate public / private business models that balance risk

Other Considerations

The nuclear power industry has recognized that it is an absolute necessity that the existing fleet of nuclear power plants operates safely and reliably. The average capacity factor for US nuclear power plants has increased from about 50% in the early 1970s to 90% for the last ten years. Current operational experience shows that the industry has an excellent safety record and has responded to events such as Three Mile Island and 9/11, resulting in improved operational and security procedures. More attention needs to be given to public acceptance and education, not only about nuclear power, but about all sources and uses of energy. This study's survey of 600 Connecticut residents in October 2010 indicates that there is lack of awareness as well as misinformation about nuclear power, fossil fuels, and renewable energy sources. Below is a summary of each of these issues.

Nuclear Safety and Security

FINDINGS

Safety is an ongoing concern of the nuclear power industry. As a result of the 1979 Three Mile Island accident, the Institute of Nuclear Power Operations (INPO) was formed to continually improve and address operational procedures at nuclear power plants. These include the on-going review of equipment, instrumentation, training, and procedures, and verification of the capability of nuclear emergency safety procedures to mitigate events that are considered beyond normal design basis, total loss of on-site and off-site power, and internal and external flooding events. The safety record of the nuclear industry has improved dramatically since the late 1980s when data was first collected. Significant events (per US operating nuclear power plant) have decreased from about 0.83 in the late 1980s to about 0.02 on average over the last five years. As defined by the NRC, significant events are events that meet specific NRC criteria, including degradation of safety equipment, a reactor scram with complications, or an unexpected response to a sudden degradation of fuel or pressure boundaries. The NRC staff identifies significant events through detailed screening and evaluation of operating experience. Lessons learned from the events that led to Japan's Fukushima Daiichi nuclear plant incident on March 11, 2011 will be used to support or strengthen existing nuclear power plant operating procedures and to develop new safety precautions, as necessary. INPO also oversees radiological and emergency preparedness to respond and protect public health and safety.

Security of large centralized power plants includes physical security of the site, fuel supply security, and cybersecurity. Nuclear power plants are "hardened" facilities with substantial protection from a spectrum of external threats, both natural and manmade, because of their robust reinforced concrete structures. Also, nuclear power plants have a large visible security system as well as other not-so-visible measures to deter and stop a terrorist attack. In addition, they have procedures to screen employees to minimize the potential of an internal threat. The concern is not the theft of nuclear material, but the potential for release of radioactive material. Other concerns are the release of radioactive material through a terrorist event similar to the 9/11 attack on the World Trade Center and Pentagon. Nuclear facilities have assessed their vulnerability to aircraft impact as well as other potential threats. While the reactor core is well protected, a potential area of vulnerability is wet storage of spent fuel. Cybersecurity is an issue facing electricity generation and transmission systems that rely on large centralized power plants. Nuclear industry 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.

RECOMMENDATION

Safety must never be taken for granted. It is imperative that the state and federal government continue to monitor and assess the safety record of the nuclear industry. On-site inspections, simulated terrorist attacks, and incorporation of the latest safety technologies are examples of the continuing diligence needed to increase the trust and confidence of the public in nuclear technology.

Nuclear Fuel Reprocessing

FINDINGS

Nuclear proliferation is a concern of the nuclear power industry. In the 1970s, the United States decided to follow a once-through fuel cycle to reduce the potential of nuclear proliferation. Understanding and minimizing the risk of nuclear proliferation is one of the four major objectives in DOE's Nuclear Energy R&D Roadmap and will be a major driver for development of a sustainable nuclear fuel cycle.

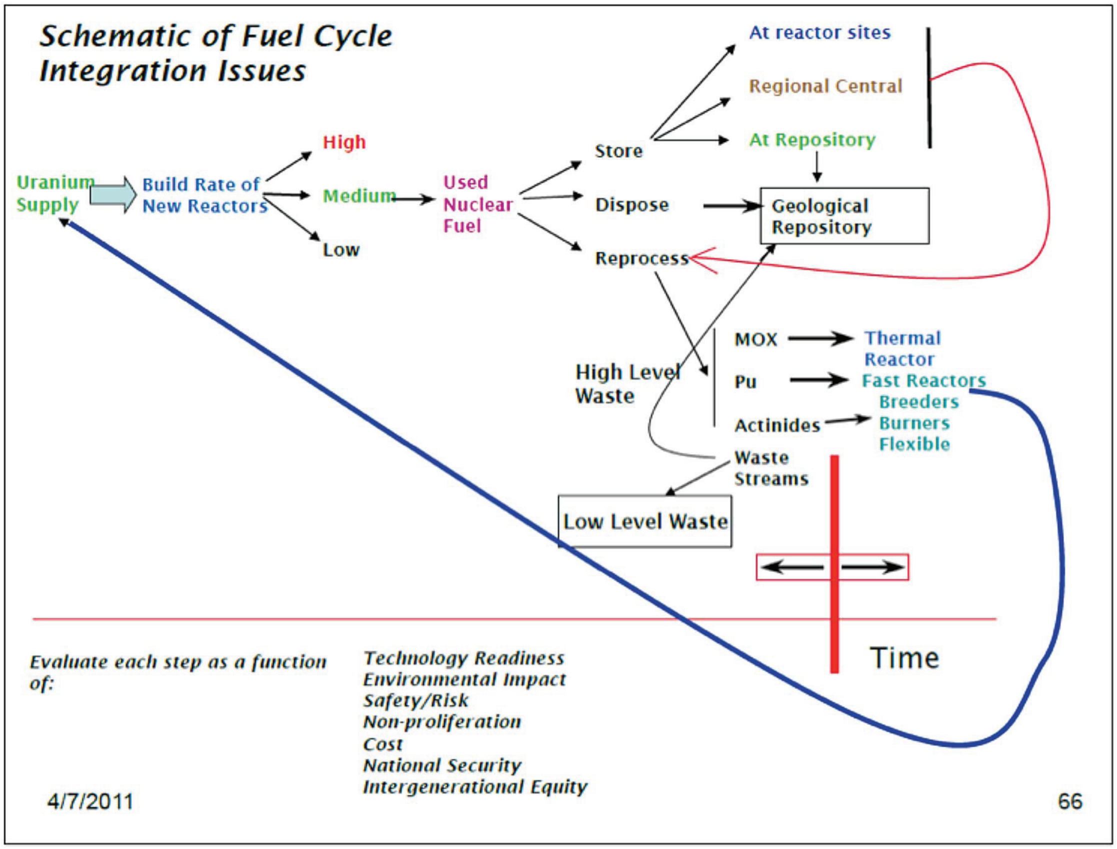


Figure ES-1: Fuel Cycle Integration Issues
(Courtesy of Andrew Kadak, Director, Nuclear Services, Exponent, Engineering and Scientific Consulting)

A schematic of nuclear fuel cycle integration issues is shown in Figure ES-1. Reprocessing of spent nuclear fuel enables separation of the useful fuel remaining and potential reduction of the volume and toxicity of the waste. However, it is important to note that independent of whether the United States continues to follow a once-through fuel cycle or moves towards fuel reprocessing, there is a need for the federal government to develop a geological repository for high-level nuclear waste. Decisions regarding reprocessing will depend on technology readiness, environmental impact, safety, non-proliferation, cost, national security, and intergenerational equity. The Blue Ribbon Commission found:

> *No currently available or reasonably foreseeable reactor and fuel cycle technologies – including current or potential reprocess and recycle technologies – have the potential to fundamentally alter the waste management challenge this nation confronts over at least the next several decades, if not longer. Put another way, we do not believe that new technology developments in the next three to four decades will change the underlying need for an integrated strategy that combines safe, interim storage of spent nuclear fuel with expeditious progress toward siting and licensing a permanent disposal facility or facilities.*

The Blue Ribbon Commission could not reach consensus on the desirability of closing the nuclear fuel cycle. The commission concluded that it is too early to commit to any particular fuel cycle as a matter of government policy, but that research, development, and deployment should continue on a range of fuel cycle technologies that have potential to deliver societal benefits in the future. They also concluded that safety, economics, and energy security are likely to be the most important factors in selecting a fuel cycle rather than waste management because a permanent repository will be needed regardless of whether or not it is decided to close the fuel cycle.

RECOMMENDATION

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. As recommended previously, the study committee concurs with the Blue Ribbon Commission regarding the urgent need to site and license a permanent repository for spent nuclear fuel.

Siting

FINDING

Siting of electricity generating facilities in Connecticut and New England is a difficult process. This study's survey indicated that residents are more accepting of renewable energy, but reality has shown that these facilities (e.g., wind farm) are as difficult to site as a fossil fuel plant.

RECOMMENDATION

Siting of a new nuclear facility in Connecticut should be located at the Millstone Power Station in Waterford or Connecticut Yankee in Haddam Neck. Millstone has the infrastructure already available, including cooling water intake structures, security force, dry cask spent fuel storage, significant switchyard equipment, etc., to support the operation of a new unit. It is expected that there would be local support because the communities surrounding these facilities are familiar with nuclear power. While the decommissioning process has been completed, the Connecticut Yankee site still has some transmission infrastructure in place for future use and was once approved for nuclear operations.

Energy Education and Public Awareness

FINDINGS

This study's survey of Connecticut residents indicated that respondents are misinformed about many energy issues and that 84% of the respondents had never looked for information about electric energy issues. It is important that Connecticut residents be more informed about energy issues in order to better evaluate the strategic decisions that state leaders will have to make regarding the state's energy future over the next 40 to 60 years , decisions that promote a strong state economy, job creation, low environmental impact, and energy security. The education must be broad based, with strong energy curricula in the public schools and effective public service announcements for Connecticut citizens.

Only 22% of the respondents were very favorable or extremely favorable toward nuclear power while 45% were not favorable. Respondents in New London County, where Millstone is located, were the most supportive of nuclear (25% very or extremely favorable and 41% not favorable) while respondents from Fairfield County were least favorable (19% very or extremely favorable and 52% not favorable). Also, 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. Of those that indicated there were operating nuclear power plants in Connecticut, only 51% were aware that the plants were located in Waterford (or Millstone). Electricity generation from fossil fuels did not fare much better with only 25% of the respondents being very favorable or extremely favorable. Renewable and green-based energy had the highest support levels, with 81% of the respondents considering this to be a very or extremely favorable alternative for the generation of electricity. However, the 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. While the electricity generating industry (all energy sources) appears to want to keep a low profile, the lack of public engagement detracts from their ability to generate public support for new projects.

RECOMMENDATION

Energy education — in the K-12 state curriculum, as well as in seminars at state colleges and universities, and through public service announcements—is needed so that the public can be more informed about the state's energy future in regard to nuclear power, fossil fuels, renewable energy, and conservation.

CONCLUDING REMARKS

Nuclear power has provided economic benefits and an emission-free source of baseload electricity for Connecticut since 1970. Reliability of the current fleet of nuclear power plants has increased significantly with capacity factors averaging about 90% over the last ten years and significant safety events averaging only 0.02 per plant over the last five years. Continued safe operation and success of the new generation of nuclear power plants is also essential to further establish public trust and confidence in this technology. Advances in nuclear technology have improved safety system design by decreasing the calculated core damage frequency by about a factor of ten. Completion of the first-build power plants in the United States will determine if improvements in design standardization and construction techniques have reduced construction costs and construction time sufficiently to allow new plants to compete in deregulated markets like Connecticut.

Two challenges must be addressed before nuclear power can be a viable alternative for baseload electricity generation in Connecticut.

- The federal government must establish and implement one or more consolidated interim storage or permanent deep geological facilities for the safe disposal of spent fuel and high-level nuclear waste.
- Policy changes must be implemented so that financing alternatives are available for constructing a nuclear power plant in a deregulated market.

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.

1.0 INTRODUCTION

The Connecticut Energy Advisory Board (CEAB) requested that the Connecticut Academy of Science and Engineering (CASE) perform an independent and unbiased study on advances in nuclear power technologies. The goal of this study is to inform and assist the leadership of the state in making decisions that are in the best interest of Connecticut citizens in regards to nuclear power in the 21st century and beyond. The scope of this study was based on work items that were identified in the Nuclear Power Section of the CEAB's 2010 Integrated Resource Plan (IRP) and the Nuclear Power Sub-Committee of the CEAB. Study items include:

- Overview of Nuclear Power
- Evolution of Nuclear Power Technology
  - Commercial Nuclear Power Technology
  - Lessons Learned from Three Mile Island; September 11, 2001 Terrorist Attack; and Fukushima Daiichi Nuclear Power Plant
  - Recent Advances in Nuclear Power Technology
  - Generation IV – Revolutionary Designs
  - Small Modular Reactors
- Nuclear Power Operation
  - US Licensing Process
  - Nuclear Security and Safety
  - Fuel Supply Security
  - Metal Clad Cylindrical Fuel Elements
  - Disposal of Spent Nuclear Fuel and Low-Level Radioactive Waste
  - Sustainability of Nuclear Fuel Cycle
  - Nuclear Proliferation
- Comparison of Nuclear Power to Alternative Energy Resources
  - Costs
  - Net Energy Analysis from Cradle to Grave
  - Comparison of Environmental Emissions from Nuclear Power and Its Full Fuel Cycle
  - Utilization of Waste Heat
- Considerations for Nuclear Power Plant in Connecticut
  - Connecticut and New England Electricity Market
    - Electric Rates
    - Need for Additional and/or Replacement Baseload Capacity
    - Economic Development
  - Siting
  - Local Acceptance: Survey of 600 Residents
  - Energy and Electricity Generation Education

Two sub-studies were also conducted as part of the larger study. They included a benchmark survey of 600 Connecticut residents on their attitudes about nuclear power that was completed by the Connecticut Economic Resource Center (CERC), and a detailed economic impact analysis by the Department of Economic & Community Development on job creation resulting from the construction and operation of a 1000 MW electricity generating facility. Both reports are included in the main body of this report, with analysis of the results in Appendices.

2.0 OVERVIEW OF NUCLEAR POWER

Nuclear technology was first developed in the 1940s during World War II by splitting atoms of either uranium or plutonium. In 1953, President Eisenhower delivered his "Atoms for Peace" speech to the United Nations, initiating the development of nuclear technology for peaceful purposes. This led to the first commercial nuclear power plant in the United States going on-line in December 1957. There are now 104 operating nuclear power plants in the United States that in 2009 generated 20% of the country's electricity and 5 operating plants in New England that generated 30% of the region's electricity (US Energy Information Administration [EIA]). Worldwide, there are 441 operating nuclear power plants in 30 countries that have 376,000 MWe of total capacity (as of October 2010) and generated 2,560 billion kWh of electricity (14% of the world's electricity) in 2009. In comparison, coal accounted for about 41%, natural gas 20%, and hydroelectric power 16% of the world's electricity in 2006 (Figure 1).

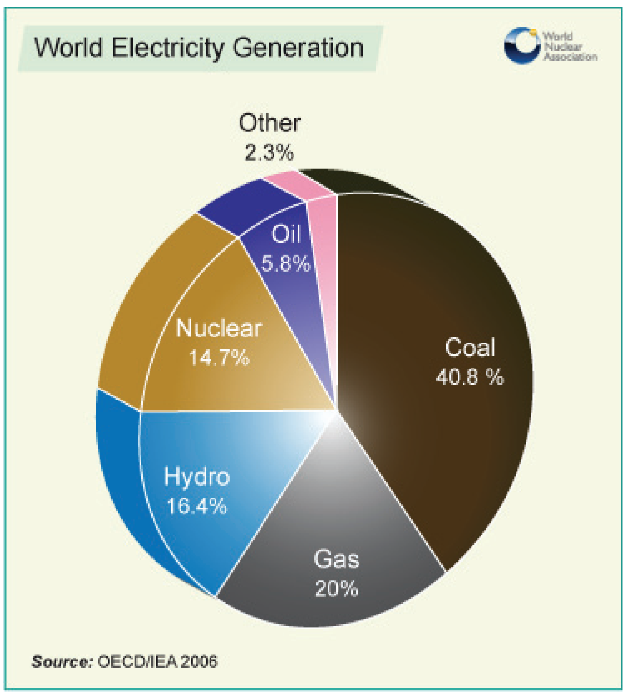


FIGURE 1: PERCENTAGE OF WORLD'S ELECTRICITY BY FUEL SOURCE
(SOURCE: WORLD NUCLEAR ASSOCIATION)

France has the highest dependency, about 75%, on nuclear power for the generation of electricity. A summary of the percentage of electricity derived from nuclear power for the top 30 countries is shown in Figure 2.

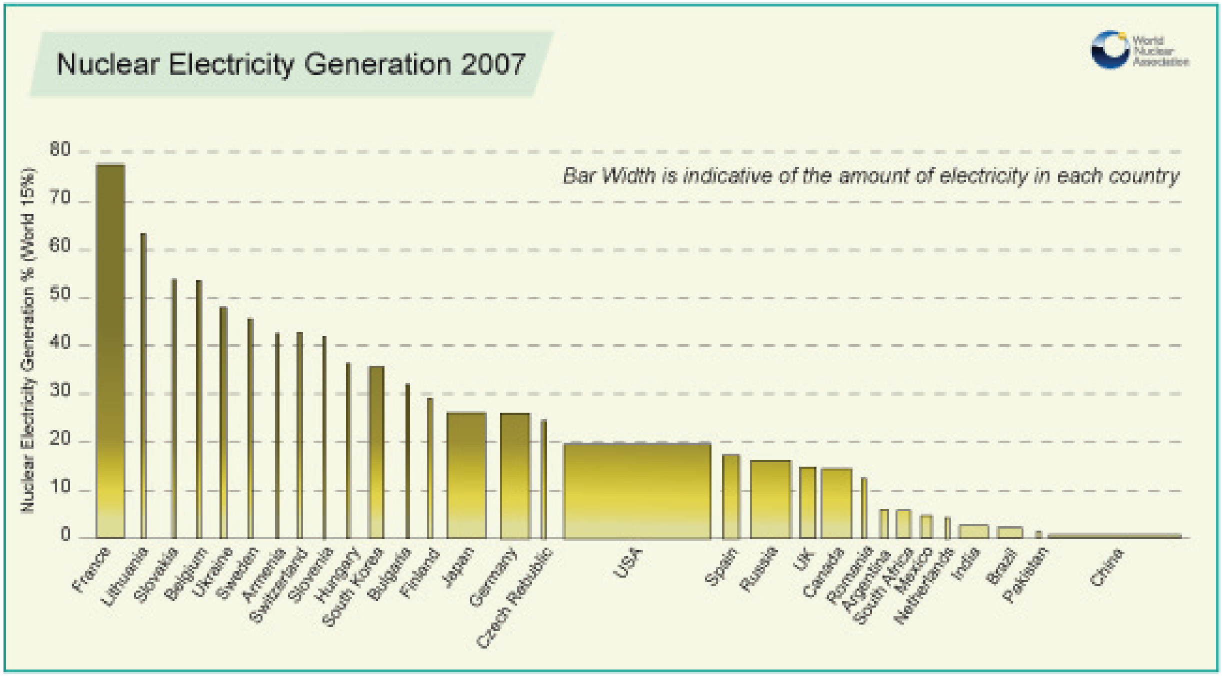


FIGURE 2: PERCENTAGE OF ELECTRICITY FROM NUCLEAR POWER
(SOURCE: WORLD NUCLEAR ASSOCIATION)

According to the World Nuclear Association (www.world-nuclear.org), there are over 58 nuclear power reactors under construction with 60,000 MWe capacity, 152 reactors that are firmly planned with 167,000 MWe capacity (expected operation within 8-10 years), and 337 reactors proposed with 383,000 MWe capacity (expected operation within 15 years).

In March 2011 the NRC reported on the status of the 30 new plants that had been announced in the United States (see Figure 3). Six of these nuclear power plants (i.e., V. C. Summer, Vogtle and Levy County) in the southeastern United States are under contract and four of these have already begun significant site preparation and procurement of long lead materials. Additionally, as noted by asterisk on Figure 3, applicants for six plants have suspended NRC review. Also, construction of the Watts Bar Nuclear Power Plant Unit 2 (Tennessee Valley Authority) is being completed after being suspended for about two decades.

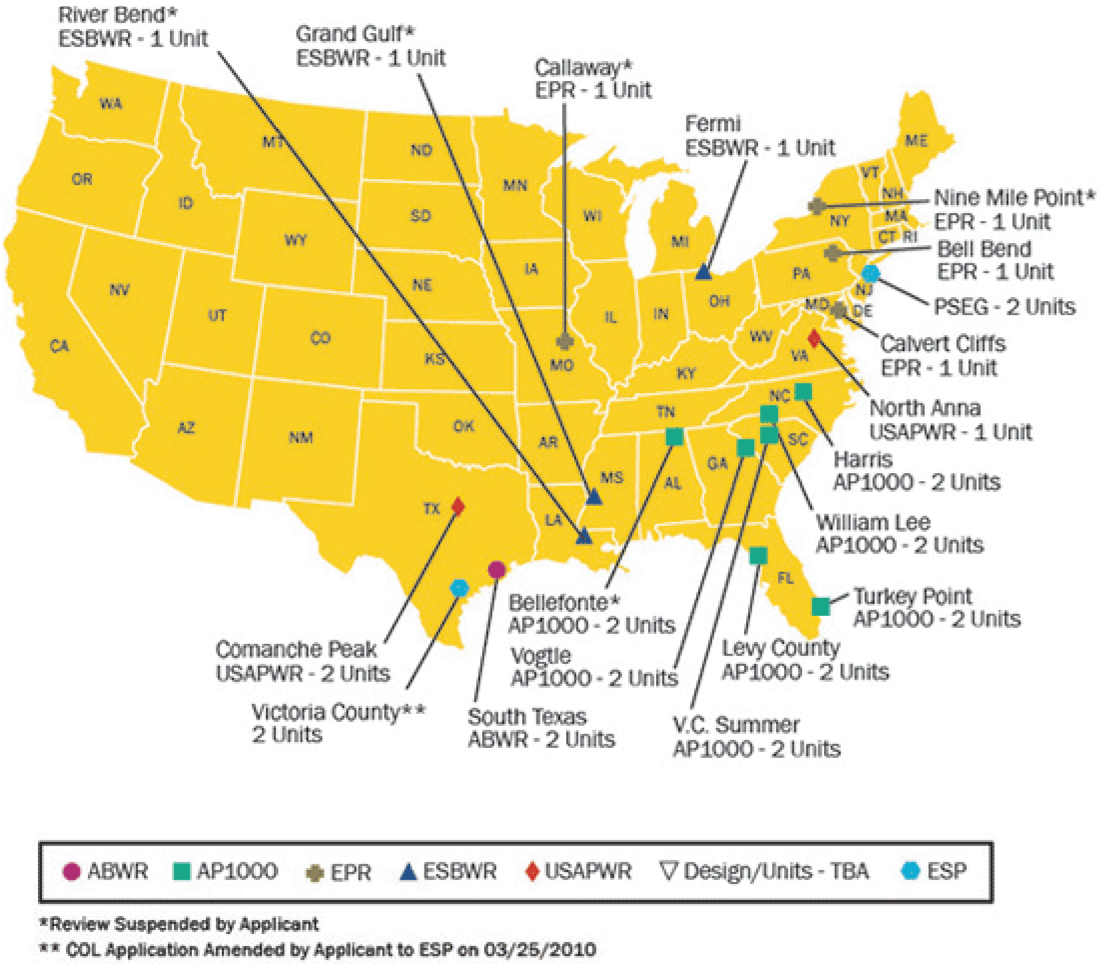


FIGURE 3: PLANNED AND ANNOUNCED NUCLEAR POWER PLANTS
IN THE UNITED STATES

(SOURCE: NRC; www.nrc.gov/reactors/new-reactors/col/new-reactor-map.html, MARCH 2011)

Currently there are five nuclear power plants operating at four sites in New England. They account for 15% of the region's electricity capacity, but 30% of the total electricity generated in 2009 (Figure 4). The much higher generation percentage is because of the high capacity factors of nuclear power plants compared to other generation sources.

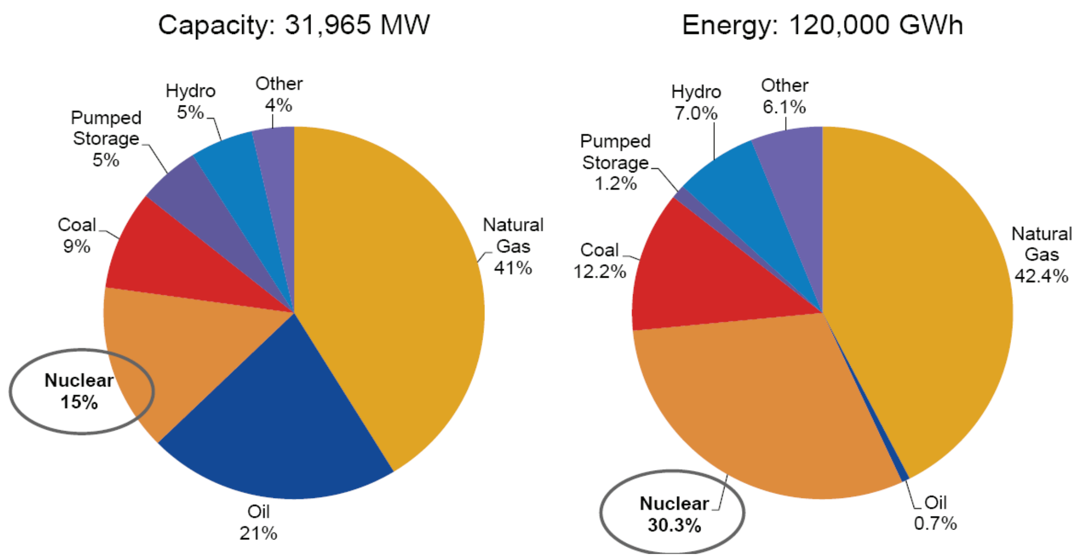


Figure 4: Capacity and Electricity Generation by Fuel Source for New England (Source: ISO New England)

The peak for nuclear power in New England was in 1990, when there were nine operating power plants that accounted for 25% of the region's electricity capacity (from ISO-NE presentation). Four of these nuclear power plants were located in Connecticut. CT Yankee, which had a capacity of 619 MWe, was shut down in 1996; Millstone – Unit 1, which had a capacity of 652 MWe, was shut down in 1995; and Millstone Units 2 and 3, with a combined capacity of 2024 MWe, are still operating. Millstone 2's license will expire in 2035 and Millstone 3's expires in 2045. The location, capacity, and the year that each New England nuclear power plant's license expires or was shut down is given in Table 1.

Table 1: New England Nuclear Power Plants – Past and Present (Source: ISO New England)

Plant Name	Location	Capacity (MW)	Shut Down	License Expires
Yankee Rowe	MA	185	1991	
CT Yankee	CT	619	1996	
Maine Yankee	ME	870	1996	
Millstone 1	CT	652	1995	
Millstone 2 & 3	CT	2024		Unit 2-2035; Unit 3-2045
Seabrook	NH	1245		2030
Pilgrim	MA	684		2012
Vermont Yankee	VT	620		2032

3.0 EVOLUTION OF NUCLEAR POWER TECHNOLOGY

The evolution of nuclear power technology from the early prototypes (Generation I) in the 1950s through the next generation of nuclear power plants (Generation IV) that is expected to be available in 2030 is shown in Figure 5. Current operating nuclear power plants in Connecticut and New England are Generation II designs. The nuclear power plants now being constructed in the southeastern United States are Generation III+ Evolutionary Designs. Improvements include standardized pre-licensed designs, combined construction and operating licenses, and utilization of modern construction techniques to reduce cost and schedule. Improved safety system designs that utilize passive processes also have been incorporated into the Generation III+ designs. Although not shown in Figure 5, the AP1000 and Economic Simplified Boiling Water Reactor (ESBWR) are examples of Generation III+ Evolutionary Designs. The Generation IV International Forum was chartered in 2001 to develop the next generation of nuclear technology. The concepts being developed use fuel cycle strategies that efficiently utilize uranium resources while minimizing waste, reducing proliferation risk, improving physical protection of the facility, increasing safety and reliability, enhancing competitive life-cycle costs, and having acceptable financial risk. The systems should also provide potential for new applications for expanded use of nuclear energy including hydrogen or synthetic hydrocarbon production, seawater desalination, process heat production, and district heating and cooling. In 2002, six promising reactor systems that have a variety of reactor energy conversion and fuel cycle technologies were identified. Initial deployment of these technologies is expected to occur between 2020 and 2030.

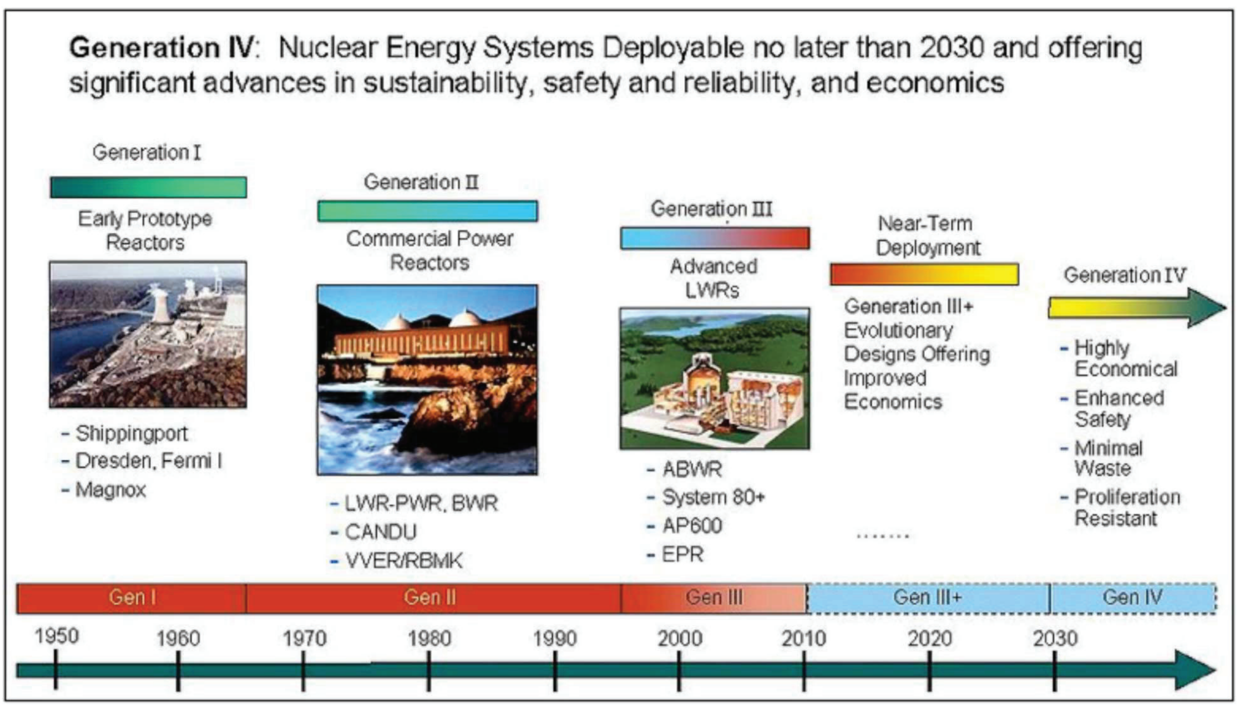


FIGURE 5: EVOLUTION OF NUCLEAR POWER TECHNOLOGY

(SOURCE: THE GENERATION IV PROGRAM, NUCLEAR ENGINEERING DIVISION, ARGONNE NATIONAL LABORATORY)

3.1 COMMERCIAL NUCLEAR POWER TECHNOLOGY

The work of the Curies, Ernest Rutherford, Bohr and others provided much of the groundwork for the great leap in understanding the atom and our ability to generate power from nuclear fission that began in the 1930s. The large incentive and funding generated by World War II produced the Manhattan project. This project also brought about the first man-made controlled nuclear reaction, essentially the first nuclear reactor that was composed of uranium oxide with graphite blocks as the moderator, assembled at the University of Chicago in 1942.

Reactor, fuel cycle and material development continued after World War II and resulted in the first US commercial nuclear power plant in Shippingport, Pennsylvania, which began operation in 1957. This light-water cooled and moderated, Pressurized Water Reactor (PWR) (light water is conventional water, as compared to water with the hydrogen replaced by deuterium [e.g., Heavy water]) was designed by Westinghouse based on existing Navy reactor designs. It produced 66 MWe, 231 MWt (29% thermal efficiency). The plant operated from 1957-1982 and was also the first commercial reactor to be decontaminated and decommissioned.

PWRs operate by maintaining liquid water around the nuclear reactor core fuel. In order to achieve moderate thermal efficiency, they operate at very high pressures to keep the high-temperature water coolant and moderator in the liquid phase. Figure 6 shows a simplified schematic of a PWR. In a typical commercial pressurized light-water reactor (1) the core inside the reactor vessel creates heat, (2) pressurized water in the primary coolant loop carries the heat to the steam generator, (3) inside the steam generator, this heat boils the feedwater on the secondary side of the steam generator tubes creating steam, and (4) the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.

The major components are the reactor vessel, which houses the nuclear fuel elements; the pressurizer; and the steam generator, which takes the high-temperature water coolant and generates steam for the turbine generator. The pressurizer allows pressure control in the PWR by maintaining a two-phase (steam-liquid) region. Without the pressurizer, small changes in average coolant temperature could produce large pressure swings if the entire system were held as a liquid.

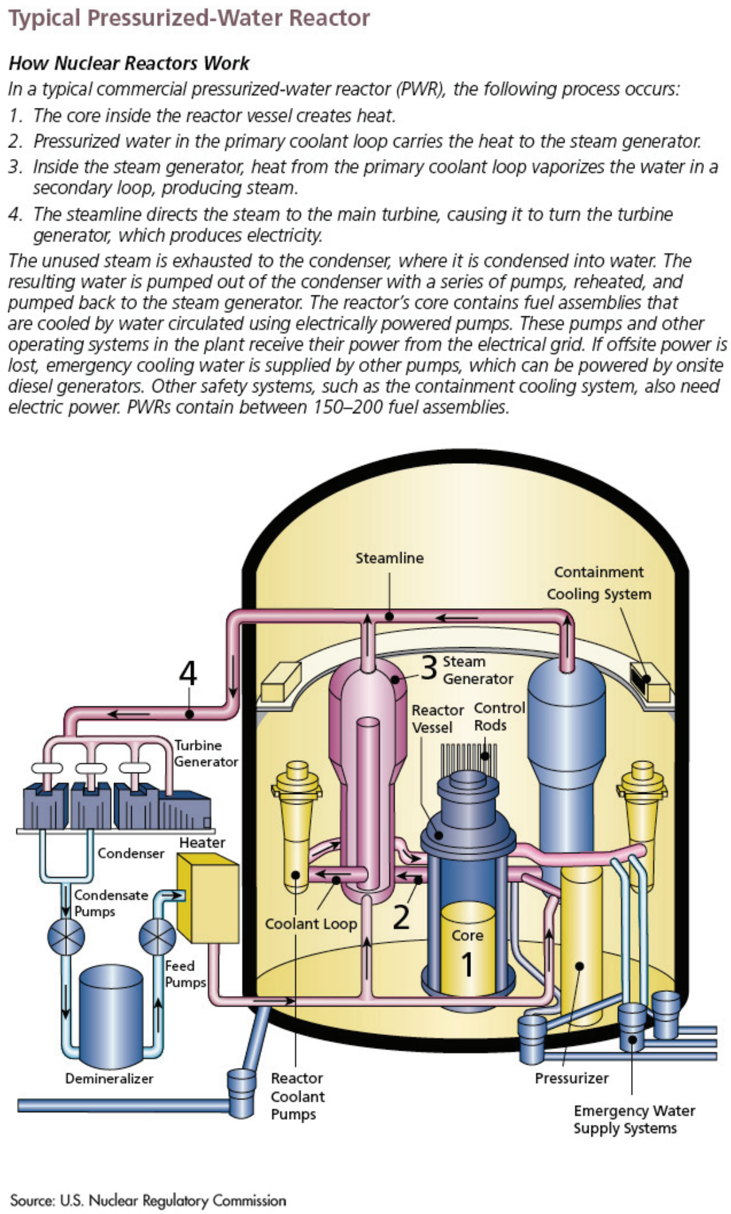


FIGURE 6: TYPICAL PRESSURIZED WATER REACTOR
(SOURCE: NUCLEAR REGULATORY COMMISSION)

Boiling-Water Reactors (BWR) have also been designed and operated for electric power production. These plants offer a small reduction in components (fewer heat exchangers) and can operate with thinner-walled pressure vessels because of the two-phase mixture operating under reduced pressure within the reactor vessel. Figure 7 shows a typical schematic of a BWR. In a typical commercial boiling-water reactor, (1) the core inside the reactor vessel creates heat;

(2) a steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat; (3) the steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line; and (4) the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.

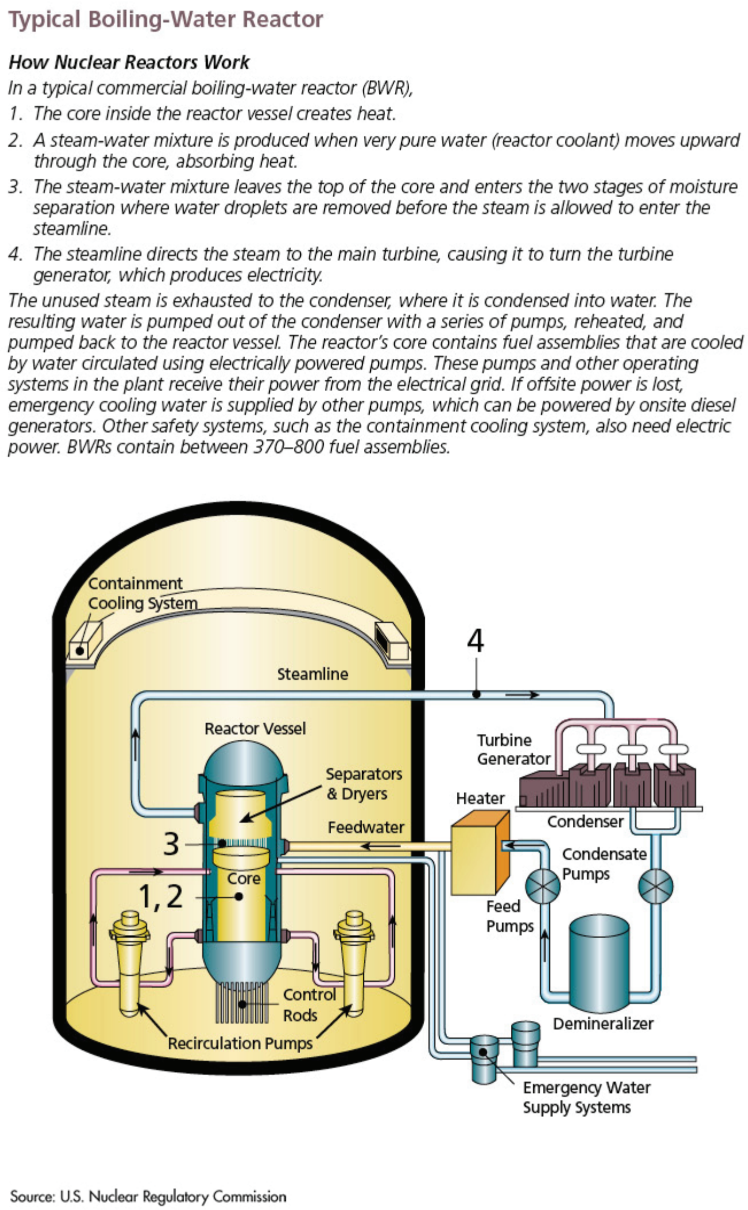


FIGURE 7: TYPICAL BOILING-WATER REACTOR
(SOURCE: NUCLEAR REGULATORY COMMISSION)

The major difference between a PWR and a BWR is that the energy generated within the core of a PWR is transferred to a secondary loop before it leaves the containment building on its way to the turbine generator. Consequently, little or no radioactive content is present in the turbine building components of a PWR. In addition, because the BWR has a two-phase mixture (saturated liquid and saturated steam) exiting the core, it is necessary to provide moisture separators and dryers to condition the steam for passage to the turbine. Since current designs elect to incorporate the moisture separator and dryer inside the reactor vessel as well as the associated recirculation pumps, the control rods for this type of reactor are typically positioned to enter from the bottom (where the effectiveness of the rods is greatest). Another difference is that power levels in the BWR can be controlled by regulating the recirculation rate of the saturated liquid exiting the core.

The US Department of Energy's (DOE) research and development objective with regard to Generation II commercial power plants is to develop technologies and other solutions that improve the reliability, sustain the safety, and extend the life of current reactors. The challenges in meeting the goal of providing the technical basis to extend life beyond 60 years are the aging and degradation of system structures and components, obsolete analog instrumentation and control technologies, and design and safety analysis tools based on 1980s-vintage knowledge bases and computational capabilities.

3.2. LESSONS LEARNED FROM THREE MILE ISLAND; THE SEPTEMBER 11, 2001 TERRORIST ATTACK; AND FUKUSHIMA DAIICHI

The nuclear power industry has responded to nuclear power plant accidents and terrorist activities to improve safety and operational procedures. The major events include Three Mile Island; the September 11, 2001 terrorist attack; and Fukushima. Chernobyl is not included in the "Lessons Learned" analysis because the design and operation of that facility is not consistent with NRC regulatory requirements. The following is a summary of the incidents and the changes implemented by the nuclear industry to address the lessons learned.

3.2.1 Three Mile Island

The worst, most well-known US commercial accident occurred at Three Mile Island (TMI) unit 2. TMI-2 was a Babcock & Wilcox Company (B&W) designed PWR rated at 880 MWe (see Figure 8). The B&W design used four reactor coolant pumps feeding two (2) Once-Through Steam Generators (OTSG). The plant was operating at close to 100% power on March 28, 1979 but three system issues were ongoing and contributed to the magnitude of damage that occurred.

1. The pressurizer had a leaking pilot-operated relief valve (PORV), which allowed reactor coolant to steadily drain from the primary system.
2. The emergency feedwater lines to both steam generators were closed. This condition prevented feedwater from entering the steam generators during the first 8 minutes of the accident.
3. Plant operators were having difficulty moving demineralizer resin to the resin regeneration tank.

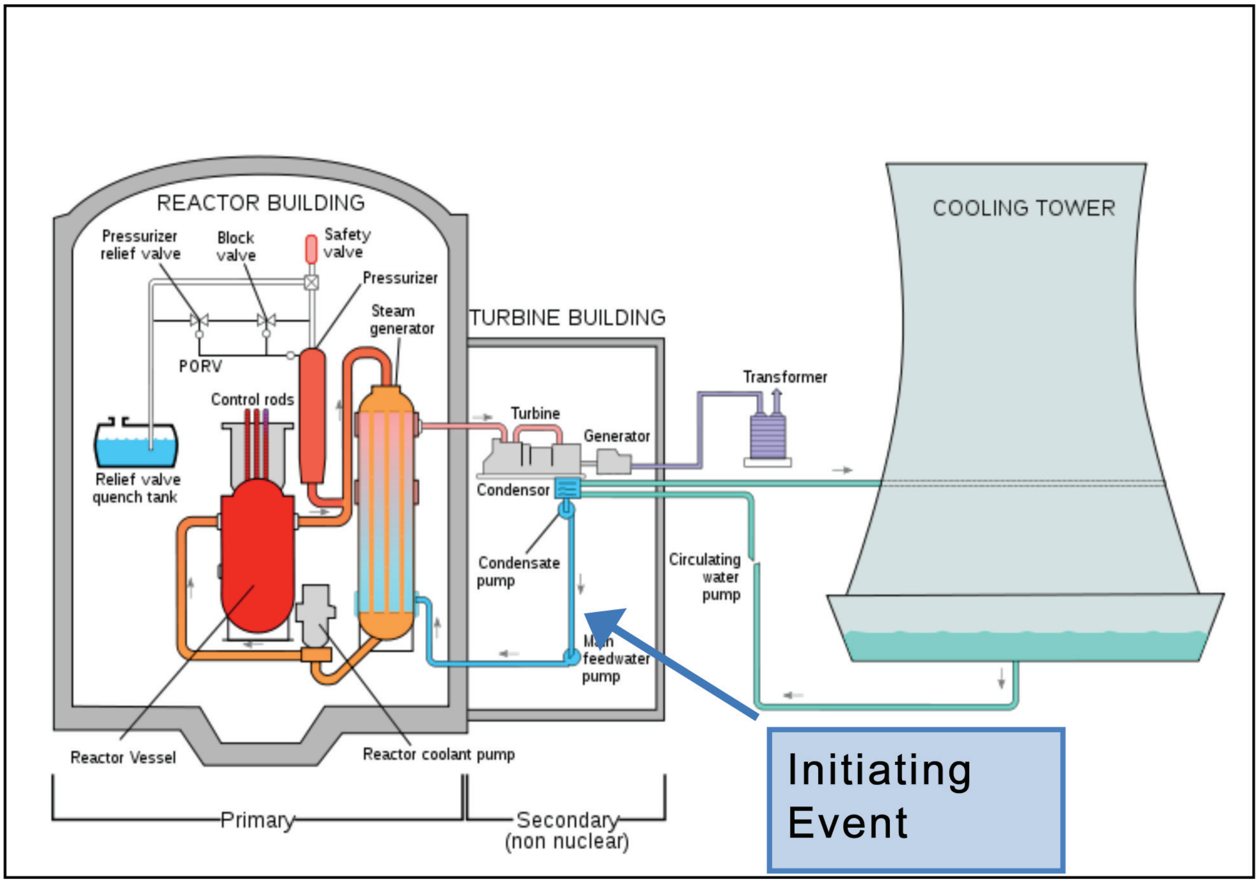


FIGURE 8: THREE MILE ISLAND (TMI-2) PLANT SCHEMATIC
(SOURCE: NUCLEAR REGULATORY COMMISSION WITH “INITIATING EVENT” ADDED)

Initiation

Maintenance activities on the demineralizer train were thought to have produced a loss of condensate flow at about 4:00 a.m. on March 28. The loss of the condensate flow tripped the main feedwater pumps (low flow) which then tripped the main turbine. Within seconds of the condensate, feedwater, and turbine shutdowns, the emergency feedwater pumps (drawing water from the condensate storage tank) started automatically. However, item 2 above prevented water from reaching the steam generators. While unthinkable today, the reactor did not trip with the loss of feedwater pumps; instead, the lack of emergency feedwater makeup to the steam generators blocked the overall heat sink, raising primary temperatures and pressures. The reactor scrammed (shut down) on high pressure about 8 seconds after the main feed pumps tripped.

The reactor coolant system (RCS) pressure began to decrease after the reactor trip (control rods fully inserted) and a signal was sent to the open pressurizer PORV to close, but the valve stayed open. The control room (CR) indicator for the PORV only indicated the status of the actuation solenoid (energized/de-energized), not the actual valve position, so the CR board now indicated that the solenoid had been de-energized, which meant the operators thought the valve was closed.

As the PORV remained open, RCS pressure continued to drop so that the High Pressure Injection (HPI) system (set point 1640 psi) automatically began pumping borated water into the reactor vessel about 2 minutes into the accident. Plant operators began throttling HPI pumps as a high water level was indicated within the pressurizer. Their training had reinforced the importance of maintaining a steam bubble in the RCS for overall pressure control. Unfortunately, the reduced injection flow was less than the mass flow of water out of the RCS through the open PORV. Due to the system configuration and operator ignorance of saturation conditions, the pressurizer remained full of water while the reactor vessel was losing liquid water, creating steam voids.

After 8 minutes the block valves on the emergency feedwater lines were opened, finally providing a heat sink for shutdown cooling.

The two reactor coolant pumps feeding the B steam generator experienced high vibration. Operators turned both pumps off at 73 minutes into the accident in response to low system pressure, low coolant flow, and high vibration. Again their training told them to avoid damaging the pump seals and a potential leak path from the RCS. The effect of this action was to steam "block" the B steam generator, with the steam and water in the RCS separating based on the significant density differences between the phases. About 100 minutes into the accident the loop A pumps were turned off, for similar reasons. The operators expected natural circulation to keep the core cool.

Up until the Reactor Coolant Pump (RCP) shut down, adequate cooling had been provided to the core from the saturated steam/water mix. However, stopping the pumps allowed phase separation in which vapor blocked the upper level of the core. Reactor coolant outlet temperatures rose rapidly within 10 minutes of the RCP shutdown. This indicated that superheated steam was forming above the core. As liquid water no longer covered the core, the fuel clad temperatures rose high enough for zirconium-steam reactions to occur. This is an exothermic reaction and produces H_2.

The operators finally closed the block valve on the pressurizer outlet line that contained the stuck open PORV, effectively ending the loss of coolant accident (LOCA). They then spent the next 13 hours trying to re-establish stable core cooling using natural and forced circulation with the steam generators as well as the low-pressure injection system and its associated heat removal system.

TMI-2 allowed a significant amount of radiation to be released from the fuel elements due to the melting and damage of all the fuel elements. In addition, the pressurizer drain tank had its rupture disk open early in the accident, allowing primary coolant to fill the containment sump. The water in the sump was automatically pumped into the auxiliary building where it eventually exceeded the tank capacity and collected on the auxiliary building floor. This leak path (pressurizer drain tank, containment sump, auxiliary building) was the leak path for fission products from the RCS and ultimately into the environment. The largest radiation release from TMI was primarily centered on noble gases which are not retained by filtration, but are retained somewhat by activated charcoal depending on the quantity and temperature of the charcoal. However, since noble gases are inert, they do not bio-accumulate and therefore did not contribute to a significant radiation dose to the local population. Iodine 131 was the isotope of major concern following the accident at TMI. Although it is volatile and can potentially be dispersed, the accident at TMI demonstrated that it is also very reactive and consequently releases were much less than dictated by NRC accident scenario evaluations.

The following TMI lessons learned/recommendations were implemented with positive results for the US nuclear industry:

1. Achieve increased focus on plant safety versus licensing new construction
2. Focus on safety for plant design and operation by utilities and plant suppliers. The Institute of Nuclear Power Operation (INPO) was established to oversee operational issues.
3. Improve training of operating personnel
4. Increase technical assessment including analysis of small break LOCA's
5. Research low-level radiation effects
6. Have detailed emergency plans for local residents
7. Provide for communicating information to the public in the event of a radiation-related emergency

3.2.2 SEPTEMBER 11, 2001 TERRORIST ATTACK

Security at nuclear facilities has always been a priority, but the terrorist attack on September 11, 2001 heightened the need for stringent security requirements with a multiple security approach. Security enhancements included the following:

- Nuclear power plants were already designed as robust structures to withstand hurricanes, tornadoes, and earthquakes. Analysis of aircraft attack on a nuclear power plant and other types of terrorist attacks showed that the likelihood of a radioactive release affecting public health and safety was low. Another study evaluated the ability of a nuclear facility to withstand large fires and explosions. Some enhancements were identified and NRC ordered these changes at nuclear power plants.
- Substantial increase of higher qualified and better trained security forces
- Stronger background checks for individuals who have unescorted access to nuclear power reactor facilities
- Additional physical barriers, intrusion detection and surveillance systems, greater stand-off distances for vehicle checks, and more restrictive site access to protect equipment and structures
- Coordination with the Department of Homeland Security, FBI, intelligence agencies, Departments of Defense and Energy, and state / local law enforcement so that the NRC can quickly act on any threat and allow for more effective emergency preparedness and response
- Increased security inspections from about 40 staff-weeks a year at nuclear power plants in 2000 to about 400 staff-weeks per year in 2005.
- More realistic force-on-force exercises with mock adversary force "attacks" with more challenging expectations at least every three years. The first three-year cycle was completed in December 2007.

- Improvements have been made to the Nuclear Materials Management and Safeguards System, a joint NRC-DOE database that captures the movement and location of certain forms and quantities of nuclear material.
- Cyber security is a growing and serious issue. Computer systems that help operate the reactors and safety equipment are isolated from the internet to protect against outside intrusion. In addition, NRC has issued advisories and orders requiring nuclear power plants to enhance protection of their other computer systems.

Nuclear power plants must also show that they can defend against a variety of terrorist attacks as outlined in NRC's Design Basis Threat (DBT). The DBT was finalized in January 2007, but the details are not publicly available.

3.2.3 FUKUSHIMA DAIICHI NUCLEAR POWER PLANT

The following is *a summary of events that took place at Fukushima Daiichi Nuclear Power Plant from Nuclear News Special Report: Fukushima Daiichi after the Earthquake and Tsunami, April 2011.* The description of events that took place continues to be updated as additional facts and sequences are understood.

An unprecedented 9.0 magnitude earthquake with an epicenter in the Pacific Ocean 80 miles east of Sendai, Japan began at 2:46 p.m. (Japan time) on March 11, 2011. All operating nuclear reactors at four nuclear power plants located along Honshu's northeast coast went into automatic shutdown (i.e., control rods went into reactor cores as intended) because of ground acceleration. All reactors at two of the nuclear power plants (Fukushima Daini and Tokai) went into cold shutdown with no reports of fuel damage, spent fuel uncovering, or major system failure. At Onagaw which was closest to the epicenter, there was a fire in the turbine building that was quickly extinguished and the plant was safely shut down less than 12 hours after the quake. Efforts to bring Units 1-4 at the Fukushima Daiichi plant to cold shutdown were hampered by the damage caused by the subsequent tsunami that struck roughly an hour after the earthquake, damaging on-site emergency power and nearby infrastructure. Units 5 and 6, which are physically separate from Units 1-4, were off-line but fuel was still in the reactors. While there were issues in maintaining a normal environment, Unit's 6 emergency diesel generator was not damaged and was used to cool the spent fuel pools at both Unit 5 and 6. It appears that there was no damage to these reactors.

The nuclear emergency at Units 1- 4 at Fukushima Daiichi began when the tsunami reached the site, resulting in the loss of all on-site emergency diesel generators and off-site power. The height of the tsunami was determined to be about 46 feet while the plant had been modified to withstand a design-basis tsunami with a height of 18.7 feet in 2000 compared to the original design of 10 feet. The following is a summary of the events that took place at Units 1-3 (Unit 4 was off-line and completely defueled).

Unit 1 (General Electric BWR-3 model): With loss of off-site power and emergency generators, plant personnel tried to maintain core cooling and shutdown activities through battery power that was designed to last 8 hours. However, the emergency core cooling system stopped delivering water less than an hour after the tsunami hit. Primary containment vessel pressure began to increase because of overheating and rose above design limits by the morning of March 12. To prevent damage to the vessel, the primary containment vessel was vented which involves the release of steam, radioactive gases, and hydrogen produced by the reaction of hot zirconium fuel cladding with water in the reactor building. Significant quantities of water needed to be added to the core to prevent overheating and further core damage, so seawater with boron was injected into the reactor core through fire protection lines as soon as it was possible. However, with no heat sink, the addition of seawater caused pressure to rise and had to be stopped. At 3:36 pm on March 12, a hydrogen explosion occurred at the top of the reactor building, blowing out a large section of the roof. Radiation levels increased substantially, making it clear that there was some fuel damage and possibly melting. The evacuation zone at this point was enlarged to a 12-mile radius.

Units 2 and 3 (General Electric BWR-4 models): Conditions at these units were slightly different, but the events followed a similar path as Unit 1 with difficulty in keeping the fuel covered with water. Venting of the containment vessel was initiated to prevent damage to the vessel. This led to an explosion occurring in the upper part of the Unit 3 reactor building. In Unit 2, part of the wall of the top floor was removed to prevent hydrogen from accumulating. However, an explosion also occurred a few hours after the containment vessel were vented, which was believed to be in the suppression chamber underneath the reactor. Once again, radioactivity was released into the reactor building.

Lack of cooling may have caused problems in the spent fuel pools that were used for the initial cooling of the fuel. These spent fuel pools were located on the upper levels of the reactor buildings. In all four units, pool cooling or water makeup could not be maintained following the loss of power. This may have been especially problematic in the Unit 4 pool because it contained very hot fuel that had been recently removed from the reactor. Initially it appeared that the fuel was hot enough to release hydrogen that exploded and destroyed a large part of the building's roof and walls. However, more recent findings, from the *Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety (June 2011),* make it unclear as to the cause of the explosion at the reactor building. If low water level were the cause, it is estimated that the explosion would have occurred earlier. Furthermore, no extensive damage to the fuel rods took place based on nuclides found in water extracted from the spent fuel pool.

To summarize:

1. The nuclear reactors appear to have withstood the earthquake. Ground acceleration was within the design basis event except at Unit 3, where the observed acceleration was 507 cm/s^2 compared to design of 449 cm/s^2.

2. The tsunami far exceeded the design basis. The resultant loss of off-site power and emergency on-site power led to a series of events that resulted in hydrogen explosions and the release of radioactive material.

3. The widespread destruction and loss of life caused by the earthquake and tsunami required a considerable amount of attention from local and national authorities and emergency providers. Therefore, the amount of outside support to safely cool down the nuclear reactors was limited. Outside support was further inhibited by the destruction to the infrastructure including transmission lines, roads, and railroads. It is noted that all reactors shut down when the earthquake occurred.

4. The major issues faced were loss of ultimate heat sink, loss of equipment, and the harsh radiation environment for field workers.

Some initial lessons learned are:

1. Diversity of emergency power sources is needed, especially with respect to maintaining a heat sink for power generating equipment.
2. Provisions are required for hydrogen monitoring and venting at the top of the reactor building.
3. Define organization of the operations group and delineation of authority to implement the severe accident management procedure.
4. Organize international support on the assessment of possible strategies to be taken and their impacts.

The lessons learned are still evolving as additional facts and information on the sequence of events are understood. Thus, the impact on US operations is ongoing and should be monitored.

3.3 ADVANCES IN NUCLEAR TECHNOLOGY

Advances in design of nuclear power plants have concentrated on simpler and standardized designs that are inherently safer, decrease capital cost, reduce construction time, and are more fuel efficient.

Safety

Generation III+ power plants that are designed with passive safety systems have up to a 72-hour period following a shutdown where no active intervention is required. Active systems rely on AC electrical power for energizing pumps, valves and cooling water systems. They typically have four trains of mechanical safety systems and two or four trains of emergency electrical systems. Core decay heat is removed by steam generators, safety injection systems, and/or accumulators; containment heat is removed by a containment spray system. Passive safety systems do not require AC power to provide safety functions, but rely on gravity, natural convection, evaporation, and materials resistant to high temperature. They use water that is already inside the plant for heat rejection and valves that fail in a safe position.

Improvements in safety design have reduced the possibility of core melt accidents. The NRC requirement for calculated core damage frequency is 10^{-4} per year. Most US plants today (i.e., Generation II design) have a calculated core damage frequency of about 5×10^{-5} per year, or a frequency that is half of the requirement. The Generation III+ designs have calculated core damage frequency of about 10 times less or 5×10^{-6} per year. For a large release of radioactivity, the calculated probability is about 10 times less, or 5×10^{-7} per year for Generation III+ systems.

Capital Cost and Construction Time

Simpler and standardized designs incorporating modular construction are expected to reduce the cost and time to build a nuclear power plant. A comparison between a Generation II Westinghouse reactor at Sizewell B in the United Kingdom and the Generation III+ AP1000 of similar power illustrates the design improvements. The footprint of the AP1000 is about 25% the size and the concrete and steel requirements have been reduced by about 80%. The modular construction will allow about one third of construction to be built off-site in parallel with on-site construction.

Changes in the licensing procedure are also expected to decrease the construction time. Standardized designs will be licensed by NRC prior to construction. Design certification is good for 15 years with the option to renew for an additional 15 years. They will go through a rigorous public process to ensure that safety issues of the certified design have been fully resolved so that they cannot be legally contested during the licensing of a particular plant. Also, utilities or merchant owners will be able to obtain a single NRC license to both construct and operate a reactor before construction begins. Details of the licensing process are discussed in Section 4.1.

Fuel Efficiency

Advances have been made to increase burn-up to reduce the amount of fuel required and the amount of spent fuel. Fuel life will also be extended by the greater use of burnable absorbers (i.e., poisons) to control power distribution early in the fuel cycle.

3.4 GENERATION IV – REVOLUTIONARY DESIGNS

The Generation IV International Forum was chartered in 2001 to develop the next generation of nuclear technology that is sustainable, economic, safe and reliable, and proliferation resistant. These goals are outlined in Table 2.

TABLE 2: NEXT GENERATION REACTOR TECHNOLOGY GOALS
(SOURCE: GEN IV INTERNATIONAL FORUM: HTTP://WWW.GEN-4.ORG/PDFS/GIF_OVERVIEW.PDF)

Goals	Description
Sustainability	Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilization for worldwide energy production. Generation IV nuclear energy systems will minimize and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.
Economics	Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources. Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.
Safety and Reliability	Generation IV nuclear energy systems operations will excel in safety and reliability. Generation IV nuclear systems will have a very low likelihood and degree of reactor core damage.
Proliferation Resistance and Physical Protection	Generation IV nuclear energy systems will be less attractive targets for diversion or theft of weapons-grade materials, and will provide increased physical protection against acts of terrorism.

The systems also should provide potential for new applications for expanded use of nuclear energy including hydrogen or synthetic hydrocarbon production, seawater desalination, process heat production, and district heating and cooling.

In 2002, six promising reactor systems that have a variety of reactor energy conversion and fuel cycle technologies were identified (see Table 3). The initial deployment of these technologies is expected to take place between 2020 and 2030. The Very High Temperature Gas Reactor (VHTR) was expected to be one of the first deployed, but the construction of the South African Pebble Bed Modular Reactor (PBMR) lost government funding in February 2010. Potential investors and customers were discouraged by increased costs and technical problems. The development costs and licensing hurdles for all of these designs will be very high, making their deployment within the intended time frame problematic.

TABLE 3: OVERVIEW OF GENERATION IV SYSTEMS
(SOURCE: GEN IV INTERNATIONAL FORUM: HTTP://WWW.GEN-4.ORG/PDFS/GIF_OVERVIEW.PDF)

System	Neutron Spectrum	Coolant	Temperature (◦C)	Fuel Cycle	Size (MWe)
VHTR (Very High Temperature Gas Reactor)	Thermal	Helium	900 – 1000	Open	250 - 300
SFR (Sodium-Cooled Fast Reactor)	Fast	Sodium	550	Closed	30-150, 300-1500, 1000-2000
SCWR (Supercritical Water-cooled Reactor)	Thermal/Fast	Water	510 – 625	Open / Closed	300-700, 1000-1500
GFR (Gas-Cooled Fast Reactor)	Fast	Helium	850	Closed	1200
LFR (Lead-Cooled Fast Reactor)	Fast	Lead	480 – 800	Closed	20-180, 300-1200, 600-1000
MSR (Molten Salt Reactor)	Epithermal	Fluoride Salts	700 – 800	Closed	1000

3.5 SMALL MODULAR REACTORS

Small modular reactors (SMRs) typically produce less than 300 MWe. SMRs offer several advantages compared to large nuclear power plants (>1000 MWe). These advantages include

- Reduced financial risk
- Shorter construction schedules due to smaller size and modular construction
- Improved quality with factory construction
- Incrementally meet electric demand
- Expanded nuclear applications such as combined heat and power, and process heat applications

The large investment for a 1000+ MW nuclear power plant is considered a risky investment because of the large size and time frame needed to construct the power plant (Moody's, 2009).

Through factory construction, SMRs are expected to further reduce cost and schedule and increase quality through greater standardization. Large power plants require more on-site construction, which is considered more complex than SMR factory-constructed modules that are transported to the site. Some of these benefits may be mitigated if multiple SMRs are built on the same site.

The potential market for SMRs is for replacement of aging power plants and for industrial and district heating applications. Siting may be easier than for large plants because some SMRs can be air cooled (meaning reduced water requirements) and the balance of plant (BOP) requires less land.

The near-term SMRs use light-water reactor (LWR) technology and standard uranium oxide fuel. There is regulatory and operating experience with these types of reactors so it is expected that deployment can be achieved by 2020. Examples of reactors using LWR technology are mPower (Babcock & Wilcox, 125 MWe), NuScale (NuScale, 45 MWe), and a Westinghouse SMR design. It is expected that non-LWR based designs would not be ready to be deployed for 15 to 20 years. The non-LWR designs would have broader applications and would not need to have their fuel replaced as frequently. Examples of non-LWR designs are GE Prism, Hyperion and DOE-sponsored helium-cooled Next Generation Nuclear Plant (NGNP).

One of the challenges facing the commercialization of SMRs is applying existing NRC regulations in a way that is economically suitable for the characteristics of small modular reactor designs. Issues include

- NRC Annual Fees
- Decommissioning Funding
- Pre-Application Engagement
- Control Room Staffing
- Emergency Preparedness
- Security
- Site Staffing
- Insurance cost

If modification of existing regulations cannot assure the safe and reliable operation of the SMRs, then the savings from the standardization of design and off-site factory fabrication may not be sufficient to make SMRs a cost-effective alternative. The 1000+ MW size of current nuclear power plants grew out of the need for incorporating economy of scale in making nuclear power competitive with other electricity generating technologies (i.e., mills/kWh cost).

According to the NRC, issues related to annual fees, prototype licensing, operational programs, decommissioning funding, and multi-module licensing have been resolved with regard to SMRs. Issues that are still being evaluated are risk-informed licensing; mechanistic source term; liability and property insurance; manufacturing licenses; and staffing, security, and emergency planning. For emergency planning, a key consideration is public dose in relation to the US Department of Environmental Protection's Protective Action Guide (PAG) values resulting from a severe accident. A summary of the status is shown in Table 4.

Table 4: Summary of Policy Issues and Near-Term SECY Dates (from NRC Briefing on Small Modular Reactors, March 29, 2011)

(Source: Nuclear Regulatory Commission: http://www.nrc.gov/reading-rm/doc-collections/commission/slides/2011/20110329/staff-20110329.pdf)

SECY Paper	Date to the Commission
Annual Fees	Memorandum dated Feb. 7, 2011
Risk-Informed Licensing	Feb. 18, 2011 (SECY-11-0024)
Multi-Module Facilities	Early Q3 FY 2011
Decommissioning Funding	Early Q3 FY 2011
Emergency Planning	Mid Q3 FY 2011
Control Room Staffing	Late Q3 FY 2011
Mechanistic Source Term	Q4 FY 2011
Physical Security	Q1 FY 2012
Insurance	TBD Following Assessment
Manufacturing Licenses	TBD Following Assessment

To accelerate the deployment of SMR designs, the DOE initiated a SMR program in FY 2011, but it has been delayed by a congressional budget continuing resolution. For LWR technology, the program will assist in the design certification and licensing activities. Also, the DOE program will support R&D activities to advance the understanding and demonstration of innovative technologies and concepts.

Deployment of SMR technology moved forward with B&W signing a letter of intent with the Tennessee Valley Authority (TVA) in June 2011. The agreement defines the project plans and conditions for designing, licensing, and constructing up to six B&W mPower reactors at TVA's Clinch River site in Tennessee with deployment of the first reactor by 2020. The letter of intent is not a binding commitment or purchase agreement, but it is a significant step in licensing and building the first B&W mPower. However, it is expected that TVA will submit a Construction

Permit Application to the NRC in 2012 and that B&W will submit a Design Certification Application for mPower to the NRC in 2013. The proposed schedule for the mPower Design Certification as well as NuScale Design Certification and other related licensing applications is shown in Figure 9.

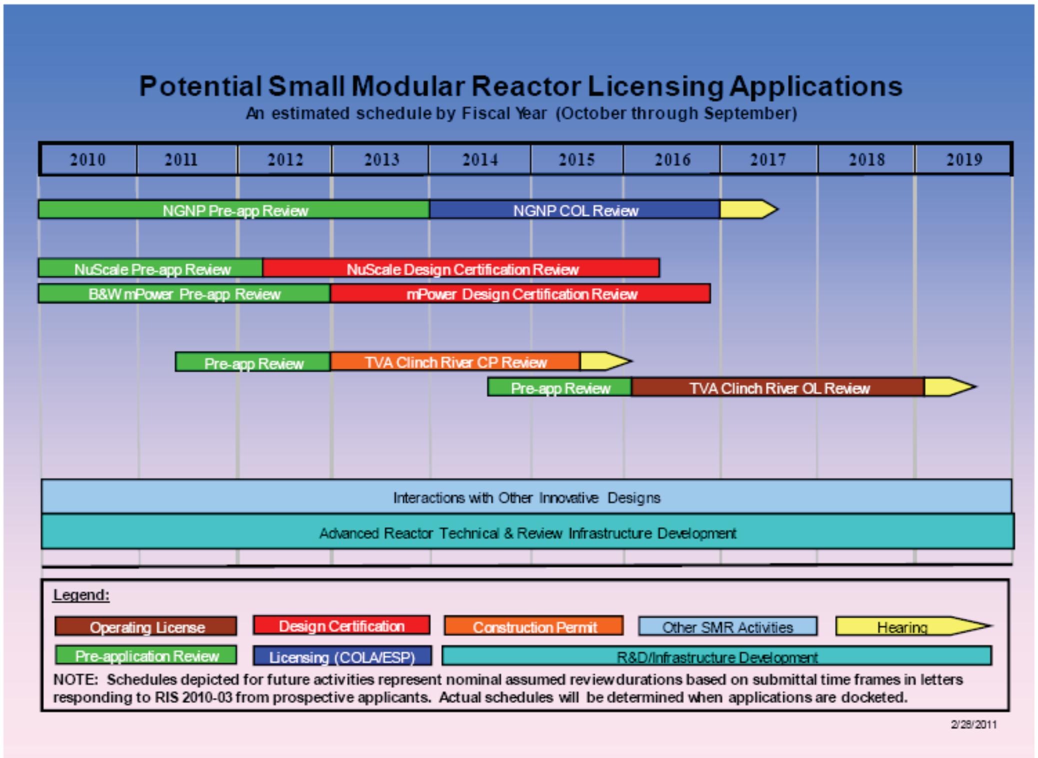


Figure 9: SMR Licensing Schedule

(Source: Nuclear Regulatory Commission: http://www.nrc.gov/reading-rm/doc-collections/commission/slides/2011/20110329/

4.0 NUCLEAR POWER PLANT OPERATION

4.1 US LICENSING PROCESS

In order to improve efficiency and provide predictability of their review process, the NRC adopted a Combined Operating License (COL) process in 1989 (10 CFR 52). This process allows a utility or any responsible entity to apply for permission to build and operate a nuclear reactor. The previous system (used by every operating nuclear power plant in the United States) required a two-step process (10 CFR 50). The licensee first had to get approval to build the nuclear facility (construction permit). After completing the construction phase, the licensee had to go through a second hearing process to be granted an operating license. During both phases, outside parties could slow or stop the licensing process based on their ability to identify potential flaws in either the construction or operating permit. The two-step system is still viable and can be used in place of applying for a COL. The new system limits external influence to the initial hearing period, and provides more confidence to applicants that their investment will be licensed and brought into the rate base. While streamlining the process, the COL application still requires about three years and costs tens of millions of dollars to complete.

While the NRC is the sole agency responsible for evaluating a reactor, they do interact with other federal, state and municipal organizations. The National Environmental Policy Act of 1969 requires every license application to include an Environmental Impact Statement (EIS). The EIS will frequently involve federal agencies, such as the Environmental Protection Agency, the US Fish and Wildlife Service or the US Army Corps of Engineers. The second major document required of any potential license applicant is a Safety Evaluation Report (SER) for the plant and its selected location.

Figure 10 provides a graphic representation of the COL process for building and operating a nuclear power station.

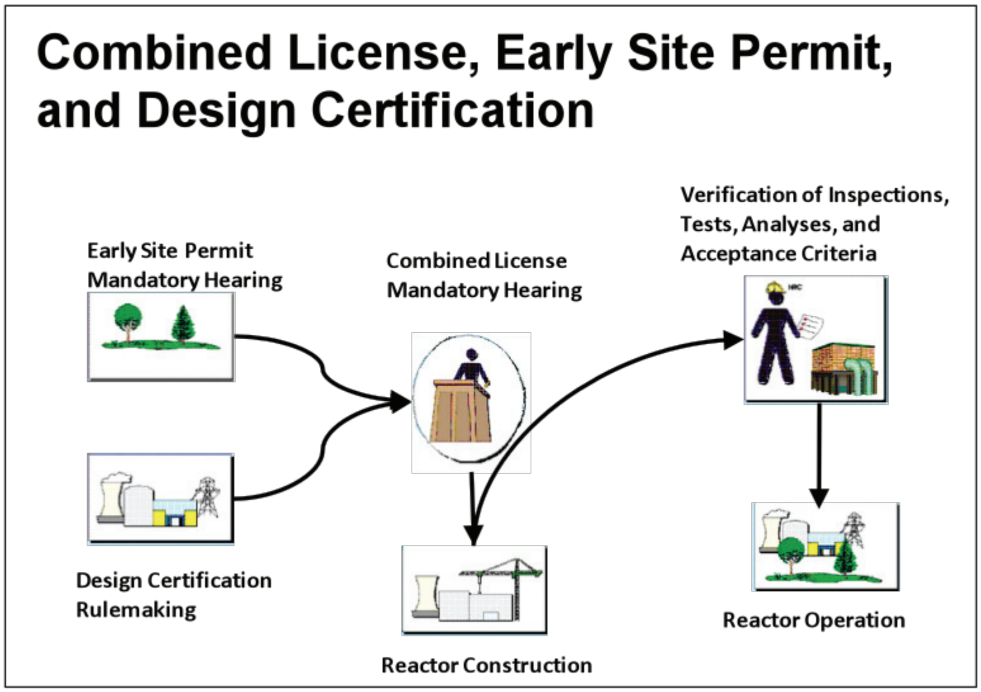


FIGURE 10: GENERAL PROCESS FOR LICENSING A NEW NUCLEAR REACTOR (NUREG/BR-0468)
(SOURCE: NUCLEAR REGULATORY COMMISSION: HTTP://WWW.NRC.GOV/READING-RM/DOC-COLLECTIONS/NUREGS/BROCHURES/BR0468/BR0468.PDF)

Early Site Permit

Based on the process identified in Figure 10, a potential licensee can seek an Early Site Permit (ESP) for approval to build an unspecified reactor design. An ESP resolves generic issues related to site safety, environmental characteristics, and emergency preparedness that are independent of the specific reactor design. Typically, various parameters, such as cooling water requirements, are included in the ESP to allow reactor design selection at a later date. This approach assures an applicant that a site is appropriate for future nuclear construction for up to 20 years. This method also reduces the eventual licensing uncertainty and resolves reactor siting issues before construction.

The ESP application must include safety and environmental characteristics of the site, and any potential physical impediments to the generation of an acceptable emergency plan. The ESP will contain:

- Site boundaries and exclusion area
- Site characteristics, (seismic, meteorological, hydrologic, and geologic)

- Location of nearby industrial, military or transportation facilities
- Existing and projected population of the area surrounding the site
- Evaluation of alternative sites (i.e., are there superior locations?)
- Proposed general location of each reactor unit on the site
- Number, type and power level of the units
- Maximum radiological and thermal effluent emissions
- Type of cooling system
- Radiological dose consequences of a hypothetical accident
- Emergency plans

As of October 2009, the NRC has issued four Early Site Permits. They are

- Clinton site in Illinois (Exelon)
- Grand Gulf site in Mississippi (System Energy Resources)
- North Anna site in Virginia (Dominion)
- Vogtle site in Georgia (Southern Company)

Two ESPs are in the NRC evaluation queue for Victoria County Station in Texas (Exelon) and Salem County in New Jersey (PSEG).

Design Certification

The NRC can provide design certification approval of a standard nuclear power plant design, independent of a site or even an application to build or operate the plant. As presently configured, a standard reactor design certification is valid for 15 years, and can be renewed for additional 15 year increments.

The reactor vendor submits a design certification application, which describes the design basis and limits of reactor operation. This application will include a safety analysis of the structures, systems and components to be used in the facility. The application must include proposed inspections, tests, analyses and acceptance criteria (ITAAC) for the standard design. This application also must include a detailed risk analysis of the design's vulnerability to certain accidents or events (probabilistic risk assessment) and an evaluation of design alternatives to mitigate the potential impacts produced by severe accidents.

The NRC has certified four reactor designs and therefore these specific designs can be referenced in an application for a nuclear power plant. The four designs are

- Advanced Boiling-Water Reactor, GE Nuclear (May 1997)
- System 80+ , Westinghouse Electric Company (formerly Combustion Engineering,

Windsor, CT) (May 1997)

- AP600, Westinghouse (December 1999)
- AP1000, Westinghouse (February 2006)

In addition, the NRC is currently reviewing five reactor designs.

- The AP1000 amended design provides more details regarding aircraft impact, modifies the pressurizer design and addresses several open design issues. This amended design will remove these open items from the COL application. The NRC expects to complete its rulemaking in the near future. There are four AP1000 reactors under construction in China and another four in the early phases in the United States.
- GE submitted an Economic and Simplified Boiling-Water Reactor (ESBWR) design. This 1,500 MWe plant incorporates passive safety systems, like natural circulation. The NRC expects to complete its rulemaking in 2011.
- Areva submitted an application for design certification of its Evolutionary Power Reactor (EPR) 1,600 MWe design. While not relying on passive systems, this design increases the redundancy of the safety systems from 2 to 4. This design is presently under construction at the Olkiluoto site in Finland, as well as sites in France and China. The NRC tentatively expects to complete its review in 2013.
- US APWR by Mitsubishi is a 1700 MWe PWR that is currently under construction in Japan. The NRC expects the design certification review for this design to continue through 2011.
- There is an ABWR Design Certification Rule (DCR) Amendment submitted by the South Texas Project Nuclear Operating Company (STPNOC) to amend the ABWR DCR of the ABWR design control document (DCD). The purpose of this amendment is to demonstrate compliance to the requirements in 10 CFR 50.150, the Commission's new aircraft impact rule.

Beyond the four licensed designs and the five under review, several vendors have submitted letters to the NRC of their intent to seek design certification for additional reactor types. In 2004, a South African firm notified the NRC of their desire to certify the PBMR. This modular, gas-cooled, pebble bed reactor is designed with online refueling that generates electricity via a gas or steam turbine. Design work on the PBMR has been halted; however, the US DOE is continuing to evaluate the PBMR design as part of its NGNP program. Toshiba has updated its NRC letter of intent for its Super-Safe, Small and Simple (4S) 10 MWe, liquid metal-cooled reactor design. They now expect to submit their final design to the NRC by 2012.
B&W submitted a letter of intent to have their 125 MWe mPower certified by the NRC. B&W expects to have design details of this light-water reactor ready for the 4th quarter of 2012. Several other companies that are developing SMR designs, including GE-Hitachi (Power Reactor Innovative Small Module, PRISM), have submitted letters of intent for design certification, but design certification documentation has not as yet been submitted to the NRC.

Limited Work Authorization (LWA)

A limited work authorization (LWA) is issued by the NRC to either an Early Site Permit holder or COL applicant. The LWA authorizes limited construction activities before the COL has been issued. However, the LWA does not guarantee a successful COL application, so activities are pursued at the applicant's own risk.

Construction activities that can be covered by an LWA include:

- Driving of piles
- Subsurface preparation
- Placement of backfill
- Concrete or permanent retaining walls within an excavation
- Installation of the foundation, including concrete
- Erection of construction facilities, e.g., concrete batching plant

The Southern Nuclear Company currently has a LWA for the Vogtle site and is proceeding with these permitted activities.

Combined License Mandatory Hearing

If an applicant with an ESP has selected a certified plant design (ABWR, System 80+, AP600, AP1000 presently) and seeks a COL, then public input is sought at an NRC Mandatory Hearing.

In addition to the Mandatory Hearing, the NRC has numerous other forums for public involvement in a typical license application, including three categories of public meetings for license review:

- Category 1 meetings are held with the license applicant; the public can observe the proceedings.
- Category 2 meetings are held with the industry, licensee, and non-governmental organizations (NGO) and focus on issues that could apply to several facilities.
- Category 3 meetings are open to all external stakeholders.

For a typical license application, the NRC will hold the following meetings that are open to the public. The meetings are listed in the order in which they occur:

- Applicant supplies NRC with an overview of the license application (Category 1)
- Applicant introduces license overview to the public (Category 3)
- Applicant and public review the environmental review process (Category 3)
- Applicant and public discuss draft EIS (Category 3)
- Applicant and NRC discuss safety Evaluation Report (Category 1)
- Applicant and NRC Advisory Committee on Reactor Safeguards discuss safety review (Category 1)

Table 5 contains the list of COL applications received by the US NRC as of March 2011.

TABLE 5: COMBINED OPERATING LICENSE APPLICATIONS RECEIVED BY THE NUCLEAR REGULATORY COMMISSION (LAST UPDATED, MARCH 10, 2011)
(SOURCE: NUCLEAR REGULATORY COMMISSION)
HTTP://WWW.NRC.GOV/REACTORS/NEW-REACTORS/COL.HTML

Proposed New Reactor(s)	Design	Applicant
Bell Bend Nuclear Power Plant	U.S. EPR	PPL Bell Bend, LLC
Bellefonte Nuclear Station, Units 3 & 4	AP1000	Tennessee Valley Authority (TVA)
Callaway Plant, Unit 2	U.S. EPR	AmerenUE
Calvert Cliffs, Unit 3	U.S. EPR	Calvert Cliffs 3 Nuclear Project, LLC and UniStar Nuclear Operating Services, LLC
Comanche Peak, Units 3 & 4	US-APWR	Luminant Generation Company, LLC (Luminant)
Fermi, Unit 3	ESBWR	Detroit Edison Company
Grand Gulf, Unit 3	ESBWR	Entergy Operations, Inc. (EOI)
Levy County, Units 1 & 2	AP1000	Progress Energy Florida, Inc. (PEF)
Nine Mile Point, Unit 3	U.S. EPR	Nine Mile Point 3 Nuclear Project, LLC and UniStar Nuclear Operating Services, LLC (UniStar)
North Anna, Unit 3	ESBWR	Dominion Virginia Power (Dominion)
River Bend Station, Unit 3	ESBWR	Entergy Operations, Inc. (EOI)
Shearon Harris, Units 2 & 3	AP1000	Progress Energy Carolinas, Inc. (PEC)
South Texas Project, Units 3 & 4	ABWR	South Texas Project Nuclear Operating Company (STPNOC)
Turkey Point, Units 6 and 7	AP1000	Florida Power and Light Company (FPL)
Victoria County Station, Units 1 & 2	ESBWR	Exelon Nuclear Texas Holdings, LLC (Exelon)
Virgil C. Summer, Units 2 & 3	AP1000	South Carolina Electric & Gas (SCE&G)
Vogtle, Units 3 and 4	AP1000	Southern Nuclear Operating Company (SNC)
William States Lee III, Units 1 and 2	AP1000	Duke Energy

4.2 NUCLEAR SECURITY AND SAFETY

Many federal, regional, and state organizations are responsible for assuring the security of electricity generation facilities and the electric grid. Security concerns include

- Physical security of the electric system (generation stations, transmission lines, substations, distribution lines), and supervisory control and data acquisition (SCADA) system
- Energy security in the form of fuel supply interruption (gas pipelines, LNG terminals and shipping, uranium supply) and cost escalation
- Foreign dependency via disruption of globalized supply chains for critical grid components and minerals used in component manufacturing processes
- Cybersecurity threats including distributed denial of services, hacking, electromagnetic pulse, embedded codes in foreign sourced components, and weakness in SCADA and inter-process communication (IPC) systems

Improvements in nuclear security and safety have been made since the late 1980s with no significant events per power plant reported in 2009 (see Figure 11). As defined by the NRC, significant events are events that meet specific NRC criteria, including degradation of safety equipment, a reactor scram with complications, or an unexpected response to a sudden degradation of fuel or pressure boundaries. The NRC staff identifies significant events through detailed screening and evaluation of operating experience. Many of the improvements have come from lessons learned from internal operational failures that occurred at Three Mile Island and potential external threats such as the September 11, 2001 terrorist attacks. The events that occurred at Fukushima Daiichi will lead to further improvements in the safe shutdown of a nuclear power plant when challenged by "beyond design" circumstances. A summary of the lessons learned was discussed in Section 3.2.

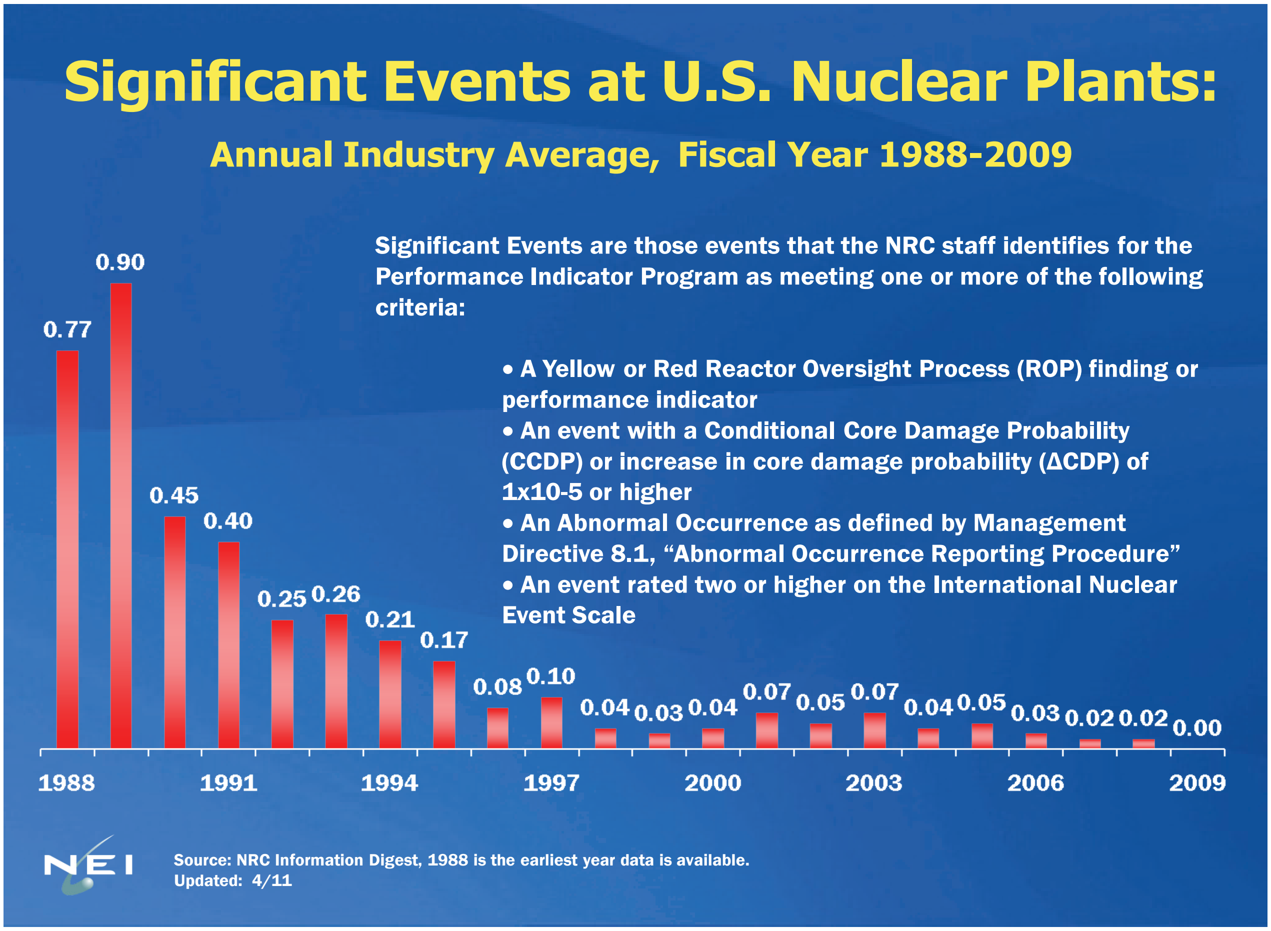


FIGURE 11: SIGNIFICANT EVENTS AT US NUCLEAR PLANTS (SOURCE: NUCLEAR ENERGY INSTITUTE FROM NUCLEAR REGULATORY COMMISSION, NRC INFORMATION DIGEST) HTTP://WWW.NEI.ORG/RESOURCESANDSTATS/DOCUMENTLIBRARY/SAFETYANDSECURITY/GRAPHICSANDCHARTS/SIGNIFICANTEVENTSATUSNUCLEARPLANTS)
NOTE: UNITS FOR SIGNIFICANT EVENTS ARE PER POWER PLANT

Nuclear power plants must show that they can defend against a set of adversary characteristics outlined in NRC's DBT. This is accomplished through physical security of nuclear power plants using multiple approaches. US commercial nuclear power plants are secure and robust structures that are built to withstand hurricanes, tornadoes, and earthquakes. They rely on access control and detection to prevent unauthorized activities. This includes armed security officers, physical barriers, surveillance systems, and access control such as picture badging, detailed information on visitors, and detailed inputs such as fingerprint scans. Intrusion detection systems rely on a variety of types also arranged in layers. Various combinations of microwave, electric field, EM fields, infrared, and closed-circuit TV pictures can allow security services to monitor barriers and identify threats. While barriers will not prevent determined entry, they can provide sufficient delay to allow both on-site security and regional police forces time to respond. In the event that intrusion is detected, additional barriers may be activated (closing/locking doors, pop-up roadway barriers).

Additionally, the NRC works closely with the US Departments of Homeland Security, Defense and Energy, the FBI, intelligence agencies, and state and local law enforcement so that threats can be acted upon quickly. This coordinated effort allows for effective emergency response from "outside the fence" should a terrorist attack occur.

Heightened security measures that have been implemented since the September 11, 2001 terrorist attacks are

- More security forces that are better trained
- More physical barriers
- Greater stand-off distances for vehicle checks
- More restrictive site access controls
- Enhanced emergency preparedness and response plans

The major risk for nuclear facilities is water being drained from the on-site used nuclear fuel pools. This can cause the waste nuclear fuel to oxidize in an endothermic reaction with water and spread radiation through the air. It is not as likely that used fuel pellets will be stolen to make a dirty bomb because of the used fuel's high temperature. The physical security is tested through "force-to-force" inspections at least once every three years by teams of highly trained government operatives who pose as terrorists. Plant managers are given two months to prepare for these planned raids to identify any potential security short comings. Over the past five years, about 8% of the attacks are considered "successful." While the NRC considers these planned "attacks" as an effective means to eliminate security holes and state that nuclear power plants are safer than ever, others feel that these "successful" raids show the vulnerability of nuclear power plants (*Newsweek* Jan. 4, 2011; http://www.newsweek.com/2011/01/06/failing-the-nuclear-security-test.html).

Energy security concerns in the form of fuel supply interruption is unlikely because of the long lead times between nuclear refueling. In comparison, the availability of the natural gas during the winter is an important security concern. In the past, electricity generators have had difficulty in obtaining natural gas supply. As Connecticut and the New England region become more dependent on natural gas, this security issue could become even greater. The prospect of natural gas availability via exploration and development of Marcellus shale gas reserves may reduce this concern as long as natural gas supply is not constrained by the capacity of the gas distribution system or other factors. One other mitigating factor is that over 7000 MW of generation capacity in New England can switch to burning oil if natural gas is not available. (CEAB Technical Paper: Energy Security, April 2010).

Cyberterrorism is a security concern for both nuclear and natural gas centralized electricity generating facilities because of their dependency on large transmission lines to connect generators with users. Also, there is a heavy dependency on a few critical links and nodes. Cyberterrorism or cyberwar can be carried out remotely through the use of computer hacking, codes, viruses, worms, and Trojan Horses to incapacitate portions of the electric system. Cybersecurity is a difficult challenge because the computer threats are constantly changing and a comprehensive cybersecurity system must be implemented over a large number of interdependent networks and information systems. However, it is important to note that computer systems that operate the reactors and other safety equipment are isolated from the internet to protect against outside intrusion.

In a more physical form, electromagnetic pulse (EMP) using an inexpensive flux compression generator (FCG) can disable generators or any device that has incorporated "unhardened" silicone-based semiconductors or chips. Another potential vulnerability is SCADA systems which are now connected to the global internet because of business and operational reasons without sufficient attention given to cybersecurity.

An example of how cyberwar has been used is Stuxnet, which is a sophisticated cyberworm that was believed to have inflicted significant damage to Iran's nuclear program by disabling gas centrifuges and computer systems. It is thought that Iran will have to replace all of their computer systems to be sure they have gotten rid of the worm. With Stuxnet now in the public domain, there is concern that hackers, criminals, or terrorist groups could use the worm to attack systems that control the electric grid (*Hartford Courant*, January 18, 2011).

To reduce vulnerability to physical or cyberattacks to the electric grid, transmission projects should use smart grid and adaptive grid technologies that allow separation of affected areas into microgrids or minigrids. This would allow for the creation of self-sufficient islands that make best use of the network resources that are still available without having a system-wide failure. In addition, the incorporation of "decentralized" distributed generation would also increase the resiliency to cyberwar by locating small, modular generators closer to the user thus reducing the importance of the transmission lines.

4.3 FUEL SUPPLY SECURITY

Uranium is the basic fuel ingredient used in the current generation of nuclear power reactors. This element is relatively plentiful—as common as tin, tungsten and molybdenum within the earth's crust. The technical ability to extract uranium from a variety of rocks in which it may be found is readily available, but the economic viability depends upon the uranium concentration and geographic location. Seawater contains uranium, but at such low concentrations (~ 1-3 ppb) that it is not anticipated to be an economically viable source for uranium in the near future.

In the latest edition of the International Atomic Energy Agency's (IAEA) "Red Book," a biennial report entitled "Uranium 2009: Resources, Production and Demand" indicates that global supplies of uranium are sufficient for approximately 80 years at present burn-up/demand rates. While this may cause concern for some, that concern should be tempered with the knowledge that these estimates are also based on uranium recovery costs below $130/kg U. If uranium demand increases, it is anticipated that additional deposits/reserves will be identified. In addition, the cost of electricity for nuclear power is not very dependent on the cost of nuclear fuel. Even a doubling of uranium costs would be expected to increase nuclear power generated electricity costs by only ~ 2.5%. Capital costs have a much greater impact on the eventual cost of electricity generated from nuclear power plants. In general, final fuel assembly costs contribute ~ 10% of the busbar electricity costs from nuclear power plants. In addition, raw uranium (as milled) only reflects about 25% of the final fuel assembly cost (isotope separation and fuel pellet/assembly manufacturing account for the remaining 75%). Based on this data, it is apparent that large swings in "as-milled" uranium prices will not produce large changes in the cost of nuclear power generated electricity.

As of 2009 (see Table 6),the United States ranked 9th in the world for uranium resources, and Australia and Canada, two strong US allies with a long history of democratic leadership, ranked

1st and 3rd. Therefore, US access to a significant percentage of worldwide uranium resources is relatively secure.

The world's currently operating nuclear power reactor fleet (~375 GWe) requires about 68,000 metric tons of uranium (raw) per year. These fuel requirements come from mine output (78% in 2009), as well as from secondary sources, including recycled plutonium and uranium from spent fuel reprocessing, nuclear weapons stockpiles, commercial stockpiles and re-enrichment of uranium tails.

Table 6: Known Recoverable Resources of Uranium 2009
(Source: World Nuclear Association: Reasonably Assured Resources plus Inferred Resources, to US$ 130/kg U, 1/1/09, from OECD NEA & IAEA, Uranium 2009: Resources, Production and Demand ["Red Book"])

	tonnes U	percentage of world
Australia	1,673,000	31%
Kazakhstan	651,000	12%
Canada	485,000	9%
Russia	480,000	9%
South Africa	295,000	5%
Namibia	284,000	5%
Brazil	279,000	5%
Niger	272,000	5%
USA	207,000	4%
China	171,000	3%
Jordan	112,000	2%
Uzbekistan	111,000	2%
Ukraine	105,000	2%
India	80,000	1.5%
Mongolia	49,000	1%
other	150,000	3%
World total	5,404,000	

In addition to the raw material (uranium) required for nuclear fuel, the uranium needs to be converted to a form that can be processed and enriched (increased concentration of U^{235}).

All of these processes need to be completed to generate the final fuel assembly. These fuel production processes could also be a bottleneck for future nuclear power growth.

Conversion

At present the world has 76,000 tonnes of conversion capacity per year. Conversion is the processing step whereby uranium oxide (U_3O_8) is converted into uranium hexafluoride for the isotope enrichment step. The United States hosts one plant with an annual production capacity (UF_6) of approximately 15,000 tonnes.

Enrichment

Enrichment is another key step in nuclear fuel assembly manufacture. This step concentrates the U^{235} from its 0.71% concentration in natural uranium to the nearly 5% concentration used for most light-water reactor fuel assemblies for 18-month operating cycles. Depending on the technology used in the enrichment plant, it can be an energy-intensive step due to the low mass difference between the U^{235} and U^{238}. The United States presently relies on gaseous diffusion to achieve nuclear fuel enrichment. Gaseous diffusion uses about 10 times as much energy as the more modern centrifuge process. A parameter called Separative Work Units (SWU) is used to quantify the amount of separation required for uranium enrichment. In the United States at present, capacity for enrichment is approximately $8X10^6$ SWU/year, which comes mainly from a gaseous diffusion plant in Paducah, Kentucky run by United States Enrichment Corporation (USEC). USEC is presently renegotiating its electric rate charges with TVA, as the existing agreement expires in 2012. Electric power rates are key to diffusion operating costs, due to diffusion's inefficiency as compared with centrifugal separation, with the predominance of electric costs in the final product costs.

Additional enrichment capacity is available from Urenco's Eunice, New Mexico, centrifuge facility. This facility has been licensed by the NRC and began commercial operation in June 2010. It will reach Phase I capacity (3.3 $X10^6$ SWU/yr) by 2013. Additional expansion of the Urenco plant is planned for the 2014-17 time frame which will bring the capacity of the plant to $5.9X10^6$ SWU.

Also, Areva has announced plans to build a $3X10^6$ SWU centrifuge enrichment plant in Eagle Rock, Idaho, that is scheduled to begin operation in 2014. Areva already has plans to increase the capacity of this plant to $6X10^6$ SWU/year by 2017.

The US DOE and USEC are reportedly negotiating loan guarantees that would allow USEC to expand its pilot centrifugal separation plant in Portsmouth, Ohio. If completed, this project could add an additional 3.8 $X10^6$ SWU/year to the US enrichment portfolio. It is estimated that the 104 operating US reactors will require $12.7X10^6$ SWU/year to supply their nuclear fuel enrichment requirements.

In addition to uranium supply and enrichment, conversion of uranium oxide to uranium hexafluoride for use in the enrichment process is important. The United States has a large plant in Metropolis, Illinois, that can convert up to 17,600 t U (as UF_6) per year. This plant is expanding and it is expected to reach 18,000 t by 2012.

4.4 METAL CLAD CYLINDRICAL FUEL ELEMENTS

This section discusses the design details related to zircaloy-clad cylindrical fuel rods, where groupings of these individual rods will be referred to as fuel assemblies or fuel bundles (Figure 12). These zircaloy-clad rods comprise the bulk of the US commercial fuel market and are used exclusively by the present generation of BWR and PWR power plants.

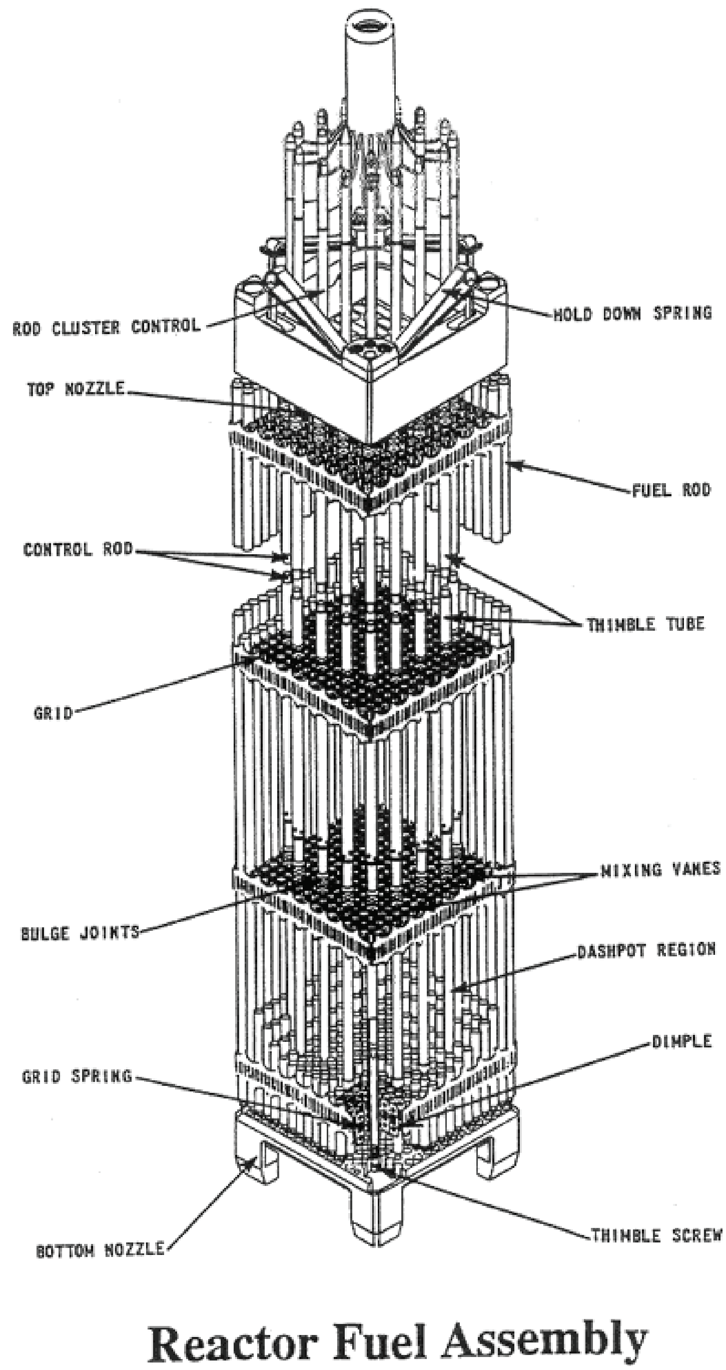


FIGURE 12: NUCLEAR FUEL ASSEMBLY - TYPICAL (SOURCE: NUCLEAR REGULATORY COMMISSION; HTTP://WWW.NRC.GOV/READING-RM/BASIC-REF/TEACHERS/REACTOR-FUEL-ASSEMBLY.HTML)

Commercial nuclear fuel rods predominantly start as uranium oxide (UO_2) pellets. Naturally occurring uranium contains ~0.7% U^{235} with the balance U^{238}. To sustain a nuclear chain reaction, the concentration of U^{235} must be increased. Oxide pellets used for commercial fuel rods in US BWR and PWR systems contain an increase in the U^{235} concentration up to levels of 3%-5%. The oxide pellets provide the first barrier for fission product release protection, housing the uranium in a ceramic with a high melting temperature. These fuel pellets are sintered at temperatures above 1700°C (~3100°F) offering a high temperature, melt resistant cylinder. After fabrication, some 240+ fuel pellets in an inert atmosphere are inserted into a zircaloy tube to create a single fuel rod. Welded metal plugs at each end of the fuel rod protect the fuel pellets from the water coolant and keep fission products from leaching throughout the reactor system during the life of the fuel. Figure 13 displays a single UO_2 fuel pellet prior to insertion in a traditional fuel rod.

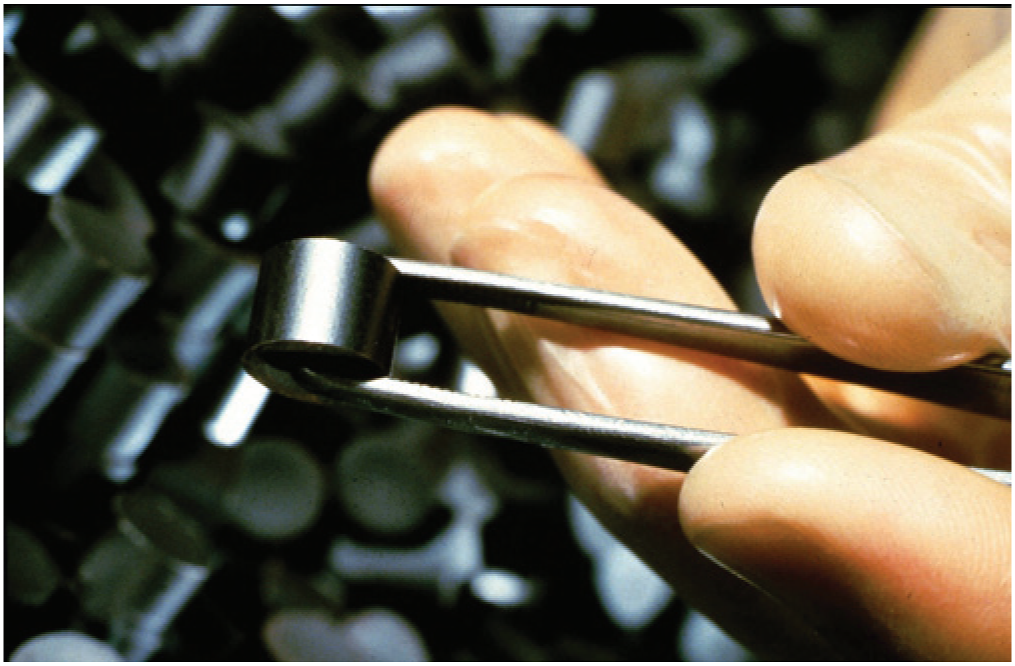


FIGURE 13: UO_2 FUEL PELLET (SOURCE: NUCLEAR REGULATORY COMMISSION; HTTP://WWW.NRC.GOV/IMAGES/READING-RM/PHOTO-GALLERY/20100907-005.JPG)

An array (for example: 12x12, 14x14) of fuel rods are grouped together into a single fuel bundle. These fuel bundles are handled as aggregate components inside the reactor core during operation and refueling. A circular grouping of hundreds of fuel bundles comprises the core (Millstone Unit 2 has 217 fuel bundles). About 1/3 of these fuel bundles are replaced during a typical maintenance refueling outage. The remaining 2/3 of the fuel bundles are rearranged to provide a uniform uranium "burn up" and power distribution within the core during the next cycle of operation.

4.5 DISPOSAL OF SPENT NUCLEAR FUEL AND LOW-LEVEL RADIOACTIVE WASTE

Spent Nuclear Fuel

Typically, a single enriched uranium fuel bundle will have operated within the reactor for three operating cycles. After its operating cycle, the fuel bundle is removed from the core, and for all US reactors, is stored at the operating unit. Initially these fuel bundles are stored in a spent fuel pool (underwater) adjacent to the reactor building. These spent fuel pools were originally designed to hold discharged fuel from approximately 10 years of operation plus a full core fuel offload. This design came about because of the belief that the US government would take custody of spent fuel shortly after its use in the commercial reactor. The spent fuel pools provide two functions: shielding and cooling. The energy from radioactive decay is strong in fuel elements after completing their three operating cycles in the core. Estimates vary, but approximately 0.3% of the full-scale power emanates from these fuel elements after three months of decay in the spent fuel pool. For the Millstone 2 reactor, which generates 2700 MW of thermal energy from 217 fuel assemblies, this means that a single fuel assembly is still issuing 37 kW of thermal energy. This energy must be removed via the water in the spent fuel pool cooling system. In addition, the high radiation fields generated by these fuel assemblies are shielded by the deep water covering them.

As reactor site spent fuel pools have become filled to capacity, utilities currently use Independent Spent Fuel Storage Installations (ISFSIs) to allow for continued plant operation and on-site storage of spent fuel. Typically ISFSIs consist of dry casks that are designed to safely hold spent fuel that is at least three years old, but normally moved after 10 years of decay. This process is in use for Millstone's Unit 2. However, all spent fuel from the ongoing operation of Millstone Unit 3 is stored in a spent fuel pool. Also, the spent fuel from the operation of Millstone Unit 1 that was shut down in November 1995 remains stored in a spent fuel pool.

Since the federal government has not as yet provided for a national repository for the disposal and storage of spent fuel, even though the Connecticut Yankee power plant at Haddam Neck has been demolished and decommissioned, spent nuclear fuel remains stored in an ISFSI. The ISFSI is located in a secure protected area on the site that is monitored with 24/7 security.

Connecticut enacted legislation prohibiting the construction of additional nuclear power plants in the state until the federal government creates a long-term repository for high level waste including spent fuel. Implementation by the federal government of the Blue Ribbon Commission recommendations to expeditiously develop one or more geological disposal or interim storage facilities should satisfy the state's requirements for the federal government assuming control of high-level nuclear waste currently stored at Connecticut Yankee and Millstone.

Low-Level Radioactive Waste

In addition to the large concern regarding spent nuclear fuel (high-level radioactive waste), the operation of nuclear reactors inherently produces low-level nuclear waste. For an operating commercial nuclear power plant, this waste can take the form of used protective clothing, cleaning material and used irradiated hardware. All of these materials need to be segregated from the public, the atmosphere and water supplies.

Low-level radioactive waste has three levels of classification depending on its form and its level of radioactivity. Class A represents the least hazardous and lowest concentration of both short-lived and long-lived radionuclides. Used personal protective clothing is typically in this category. Class B wastes represent an intermediate hazard and could be comprised of dried resins used to treat reactor coolant. Class C wastes are the highest hazard among the low-level waste category that are still suitable for shallow land burial. Examples of Class C waste can include materials similar to those identified as Class B waste, but with a higher specific radioactivity. Also, radioactive wastes that are classified as greater than Class C wastes are not suitable for near-surface disposal. The federal government is responsible for the final disposal of these wastes.

In order to handle the volume of low-level waste (LLW) generated in the United States, Congress mandated that states take responsibility for their individual waste (Low-Level Radioactive Waste Policy Act of 1980, and 1986 amendment), but also encouraged the formation of interstate compacts to establish regional solutions. While nuclear power plants generate a significant portion of the low-level waste, they are not the exclusive source of LLW. Other generators include medical and research facilities.

As a result of the federal law, Connecticut joined the Atlantic Interstate Low-Level Radioactive Waste Management Compact. This three-state Compact (Connecticut, New Jersey, and South Carolina) was formed to dispose of all the low-level waste from the three member states. A licensed and operating disposal site for low-level waste located in Barnwell, South Carolina, is presently handling waste from the compact members. While the Barnwell site has been operating for many years, it is only over the past two-and-a-half years that the three-state compact has excluded waste from outside the member region. In the first year of regional operations (July 2008 – June 2009) about 11,000 ft^3 of waste was disposed of in the Barnwell facility. In its second full year of operation (July 2009- June 2010) the facility accepted 34,000 ft^3 of waste. However, nearly 80% of the material buried in this second year consisted of four steam generators from the steam generator replacement at the Salem, New Jersey, Unit 2 nuclear plant.

South Carolina has committed to accepting up to 800,000 ft^3 of low-level waste from Connecticut and New Jersey as part of the Atlantic compact. Less than 50,000 ft^3 has been used in the first two years of this agreement, and a significant percentage of the used volume came from the one-time steam generator replacement project. Therefore it has been projected that the site has adequate low-level waste burial capacity to meet disposal needs for many years for the six operating plants in Connecticut and New Jersey, and the seven operating plants in South Carolina. The site's capacity also includes enough storage volume to handle the waste associated with the decommissioning of the operating plants from these states.

4.6 SUSTAINABILITY OF NUCLEAR FUEL CYCLE

A decision on how to operate a nuclear fuel cycle is complicated, with many input decisions. These inputs include cost, high-level waste volume and heat load. Heat load can be the limiting factor for capacity at a high-level storage site. Figure 14 includes several options for how to operate a nuclear fuel cycle.

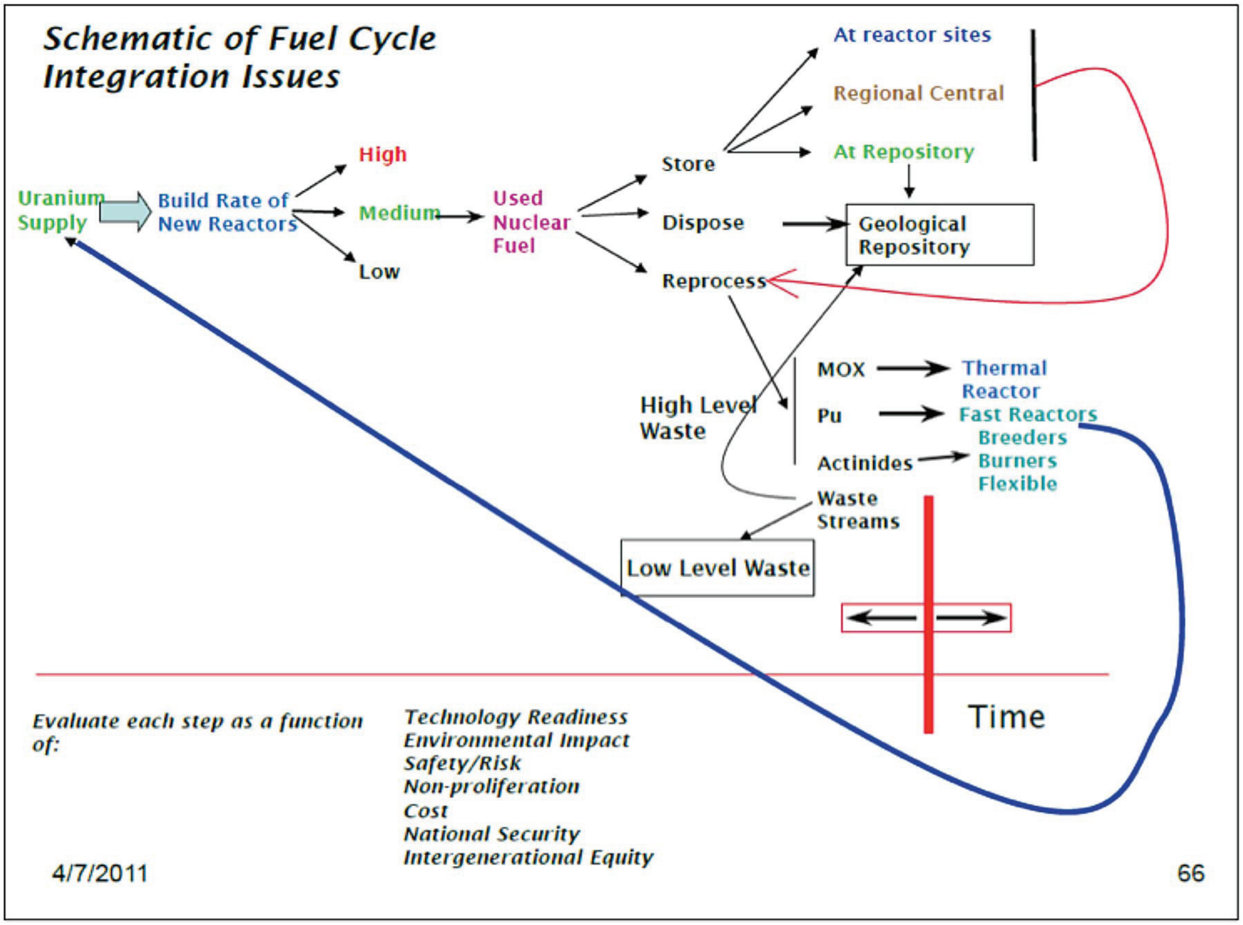


Figure 14: Fuel Cycle Integration Issues (Courtesy of Andrew Kadak, Director, Nuclear Services, Exponent, Engineering and Scientific Consulting)

Figure 15 shows the nominal fuel isotope makeup before irradiation (left side) for fuel enriched to 3.3% U^{235} and after it has completed its "burnup" in the core (approximately three operating cycles, as spent fuel). What is noteworthy in this graphic is the large amount of U^{238} remaining in the fuel after its use in the reactor core, as well as the production of Pu in the spent fuel. U^{238} is a fertile material (not directly fissionable, except by very high energy neutrons). However, it can produce fissile material (fissile → capable of fissioning by low energy neutrons). Plutonium 239 is generated by neutron absorption of U^{238} and this same plutonium may absorb additional neutrons producing higher atomic mass isotopes (Pu^{240}, Pu^{241}, Pu^{242}). For future nuclear fuel cycles, the recovered Pu and U from reprocessing can be used in generating fission energy.

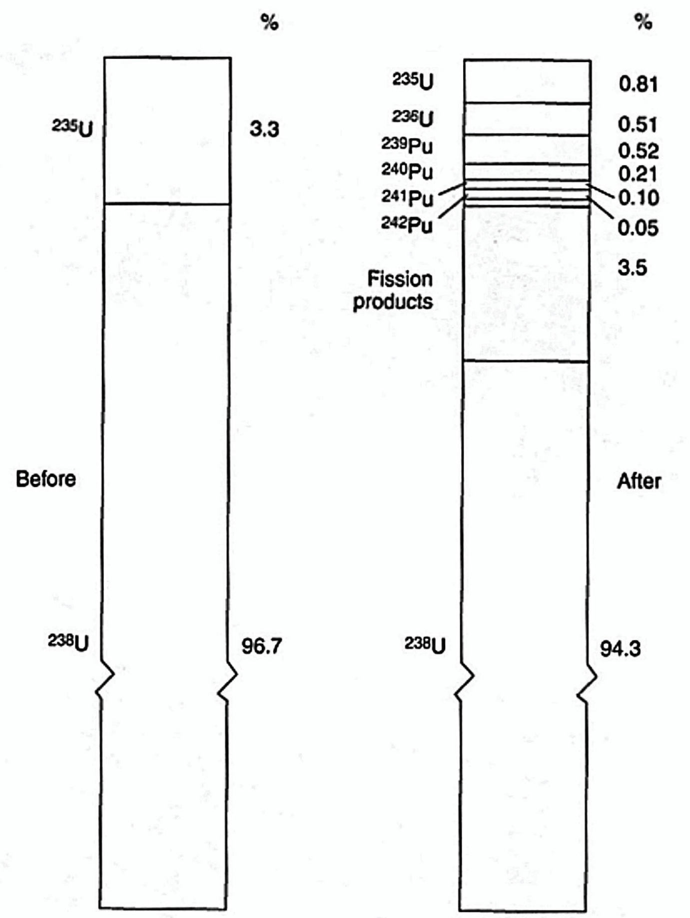


Figure 15: Typical Fuel Makeup Pre and Post Operation (Source: Nuclear Energy: An Introduction to the Concepts, Systems and Applications of Nuclear Processes, 6th Edition, Raymond Murray, Elsevier, 2009)

Both plutonium and uranium have the potential to generate substantial energy by either direct fission or the production of fissile material through neutron capture. Therefore, over 95% of the material (not including cladding) in the spent fuel has potential use for producing additional fuel. The resulting mixed oxide (plutonium and uranium MOX) fuel can be used in place of virgin enriched uranium fuel. This procedure of using MOX fuel in traditional fuel elements has been successfully accomplished in several countries including the United States, and is practiced today in France, Russia and Japan. The production of MOX fuel will require reprocessing of spent fuel, including separation of fission products from the recovered plutonium and uranium.

Reprocessing spent nuclear fuel for production of additional nuclear fuel to be used in nuclear reactors has the following potential benefits:

1. Reduces the volume of high-level radioactive waste that needs to be stored
2. Reuses uranium/plutonium fertile/fissile material, and thereby reduces the quantity of uranium mined
3. Removes spent fuel elements from commercial nuclear reactor sites prior to the opening of a federal high-level waste repository, with the fission products and actinides typically residing at a fuel reprocessing plant
4. Reduces the length of time the original spent fuel needs to be sequestered due to high radiotoxicity, with the reprocessed spent fuel still needing to be sequestered

The predominant process used for reprocessing spent fuel is the PUREX process, which was developed in the 1950s in the United States. The majority of the spent fuel reprocessing steps use solvents and precipitations to separate and recover the uranium and plutonium. Because uranium and plutonium are chemically different with different chemical and valence states, it is possible to separate them individually. Therefore, the PUREX process can produce separate streams of uranium and plutonium, which means that care must be exercised to ensure that plutonium is not diverted for nuclear weapons production. Figure 16 shows a simplified schematic of the PUREX spent fuel reprocessing system.

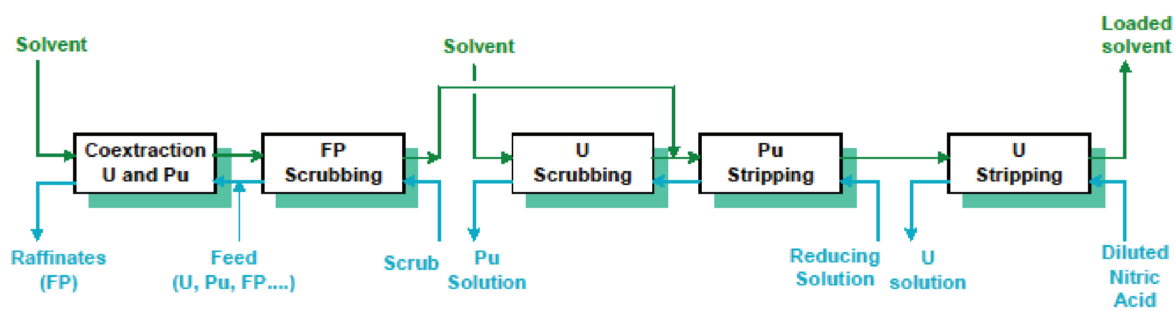


FIGURE 16: COUNTERCURRENT PUREX FLOWSHEET (SOURCE: NUCLEAR REGULATORY COMMISSION SEMINAR; PRESENTATION BY DR. TERRY TODD, IDAHO NATIONAL LABORATORY, SLIDE 32; HTTP://WWW.NE.DOE.GOV/PDFFILES/NRCSEMINARREPROCESSING_TERRY_TODD.PDF)

One major rationale for not reprocessing comes from the sequential stripping of uranium and plutonium. These step-wise operations produce a fairly pure plutonium and uranium stream. Since the uranium stream has a relatively low enrichment (0.8% - 0.9% U^{235}), it is not a nuclear proliferation concern. However the lower mass and volume of the plutonium stream, which is required for creating a weapon, raises proliferation concerns.

Areva has developed a co-extraction (COEX) process that extracts plutonium and uranium together to create a mixed uranium and plutonium product. This product is still very useful for fuel recycling, but makes the recycled fuel essentially useless as a starting product for development of a weapon.

Reprocessing Rationale

1. **Reduce Volume**
   A large percentage of the material in spent fuel has value as future reactor fuel (uranium and plutonium); therefore, it will be possible to reuse a significant fraction of the spent fuel and greatly reduce the volume of material required to be housed in any high-level waste repository. This volume reduction can be as high as 95% due to the large concentration of uranium and plutonium remaining in the spent fuel.

2. **Reuse Uranium/Plutonium**
   As already identified, a large fraction of the material in spent fuel is uranium (both $U^{235}$and U^{238}) and plutonium. While the vast majority of the uranium is the fertile version U^{238} (~99%), some of the uranium is the fissile U^{235} (~1%). In addition, neutron capture has altered some of the original U^{238} into various isotopes of plutonium. Both of these materials (uranium and plutonium), have value as future nuclear fuel in all of their isotopic versions. Reuse of this material in a LWR can displace about 20-25% of the fresh uranium fuel that would otherwise need to be manufactured. While recycling can reduce the amount of new fuel required, the reprocessing step still generates high-level radioactive waste that will require a long-term repository.

3. **Remove Spent Fuel from Commercial Nuclear Power Sites**
   At the present time, all commercial nuclear fuel assemblies are retained at the reactor site. If reprocessing is instituted, it will allow commercial nuclear power plant operators to remove these spent fuel assemblies from their sites, and from their oversight, even before a long-term high-level repository is open. However, the reprocessing facility will still need to provide for storage of the waste generated from reprocessing the spent fuel until the federal government implements a plan for long-term storage of nuclear waste.

4. **Reduce Spent Fuel Sequestration Time**
   Public perception of spent fuel is that the entire assembly needs to be carefully guarded and housed away from human contact for centuries. In fact it is a small percentage (~ 4%) of the fuel mass that contains high-level, long-lived radioactive wastes. These wastes come predominantly from the fission products (large atom fragments and minor actinides heavy nuclei — for example neptunium, americium, etc.). Fuel reprocessing would allow separation and minimization (volume and mass) of these high-level, high radioactive wastes. The three largest components of the spent fuel radiotoxicity are fission products, minor actinides and plutonium. All three of these predominant radiotoxic components can be removed from the spent fuel through reprocessing.

4.7 NUCLEAR PROLIFERATION

One large geo-political concern arising from using nuclear power plants is the risk of proliferation of nuclear weapons. Both Uranium-235 and Plutonium (Pu^{239} and Pu^{241}) are fissile and can be used to create a fission nuclear weapon of significant yield. Both types were dropped on Japan at the close of World War II. While U^{235} can be extracted from uranium ore through various enrichment methods (gaseous diffusion and centrifuge) plutonium is not naturally occurring and can only be generated by neutron bombardment of U^{238}. This neutron bombardment routinely occurs in operating nuclear power plants; hence these electric power

generators and research reactors also produce significant quantities of plutonium.
There are four basic classes of nuclear materials:

1. Source materials: natural uranium and thorium
2. Special Nuclear Materials (SNM): U^{235} enriched above natural levels, and/or plutonium
3. Depleted uranium
4. By-product materials: radioactive isotopes and transuranic elements produced by fission.

Of these materials, SNM generally cause the greatest concern because they can sustain a nuclear chain reaction and have the potential to be configured into a nuclear weapon. The table below shows the approximate masses of these SNMs required to achieve a critical mass and therefore create a nuclear explosive.

Table 7: Critical Masses of Several Special Nuclear Materials
(Source: Nuclear Engineering: Theory and Technology of Commercial Nuclear Power, 2nd Ed, Ronald Knief, American Nuclear Society, 2008)

Material	**Mass (kg Metal)**
U^{235} (enriched≥93%)	17
U^{235} (enriched ≥20%)	250
U^{235} (enriched ≥10%)	1000
U^{235} (enriched ≤5%)	∞
Pu^{239} (concentration ≥95%)	4

Most of the international community has adopted the Nuclear Non-Proliferation Treaty (NPT) to limit the spread of nuclear weapons, while still allowing for the peaceful production of electricity from fission reactors. The NPT began its actions in 1970 and was extended indefinitely in 1995. The NPT is an agreement among the five states that had publicly disclosed the existence of their nuclear weapons program (United States, Great Britain, France, Russia and China) and the remaining signatories (182 remaining countries). This agreement allows the non-weapon state signatories to receive technical assistance and trade involving nuclear technology. In exchange these non-weapon states have agreed to allow the IAEA to undertake regular inspections of civil nuclear facilities to verify that fissile material is not being diverted away from the civil programs.

While the NPT program has generally been successful, several states have garnered nuclear weapons technology including India and Pakistan. Other states are working toward nuclear weapons or have already produced them including Iran, North Korea and Israel.

The IAEA safeguards include material accountability, physical security, and containment plus surveillance. All NPT non-weapon states must accept these safeguards, which apply to all nuclear facilities in their country. The NPT is supplemented by bilateral agreements or more inclusive treaties such as Euratom Safeguards. The terms of the NPT cannot be enforced by the IAEA, but rather by diplomatic and economic measures from signatories. This is most recently evidenced by events in North Korea.

North Korea, Iraq and Iran show the benefits and weaknesses of the safeguards present under the NPT. Both Iraq and Iran set up enrichment equipment at facilities that were not declared to the IAEA, and therefore not subject to inspection. North Korea relied on research reactors (non-commercial reactors) and a fuel reprocessing plant to produce weapons grade plutonium. All three countries proceeded with various levels of IAEA oversight, but no obvious diversion was found by the IAEA inspectors. While the change in government in Iraq has ended that nuclear weapons development program, both Iran and North Korea proceed despite international sanctions and trade limits.

It should be pointed out that most nations have not acquired nuclear weapons through a civil nuclear power program (exceptions are India and Pakistan). The amount of natural uranium required for weapons development is not large (~ 5 metric tonnes). Therefore it is unlikely that avoiding nuclear power will solve the international problem of nuclear weapons proliferation.

Specific weapons proliferation concerns regarding North Korea, Iran, Iraq and Syria include the following:

- North Korea created weapons-grade plutonium using a research reactor and a fuel reprocessing facility in defiance of its NPT obligations. In 2006 and again in 2009, it exploded nuclear devices.
- Iran's previously undeclared nuclear facilities became the subject of IAEA inquiry and the IAEA announced that Iran appeared to be in violation of its NPT agreements starting in 2002. Iran has continued to enrich uranium in defiance of the UN Security Council.
- Iraq attempted to enrich uranium to weapons-grade in the 1990s, in violation of NPT obligations.
- Syria constructed a nuclear reactor in breach of NPT obligations.

5.0 COMPARISON OF NUCLEAR POWER TO ALTERNATIVE ENERGY RESOURCES

5.1 COSTS

A cost analysis of nuclear power compared to a natural gas combined-cycle gas turbine (CCGT) facility was completed as part of the economic impact study. The most often cited costs are overnight costs, all-in-costs and busbar cost. Overnight cost is an estimate of the raw materials, manufacturing of components, and labor costs. Including the financing costs is the all-in-cost, sometimes called the installed cost. The busbar, or the cost to deliver electricity to the grid, includes fuel, operation and maintenance, and additional incremental capital costs. For nuclear power plants, the cost to dispose of nuclear waste and to decommission the nuclear facility is also included. In constant, level dollar terms over the life of the plant, the busbar cost is the levelized cost of electricity (LCOE). Thus, the LCOE is the net present value of the total life-cycle costs of the power plant divided by the quantity of energy produced over the plant's life. The Du and Parsons (2009) model and data were primarily used in performing the cost analysis. The estimated overnight cost by Du and Parsons (2009) for a 1000 MW nuclear power plant was \$4,000/kWe in 2007 dollars. In comparison, the overnight cost of a combined-cycle natural gas facility is \$850/kWe. Cooper's (2009) review of nuclear power studies shows that there is a wide range of estimates of overnight cost. Studies performed between 2007 and 2009 by utilities range from \$2300 to \$5800/kWe. Independent studies tend to give higher estimates ranging from \$4100 to \$10,400/kWe. The effectiveness of the advanced construction techniques utilized in the design of the Generation III+ designs will not be known until the first build nuclear power plants are completed. At that point, the state will be better able to evaluate the overnight cost of nuclear power plant and ultimately, the LCOE.

The financial and operating parameters assumed for calculating the LCOE for a nuclear power plant and a natural gas CCGT are listed in Table 8. The parameters that are different for the two facilities are highlighted. The most important LCOE elements for the nuclear power plant are return on investment and the overnight cost and how it is treated financially (i.e., weighted cost of capital of 10% compared to 7.8% for CCGT). In contrast, the price of natural gas is the most significant factor for CCGT.

TABLE 8: LCOE FINANCIAL AND OPERATING PARAMETERS (NOTE: SHADED INFORMATION INDICATES PARAMETERS WITH DIFFERENCES BETWEEN THE NUCLEAR APWR AND CCGT)

Parameter	AP 1000 Advanced Pressurized Water Reactor	Combined Cycle Natural Gas (CCGT)
Economic Life	40 years (Analysis also performed for 60-year life	40 years
Capacity factor	90% (Increased from Du and Parsons (2009) study from 85% based on data from ISO-NE)	85%
Heat Rate	10,400 Btu/kWh	6,800 Btu/kWh
Overnight Cost	$4,000/kWe (2007 dollars)	$850/kWe (2007 dollars)
O&M Fixed Costs	$56.44/kW/yr	$12.65/kW/yr
O&M Variable Costs	0.42 mills/kWh	0.41 mills/kWh
O&M Real Escalation Rate	1%/yr	1%/yr
Incremental Capital Costs	$40/kWh/yr	$10.20/kWh/yr
Fuel Costs	$0.67/mmBtu	$7.00/mmBtu
Inflation Rate	3%/yr	3%/yr
Real Fuel Escalation Rate	0.5%/yr	0.5%/yr
Tax Rate	37%	37%
Construction Period	5 years	2 years
FINANCING		
Equity Return	15% nominal net of income taxes	12% nominal net of income taxes
Debt Return	8% nominal	8% nominal
Inflation	3%/yr	3%/yr
Income Tax Rate (applied after expenses, interest & tax depreciation)	37%	37%
Equity	50%	40%
Debt	50%	60%
Weighted Average Cost of Capital	10%	7.8%
Depreciation	15-year	15-year
Waste Fee	1 mill/kWh	NA
Decommissioning cost:	$700 million (2007 dollars)	NA
Carbon Intensity	Zero (0) kg-C/mmBtu	14.5 kg-C/mmBtu
Carbon Cost	NA	$0/t CO_2 (Other scenarios analyzed)
Construction Schedule	10%, 25%, 30%, 25%, and 10% over 5 years	50% and 50% over 2 years

Using the Du and Parsons (2009) model with the parameters listed in Table 8 along with the following assumptions yielded a LCOE of $0.079/kWh for a nuclear plant and $0.065/kWh for a CCGT. These assumptions are

- Two potential sites exist for the construction of a nuclear power plant or a CCGT plant (Connecticut Yankee and Millstone).
- An unregulated electricity market, 1,000 MWe nuclear and gas-fired plants.
- Use of an open, once-through nuclear fuel cycle with spent fuel stored on-site. Each plant is owned and operated by a merchant generating company.
- Nuclear power plant decommissioning "cost" is accounted for as an extra upfront fee, but is actually recovered over the lifetime of the power plant via a kWh fee. While not included, there would be a "cost" associated with the decommissioning of a CCGT power plant.

Many of the current fleet of nuclear power plants has had their operating licenses extended from 40 to 60 years. This 20-year increase in economic life decreases the LCOE by $0.003 from $0.079/kW to $0.076/kW. Additionally, the operating licenses for the current generation of nuclear power plants being licensed today is 60 years.

The addition of a carbon tax or cap and trade cost will increase the LCOE of the natural gas CCGT facility. A carbon charge of $41.17/ton CO_2 will equalize the LCOE of the CCGT and nuclear power plants at $0.079/kWh. This compares to the current Regional Greenhouse Gas Initiative (RGGI) price of $1.90/ton CO_2.

In addition, a sensitivity analysis was performed for each cost and operational parameter in the LCOE calculation by increasing each parameter by 10% from the base case values while keeping the other parameters fixed. The LCOE is most sensitive to the parameters shown in Table 9. The results support that the LCOE of nuclear power plants are most sensitive to overnight cost (i.e., capital cost) and financing parameters while natural gas CCGT is most sensitive to fuel costs and thus fuel efficiency (i.e., heat rate).

TABLE 9: SENSITIVITY OF 10% INCREASE FROM BASE CASE ON THE LCOE FOR A NUCLEAR AND CCGT PLANT (40-YEAR ECONOMIC LIFE CASE)

Parameter	Change in LCOE	
	Nuclear	CCGT
Capacity Factor	-8.09%	-1.63%
Heat Rate	0.96%	8.13%
Overnight Cost	7.13%	1.47%
Fuel Cost	0.96%	8.13%
Inflation Rate	-2.95%	-0.40%
Tax Rate	1.44%	0.15%
Debt Fraction	-4.98%	-0.61%
Debt Rate	2.60%	0.47%
Equity Rate	7.89%	0.75%

It is important to highlight that the electric rate payer benefits as long as LCOE of the new baseload facility is less than the price bid by the highest marginal generator that is needed to meet that hour's load. This reduction in the highest bid accepted by ISO-NE is the generation cost savings that will be passed along to the rate payer. In this study's analysis, the difference between the nuclear power plant's LCOE of $0.079/kWh and natural gas of $0.065/kWh is additional profits for the merchant generating company beyond the equity return assumed in the base case analysis (15% for a nuclear plant and 12% for CCGT). The lower cost of the CCGT compared to nuclear power plant is savings that do not directly benefit Connecticut's residents and businesses.

5.2 NET ENERGY ANALYSIS FROM CRADLE TO GRAVE

A variety of groups have attempted to conduct Net Energy Analyses of various power generation systems. These analyses are important in that they examine the whole spectrum of energy used in mining, transporting and plant construction. Operating inefficiencies such as power conversion are also included in the accounting.

TABLE 10: ENERGY RESOURCE REQUIREMENT INPUT PER ANNUAL ENERGY OUTPUT

(SOURCE: NET ENERGY ANALYSIS: POWERFUL TOOL FOR SELECTING ELECTRIC POWER OPTIONS, S. BARON, BROOKHAVEN NATIONAL LABORATORY, UPTON, NY; PRESENTED AT THE ENERGY AND ENVIRONMENT: TRANSITIONS IN EAST CENTRAL EUROPE, PRAGUE, CZECHOSLOVAKIA, NOVEMBER 1-5, 1994)

Energy Systems	**Capital Energy** (Tot. Energy Input/ Annual Energy Output) [BTU/ BTU/year]		Operating Energy (Non-Fuel) (Annual Energy Input/ Annual Energy Output)	**Capitalized Energy Input** (Payback, yrs)
	Range	Avg.	Avg.	
Oil PP	0.3-0.4	0.4	0.04	1.6
Coal PP	0.35-0.4	0.4	0.03	1.3
LWR	0.30-0.36	0.3	0.06	2.1
LMFBR	0.50-0.70	0.6	0.01	0.9
Syn. Liq. From Coal	0.24-0.30	0.3	0.6	18
Syn. Gas from Coal	0.48	0.5	0.6	18
Oil from Oil Shale	0.3-0.4	0.4	0.5	15
Solar Heating	5.0-10.0	7	0.2	11
Solar Electric, thermal	5.0-12.0	8	0	8
Solar Electric, PV	10.0-20.0	15	0	15
Biomass-Ethanol	0.5	0.5	1.25-1.50	37.0-45.0

Table 10 shows the results of a Brookhaven National Laboratory analysis from 1994. The column headed "Capitalized Energy Input"may be the most important and simplest to understand. It estimates the years of plant operation required to "pay back" the initial investment in plant construction — the lower the number, the more efficient the energy system. It shows that LWRs have a payback period of about 2 years. Unfortunately, the age of this specific report precluded the inclusion of the very popular combined-cycle power plants that are dominating the new power plant construction field.

In addition to the Brookhaven report, the World Nuclear Association (WNA) has also produced a net energy analysis breakdown, which is more recent and provides a wider variety of power sources. Table 11 contains this summary from the WNA. The column, "Input % of lifetime output" identifies the percentage of the lifetime energy output that is needed to construct the power plant — a lower value is preferred in this column. Not surprisingly, hydropower represents some of the best lifetime returns, requiring an average of 2% input for the lifetime output. Nuclear power is also a strong contributor, with values approaching 2% for fuel produced by centrifuge enrichment. Less efficient diffusion processes will be shut down within about 5 to 8 years as the new centrifuge plants are brought online.

TABLE 11: NET ENERGY ANALYSIS (SOURCE: WORLD NUCLEAR ASSOCIATION LIFE CYCLE ENERGY RATIOS FOR VARIOUS TECHNOLOGIES - * IN IAEA 1994, TECDOC 753)

		Source	R3 Energy Ratio. (output/input)	Input % of lifetime output
Hydro		Uchiyama 1996	50	2.0
		Held et al 1977	43	2.3
	Quebec	Gagnon et al 2002	205	0.5
Nuclear (centrifuge enrichment)		see table 1.	59	1.7
	PWR/BWR	Kivisto 2000	59	1.7
	PWR	Inst. Policy Science 1977*	46	2.2
	BWR	Inst. Policy Science 1977*	43	2.3
	BWR	Uchiyama et al 1991*	47	2.1
Nuclear (diffusion enrichment)		see table 1.	21	4.8
	PWR/ BWR	Held et al 1977	20	5.0
	PWR/BWR	Kivisto 2000	17	5.8
		Uchiyama 1996	24	4.2
	PWR	Oak Ridge Assoc.Univ. 1976*	15.4	6.5
	BWR	Oak Ridge Assoc.Univ. 1976*	16.4	6.1
	BWR	Uchiyama et al 1991*	10.5	9.5
Coal		Kivisto 2000	29	3.5
		Uchiyama 1996	17	5.9
		Uchiyama et al 1991*	16.8	6.0
	unscrubbed	Gagnon et al 2002	7	14
		Kivisto 2000	34	2.9
Natural gas	- piped	Kivisto 2000	26	3.8
Natural gas	- piped 2000 km	Gagnon et al 2002	5	20
	LNG	Uchiyama et al 1991*	5.6	17.9
	LNG (57% capacity factor)	Uchiyama 1996	6	16.7
Solar		Held et al 1997	10.6	9.4
Solar PV	rooftop	Alsema 2003	12-10	8-10
	ground	Alsema 2003	7.5	13
	amorphous silicon	Kivisto 2000	3.7	27
Wind		Resource Research Inst.1983*	12	8.3
		Uchiyama 1996	6	16.7
		Kivisto 2000	34	2.9
		Gagnon et al 2002	80	1.3
		Aust Wind Energy Assn 2004	50	2.0
		Nalukowe et al 2006	20.24	4.9
		Vestas 2006	35.3	2.8

5.3 COMPARISON OF ENVIRONMENTAL EMISSIONS WITH NUCLEAR POWER AND ITS FULL FUEL CYCLE

It should be clear that nuclear fission does not produce traditional criteria pollutants (e.g., NO_X, SO_X, etc.) compared to fossil fuel combustion. Also, the fission process does not create CO_2 emissions. However, nuclear power plants use concrete, and the production of concrete produces CO_2 emissions. Therefore, a comparison of energy sources needs to include construction materials, decommissioning, and mining and other fuel preparation steps. Using this type of analysis, the estimated lifetime CO_2 emissions for nuclear power, fossil fuel- generated electricity, and renewable sources such as hydropower, wind, and solar energy are shown in Figure 17. Nuclear power had the lowest average lifetime emission of about 3 g CO_2/kWh electricity delivered.

Renewable energy sources such as hydropower and wind power also had low average lifetime CO_2 emissions of 5 and 10.5 grams (g) CO_2/kWh generated, respectively. In comparison, fossil fuel-generated electricity has CO_2 emissions that are over 100 times greater than nuclear power. For example, the average lifetime emissions for natural gas-fired CCGT and coal-fired power plants are about 400 and 700 g CO_2/kWh electricity delivered, respectively.

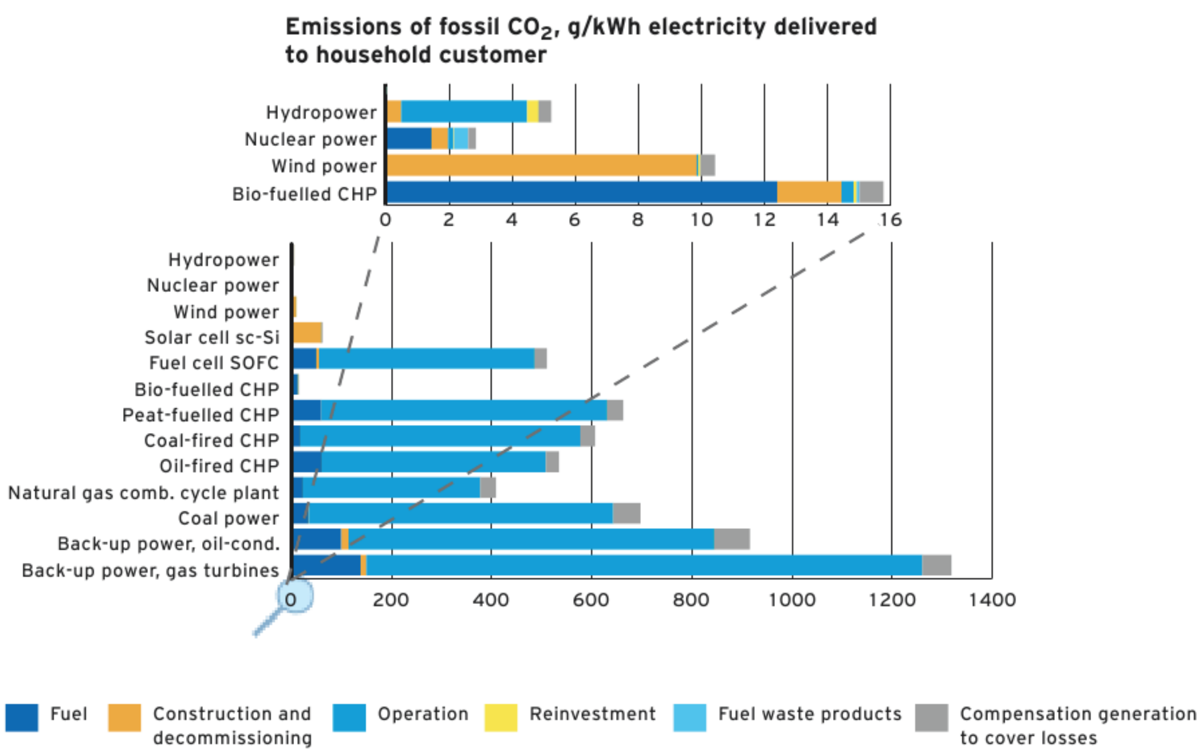


FIGURE 17: CO_2 EMISSIONS PER KWH ELECTRICITY DELIVERED TO HOUSEHOLD CUSTOMER (SOURCE: HTTP://WWW.VATTENFALL.COM/EN/FILE/2005-LIFECYCLEASSESSMENT_8459810.PDF)

5.4 UTILIZATION OF WASTE HEAT

Nuclear power plants utilize a Rankine Cycle to generate electricity, which is about 35% efficient. Therefore, nearly 2/3 of the energy from the nuclear fission reaction must be rejected or "wasted." Utilization of this "waste" heat to meet neighboring industrial, commercial, and residential thermal requirements has the potential to significantly increase the energy efficiency of the nuclear power plant or other large, centralized electric generating facility. The benefits from integrating the state's electricity and thermal requirements include:

- Reduced energy consumption, since waste heat from all electricity generating facilities is about equivalent to the fossil fuels utilized by Connecticut's industrial, commercial, and residential sectors. (See "A Study of the Feasibility of Utilizing Waste Heat from Central Electric Power Generating Stations and Potential Applications", Connecticut Academy of Science and Engineering, 2009; http://www.ctcase.org/reports/waste_heat.pdf)
- Utilizing the waste heat will reduce the approximately $3.8 billion that is spent each year in Connecticut by the residential, commercial, and industrial sectors on fossil fuels imported from out of state and from outside the country
- Use of power plant waste heat to meet needs currently satisfied by separate burning of fossil fuel will reduce carbon dioxide and other emissions accordingly
- Utility corridors that bundle all services in a common right of way could provide sound infrastructure that will serve Connecticut for many years, providing an incentive for in-state business development, job creation, and promotion of smart growth strategies
- Increased national security by reducing dependence on imported fossil fuels
- Reduced peak electricity demand resulting from the use of chilled water loops (absorption chillers driven by steam/hot water for air conditioning), thus reducing the need to make investments in peaking units that run less than 50 hours a year

The economic and business practicality of district heating and cooling systems depends on careful planning with regard to distribution of the heat and cooling as well as establishment of customer agreements consistent with the requirements of favorable return on the plant capital investment. Distribution requires laying piping systems across a broad geographic area surrounding a central plant which provides electricity, heating and cooling. Providing the heat at useful temperatures requires that the plant be optimized for this purpose, which means a reduction in electric generation efficiency and electric capacity.

To take advantage of the integration of electricity and thermal requirements, the nuclear power plant (or other electricity generating facility) needs to be near population centers, commercial businesses, and/or industrial users. Typically, chilled water can be piped effectively a distance of about 4 miles and hot water/steam loops can extend about 12 miles from the power plant.

The most likely locations for a new nuclear facility in Connecticut are at Millstone in Waterford or at the site of the former Connecticut Yankee nuclear power plant in Haddam Neck. Neither of these locations is near the core population and business centers of the state, which run from southwestern Connecticut through central Connecticut (see Figures 18 and 19). However, Millstone is about 3 miles southwest of New London, where there is an area of higher population and business density. A study is needed to determine the heating and cooling requirements of this area and how it could be met by an integrated thermal and electricity generating nuclear facility. The analysis should also consider the following elements that are required to further encourage the development of a cogeneration facility.

- Develop a government or private organization to purchase power plant heat and distribute it to multiple customers as is done in many locations in Canada, Europe and the United States
- Develop Waste Heat Enterprise zones to promote local development that utilizes the waste heat as part of a smart growth policy. Developers would likely be attracted to locations where only a connection is required to the heating and cooling loop, thereby eliminating the upfront capital costs for mechanical equipment such as boilers and chillers. Furthermore, this would make additional space available for income-generating purposes that otherwise would be occupied by mechanical equipment.
- Provide Class I or Class II renewable energy credits for use of rejected heat from electricity generating facilities

Encourage high population areas such as New London to develop master utility plans so that utility upgrades (i.e., water, gas, electricity, cable, and phone) can be coordinated along with installation of district heating and/or cooling loops.

FIGURE 4.1: CONNECTICUT ELECTRICITY GENERATION PLANTS GREATER THAN 65 MW WITH POPULATION DENSITY

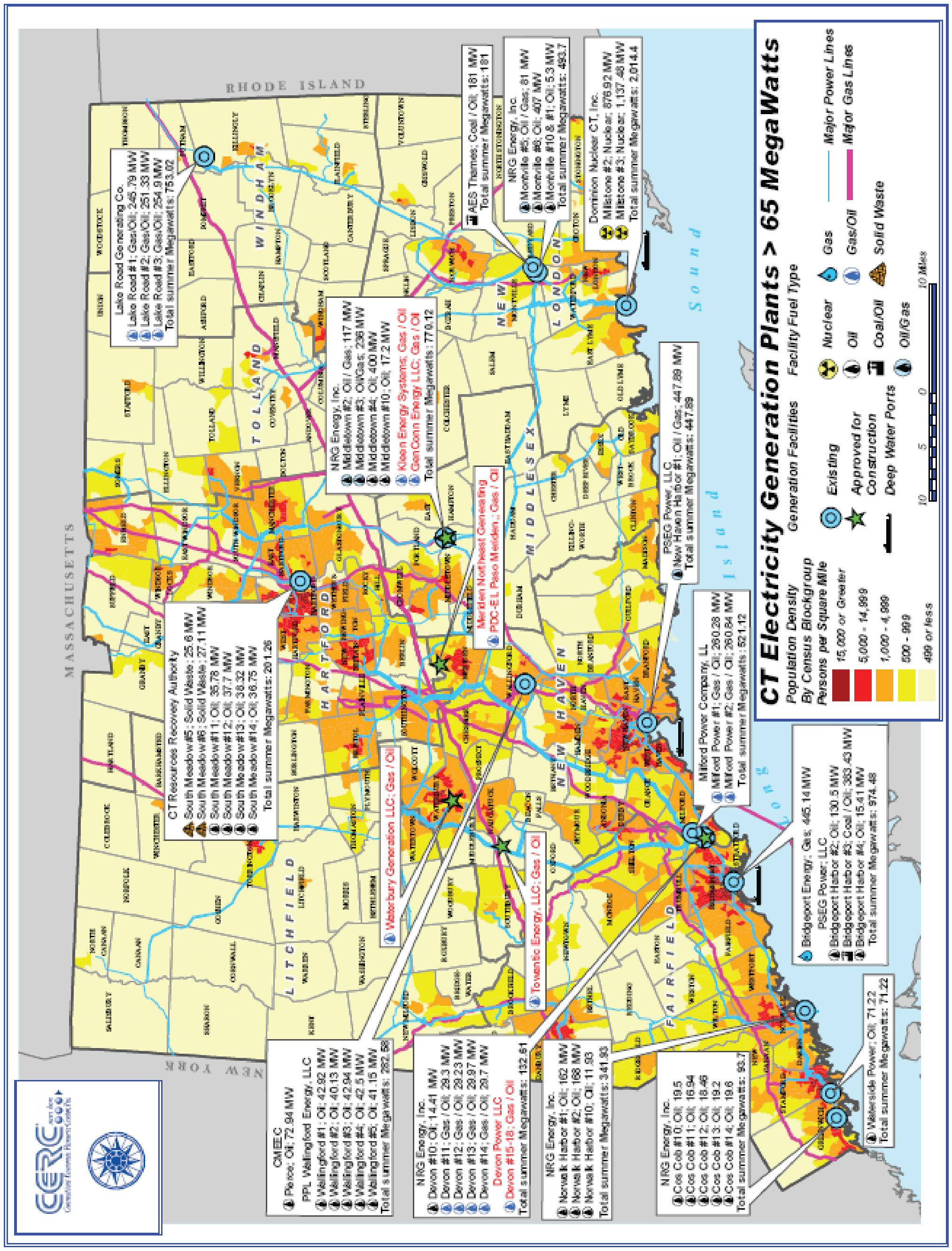


FIGURE 18: CONNECTICUT ELECTRICITY GENERATION PLANTS GREATER THAN 65 MW WITH POPULATION DENSITY (FIGURE 4.1, A STUDY OF THE FEASIBILITY OF UTILIZING WASTE HEAT FROM CENTRAL ELECTRIC POWER GENERATING STATIONS AND POTENTIAL APPLICATIONS, CONNECTICUT ACADEMY OF SCIENCE AND ENGINEERING [2009])

FIGURE 4.2: CONNECTICUT ELECTRICITY GENERATION PLANTS GREATER THAN 65 MW WITH POPULATION DENSITY AND EMPLOYERS WITH GREATER THAN 15 EMPLOYEES

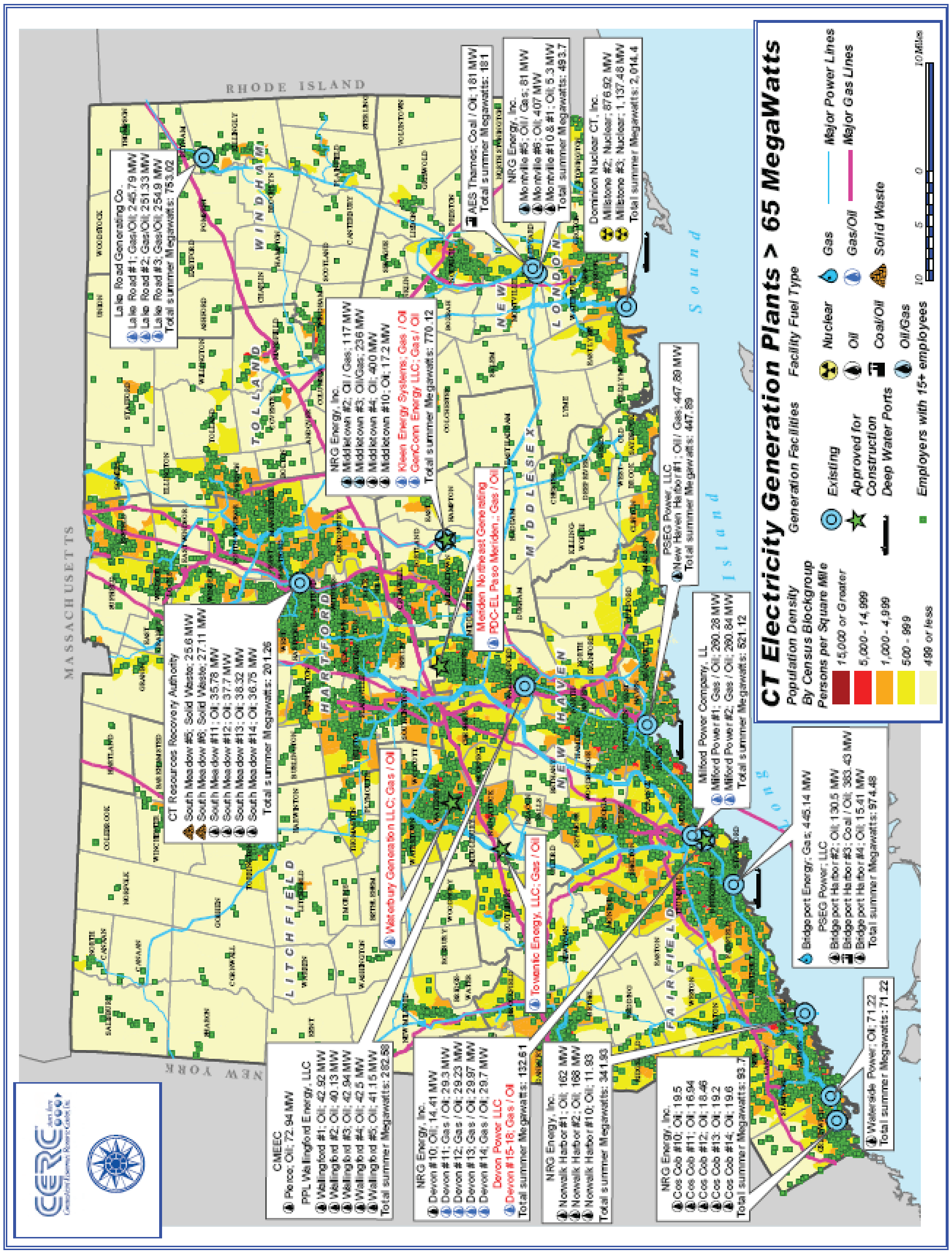


FIGURE 19: CONNECTICUT ELECTRICITY GENERATION PLANTS GREATER THAN 65 MW WITH POPULATION DENSITY AND EMPLOYERS WITH GREATER THAN 15 EMPLOYEES (FIGURE 4.2, A STUDY OF THE FEASIBILITY OF UTILIZING WASTE HEAT FROM CENTRAL ELECTRIC POWER GENERATING STATIONS AND POTENTIAL APPLICATIONS, CONNECTICUT ACADEMY OF SCIENCE AND ENGINEERING (2009)

6.0 CONSIDERATIONS FOR A NUCLEAR POWER PLANT IN CONNECTICUT

6.1 CONNECTICUT AND NEW ENGLAND ELECTRICITY MARKET

6.1.1 *Electric Rates*

Connecticut's electricity rates have been the second highest in the country (exceeded only by Hawaii) since 2007. As of February 2011, the average rate was $0.164 per kilowatt-hour (kWh) or 69% higher than the national average of $0.097 per kWh (EIA). Historically Connecticut has had significantly higher electricity rates than the national average (see Figure 20). Prior to deregulation of the wholesale electricity market in 1998, Connecticut's average retail electricity rates were between 40% and 54% greater than the national average. Average retail electricity rates initially dropped relative to the national average with rates being between 32% and 37% greater than the national average. However, starting in 2005 there has been a significant increase in electricity rates in Connecticut compared to the national average with a peak of 84% above the national average in 2009. Not surprisingly, high energy costs were the most important issue mentioned in this study's survey of 600 Connecticut residents in October 2010.

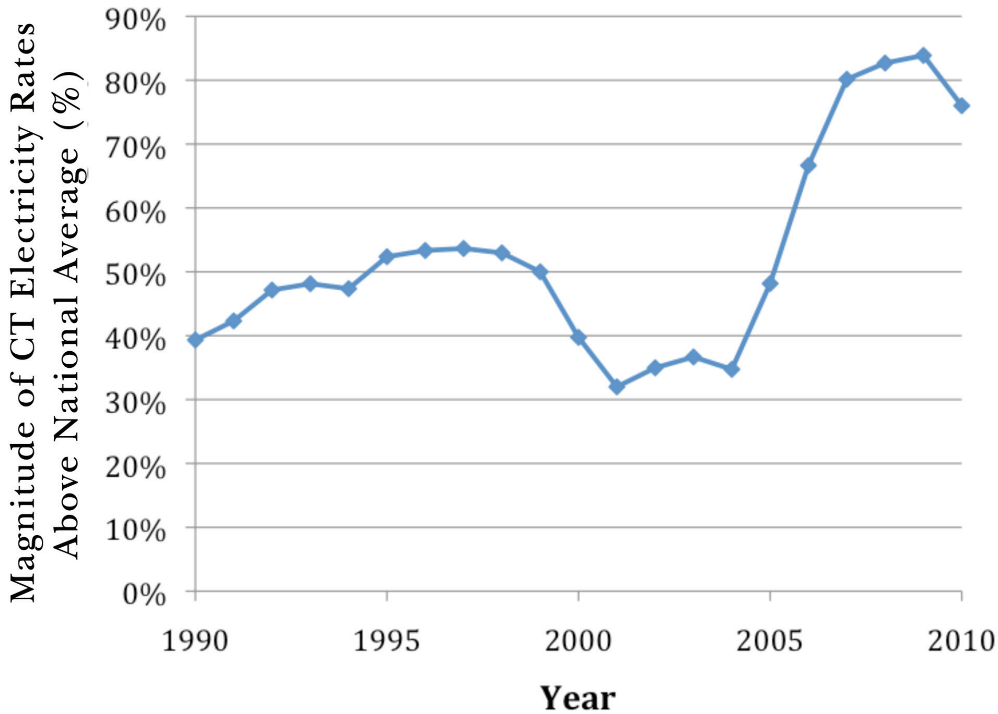


FIGURE 20: MAGNITUDE OF CONNECTICUT AVERAGE RETAIL ELECTRICITY RATES ABOVE THE NATIONAL AVERAGE FROM 1990 – 2010 (SOURCE: EIA)

Connecticut's high electrical rates cannot be addressed solely as a state issue but must be dealt with on the regional level because the electrical wholesale market is administered by the ISO-NE under rules approved by the Federal Energy Regulatory Commission (FERC). Electrical rates throughout New England are also relatively high, with an average rate of $0.146 per kWh, which is 51% higher than the national average (EIA, February 2011).

Connecticut and the region's high electricity rates are likely caused by several factors, including:

- The state does not have any indigenous energy resources.
- Connecticut legislation that deregulated the electricity industry required electric companies to sell their power plants and buy power on the wholesale market. Vermont did not deregulate and had an average rate of $0.138 per kWh in February 2011, which is 16% less than Connecticut. New Hampshire allowed electric utilities to own power plants and had an average rate of $0.150 per kWh, which is 9% less than Connecticut.
- The region's dependence on power plants that use natural gas as their primary fuel set the price of electricity about 90% of the time as compared to use of other types of power plants that use lower cost fuels such as coal, or hydroelectric power. Coal is used to generate 45% of the electricity in the United States compared to only 12% in New England (EIA, 2010), and hydroelectric power is used to generate 37% of the electricity for the Pacific Northwest contiguous states (Washington, Oregon, and California) compared to 7% in New England (Edison Electronic Institute).
- Congestion of the electrical grid adds to the price of electricity, especially in the southwestern third of the state. For example, less efficient plants operate more than they would need to if congestion were not a problem in order to maintain system reliability. Congestion has decreased following the completion of the Bethel-Norwalk and Norwalk-Middletown transmission lines in October 2006 and December 2008, respectively. This has decreased federally-mandated congestion charges (FMCC) to 0.85 cents per kWh for Connecticut Light & Power (CL&P) and a negligible amount for United Illuminating (UI) customers. However, transmission rates have increased by 1.07 cents per kWh for CL&P customers and by 0.93 cents per kWh for UI customers from 2000 to 2009, according to DPUC.
- Environmental regulations play a role in higher rates. It was estimated by DPUC that state legislation (PA 98-28) requiring electric companies to purchase renewable resources adds about 0.45 cents per kWh, with an additional charge of 0.10 cents per kWh for funding renewable energy programs. Additionally, a 0.30 cents per kWh charge for conservation programs has the potential of reducing electricity rates more than the cost of the program, if the program is successful at reducing the growth of peak demand and increasing electricity efficiency. Coal, a less expensive fuel than natural gas, is utilized sparingly in Connecticut because of the state's stringent air pollution standards and RGGI.
- Connecticut is a relatively high-cost state in terms of salary, taxes, and land which results in higher prices than the national average.

These factors do not work alone but rather in combination, resulting in high electricity rates. For example, Connecticut does not have any natural gas resources so it must be transported by pipeline from other parts of the United States and Canada. The transmission cost adds about $1 per 100 ft^3 of gas or about 1 cent per kWh to the cost of fuel for natural gas generating facilities in Connecticut. Because of how the deregulated market works in Connecticut, the price of natural gas sets the market price of electricity about 90% of the time. Therefore, Connecticut residents pay a natural gas transportation "penalty" on all electricity generated even if the power is generated by power plants that use fuels other than natural gas.

6.1.2 Need for Additional and/or Replacement Baseload Capacity

Nuclear power plants run continuously and operate as baseload electricity generation units. The need for new baseload electricity generation in New England depends on the following factors:

- Change in baseload demand
    - Economic and population growth
    - Technological advances (e.g., LED lighting, plug-in hybrid cars)
- New and retirement of baseload electricity generating facilities. Examples are:
    - Kleen Energy CCGT (new)
    - VT Yankee nuclear (likely retirement in 2012 because of state legislature opposition)
    - Pilgrim nuclear (license expires in 2012 and will likely be able to continue to operate until Nuclear Regulatory Commission makes a final decision)
    - Distributed Generation
- Import of baseload electricity generation from Canada
    - New Brunswick is contemplating an additional nuclear reactor at Point LePreau that would sell power into the New England market
    - Hydro-Quebec is planning to build a 140 mile, 1,200 MW high voltage DC transmission line to New Hampshire with construction expected to start in 2013

6.1.2.1 CHANGE IN BASELOAD DEMAND

ISO-NE provides annual ten-year forecasts for peak power demand and total electricity consumption, but ISO-NE does not forecast change in baseload demand. A detailed analysis of change in baseload demand is not included in the scope of this study, but the following provides a summary of the factors that show that there are no clear indicators for the direction in baseload demand in Connecticut or New England.

The historical peak demand from 2000-2009 and the forecasted peak demand for New England is shown in Figure 21. With the economic decline in 2009, the projected peak demand for 2010 is about 1,000 MW less than the 2009 projected demand, which was based on the previous year's estimate. This reduction in the RSP10 versus RSP09 forecast narrows to 500 MW by 2018. Even with a slowdown in the economy and the adjusted change in peak demand, the peak demand is expected to grow because it occurs on the hottest days of the year and is heavily dependent on lifestyle choices as compared to price alone.

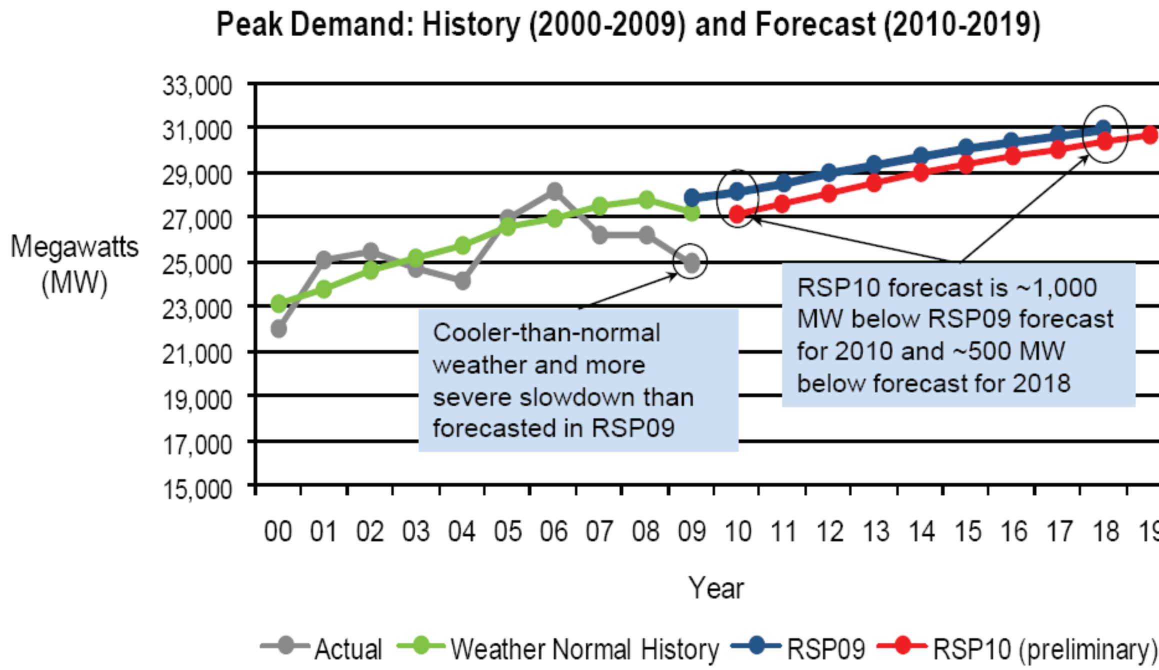


FIGURE 21: HISTORICAL AND FORECASTED PEAK ELECTRICITY DEMAND FOR NEW ENGLAND (SOURCE: ISO NEW ENGLAND)

For Connecticut, the normal weather (50/50) peak was predicted to be 6,805 MW in 2009 (50/50 peak load is the actual peak load adjusted for normal weather conditions.) It is expected to grow an annual rate of 1.18%, reaching a normal weather peak load of 7,562 MW in 2018. Because of the need to provide electrical services without disruption (i.e., brownouts, blackouts, and damage to equipment), electricity capacity planning is based on a 90/10 worst-case hot weather scenario forecast. This forecast assumes that hot-weather conditions would only be exceeded once every ten years. Based on this analysis, ISO-NE forecasted a projected worst-case peak load of 8,025 MW in 2009 and expects it to grow annually at a rate of 0.91%, reaching 8,705 MW by 2018 (Connecticut Siting Council – 2009 Forecast of Loads and Resources).

Electricity consumption in Connecticut in 2009 was approximately 31,890 GWh. ISO-NE forecasts that total electricity generation by Connecticut utilities will decline at a weighted annual average of 0.21% to 31,394 GWh by 2018 (see Figure 22). Even though the peak demand is expected to increase, ISO-NE bases their forecast for a decline in electricity consumption on changing customer behavior in response to the economy and electric rates, and also due to efficiency efforts encouraged by the utilities and the state (Connecticut Siting Council – 2009 Forecast of Loads and Resources).

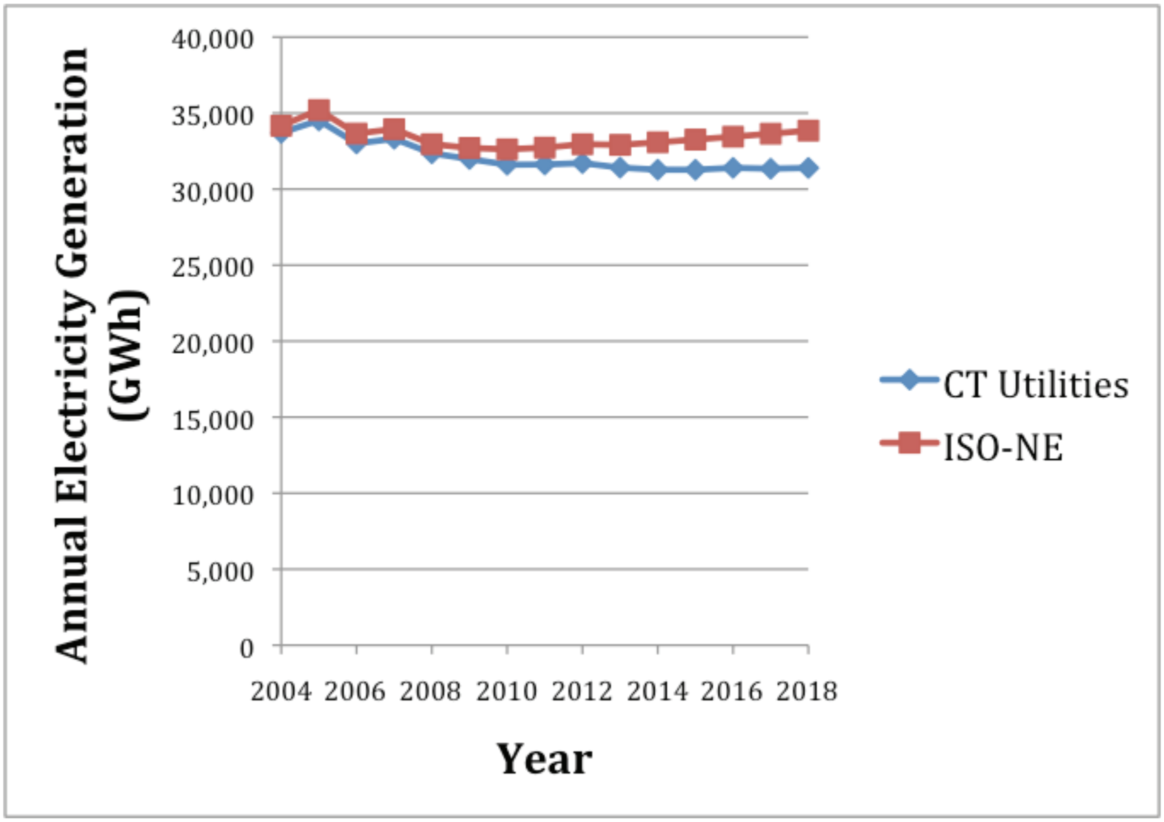
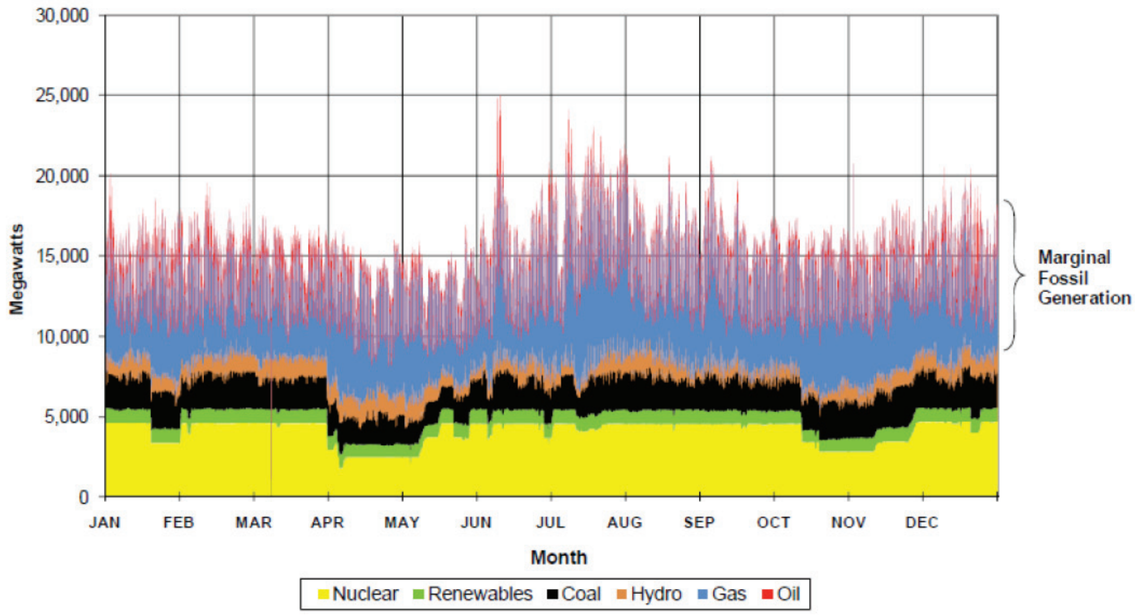


FIGURE 22: CONNECTICUT AND UTILITY ELECTRICITY GENERATION REQUIREMENTS
(SOURCE: CONNECTICUT SITING COUNCIL – 2009 FORECAST OF LOADS AND RESOURCES)

To illustrate how electricity consumption changes on a daily and seasonal basis, the variation in electricity load for 2008 in New England is shown in Figure 25. Also, the contribution of nuclear power, renewable energy, coal, hydroelectric, natural gas, and oil is shown. Nuclear, coal, hydroelectric and renewables (i.e., solid waste incinerators) tend to provide the baseload with higher cost natural gas and oil generators making up the difference to meet actual demand for that day. Also, Figure 23 shows how the planned maintenance of nuclear facilities in the spring and fall affects the electricity generation market.



Source: *2008 New England Electric Generator Air Emissions Report*, ISO New England, August 2010.

FIGURE 23: NEW ENGLAND DAILY VARIATION & FUEL SOURCE FOR ELECTRICITY GENERATION IN 2008 (SOURCE: ISO NEW ENGLAND)

Electricity demand can also be shown by the relationship between load and price duration. This relationship for Connecticut in 2005 is presented in Figure 24. For Connecticut, the minimum load in 2005 was about 2,500 MW.

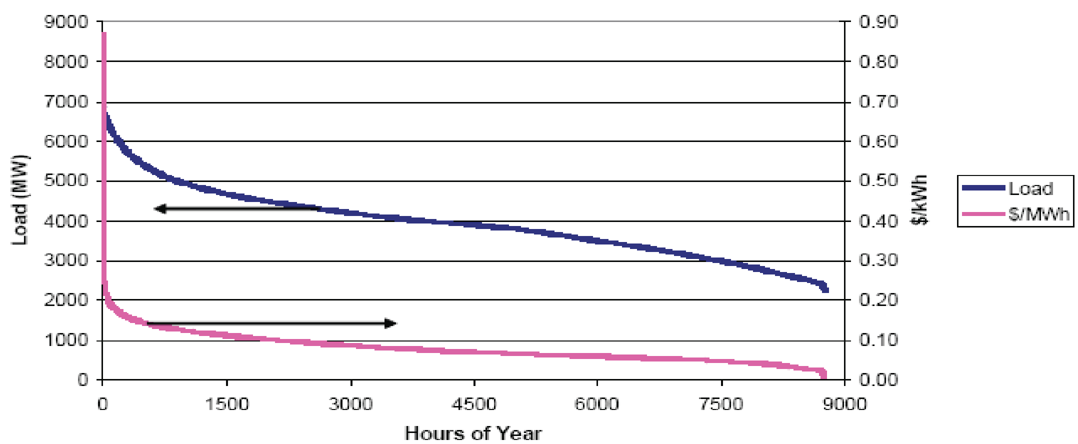


FIGURE 11: 2005 CT LOAD DURATION AND PRICE DURATION CURVE

FIGURE 24: 2005 CT LOAD DURATION AND PRICE DURATION CURVE (SOURCE: CASE REPORT - ENERGY ALTERNATIVES AND CONSERVATION, 2006)

Adoption of new technology will also impact change in baseload electricity demand. Replacement of incandescent lights with compact fluorescents or even more energy-efficient LED lighting will contribute to reducing electricity consumption. Also, future government (state and federal) and Connecticut Energy Efficiency Fund incentives to replace older, inefficient appliances with new, more efficient appliances will reduce electricity consumption. On the other hand, the introduction of plug-in hybrids and electric cars into the market, as adoption grows, will lead to higher baseload demand, especially if time-of-use electricity rates were adopted as a potential means for reducing peak electricity demand. This could lead to much flatter electricity demand curves where baseload generation would be a larger percentage of total electricity consumption.

6.1.2.2 RETIREMENT OF BASELOAD ELECTRICITY GENERATING FACILITIES

Retirement of existing electricity capacity is also an important driver for the need for new generation capacity. Millstone units 2 and 3 have had their operating licenses extended from 40 to 60 years and now expire in 2035 and 2045, respectively. Seabrook and Pilgrim are awaiting NRC action on their 20-year license extensions. Vermont Yankee received a 20-year license extension from the NRC, but some Vermont lawmakers are trying to shut down the plant despite the license extension. This case is currently being litigated.

For existing baseload fossil fuel generating facilities, it may be determined that it is more cost effective to be retrofitted or refurbished instead of being retired and replaced.

6.1.2.3 IMPORT OF BASELOAD ELECTRICITY FROM CANADA

The importation of electricity into the New England market also needs to be considered when evaluating the need for additional electricity generation. New Brunswick, Canada, is in the process of considering the development of an additional nuclear reactor at Point LePreau that would sell power in the New England market. Also, Hydro-Quebec signed a letter of understanding with Northeast Utilities and NSTAR for a 1,200 MW DC line between Des Cantons substation and a substation in southern New Hampshire in December 2008. Agreements are currently being negotiated to supply electricity starting in the middle of the decade.

6.1.2.4 REPLACEMENT OF MARGINAL GENERATORS

While there are no clear indicators for the direction in baseload demand in Connecticut or New England, an ISO-NE analysis found that the replacement of marginal units that were assumed to be a moderately efficient, combined-cycle gas-fired power plant with a new low-cost plant will reduce electric rates. For example, the addition of 1000 MW of supply will save New England consumers $600 million a year (2005 $) and reduce wholesale electricity prices by 5.7% (ISO-NE, Electricity Costs White Paper, June 2006).

6.1.3 Economic Development

The Department of Economic and Community Development and the Connecticut Economic Resource Center conducted a study as part of this project to determine the economic impact related to the construction and operation of a new and replacement 1000 MW baseload nuclear power plant. For comparison, the economic impact of constructing a 1000 MW baseload natural gas CCGT was determined in order to compare the relative net economic benefit of each plant. A summary of the analysis is given below and the full report is in Attachment 1.

The first analysis consisted of analyzing the economic and fiscal benefits of replacing an existing nuclear plant at Millstone with either a new nuclear reactor or a CCGT plant. It was assumed that there is no change in the wholesale price of electricity because baseload capacity is not changed, and that employment and procurement activities remain the same. Therefore, this scenario results in short-term gains of employment and state GDP from the large construction project to build either the nuclear or CCGT plant. A summary of the economic impact is presented in Table 14. The differences in economic impact are primarily due to the difference in construction costs between the two facilities. Assuming that construction began in 2009 and lasted for five years, the total construction cost of the nuclear plant is $4,504 million. For the CCGT plant, construction started in 2012 and lasts for two years with a total construction cost of $1,000 million, which includes the cost of extending the natural gas pipeline to Millstone. The 4.5 times higher construction cost of the nuclear power plant relates to approximately the same total increase for the economic variables in Table 14.

TABLE 14: ECONOMIC IMPACT OF REPLACING A NUCLEAR PLANT WITH A NUCLEAR OR CCGT PLANT AT MILLSTONE (FROM ATTACHMENT 1: ECONOMIC IMPACT ANALYSIS – NOTE: THIS VERSION OF THIS TABLE DOES NOT INCLUDE 2014, WHICH IS PRIMARILY RELATED TO NUCLEAR DECOMMISSIONING.); SOURCE: THE REMI MODEL AND THE AUTHORS' CALCULATIONS

Economic Variable		2009	2010	2011	2012	2013	TOTAL
Total employment	Nuclear	7,993	20,320	24,756	19,249	6,021	**78,339**
	CCGT	NA	NA	NA	8,685	8,368	**17,053**
Construction employment	Nuclear	5,708	14,660	18,194	14,636	5,365	**58,563**
	CCGT	NA	NA	NA	6,263	6,187	**12,450**
State GDP (mil nominal $)	Nuclear	$460.5	$1,214.9	$1,495.1	$1,161.2	$313.4	**4,645**
	CCGT	NA	NA	NA	$543.5	$531.1	**1,075**
Output (mil nominal $)	Nuclear	$780.5	$2,051.6	$2,516.2	$1,948.9	$530.0	**7,827**
	CCGT	NA	NA	NA	$917.4	$894.6	**1,812**
Personal Income (mil nominal $)	Nuclear	$393.6	$1,055.8	$1,400.3	$1,225.8	$556.5	**4,632**
	CCGT	NA	NA	NA	$472	$507.80	**980**
Net State Revenue (mil nominal $)	Nuclear	$77.78	$190.7	$218.66	$147.7	$0.53	**635**
	CCGT	NA	NA	NA	$87.65	$77.71	**165**

In the second scenario, 1000 MW of baseload capacity is added to Millstone or built at the Connecticut Yankee site with construction and operation of the facility by a merchant owner from 2009 through 2050. The analysis assumes the sites are identical because they have the same construction costs and absorb the labor and procurement activities of the marginal plant being replaced in the ISO-NE region. Therefore, there is no net new direct employment or procurement in Connecticut. Siting and permitting costs for both the nuclear and CCGT plant are assumed to be the same and are not included in the analysis.

The results of the analysis are presented in Table 15. As in the previous case, the difference between the economic impact of a nuclear and CCGT plant is the cost of construction. The drivers of new net economic activity are reduction in the wholesale price of electricity to Connecticut users and the relatively large but short-term construction phases. Adding baseload capacity has long-term benefits in the form of reduced wholesale price for electricity and net new employment, procurement and taxes in the economy as a whole.

Table 15: Economic Impact of Adding a Nuclear and CCGT Plant at Millstone or Connecticut Yankee (from Attachment 1: Economic Impact Analysis); Source: The REMI model and the authors' calculations

	Annual Average Change from Baseline (2009-2050)			
Economic Variable	**Add Nuclear Plant at Millstone or CT Yankee**		**Add CCGT Plant at Millstone or CT Yankee**	
Total Employment (Persons)	2,420		1,333	
Construction (Jobs)	957		254	
	Ann. Avg. Change	**Net Present Value**	**Ann. Avg. Change**	**Net Present Value**
Gross Domestic Product (mil nominal $)	$516.6	$7,594.8	$471.1	$5,768.4
Output (mil nominal $)	$845	$12,576.3	$773.6	$9,581.7
Personal Income (mil nominal $)	$363.6	$6,154.1	$247.6	$3,291.8
Net State Revenue (mil nominal $)	$27.4	$586	$18.6	$306.2

The study acknowledges that it is conceivable that total employment would not be the same for a nuclear versus a CCGT plant because the CCGT would not require the operation and maintenance workforce that a nuclear plant does. The study committee believes that this would be the case and that the difference in employment should be reflected in the economic impact study. For the scenario in which a third reactor at Millstone is constructed, it is estimated that an additional 450 jobs would be created to operate and maintain the new unit (nextbigfuture.com, 2007). It is uncertain how many additional guards might be needed to secure the third reactor or if the current security force would be sufficient. If a nuclear power plant were to be built at Connecticut Yankee, a staff of approximately 700 would be needed to operate and maintain the facility (nextbigfuture.com, 2007). In addition, the security force that currently guards the spent nuclear fuel at the Connecticut Yankee site would need to be augmented. NEI reports that there are about 8000 security guards that protect the 104 nuclear power plants in the United States, or about 80 guards per plant on average (http://www.nei.org/keyissues/safetyandsecurity/plantsecurity). In contrast, it is estimated that a staff of about 25 is needed to operate and maintain a CCGT. Therefore, at a minimum, an additional 425 jobs would be created for operation of a third nuclear power plant in Connecticut. In addition, the construction of a nuclear power plant would add an average of 15,700 jobs per year over the five-year construction period compared to 8,525 jobs per year over the two-year construction period for a CCGT power plant.

6.2 SITING

Siting of an electricity generating facility in Connecticut and New England is a difficult process. This 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, if not more difficult, to site than a fossil fuel plant.

Siting of a new nuclear facility in Connecticut should be located at the Millstone Power Station in Waterford or the Connecticut Yankee in Haddam Neck. The Millstone site has the infrastructure advantages for managing spent nuclear fuel and significant switchyard equipment still in place from operation of the now retired Millstone Unit 1. Other infrastructure advantages include training facilities, warehouses, and the cooling water intake structure, as well as administrative staff. It is expected that there would be local support because the communities surrounding these facilities are familiar with nuclear power. While the decommissioning process has been completed at the Connecticut Yankee site, there is still some transmission infrastructure in place for future use and the site was once approved for nuclear operations. These two sites are likely also to have the least public opposition because one has an operating nuclear power plant and the other is a site of a former nuclear power plant.

6.3 LOCAL ACCEPTANCE: SURVEY OF 600 RESIDENTS

CERC was commissioned by CASE to assess Connecticut residents' opinions on energy and specifically, nuclear power. This section provides 1) a summary of survey findings as they pertain to the major energy issues identified by the respondents; their knowledge of electricity generation in Connecticut; their acceptance of nuclear, fossil fuels, and other alternative forms of power; and 2) the need for educating the public about nuclear power and energy issues in general.

The survey consisted of random calls to 600 residents who were at least 18 years old and were distributed evenly between Fairfield County, Hartford and New Haven Counties, New London County, and the rest of the state. The survey took place October 8-27, 2010, and had a confidence level of 95% with an uncertainty interval at the county level of 8% and uncertainty interval at the state level of 4%. The survey questions, results, and analysis of data by CERC are found in Attachment 2.

6.3.1 Energy Issues Identified by Connecticut Residents

The Connecticut residents who responded to this survey expressed the opinion that energy is an important issue that must be addressed. About three quarters of the respondents think that the situation in the United States and Connecticut is very serious or serious. The most important US electric energy issue mentioned was energy prices (31%) followed by environmental issues

(18%), petroleum dependency (14%), limited energy resources (10%), renewable / green energy sources (7%), nuclear energy (6%), and national security (6%). (Respondents were allowed to mention more than one issue: a total of 1083 responses were provided by the 600 people surveyed.) When asked specifically about these issues, an overwhelming majority are concerned that future oil supplies will decline and that prices will rise significantly (78% strongly agree or agree) and that climate change requires new ways of producing electricity (83% strongly agree or agree). Furthermore, 88% of the respondents strongly agree or agree that environmental conditions demand more electricity generation from clean energy sources.

Follow-up questions then were asked about energy prices, environmental issues, and petroleum dependency. Respondents were asked about the cost to produce electricity from fossil fuels, renewable energy sources, and nuclear energy. The ranges for responses were from very cheap, somewhat cheap, moderately priced, somewhat expensive, to very expensive. Fossil fuels were seen as very expensive by 52% of the respondents compared to 32% for renewable / green energy, and 17% for nuclear power. For nuclear power, 31% did not know how to answer this question.

Future energy demands (33%), climate change (19%), and air quality (16%) were given as the most important environmental issues facing the United States. The issue of climate change was explored further because nuclear power has the potential to significantly reduce greenhouse gas emissions. Fifty nine percent thought that climate change was serious or very serious, 29% thought the situation was somewhat serious, and 12% of residents did not consider the situation to be serious.

The majority of respondents (56%) think that it is very or extremely important that Connecticut reduce its reliance on fossil fuels. This issue was more important for younger people (30-44 years old) compared to older people (55+ years old). When asked an open-ended question on how Connecticut should reduce its reliance on fossil fuels, 32% of the respondents did not know how to answer this question. The most common other responses were to increase solar power (18%), increase wind power (16%), increase “green” power (12%), and increase hydroelectric power (8%). Only 1% of the respondents cited that the state should use more nuclear power.

6.3.2 Knowledge of Electricity Generation in Connecticut

One of the more notable findings from the survey was that 69% of the residents incorrectly thought that fossil fuels accounted for the majority of the electricity generated in Connecticut and an additional 18% did not know or were not sure about the fuel source used to generate electricity. Only 12% of the respondents were correct in responding that nuclear energy accounted for most of the electricity generated in Connecticut. From the Department of Energy’s Energy Information Administration, 50.9% of the electricity generated in Connecticut was from nuclear energy in 2008. The next most important energy sources for generating electricity were natural gas, which accounted for 26.5% and coal, which accounted for 14.4%. The complete breakdown with percentages listed is shown in Figure 25.

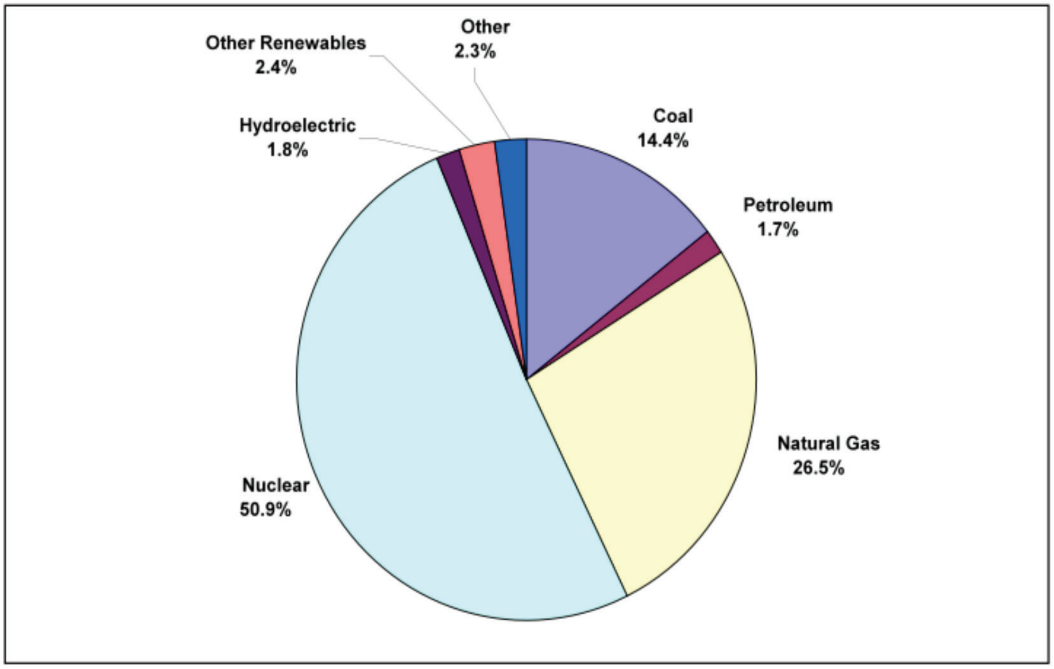


FIGURE 25: CONNECTICUT'S ELECTRIC POWER INDUSTRY GENERATION BY PRIMARY ENERGY SOURCE, 2008 (SOURCE: EIA; HTTP://WWW.EIA.DOE.GOV/CNEAF/ELECTRICITY/ST_PROFILES/SEPT05CT.XLS)

To follow up on the respondents understanding about the generation of electricity from nuclear energy in Connecticut, slightly more than half (52%) of the respondents did know that there was an operating nuclear power plant in Connecticut. Twenty-six percent of the respondents did not know there was a nuclear power plant in the state and 21% were not sure. Of those who responded that there was a nuclear power plant, the majority stated that there were one or two power plants in Connecticut (89%). Both of these responses could be considered correct because it is uncertain if the respondents considered Millstone Units 2 and 3 as one nuclear power plant or as two. Of the respondents who knew about a nuclear power plant in Connecticut, 54% mentioned Waterford, Millstone or Niantic as the location, with Waterford being the most frequently referenced at 43%.

Interestingly, most of the respondents (84%) had never looked for information about electric energy issues. Within the group of respondents, men were more likely to have looked for information (24%) compared to women (11%), but there still appears an overall need to have Connecticut residents more informed about electric energy issues. For those respondents who had investigated electric energy issues, the internet (71%), newspapers (51%), and books/magazines (43%) were the most common sources for information (Note that respondents could list more than one source with 98 respondents giving a total of 220 responses). Those respondents who had not yet conducted any research cited internet, newspapers, and books/magazines as the preferred sources.

6.3.3 Acceptance of Nuclear, Fossil Fuel, and Alternative Forms of Power

Respondents were asked how favorable or unfavorable each type of electric energy source was in contributing to reliable and secure power in the future. Nuclear power was not favorable to 47% of respondents and only about 20% responded that it was very favorable or extremely favorable. With regard to nuclear power, there was a significant difference between counties. In New London County, home of the Millstone Nuclear Power Plant, 41% of the responses were not favorable. This percentage increased to 52% in Fairfield County. Fossil fuel generation was viewed as not favorable by about 23% of the respondents, which is considerably less than the 47% of the respondents that viewed nuclear power as not being favorable. On the other hand, 82% of the respondents were extremely favorable or very favorable toward renewable / green based energy in making a substantial contribution as a reliable and secure supply of power in the future.

Overall, respondents did not want to increase the usage of nuclear power in Connecticut. Only 12.5% wanted to increase usage while 33% did not want to use nuclear power at all. Respondents reacted in a similar fashion to fossil fuel based generation with only 1.3% wanting to increase usage of fossil fuels and about 13% not wanting to use fossil fuels for electricity generation at all. The great majority of respondents (73%) want to increase the use of renewable and green energy sources.

The lack of support for nuclear power is likely related to the respondents thinking that nuclear power plants cannot be operated in a safe manner. About 35% of the respondents strongly disagreed or disagreed that a nuclear facility can be operated safely while 20% were not sure or did not know how to answer the question. There was a significant difference between the safety concerns of New London County and Fairfield County respondents. Forty six percent of the respondents in New London County and only 33% of Fairfield County respondents agreed or strongly agreed that nuclear power plants could be operated safely. Respondents were also concerned about terrorism being a major threat to nuclear power plants with about 75% agreeing or strongly agreeing that this is a major threat.

The respondents were also asked if Connecticut should build a new nuclear power plant for additional electric capacity. Sixty four percent of the respondents said no, 15% said yes, and 21% were not sure. The one group that was in most favor (40%) of building a new nuclear facility were those respondents that had some graduate work or a graduate degree.

A majority of respondents were opposed or strongly opposed to having a fossil fuel (63%) or nuclear power plant (73%) built within 5 miles of their home. The opposition to these facilities near their home did not change much even if this would reduce their property taxes. New London County respondents were most supportive of building a nuclear power plant (24%) while Fairfield County respondents were the least supportive (10%). The opposition to fossil fuel based generation and nuclear power is likely related to the respondents' belief that these sources of power are harmful to the environment. About 57% of the respondents thought that both fossil fuel based generation and nuclear power were very harmful or moderately harmful. Only a small fraction of the respondents (5% for fossil fuels and 10% for nuclear power) thought that these processes were not at all harmful to the environment.

In contrast to fossil fuels and nuclear power, about half of the respondents supported or strongly supported having a renewable energy or green power plant within 5 miles of their home. This was supported by about 70% of the respondents who thought that renewable energy sources were not harmful at all to the environment. Further questions about which renewable energy sources are considered desirable are needed to determine the depth of public support for renewable energy based electric generation. The term renewable energy in Connecticut refers to electricity supplied from energy sources such as wind and solar power, geothermal, hydropower, and various forms of biomass, including solid waste (http://www.ct.gov/dep/cwp/view.asp?a=2684&Q=421852&depNav_GID=1619). It is not uncommon in Connecticut and New England to have strong opposition to the proposed construction of specific renewable energy facilities. For example, there has been strong opposition to constructing two wind turbines in Putnam, Connecticut, and the permit application for a biodiesel facility in Suffield, Connecticut, was withdrawn in part due to strong opposition by local residents. Given past opposition to these types of projects, it is also likely that many of the respondents who were supportive of renewable energy sources in the abstract would likely be strongly opposed to proposals to build specific renewable energy facilities, such as a waste-to-energy facility or wind farm, in their neighborhoods.

6.3.4 *Need for Education on Energy Issues*

Several of the findings from this survey highlight the need to educate Connecticut residents on energy and nuclear power issues. For example, a high percentage of respondents did not know how to respond to the statements listed in Table 16.

TABLE 16: PERCENTAGE OF RESPONDENTS THAT WERE NOT SURE HOW TO RESPOND TO NUCLEAR POWER AND ENERGY POLICY ISSUES (SOURCE: ATTACHMENT 2: ASSESSING CONNECTICUT RESIDENTS' OPINIONS OF NUCLEAR POWER PHONE SURVEY RESULTS EXECUTIVE SUMMARY: DECEMBER 2010; CERC)

Statement	**Percentage of Respondents That Were Not Sure How to Respond**
Nuclear waste can be stored safely for many years	52
Nuclear material is sufficiently protected against misuse	50
It is very unlikely there would be a serious accident at a nuclear power plant in the next ten years	46
Disposal of radioactive waste is under control	40
Nuclear proliferation is a major threat to national security	38
Geopolitical instability in the Mideast is a significant challenge to the energy future of the United States	34
National security depends on reducing the use of oil	34

As previously stated, 84% of the respondents had never looked for information about electric energy issues even though energy is considered an important issue. This leads to an incorrect perception of the energy sources used for generating electricity and a lack of clarity on the inter-relationship among energy, electricity generation, and environmental issues. For example:

1. The majority of respondents were misinformed or not aware that nuclear energy accounts for about half of the electricity generated in Connecticut
2. There was a common perception that renewable energy such as solar PV and wind power could be used to replace a baseload power source such as fossil fuel (coal and natural gas) or nuclear power
3. The majority of the respondents described climate change as serious or very serious, but only 12.5% of the respondents supported the increase of nuclear power as an alternative for reducing greenhouse gas emissions

Policies to respond to the energy issues identified, such as price, clean energy generation, and petroleum dependency, require that residents be more informed so that they can make critical decisions on how proposed solutions will or will not achieve their intended goals.

6.4 ENERGY AND ELECTRICITY GENERATION EDUCATIONAL INITIATIVE

6.4.1 K-12 Education

Education for K-12 is likely a good place to start in increasing knowledge about energy and electricity generation. For example, the survey indicated that younger adults were found to be more likely to have replaced conventional light bulbs with energy efficient ones, purchased "energy star" qualified products, and participated in community recycling programs. This commitment to energy conservation and environmental awareness is likely a result of these issues being addressed in school in much more depth over the past 10 or 15 years than they were 25 or more years ago.

Connecticut's Core Science Curriculum Framework (State Department of Education; http://www.whitememorialcc.org/pdf/sciencecoreframework2005v2.pdf) was reviewed to identify topics where it would be appropriate to include basic fundamentals about sources of energy (fossil fuel, renewable, and nuclear) and electricity generation, distribution, and usage. CASE's incorporation of these fundamentals and key world issues and technologies is consistent with the Connecticut State Department of Education's view of science literacy, which is a combination of understanding major science concepts and theories, using scientific reasoning, and recognizing the complex interactions among science, technology and society. In addition, these topics support students' abilities to read, write, research, use mathematical skills, and critically analyze policy decisions. While it is believed that these important societal issues will provide a meaningful science experience that will motivate students to pursue a science-related career, the topics suggested are a baseline or a minimum for what all Connecticut students should know by the end of Grade 10 so that they can actively participate in the development of Connecticut's energy policy.

The Core Science Curriculum is organized around 11 conceptual themes. Theme II – "Properties of Matter" and Theme III – "Energy Transfer and Transformation" are the core areas where basic fundamentals about energy are taught. Theme XI – "Science and Technology in Society" is the part of the curriculum where students can learn how electricity is generated, distributed, and utilized in Connecticut. The following are the topics covered in Themes II and III, and the pertinent topics related to energy in Theme XI.

Theme II. Properties of Matter – How does the structure of matter affect the properties and uses of materials?

- Properties of Objects **(K.1)**
- Properties of Materials **(2.1)**
- States of Matter **(3.1)**
- Elements, Compounds and Mixtures **(6.1)**
- Chemical Reactions **(9.4)**
- Carbon Compounds **(9.5)**

Theme III. Energy Transfer and Transformations – What is the role of energy in our world?

- Electricity and Magnetism **(4.4)**
- Sound and Light **(5.1)**
- Energy and Work **(7.1)**
- Energy Conservation and Transformation **(9.1)**
- Electrical Forces **(9.2)**

Theme XI. Science and Technology in Society – How do science and technology affect the quality of our lives?

- Conservation of Materials **(3.4)**
- Batteries, Bulbs and Magnets **(4.4)**
- Energy and Power Technologies **(9.3)**
- Human Environmental Impacts **(9.8, 9.9)**

Connecticut's Core Science Curriculum Framework lists the content standards and expected performance for each of the sub-topics listed under Themes. These are listed in Appendix C. Within the "Content Standards" developed by the State of Connecticut, the CASE Study Committee has provided suggestions for energy topics that could be included under "Expected Performance" to enhance student understanding of energy and electricity issues. They are:

Grade 3

Core Themes, Content Standards and Expected Performances

Content Standards	Expected Performances
Science and Technology in Society – How do science and technology affect the quality of our lives? **3.4 - Earth materials provide resources for all living things, but these resources are limited and should be conserved.** ♦ Decisions made by individuals can impact the global supply of many resources.	**B 7.** Describe how earth materials can be conserved by reducing the quantities used, and by reusing and recycling materials rather than discarding them. ***CASE SUGGESTION: Include fossil fuels as an "earth's material" and renewable energy sources as a "recycled material."***

Grade 6

Core Themes, Content Standards and Expected Performances

Content Standards	Expected Performances
Energy in the Earth's Systems – How do external and internal sources of energy affect the Earth's systems? **6.3 - Variations in the amount of the sun's energy hitting the Earth's surface affect daily and seasonal weather patterns.** ♦ Local and regional weather are affected by the amount of solar energy these areas receive and by their proximity to a large body of water.	**C 7.** Describe the effect of heating on the movement of molecules in solids, liquids and gases. **C 8.** Explain how local weather conditions are related to the temperature, pressure and water content of the atmosphere and the proximity to a large body of water. **C 9.** Explain how the uneven heating of the Earth's surface causes winds. ***CASE SUGGESTION: Include wind power under C.9 and add a new topic that discusses solar-thermal energy applications***
Science and Technology in Society – How do science and technology affect the quality of our lives? **6.4 - Water moving across and through earth materials carries with it the products of human activities.** ♦ Most precipitation that falls on Connecticut eventually reaches Long Island Sound.	**C 10.** Explain the role of septic and sewage systems on the quality of surface and ground water. **C 11.** Explain how human activity may impact water resources in Connecticut, such as ponds, rivers and the Long Island Sound ecosystem. ***CASE SUGGESTION: Include hydroelectric power (traditional dam systems and run-of-the-river low impact systems***

Grade 9
Core Themes, Content Standards and Expected Performances
Strand I: Energy Transformations

Content Standards	Expected Performances
Energy Transfer and Transformations – What is the role of energy in our world? **9.2 - The electrical force is a universal force that exists between any two charged objects.** ♦ Moving electrical charges produce magnetic forces, and moving magnets can produce electrical force. ♦ Electrical current can be transformed into light through the excitation of electrons.	**D 4.** Explain the relationship among voltage, current and resistance in a simple series circuit. **D 5.** Explain how electricity is used to produce heat and light in incandescent bulbs and heating elements. ***CASE SUGGESTION: Update to include CFLs and LEDs*** **D 6.** Describe the relationship between current and magnetism. ***CASE SUGGESTION: Include turbine-generator system***
Science and Technology in Society – How do science and technology affect the quality of our lives? **9.3 - Various sources of energy are used by humans and all have advantages and disadvantages.** ♦ During the burning of fossil fuels, stored chemical energy is converted to electrical energy through heat transfer processes. ♦ In nuclear fission, matter is transformed directly into energy in a process that is several million times as energetic as chemical burning. ♦ Alternative energy sources are being explored and used to address the disadvantages of using fossil and nuclear fuels.	**D 7.** Explain how heat is used to generate electricity. **D 8.** Describe the availability, current uses and environmental issues related to the use of fossil and nuclear fuels to produce electricity. **D 9.** Describe the availability, current uses and environmental issues related to the use of hydrogen fuel cells, wind and solar energy to produce electricity ***CASE SUGGESTION: CASE can assist with the development of curricula to support D.7, D.8, and D.9. It is important that these topics include how daily electricity demand is met by baseload, intermediate, and peaking facilities. Also, power density of various power sources is an important topic because it impacts land use, logistics of fuel supply and disposal. This is an integrating concept because it touches on technology and the environment. Further, energy storage is an important topic because it is absolutely essential if renewable energy sources are to make a significant contribution to our overall supply picture.***

Grade 9
Core Themes, Content Standards and Expected Performances
Strand II: Chemical Structures and Properties

Content Standards	Expected Performances
Properties of Matter – How does the structure of matter affect the properties and uses of materials? **9.5 – Due to its unique chemical structure, carbon forms many organic and inorganic compounds.** ♦ Carbon atoms can bond to one another in chains, rings and branching networks to form a variety of structures, including fossil fuels, synthetic polymers and the large molecules of life.	**D 13.** Explain how the structure of the carbon atom affects the type of bonds it forms in organic and inorganic molecules. **D 14.** Describe combustion reactions of hydrocarbons and their resulting by-products. ***CASE SUGGESTION: Incorporate design of boiler, internal combustion engine, and gas turbine into this topic*** **D 15.** Explain the general formation and structure of carbon-based polymers, including synthetic polymers, such as polyethylene, and biopolymers, such as carbohydrate.
Science and Technology in Society – How do science and technology affect the quality of our lives? **9.6 - Chemical technologies present both risks and benefits to the health and well-being of humans, plants and animals.** ♦ Materials produced from the cracking of petroleum are the starting points for the production of many synthetic compounds. ♦ The products of chemical technologies include synthetic fibers, pharmaceuticals, plastics and fuels.	**D 16.** Explain how simple chemical monomers can be combined to create linear, branched and/or cross-linked polymers. **D 17.** Explain how the chemical structure of polymers affects their physical properties. **D 18.** Explain the short- and long-term impacts of landfills and incineration of waste materials on the quality of the environment ***CASE SUGGESTION: Trash-to-energy power plants are classified as a renewable energy source. Is this classification consistent with the impact of incineration of waste materials on the quality of the environment?***

For students who have a desire to further their science education, the Connecticut's Core Science Curriculum Framework includes enrichment content standards for high school science. The content and supportive concepts in earth science, chemistry, and especially physics, where heat and thermodynamics are introduced, are excellent opportunities for a much more in-depth and thorough coverage of energy and electricity generation topics (see Appendix C for complete listing of Content Standards and Expected Performance).

With a greater understanding of electricity generation and nuclear power, this may motivate some high school students to learn more about nuclear physics. However, most high schools likely do not have the resources to offer such a specialized course. To fill this gap of offering courses that meet student needs and interests, Connecticut high school students can take on-line courses from the Virtual High School (http://www.govhs.org/Pages/Academics-Catalog). The Virtual High School offers full year Advanced Placement courses and over 200 full semester courses in Arts, Business, English Language Arts, Life Skills, Mathematics, Science, Social Studies, and Technology.

The existing Virtual High School course that would educate students about nuclear power is *Nuclear Physics: Science, Technology & Society*. This course focuses on having students answer the question: “What should an informed citizen know about nuclear issues?” The course description and the weekly objectives are listed in Appendix D. More detailed information about the Nuclear Physics course can be found at http://www.govhs.org/vhsweb/coursecatalog11.nsf/8864151b57667f30852568b9007ffb47/2aca8c8ae610b44f852569b2005582b9?OpenDocument.

6.4.2 Connecticut Resident Education

The survey findings indicate that residents need to be better informed and educated on energy and electricity generation, transmission, and distribution issues. Because 84% of the respondents have never looked for information about electric energy issues, it is important that a proactive approach be taken in educating the public. Suggestions for achieving this include developing public service announcements and energy programming for use on public television.

One general issue that appears to present much confusion is the difference between the capacity of electricity generation to meet the peak demand and actual electricity consumed annually. By understanding these overlying concepts, the public would likely better appreciate the importance of reducing the peak demand as well as reducing overall electricity consumption. In this area, the state developed a Real-Time Energy and Air Quality Report for the purpose of informing the public about statewide electricity demand and air quality, especially for use to show the results of efforts to reduce consumption during periods of high demand.

Public service announcements and television programming should be developed to inform residents about different sources of electrical generation, fuel dependency issues, and cost of energy and electricity consumed in Connecticut. Data should also be presented about air emissions and other environmental impacts of each energy source. To complement the Real-Time Energy Report, data should be presented on the cost of generating electricity at peak demand compared to other times. The public service announcements and TV programming should not advocate for one technology or source of energy, but should provide data from agencies such as the Energy Information Administration and ISO-NE to inform residents so that they can make their own judgments about public policy decisions. Because public service announcements and even TV programming will only be able to provide limited information, more detailed data should be available through a readily accessible website. The internet is recommended because it provides a low-cost means for providing this information in easily updatable format and because 71% of the respondents who had investigated energy issues said that they had used the web as a source of information.

7.0 SUMMARY OF FINDINGS, RECOMMENDATIONS AND CONCLUDING REMARKS

BRIEF STATEMENT AND OVERVIEW OF PRIMARY CONCLUSIONS

Brief Statement of Primary Conclusions

Nuclear power has been the primary source of emission-free electricity generation in Connecticut since 1970. The operating licenses of existing nuclear power plant units in Connecticut—Millstone Unit 2 and Unit 3—have been extended to 2035 and 2045, respectively. While retirement of these units is well into the future, planning for their replacement with next generation nuclear power technologies, as well as consideration of nuclear power for additional or replacement baseload generation, will require many years of planning and approvals. The state's energy plans and policies should address the role that nuclear power will play in the state's energy future. Construction of a new or replacement nuclear power generating unit in Connecticut would provide many benefits including:

- Lower-cost baseload generation by replacing marginal-cost electricity generators with nuclear power
- Emission-free electricity generation
- Fuel diversity to reduce the New England region's reliance on natural gas and fossil fuels for electricity generation
- Creation of new jobs by expanding the highly trained workforce for safely operating nuclear power plant units

To achieve these benefits, the nuclear industry must successfully demonstrate that advanced construction and modular manufacturing techniques will provide necessary assurances that nuclear power plants can be constructed and delivered on budget and on schedule, and that new and current nuclear plants will be operated at a high level of safety and security.

Furthermore, the state's leadership must aggressively demand that the federal government meet its legal obligations regarding spent nuclear fuel by expeditiously providing for the storage, geologic disposal, and funding of nuclear waste management.

Overview

Construction of new nuclear power plants in the United States, until recently, had been dormant for many years. Evolutionary improvements in design provide technological and safety advancements for the plants that have been in operation for many years in the United States and other countries. Modular construction methodology and standardization of plant design offer the potential to shorten construction schedules and provide on-budget project delivery. In the future, commercialization of emerging small modular nuclear reactor designs may provide other opportunities for nuclear power deployment if pilot projects are successful and regulatory issues that ensure the safe and economical operation of these units are resolved. Nuclear power has provided and continues to provide a significant percentage of baseload electricity generation in Connecticut and the New England region that is emission free. Adding or replacing baseload electricity generation for the state and the New England region involves many considerations. Decisions made by the leadership of the state and the region should be based on achieving regional goals that include a variety of factors such as cost of electricity, meeting air quality goals, Regional Greenhouse Gas Initiative (RGGI) and Renewable Portfolio Standards (RPS) goals, fuel diversity, and reliability. All options to achieve these goals should be considered, including nuclear power for either additional or replacement baseload generation, both for the short and long term, along with a continued commitment and effort to maximize energy efficiency and to reduce peak demand. Lead times for securing approval and for construction of a new nuclear power plant, or any electricity generating facility, are significant. Therefore, it is necessary to look well into the future to consider options for replacing existing generation and for providing additional generation.

The recent earthquake and tsunami that caused the incident at the Japan Fukushima Daiichi nuclear power plant facility in March 2011 has raised public concern over the use of nuclear power in many countries, including the United States. This tragic event provides an opportunity for reflection and action by industry, as well as federal and state government leadership, and for restoring public trust and confidence in the nuclear industry. US involvement in international nuclear energy leadership will be important for assuring that safety standards for nuclear power plant operations are maintained globally.

A Blue Ribbon Commission on America's Nuclear Future was established under the authority of the US Department of Energy (DOE) in accordance with provisions of the Federal Advisory Committee Act to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle and to recommend a new plan. The Commission's draft report to the Secretary of Energy was completed in July 2011 (http://brc.gov/sites/default/files/documents/brc_draft_report_29jul2011_0.pdf). The report provides advice, evaluates alternatives, and makes recommendations on reactor and fuel cycle technology and on the transportation, disposal and permanent storage of spent nuclear fuel.

In Connecticut, legislation prohibits the construction of a new nuclear power plant until such time as the federal government provides for the disposal and permanent storage of spent nuclear fuel that is currently being stored at Connecticut's two nuclear power plant sites – Connecticut Yankee in Haddam Neck and the Millstone Power Station in Waterford. Therefore, the Study Committee supports the Blue Ribbon Commission's findings that recommend, "prompt efforts to develop, as expeditiously as possible, one or more permanent deep geological facilities for the safe disposal of spent fuel and high-level nuclear waste; and prompt efforts to develop, as expeditiously as possible, one or more consolidated interim storage facilities as part of an integrated, comprehensive plan for managing the back end of the nuclear fuel cycle " and recommends that the state and regional leadership use their resources to encourage the federal government to act on these findings and provide a long-term and sustainable solution for the disposal and storage of spent nuclear fuel.

The significant financial commitment necessary to construct a nuclear power plant in a deregulated electricity market is another major challenge that needs to be addressed in order to consider nuclear power as a viable baseload alternative. Stable policies that reduce financial risk and provide confidence to allow for private investment are needed. Examples include providing long-term contracts for the electricity generated and economic incentives for emission-free electricity generation.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

To provide an overall framework for the considerations that will influence decisions pertaining to potential construction of a large centralized power plant in Connecticut, this report first presents findings and recommendations regarding the Connecticut and New England electric markets, including an analysis of the need for additional or replacement baseload electricity generation.

First, nuclear power is compared to natural gas as a means of meeting future baseload needs for generation of electric power. Next, advances in design, permitting, and construction practices for nuclear power plants are presented. This is followed by an evaluation of the advantages and safety and security risks of nuclear power to identify the issues that must be addressed before the state can consider nuclear power as a viable alternative for meeting future electricity generation needs for the region. Finally, a review of this study's survey on public acceptance of nuclear power and overall understanding of energy issues provides the basis for the Study Committee's recommendations stressing the need for the general public to become more knowledgeable about energy issues.

Several factors to be considered include:

- Fuel diversity is critical to stabilizing electricity generation costs in Connecticut and throughout New England. Almost all new electric generating facilities in the New England region over the past ten years utilize natural gas as their primary fuel. The Independent System Operator New England (ISO -NE) estimates that even adding 5,400 MW of new capacity from a non-gas-fired technology or resource will not have significant impact on the region's dependence on natural gas (ISO-NE, 2007). Because the cost to generate electricity from a natural gas combined-cycle gas turbine (CCGT) power plant is very sensitive to the price of natural gas, increasing the region's reliance on natural gas would further expose New England to potentially high electricity prices. In contrast, the cost to generate electricity from nuclear power plants is not sensitive to the cost of fuel. Therefore, the state and the region should consider adopting policies and practices to assure that decisions on building electricity generating facilities in the future consider the need for fuel diversity.
- Nuclear power provides zero carbon emission baseload generation and thus contributes to meeting state and regional environmental goals including those established by the RGGI. Therefore, the environmental consequences of replacing nuclear power generation with anything other than a zero-emission-based generation would have negative air emissions impacts.
- Construction and operation of a nuclear power plant results in increased job creation compared to natural gas facilities, where cost of fuel is the largest expense.
- However, the study committee supports the state's legislatively mandated moratorium on constructing a new nuclear power plant in Connecticut until the federal government provides a regional interim storage facility or a geological disposal facility in accordance with the Nuclear Waste Policy Act of 1982. Specifically:

a. Spent nuclear fuel storage is a valid concern.

b. The State of Connecticut should join other affected states to aggressively demand that the federal government meet its legal obligations regarding spent fuel disposal and storage by expeditiously implementing the Blue Ribbon Commission on America's Nuclear Future's recommendations on interim storage, geologic disposal, and funding of nuclear waste management.

c. Until the federal government acts in full, the State of Connecticut should interface with the NRC, Dominion and Connecticut Yankee to obtain assurance that spent fuel stored in Connecticut is safe, under all conditions.

- Financing of a nuclear power plant in a deregulated market will be a challenge. The high overnight cost and financing premium for nuclear power plants will likely make the financial risk to a merchant owner outweigh the potential benefits. Implementation of stable policy to address this issue is needed to make nuclear power a viable alternative for new electricity generation in Connecticut. Examples include providing long-term contracts for the electricity generated and economic incentives for emission-free electricity generation. The situation might change significantly if the nuclear industry establishes good performance on the early new plant construction projects being conducted in other states and/or if significant carbon emissions penalties are implemented on generating facilities. Elimination of the financing premium for nuclear power plants provides a levelized cost of electricity (LCOE) that is very competitive to a CCGT power plant.

Even with the addition of low cost baseload electricity generation, the Study Committee is concerned that Connecticut electricity ratepayers will not see the full savings from this investment. The realities of deregulation limit the benefit to only the reduction in the market-clearing price and do not provide ratepayers with the difference between the market-clearing price of the marginal generator and the price of the new low-cost electricity generator. The state should implement a policy where rate payers see a greater share of the benefits of low cost electricity generation.

Connecticut and New England Electric Rates

FINDINGS

Connecticut's electricity rates have been the second highest in the country, after Hawaii's, since 2007. As of February 2011, the average rate was $0.164 per kilowatt-hour (kWh) or 69% higher than the national average of $0.097 per kWh (EIA). Not surprisingly, high energy costs were the most important issue mentioned in this study's survey of 600 Connecticut residents in October 2010.

Connecticut's high electrical rates cannot be addressed solely as a state issue but must be dealt with on a regional level because the electrical wholesale market is administered by ISO-NE under rules approved by the Federal Energy Regulatory Commission (FERC). Electrical rates throughout New England are also relatively high, with an average rate of $0.146 per kWh that is 51% higher than the national average (EIA, February 2011).

Connecticut and the region's high electricity rates are likely caused by several factors including:

- The state does not have any indigenous energy resources.
- Connecticut legislation that deregulated the electricity industry required electric companies to sell their power plants and buy power on the wholesale market. Vermont did not deregulate and had an average rate of $0.138 per kWh in February 2011, which is 16% less than Connecticut. New Hampshire allowed electric utilities to own power plants and had an average rate of $0.150 per kWh, which is 9% less than Connecticut.
- As a result of the region's dependence on power plants that use natural gas as their primary fuel, these plants set the price of electricity about 90% of the time. Power plants that use lower-cost fuels such as nuclear, coal, or hydroelectric power, rarely set the cost of power in the region. Coal is used to generate 45% of the electricity in the United States compared to only 12% in New England (EIA, 2010). Hydroelectric power is used to generate 37% of the electricity for the Pacific Northwest states (Washington, Oregon, and California) compared to 7% in New England (Edison Electronic Institute).
- Congestion of the electrical grid adds to the price of electricity, especially in the southwestern third of the state. For example, in order to maintain system reliability, less efficient plants operate more often than they would need to if congestion was not a problem. Congestion decreased following the completion of the Bethel-Norwalk and Norwalk-Middletown transmission lines in October 2006 and December 2008, respectively. This decreased federally-mandated congestion charges (FMCC) to 0.85 cents per kWh for Connecticut Light & Power (CL&P) and these charges are negligible for United Illuminating (UI) customers. However, transmission rates increased by 1.07 cents per kWh for CL&P customers and by 0.93 cents per kWh for UI customers from 2000 to 2009 according to Department of Public Utility Control ([DPUC]; Effective July 1, 2011 DPUC was renamed the Public Utilities Control Authority within the Department of Energy and Environmental Protection).
- Environmental regulations play a role in higher rates. It was estimated by DPUC that state legislation (PA 98-28) requiring electric companies to purchase renewable resources adds about 0.45 cents per kWh, plus an additional charge of 0.10 cents per kWh for funding renewable energy programs. Additionally, a 0.30 cents per kWh charge for conservation programs has the potential of reducing electricity rates more than the cost of the program, if the program is successful at reducing the growth of peak demand and increasing electricity efficiency. Also, coal, a less expensive fuel than natural gas, is utilized sparingly in Connecticut because of the state's stringent air pollution standards and RGGI.
- Connecticut is a relatively high-cost state in terms of salary, taxes, and land, which results in higher prices than the national average.

These factors do not work alone but rather in combination, resulting in high electricity rates. For example, Connecticut does not have any natural gas resources so gas must be transported by pipeline from other parts of the United States and Canada. The transmission cost adds about $1 per 100 ft^3 of gas or about 1 cent per kWh to the cost of fuel for natural gas generating facilities in Connecticut. Because of how the deregulated market works in Connecticut, the price of natural gas sets the market price of electricity about 90% of the time. Therefore, Connecticut residents pay a natural gas transportation "penalty" on all electricity generated even if the power is generated by power plants that use fuels other than natural gas.

RECOMMENDATION

The current structure of the New England regional and Connecticut electricity markets is not conducive to adding new or replacement low-cost baseload electricity generation and having the full cost savings realized in lower electricity prices. Changes are needed in the "deregulated" market so that replacement of inefficient electricity generating facilities or the addition of new low-cost generation more fully translates into lower electricity prices that will make Connecticut more competitive in attracting businesses and creating jobs. Connecticut should develop a plan that allows lower costs of generation from baseload plants to be passed on to consumers.

Need for Additional or Replacement Baseload Generation and Impact on Electric Rates

FINDINGS

There are no clear indicators for the direction in baseload demand in Connecticut or New England. An increase in electric demand through upward growth of the state/regional economy, population, and/or population of electric cars may necessitate the need for additional baseload. A decrease in demand through conservation, manufacturing moving out of state/region/country, or a decrease in population would likely make current baseload capacity sufficient. However, an ISO-NE analysis found that the replacement of marginal units with a new low-cost plant will reduce electric rates. For example, the addition of 1000 MW of supply would save New England consumers $600 million a year (2005 $) and reduce wholesale electricity prices by 5.7% (ISO-NE, Electricity Costs White Paper, June 2006).

Retirement of existing electricity capacity is also an important driver with respect to the need for new generation capacity. Millstone units 2 and 3 have had their operating licenses extended from 40 to 60 years and will now expire in 2035 and 2045, respectively. Seabrook and Pilgrim are awaiting NRC action on their 20-year license extensions. Vermont Yankee received a 20-year license extension from the NRC, but some Vermont lawmakers are trying to shut down the plant despite the license extension. This case is currently being litigated.

Also, it may be determined that it is more cost effective for the existing baseload fossil fuel generating facilities to be retrofitted or refurbished instead of being retired and replaced.

Other factors that need to be accounted for include:

- the importation of new baseload generation from other regions or Canada with the associated requirement of likely needing more transmission capacity;
- improved economics and reduced vulnerability could prompt a move toward distributed generation as compared to continued reliance on large centralized power plants; and
- adding to this landscape of uncertainty, there are two natural gas/low sulfur oil facilities (NRG Meriden Project and GE owned Oxford/Towantic) of about 540 MW each that are already in the permitting process and could be favorably positioned to respond to a Connecticut RFP for new generation.

RECOMMENDATION

Connecticut should be proactive in developing in-state electricity generating facilities to meet the state's demand, and should consider potential benefits of achieving lower electricity prices through lower generation costs and electricity congestion charges, and potential job creation by being an exporter of electricity.

Comparison of Baseload Alternatives: Nuclear Power and Natural Gas

FINDINGS

Because of the time required to site, design, license, and construct new generating facilities, it is important to understand the advantages and disadvantages of nuclear power, other potential baseload sources, and effectiveness of energy efficiency programs to help guide sound policy decisions that will have significant implications for the state of Connecticut and the New England Region for the next 40 to 60 years. Potential fuel sources to be considered are nuclear power, natural gas, coal and renewable energy options such as wind, solar, hydroelectric and biomass. Natural gas is a viable alternative that has been used as the primary fuel for nearly all of the new generating capacity built in Connecticut and New England in the past ten years. Coal, which is in general a lower-cost fuel than natural gas and is used as the primary fuel for generation in many regions of the United States, is not considered a likely alternative because of the stringent air pollution standards in Connecticut. Solar and wind power are not considered baseload sources of power in Connecticut because they generate electricity on an intermittent basis. Biomass, specifically solid waste, is used as a baseload source of electricity in Connecticut. There are six solid waste burning facilities in the state that generate a total of about 160 MW of electricity. However, there is not enough solid waste disposed of in the state to generate an additional 1000 MW of electricity. Hydroelectric power does produce 1.6% of the electricity in Connecticut (EIA, 2009), but future hydroelectric power will likely be small-scale, run-of-the-river type of facilities because of the environmental standards required for securing siting approval for constructing large dams for electricity generation.

In 2009 (EIA), 53% of the state's electricity generation was supplied bynuclear power. In New England, nuclear power accounted for 30% of the generated electricity between 2007 and 2009 (ISO-NE). Nuclear power has been a very reliable source of electricity with availability and capacity factors between 89% and 92% from 2007 to 2009 (ISO-NE). However, Connecticut and New England's system-wide capacity is heavily dependent on natural gas. For example, natural gas-fired power plants accounted for 41% of New England's total capacity in 2010 (ISO-NE, 2011; New England 2011 Regional Profile" see http://www.iso-ne.com/nwsiss/grid_mkts/key_facts/ne_01-2011_profile.pdf). Therefore, the region is heavily dependent on natural gas during peak electricity usage. This is further compounded because natural gas is also used for space and process heating and accounts for 23% of the total energy consumed (electricity, transportation, and space and process heating) in New England compared to 11% for nuclear power (2008 EIA).

In conclusion, provided the federal government begins to meet its nuclear spent fuel disposal obligations, natural gas and nuclear power are the most viable alternatives for a 1000 MW centralized power plant in Connecticut. The findings from a comparison of large-scale nuclear power to natural gas electricity generation are summarized in the Executive Summary (see Table ES-1).

RECOMMENDATION

Fuel diversity should be promoted by the state as both a strategy to stabilize electricity prices and a regional policy. Since deregulation of the electricity market, essentially all new electricity generation uses natural gas as its primary fuel. Over-reliance on natural gas leads to price instability and potential gas pipeline transmission constraints, especially during cold weather periods when there is increased demand for natural gas for space heating.

Advances in Nuclear Power

FINDINGS

The nuclear industry has made advances in nuclear technology that increase safety and reliability while reducing construction costs and schedule. These include:

- Passive safety systems that operate without auxiliary AC power (either off-site or on-site)
- Deployment of only standard plant designs that are complete before construction begins and are pre-licensed by the NRC
- Combined NRC construction and operating license that streamlines the licensing process while providing a consolidated process and opportunity for public review before construction of the plant begins
- 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

With new construction techniques, nuclear power has the potential to be a low-cost source of baseload power. However, these improvements must first be demonstrated in the United States. Currently, there are five nuclear power plant units under construction. They are Watts Bar 2 (Tennessee valley Authority), Vogtle 3 & 4 (Southern Nuclear), and V.C. Summer 2 & 3 (SCANA). Successfully delivering the first projects on schedule and within budget and continuing to maintain safe and reliable operation of the existing fleet will help establish financial market confidence for follow-on projects. This will likely reduce or eliminate the "nuclear premium" for the financing of nuclear projects, thus reducing the levelized cost of electricity. However, additional costs may result from new safety requirements and regulations that arise from findings from studies of the events at the Fukushima Daichii power plant. In Connecticut, with marginal natural gas facilities setting the cost of electricity, the benefit will likely be to make the construction and operation of a nuclear power plant more attractive for investors, but it is uncertain if this will result in a decrease in the price of electricity.

RECOMMENDATION

The first-build construction of four Generation III+ nuclear facilities in the United States should be monitored by the Connecticut Energy Advisory Board (CEAB), the Department of Energy and Environmental Protection and other state leaders to verify that advances in construction techniques have achieved the anticipated benefits of lower construction costs and shorter construction time frames, with the new plants being delivered on schedule and on budget.

Advantages of Nuclear Power

FINDINGS

The primary advantages of generating electricity from a nuclear power plant compared to a natural gas CCGT power plant are the following: construction, operation, and maintenance are the most significant lifetime costs of a nuclear power plant. Approximately 15,600 jobs per year (in 2010, 0.9% of the state's 1,723,900 total employment) would be created during the five-year construction phase (78,000 total job years) and about 450 jobs to operate and maintain an additional unit at Millstone. The number of security-related jobs that would be created to guard the additional unit is uncertain. If the nuclear power plant were at a different site, a staff of approximately 700 would be required to operate and maintain the facility (http://nextbigfuture.com/2007/11/staffing-expanding-nuclear-industry.html, 2007). Security of the site would require about 80 officers based on approximately 8,000 officers that currently protect the 104 nuclear power plants in the United States (http://www.nei.org/keyissues/safetyandsecurity/plantsecurity). In contrast, approximately 8,500 jobs per year would be created during the two-year construction phase of a combined-cycle natural gas power plant (17,000 total job years), with 25 jobs created to operate and maintain the facility. The most significant lifetime cost for a combined-cycle natural gas plant is fuel. Since Connecticut does not have indigenous natural gas resources, the majority of the cost of operating natural gas generating electric facilities flows out of the state.

- Diversification of fuel supply helps to stabilize electricity prices. The state's dependence on natural gas has been increasing since almost all new electricity generating facilities built in the last ten years use natural gas as their primary fuel source.
- There are sufficient known global supplies of uranium for at least 80 years at uranium recovery costs below $130/kg U with major suppliers being Canada (1st) and Australia (3rd). Because cost of raw uranium only accounts for about 2.5% of the cost of electricity generated, any supply constraints or increase in global demand will not have a large impact on electricity prices. There also appears to be significant reserves of natural gas in the United States, but transmission pipeline constraints may limit availability during periods of high demand such as during cold periods when natural gas for generating electricity competes with space heating needs. The New England region's reliance on natural gas could increase vulnerability of sufficient supply, thus increasing the volatility of electricity prices.
- Nuclear power generates 69% of the emission-free electricity in the United States with hydroelectric power accounting for 22% and solar/wind/geothermal accounting for 9% in 2010 (http://www.nei.org/filefolder/Infographic_-_Emission_Free_Sources_2010.jpg). While natural gas has lower greenhouse gas emissions compared to coal, there is concern that the extraction of natural gas from shale deposits releases methane, which is a much more potent greenhouse gas than carbon dioxide (*MIT Technology Review*, Just How Green is Natural Gas?, 2011). Also, combustion of natural gas produces nitrogen

oxides, which can be removed by ammonia injection, and very low levels of sulfur oxides.

- High reliability with US nuclear power plant capacity factors averaging about 90% over the last ten years (http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/usnuclearindustrycapacityfactors/)

RECOMMENDATION

Nuclear power should be considered for baseload generation to balance the reliance on natural gas once the federal government has developed a permanent federal repository or a regional centralized interim storage facility for spent nuclear fuel. Benefits of developing a new nuclear power plant unit in Connecticut include the potential for higher in-state job creation during both construction and operation and emission-free electricity generation. In contrast, the major expense of a CCGT power plant is the cost of natural gas which must be imported into the state.

Issues Facing the Expansion of Nuclear Power in Connecticut

Disposal and Storage of Spent Nuclear Fuel

FINDINGS

To enable consideration of building a new nuclear power plant in Connecticut, it is necessary to satisfactorily resolve the issue of the 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 that states, "*No construction shall commence on a fifth nuclear power facility until the Commissioner of Environmental Protection finds that the United States Government, through its authorized agency, has identified and approved a demonstrable technology or means for the disposal of high level nuclear waste. As used in this section, 'high level nuclear waste' means those aqueous wastes resulting from the operation of the first cycle of the solvent extraction system or equivalent and the concentrated wastes of the subsequent extraction cycles or equivalent in a facility for reprocessing irradiated reactor fuel and shall include spent fuel assemblies prior to fuel reprocessing.*"

At the present time, the United States does not have a nuclear spent fuel disposal and storage program. The Obama Administration has decided that the proposed Yucca Mountain repository facility is not an option and DOE has withdrawn its license application, which was filed in June 2008, from NRC. Congress needs to act on this issue because Public Law 107-200 that was passed in July 2002 contradicts this decision by stating "Approving the site of Yucca Mountain, Nevada for the development of a repository for the disposal of high-level radioactive waste and spent nuclear fuel, pursuant to the Nuclear Waste Policy Act of 1982."

The financial consequence of federal inaction is that 66 utilities have successfully sued DOE for breach of contract for not accepting spent nuclear fuel from nuclear power plants. Congress has started paying utilities for contract default with a potential cost to taxpayers that could exceed $11 billion.

The Blue Ribbon Commission provided recommendations for developing a safe, long-term solution to managing the nation's used nuclear fuel and nuclear waste. Preliminary conclusions and recommendations included

- The United States should proceed expeditiously to develop one or more permanent deep geological facilities for the safe disposal of high-level nuclear waste. Geologic disposal in a mined repository is the most promising and technically acceptable option available for safely isolating high-level nuclear wastes for very long periods of time.
- 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 the funds that nuclear utility ratepayers are providing for the purpose of nuclear waste management (Nuclear Waste Fund).
- A new, single-purpose organization is needed to develop and implement a focused, integrated program for the transportation, storage, and disposal of nuclear waste.
- A new approach that is consent-based, transparent, phased-in, adaptive, and science-based is needed to site and develop nuclear waste management and disposal facilities.

RECOMMENDATION

The 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. This issue must be resolved before nuclear power can be considered a viable alternative to natural gas as a baseload source of electricity in Connecticut. To achieve this, the State of Connecticut should join other affected states and aggressively demand that the federal government meets its legal obligation regarding management of spent fuel and high-level nuclear waste.

Financing of a 1000 MW Nuclear Power Plant

FINDINGS

The overnight cost and financing are the most significant factors that impact the levelized cost of electricity from a nuclear power plant. Elimination of the nuclear financing premium makes the LCOE of nuclear power very competitive with that of a CCGT power plant. However, in a deregulated market, it is unlikely that a 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 the construction of a nuclear power plant that is estimated to have an overnight capital cost of approximately $4-5 billion. (The Economic Impact Analysis [Attachment 1] assumed an overnight cost of $4 billion [2007 dollars] for a 1000 MWe reactor plant. It is noted that an 1100 MWe AP1000 reactor plant has an estimated nominal overnight cost of $5 billion [2011 dollars]). This will likely be the case even if:

- the first-build nuclear power plants are completed on budget and on schedule
- the contracting structure for project construction assigns the majority of the financial risk associated with on-budget and on-schedule project delivery to suppliers and not

the merchant owner.

RECOMMENDATION

Stable policies that reduce financial risk and provide confidence to allow for private investment are needed. Examples include:

- loan guarantees beyond the first-build reactors
- long-term contracts for the electricity generated
- economic incentive for fuel diversification
- economic incentives for emission-free electricity generation, e.g., product tax credits
- appropriate public / private business models that balance risk

Other Considerations

The nuclear power industry has recognized that it is an absolute necessity that the existing fleet of nuclear power plants operates safely and reliably. The average capacity factor for US nuclear power plants has increased from about 50% in the early 1970s to 90% for the last ten years. Current operational experience shows that the industry has an excellent safety record and has responded to events such as Three Mile Island and 9/11, resulting in improved operational and security procedures. More attention needs to be given to public acceptance and education not only about nuclear power, but about all sources and uses of energy. This study's survey of 600 Connecticut residents in October 2010 indicated that there is lack of awareness and misinformation about nuclear power, fossil fuels, and renewable energy sources. Below is a summary of each of these issues.

Nuclear Safety and Security

FINDINGS

Safety is an ongoing concern of the nuclear power industry. As a result of the 1979 Three Mile Island accident, the Institute of Nuclear Power Operations (INPO) was formed to continually improve and address operational procedures at nuclear power plants. These include the on-going review of equipment, instrumentation, training, and procedures, and verification of the capability of nuclear emergency safety procedures to mitigate events that are considered beyond normal design basis, total loss of on-site and off-site power, and internal and external flooding events. The safety record of the nuclear industry has improved dramatically since the late 1980s when data was first collected. Significant events (per US operating nuclear power plant) have decreased from about 0.83 in the late 1980s to about 0.02 on average over the last five years. As defined by the NRC, significant events are events that meet specific NRC criteria, including degradation of safety equipment, a reactor scram with complications, or an unexpected response to a sudden degradation of fuel or pressure boundaries. The NRC staff identifies significant events through detailed screening and evaluation of operating experience. Lessons learned from the events that led to Japan's Fukushima Daiichi nuclear plant incident on March 11, 2011, will be used to support or strengthen existing nuclear power plant operating procedures and to develop new safety precautions, as necessary. INPO also oversees radiological and emergency preparedness to respond and protect public health and safety. Security of large centralized power plants includes physical security of the site, fuel supply security, and cyber security. Nuclear power plants are "hardened" facilities with substantial protection from a spectrum of external threats, both natural and manmade, because of their robust reinforced concrete structures. Also, nuclear power plants have a large visible security system as well as other not-so-visible measures to deter and stop a terrorist attack. In addition, they have procedures to screen employees to minimize the potential of an internal threat. The concern is not the theft of nuclear material, but the potential for release of radioactive material. Other concerns are the release of radioactive material through a terrorist event similar to the 9/11 attack on the World Trade Center and Pentagon. Nuclear facilities have assessed their vulnerability to aircraft impact as well as other potential threats. While the reactor core is well protected, a potential area of vulnerability is wet storage of spent fuel. Cyber security is an issue facing electricity generation and transmission systems that rely on large, centralized power plants. Nuclear industry 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.

RECOMMENDATION

Safety must never be taken for granted. It is imperative that the state and federal government continue to monitor and assess the safety record of the nuclear industry. On-site inspections, simulated terrorist attacks, and incorporation of the latest safety technologies are examples of the continuing diligence needed to increase the trust and confidence of the public in nuclear technology.

Nuclear Fuel Reprocessing

FINDINGS

Nuclear proliferation is a concern of the nuclear power industry. In the 1970s, the United States decided to follow a once-through fuel cycle to reduce the potential of nuclear proliferation. Understanding and minimizing the risk of nuclear proliferation is one of the four major objectives in DOE's Nuclear Energy R&D Roadmap and will be a major driver in the development of a sustainable nuclear fuel cycle.

A schematic of nuclear fuel cycle integration issues is shown in Figure 14. Reprocessing of spent nuclear fuel enables separation of the useful fuel remaining and potential reduction of the volume and toxicity of the waste. However, it is important to note that independent of whether the United States continues to follow a once-through fuel cycle or moves towards fuel reprocessing, there is a need for the federal government to develop a geological repository for high-level nuclear waste. Decisions regarding reprocessing will depend on technology readiness, environmental impact, safety, non-proliferation, cost, national security, and intergenerational equity. The Blue Ribbon Commission found:

> *"No currently available or reasonably foreseeable reactor and fuel cycle technologies—including current or potential reprocess and recycle technologies—have the potential to fundamentally alter the waste management challenge this nation confronts over at least the next several decades, if not longer. Put another way, we do not believe that new technology developments in the next three to four*

decades will change the underlying need for an integrated strategy that combines safe, interim storage of spent nuclear fuel with expeditious progress toward siting and licensing a permanent disposal facility or facilities."

The Blue Ribbon Commission could not reach consensus on the desirability of closing the nuclear fuel cycle. The commission concluded that it is too early to commit to any particular fuel cycle as a matter of government policy, but that research, development, and deployment should continue on a range of fuel cycle technologies that have potential to deliver societal benefits in the future. They also concluded that safety, economics, and energy security are likely to be the most important factors in selecting a fuel cycle rather than waste management, because a permanent repository will be needed regardless of whether or not it is decided to close the fuel cycle.

RECOMMENDATION

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. As recommended previously, the study committee concurs with the Blue Ribbon Commission regarding the urgent need to site and license a permanent repository for spent nuclear fuel.

Siting

FINDING

Siting of electricity generating facilities in Connecticut and New England is a difficult process. This study's survey indicated that residents are more accepting of renewable energy, but reality has shown that these facilities (e.g., wind farm) are as difficult to site as a fossil fuel plant.

RECOMMENDATION

Siting of a new nuclear facility in Connecticut should be located at the Millstone Power Station in Waterford or Connecticut Yankee in Haddam Neck. Millstone has the infrastructure already available including cooling water intake structures, security force, dry cask spent fuel storage, significant switchyard equipment, etc., that would support the operation of a new unit. It is expected that there would be local support because the communities surrounding these facilities are familiar with nuclear power. While the decommissioning process has been completed at the Connecticut Yankee site, the site still has some transmission infrastructure in place for future use and was once approved for nuclear operations.

Energy Education and Public Acceptance

FINDINGS

This study's survey of Connecticut residents indicated that respondents are misinformed about many energy issues and that 84% of the respondents had never looked for information about electric energy issues. It is important that Connecticut residents be better informed about energy issues that will help support the state's leadership in making strategic decisions regarding the state's energy future over the next 40 to 60 years—decisions that promote a strong state economy, job creation, low environmental impact, and energy security. The education must be broad based, with strong energy curriculums in the public schools and effective public service announcements for Connecticut citizens.

Only 22% of the respondents were very favorable or extremely favorable toward nuclear power while 45% were not favorable. Respondents in New London County, where Millstone is located, were the most supportive of nuclear (25% very or extremely favorable and 41% not favorable) while respondents from Fairfield County were least favorable (19% very or extremely favorable and 52% not favorable). Also, 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. Of those that indicated there were operating nuclear power plants in Connecticut, only 51% were aware that the plants were located in Waterford (or Millstone). Electricity generation from fossil fuels did not fare much better, with only 25% of the respondents being very favorable or extremely favorable. Renewable and green-based energy had the highest support levels with 81% of the respondents considering this to be a very or extremely favorable alternative for the generation of electricity. However, the 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. While the electricity generating industry (all energy sources) appears to want to keep a low profile, the lack of public engagement detracts from their ability to generate public support for new projects.

RECOMMENDATION

Energy education—in the K-12 state curriculum, as well as in seminars at state colleges and universities, and through public service announcements—is needed so that the public can be more informed about the state's energy future in regard to nuclear power, fossil fuels, renewable energy, and conservation.

CONCLUDING REMARKS

Nuclear power has provided economic benefits and an emission-free source of baseload electricity for Connecticut since 1970. Reliability of the current fleet of nuclear power plants has increased significantly with capacity factors averaging about 90% over the last ten years and significant safety events averaging only 0.02 per plant over the last five years. Continued safe operation and success of the new generation of nuclear power plants is also essential in further establishing public trust and confidence in this technology. Advances in nuclear technology have improved safety system design by decreasing the calculated core damage frequency by about a factor of ten. Completion of the first-build power plants in the United States will determine if improvements in design standardization and construction techniques have reduced construction costs and construction time sufficiently to allow new plants to compete in deregulated markets like Connecticut.

Two challenges must be addressed before nuclear power can be a viable alternative for baseload electricity generation in Connecticut:

- The federal government must establish and implement one or more consolidated interim storage or permanent deep geological facilities for the safe disposal of spent fuel and high-level nuclear waste.

- Policy changes must be implemented so that financing alternatives are available for constructing a nuclear power plant in a deregulated market.

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.

APPENDIX ES-1:

COMPARISON OF LARGE-SCALE ELECTRICITY GENERATING FACILITIES - NUCLEAR POWER VERSUS NATURAL GAS

(IN TABLE FORMAT)

Table ES-1: Comparison of Large-Scale Electricity Generating Facilities - Nuclear Power versus Natural Gas

	Nuclear Energy	Natural Gas	Comments
Levelized Cost of Electricity (LCOE)	Estimated LCOE of $0.079/kWh from Economic Impact Analysis. LCOE is most sensitive to overnight cost and nuclear financing premium. Reduction in LCOE may be achievable through successful US demonstration of advanced construction and modular manufacturing techniques that decrease construction cost and schedule. Proven reduced-cost construction techniques may take up to 10 years to reduce or eliminate nuclear premium for project financing.	Estimated LCOE of $0.065/kWh from Economic Impact Analysis for assumed natural gas price of $7 per MMBtu. Cost of generating electricity is sensitive to price of natural gas and power plant efficiency. Promise of Marcellus Shale Gas has reduced price to between $4 and $5 per MMBtu but price hit a peak of over $13 per MMBtu in July 2008 illustrating the volatile nature of gas prices.	Elimination of nuclear financing premium makes nuclear LCOE competitive with natural gas. However, realities of deregulation make it uncertain as to the extent to which additional or replacement of baseload generation with efficient lower-cost alternatives will affect electricity rates in Connecticut. Difference in LCOE below clearing price may not change electricity rates.
Economic Development	Approximately 15,600 jobs per year created during five-year construction phase. A staff of about 450 would be needed to operate and maintain a third unit at Millstone and a staff of about 750 would be required at new site.	Approximately 8,500 jobs per year created during two-year construction phase and 25 jobs to operate and maintain facility.	Construction, operation and maintenance, and security, which are drivers for creating jobs, are the most significant lifetime costs of a nuclear power plant.
Construction Period	Four years from first concrete (18 months ahead of that for site preparation, long lead material procurement, etc.) to fuel load per signed contracts for AP1000 in the United States. Additional years from initial site visit to start of procurement of long lead items.	Two years construction period after about 18 months for site preparation and procurement of long lead items.	Advanced construction techniques, as implemented today, incorporated into Generation III+ designs that reduce construction period must be demonstrated in US first-build nuclear facilities, e.g., at the already started Vogtle, Georgia site and V.C. Summer, South Carolina site
Overnight Cost	$4000/kWe in 2007 dollars for plant not including electricity transmission and cooling costs.	$850/kWe in 2007 dollars for plant not including gas pipeline, electricity transmission and cooling costs.	Advanced construction techniques incorporated into Generation III+ designs that reduce construction costs must be demonstrated in US first-build nuclear facilities to verify overnight costs.

Design Life	Design life is 60 years for Generation III+ nuclear power plants which helps to offset large capital investment. Current plants were designed for 40 years but license has been extended to 60 years in most cases. Additional license extensions beyond 60 years may be possible for current plants. DOE and industry programs to assess such additional lifetime extension are already ongoing.	Typically design life is 40 years for a combined-cycle natural gas system. Improvements in technology resulting in higher efficiencies have made it more cost effective to construct new facilities than upgrade existing facilities. It is uncertain if the "replace versus upgrade" philosophy will be the preferred financial alternative in 40 years.	Both technologies have demonstrated long useful lives. Consideration should be given to the fact that design life of a nuclear power plant is 60 years compared to 40 years for a combined-cycle natural gas system.
Fuel Diversification	Nuclear energy provided 20% of the state's total energy demand (transportation, residential, commercial, and industrial) and 50% of the electricity generated in 2008. Nuclear energy is used only for generating electricity so it does not compete with space heating or transportation fuels.	Natural gas provided 21% of the state's total energy demand in 2008 for electricity and space heating. Natural gas consumption surges during cold periods which can lead to higher prices as demand and shortages may result if pipeline capacity is strained. State's dependence on natural gas has been increasing since almost all new electricity generating facilities in the last ten years use natural gas as their primary fuel source.	Fuel diversification is an important consideration in creating a stable market. Overreliance on natural gas could increase vulnerability of sufficient supply, thus increasing the volatility of electricity prices.
Utilization of Waste Heat	Integration of thermal and electrical requirements provides the most efficient use of energy. Siting of a new nuclear power plant will likely be at Millstone or Connecticut Yankee. This limits demand for heating and cooling applications because neither of these locations is near a large population and/or business center. Public concern may also arise from utilizing waste heat from a nuclear power plant.	As with a nuclear power plant, design of facility from onset should include integration of thermal and electrical requirements. Siting of natural gas facility is likely more flexible allowing it to be closer to large population centers where centralized heating and cooling systems are most efficient.	Integration of thermal and electrical requirements is a desirable attribute of a centralized electricity generating facility. However, substantial infrastructure is needed to actually utilize the waste heat from any power plant, e.g., steam or hot water distribution to building and industrial facilities and return condensate treatment.

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Operational Experience	The Institute of Nuclear Power Operations (INPO) was created after the Three Mile Island incident and charged with verifying the safe operation of nuclear power plants. This has resulted in the decrease of significant events per US operating plant from about 0.83 in late 1980s to about 0.02 on average over the last five years. Generation III+ plant designs are inherently safer than earlier plant designs with 10 times lower calculated core damage frequency compared to the current fleet of reactors.	Most natural gas accidents are from excavation that disturbs natural gas pipelines. Across the United States, injuries requiring hospitalization or deaths have ranged from 30 to 60 per year over the last 10 years (US Department of Transportation).	Due diligence in following all safety requirements during the construction and operation of a power plant is paramount to minimize health and safety issues.
Physical Site Security	In accordance with federal regulations, a nuclear power plant has a large visible security system and large staff of well-trained and armed security guards, as well as other not-so-visible measures to deter and stop a terrorist attack. Employees are screened to minimize the potential of an internal threat. The concern is not the theft of nuclear material, but the potential for release of radioactive material.	The Transportation Security Administration (TSA) assesses with high confidence that the terrorist threat to the US pipeline infrastructure is low (1/18/2011).	Very limited additional physical site security is needed if a new nuclear plant unit is added at Millstone, where radioactive material is already stored and security forces and procedures are already in place.
Fuel Security	Global supplies of uranium are sufficient for approximately 80 years at present burn-up/demand rates at uranium recovery costs below $130/kg U. Additional deposits will likely be identified if uranium costs increase but would not have much effect on cost of nuclear power because raw uranium accounts for only about 2.5% of the cost of electricity generated. The United States ranks 8th in the world for uranium resources; Australia and Canada rank 1st and 3rd in deposits.	88.5% of the natural gas consumed in the US is produced in the US with Canada providing an additional 10.5%. U.S. supply of natural gas is sufficient for approximately 100 years at current rates of consumption. (http://www.naturalgas.org/overview/resources.asp)	Availability of uranium should not be a concern in the foreseeable future. There are significant reserves of natural gas in the United States and Canada, but transmission pipeline constraints may limit natural gas availability during periods of high demand such as during cold weather when gas is being used for space heating and for electricity generation.

Siting	A new nuclear facility should be sited at Millstone Power Station. The site has infrastructure for managing spent nuclear fuel and significant switchyard equipment still in place from the Unit 1 reactor. Connecticut Yankee is another potential site. Removing spent nuclear fuel and redevelopment of the site is likely a better option than construction of a new power plant at CY.	Facility would need to go through standard siting procedures with a favored location likely being on the same site as a retired fossil fuel power plant. Other attributes of potential sites include being near existing natural gas transmission pipelines (although pipeline capacity may be an issue), electrical transmission lines, cooling water source, and community acceptance of the project.	Siting of a nuclear power plant at an existing facility like Millstone should have relatively strong local support because of the community's familiarity with nuclear power, tax benefits and additional job creation.
Acceptance	22% responded as being very favorable or extremely favorable, 23% somewhat favorable, and 45% not favorable toward nuclear power. 9.5% were not sure.	25% responded as being very favorable or extremely favorable, 46% somewhat favorable, and 23% not favorable toward fossil fuel-based generation. 6% were not sure.	Residents were most favorable toward renewable / green-based energy. Experience with siting wind farms, trash-to-energy plants, and dam-based hydroelectric facilities does not support the high overall support indicated by the survey. Also, these are not viable alternatives for a 1,000 MW baseload power plant.
Energy Education	48% of the respondents did not know or were not sure that there was an operating nuclear power plant in Connecticut. Only 12% of the respondents were correct in responding that nuclear energy accounted for most of the electricity generated in Connecticut with 69% incorrectly responding that fossil fuels accounted for the majority of the electricity generated.	Survey questions were not asked specifically about natural gas.	Energy and electricity generation education is needed. Survey results indicated that respondents are misinformed about many energy issues. Furthermore, most of the respondents (84%) had never looked for information about electric energy issues. Energy education must be strengthened in the school system and public service announcements are needed so citizens of the state can make informed decisions about the state's energy future.

APPENDIX A
GUEST SPEAKERS

The following is a list of guest speakers that provided presentations to the CASE Study Committee.

September 10, 2010

- ***Advances in Nuclear Power Technology***
  Dr. Regis A. Matzie *(Study Committee Member)*
  Former Senior VP & Chief Technology Officer**,** Westinghouse Electric Company, LLC

- ***Nuclear Power in New England***

  - Stephen Rourke, Vice President, System Planning, ISO-New England

  - Anne George, Vice President, External Affairs and Corporate Communications, ISO-New England

  - Eric Johnson, Senior External Affairs Representative, ISO-New England

October 18, 2010

- **Nuclear Regulatory Commission**

  - ***Dry Spent Fuel Storage***
    Bernie White, Technical Assistant, Division of Spent Fuel Storage and Transportation
    Office of Nuclear Material Safety and Safeguards

  - ***New Reactors: NRC Plans, Process & Progress***
    Joe Colaccino, Chief, EPR Projects Branch, Office of New Reactors

- **The Atlantic Interstate Low-Level Radioactive Waste Compact**

  - ***Atlantic Compact Commission: Update on Activities from 2000 through 2010***
    Max Batavia, Executive Director

  - ***Low Level Radioactive Waste Disposal***
    Kevin McCarthy (*Study Committee Member)* Atlantic Compact Commissioner for Connecticut

November 23, 2010

- **Tour of Millstone Power Station and Reactor Simulation & Presentation**
  Dan Weekley, Managing Director, Northeast, Dominion

December 14, 2010

- ***Status of Progress on Economic Impact Analysis***
  Stan McMillen, Managing Economist, CT Department of Economic and Community Development

February 4, 2011

- ***B & W mPower, A Practical, Scalable, Modular, ALWR***
  Jeff Halfinger, Program Director, Babcock & Wilcox

- ***Industry Perspective on Closing the Fuel Cycle***
  Paul Murray, Technical Director for Strategic Programs, AREVA

March 8, 2011

- ***International Atomic Energy Agency (IAEA) Presentation***
  Geoffrey Shaw, PhD, Representative of the Director General of the IAEA to the United Nations; Director, New York Office of the IAEA

- ***Economic Impact Analysis Update***
  Stan McMillen, PhD, Managing Economist, CT Department of Economic and Community Development

- ***Markets & Mechanics* and *The New England RGGI***
  Donald W. Downes, *(Study Committee Member)* Chairman, DPUC (ret.)

April 7, 2011

- ***Is now the time to start building nuclear power plants in New England (again)? What are the challenges?***
  Andrew Kadak, PhD, Director and Principal, Nuclear Services, E^{x}ponent®
  Engineering and Scientific Consulting

May 10, 2011

- **Discussion with Frank von Hippel, PhD** *(via phone)*
  Professor of Public and International Affairs, Princeton University
  Co-chair, International Panel on Fissile Materials

May 20, 2011

- ***Economic Impact Analysis Presentation***
  Stan McMillen, PhD, Managing Economist, CT Department of Economic and Community Development

APPENDIX B
RECORDINGS OF PRESENTATIONS

Recordings of presentations made to the CASE Study Committee for the *Advances in Nuclear Power Technology* study courtesy of the Office of Research, Connecticut Department of Transportation.

(Note: Titles are hyperlinks to the presentations.]

- The Uncertain Future of Nuclear Energy after Fukushima
  Presented by Professor Frank von Hippel; May 10, 2011

- About mPower Reactor Technologies
  Presented by Mr. Jeff Halfinger, Babcock and Wilcox Company; February 4, 2011

- An Industry Perspective on Closing the Nuclear Fuel Cycle
  Presented by Mr. Paul Murray-AREVA; February 4, 2011

- Nuclear Power in the United States
  Presented by Dr. Pete Lyons, Acting Assistant Secretary for Nuclear Energy, U.S. Department of Energy; January 18, 2011

- Advances in Nuclear Power Technologies
  October 18, 2010

  - ***Dry Spent Fuel Storage***
    Presented by 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***
    Presented by Joe Colaccino, Chief, EPR Projects Branch, Office of New Reactors, Nuclear Regulatory Commission

  - ***Atlantic Compact Commission: Update on Activities from 2000 through 2010***
    Presented by Max Batavia, Executive Director, The Atlantic Interstate Low-Level Radioactive Waste Compact

  - ***Low Level Radioactive Waste Disposal***
    Presented by Kevin McCarthy (Study Committee Member) Atlantic Compact Commissioner for Connecticut

APPENDIX C
CONNECTICUT'S CORE SCIENCE CURRICULUM FRAMEWORK

Theme II – Properties of Matter, Theme III – Energy Transfer and Transformations, and Selected Topics from

Theme XI – Science and Technology in Society
(State Department of Education;
http://www.whitememorialcc.org/pdf/sciencecoreframework2005v2.pdf)

<table>
<tr><th colspan="2">Grade 3
Core Themes, Content Standards and Expected Performances</th></tr>
<tr><th>Content Standards</th><th>Expected Performances</th></tr>
<tr><td>Properties of Matter – How does the structure of matter affect the properties and uses of materials?
3.1 - Materials have properties that can be identified and described through the use of simple tests.
♦ Heating and cooling cause changes in some of the properties of materials.</td><td>B 1. Sort and classify materials based on properties such as dissolving in water, sinking and floating, conducting heat, and attracting to magnets.
B 2. Describe the effect of heating on the melting, evaporation, condensation and freezing of water.</td></tr>
<tr><td>Science and Technology in Society – How do science and technology affect the quality of our lives?
3.4 - Earth materials provide resources for all living things, but these resources are limited and should be conserved.
♦ Decisions made by individuals can impact the global supply of many resources.</td><td>B 7. Describe how earth materials can be conserved by reducing the quantities used, and by reusing and recycling materials rather than discarding them.</td></tr>
</table>

Grade 4

Core Themes, Content Standards and Expected Performances

Content Standards	Expected Performances
Energy Transfer and Transformations – What is the role of energy in our world? **4.4 - Electrical and magnetic energy can be transferred and transformed.** ♦ Electricity in circuits can be transformed into light, heat, sound and magnetic effects. ♦ Magnets can make objects move without direct contact between the object and the magnet.	**B 14.** Describe how batteries and wires can transfer energy to light a light bulb. **B 15.** Explain how simple electrical circuits can be used to determine which materials conduct electricity. **B 16.** Describe the properties of magnets, and how they can be used to identify and separate mixtures of solid materials.

Grade 5

Core Themes, Content Standards and Expected Performances

Content Standards	Expected Performances
Energy Transfer and Transformations – What is the role of energy in our world? **5.1 - Sound and light are forms of energy.**	**B 17.** Describe the factors that affect the pitch and loudness of sound produced by vibrating objects.
♦ Sound is a form of energy that is produced by the vibration of objects and is transmitted by the vibration of air and objects.	**B 18.** Describe how sound is transmitted, reflected and/or absorbed by different materials.
♦ Light is a form of energy that travels in a straight line and can be reflected by a mirror, refracted by a lens, or absorbed by objects.	**B 19.** Describe how light is absorbed and/or reflected by different surfaces.

Grade 6

Core Themes, Content Standards and Expected Performances

Content Standards	Expected Performances
Properties of Matter – How does the structure of matter affect the properties and uses of materials? **6.1 - Materials can be classified as pure substances or mixtures, depending on their chemical and physical properties.** ♦ Mixtures are made of combinations of elements and/or compounds, and they can be separated by using a variety of physical means. ♦ Pure substances can be either elements or compounds, and they cannot be broken down by physical means.	**C 1.** Describe the properties of common elements, such as oxygen, hydrogen, carbon, iron and aluminum. **C 2.** Describe how the properties of simple compounds, such as water and table salt, are different from the properties of the elements of which they are made. **C 3.** Explain how mixtures can be separated by using the properties of the substances from which they are made, such as particle size, density, solubility and boiling point.
Energy in the Earth's Systems – How do external and internal sources of energy affect the Earth's systems? **6.3 - Variations in the amount of the sun's energy hitting the Earth's surface affect daily and seasonal weather patterns.** ♦ Local and regional weather are affected by the amount of solar energy these areas receive and by their proximity to a large body of water.	**C 7.** Describe the effect of heating on the movement of molecules in solids, liquids and gases. **C 8.** Explain how local weather conditions are related to the temperature, pressure and water content of the atmosphere and the proximity to a large body of water. **C 9.** Explain how the uneven heating of the Earth's surface causes winds.
Science and Technology in Society – How do science and technology affect the quality of our lives? **6.4** - **Water moving across and through earth materials carries with it the products of human activities.** ♦ Most precipitation that falls on Connecticut eventually reaches Long Island Sound.	**C 10.** Explain the role of septic and sewage systems on the quality of surface and ground water. **C 11.** Explain how human activity may impact water resources in Connecticut, such as ponds, rivers and the Long Island Sound ecosystem.

Grade 7

Core Themes, Content Standards and Expected Performances

Content Standards	Expected Performances
Energy Transfer and Transformations – What is the role of energy in our world? **7.1 - Energy provides the ability to do work and can exist in many forms.** ♦ Work is the process of making objects move through the application of force. ♦ Energy can be stored in many forms and can be transformed into the energy of motion.	**C 12.** Explain the relationship among force, distance and work, and use the relationship (W=F x D) to calculate work done in lifting heavy objects. **C 13.** Explain how simple machines, such as inclined planes, pulleys and levers, are used to create mechanical advantage. **C 14.** Describe how different types of stored (potential) energy can be used to make objects move.

Grade 9

Core Themes, Content Standards and Expected Performances

Strand I: Energy Transformations

Content Standards	Expected Performances
Energy Transfer and Transformations – What is the role of energy in our world? **9.1 - Energy cannot be created or destroyed; however, energy can be converted from one form to another.** ♦ Energy enters the Earth system primarily as solar radiation, is captured by materials and photosynthetic processes, and eventually is transformed into heat.	**D 1.** Describe the effects of adding energy to matter in terms of the motion of atoms and molecules, and the resulting phase changes. **D 2.** Explain how energy is transferred by conduction, convection and radiation. **D 3.** Describe energy transformations among heat, light, electricity and motion.
Energy Transfer and Transformations – What is the role of energy in our world? **9.2 - The electrical force is a universal force that exists between any two charged objects.** ♦ Moving electrical charges produce magnetic forces, and moving magnets can produce electrical force. ♦ Electrical current can be transformed into light through the excitation of electrons.	**D 4.** Explain the relationship among voltage, current and resistance in a simple series circuit. **D 5.** Explain how electricity is used to produce heat and light in incandescent bulbs and heating elements. **D 6.** Describe the relationship between current and magnetism.

Science and Technology in Society – How do science and technology affect the quality of our lives? **9.3 - Various sources of energy are used by humans and all have advantages and disadvantages.** ♦ During the burning of fossil fuels, stored chemical energy is converted to electrical energy through heat transfer processes. ♦ In nuclear fission, matter is transformed directly into energy in a process that is several million times as energetic as chemical burning. ♦ Alternative energy sources are being explored and used to address the disadvantages of using fossil and nuclear fuels.	**D 7.** Explain how heat is used to generate electricity. **D 8.** Describe the availability, current uses and environmental issues related to the use of fossil and nuclear fuels to produce electricity. **D 9.** Describe the availability, current uses and environmental issues related to the use of hydrogen fuel cells, wind and solar energy to produce electricity.

Grade 9

Core Themes, Content Standards and Expected Performances

Strand II: Chemical Structures and Properties

Content Standards	Expected Performances
Properties of Matter – How does the structure of matter affect the properties and uses of materials? **9.4 - Atoms react with one another to form new molecules.** ♦ Atoms have a positively charged nucleus surrounded by negatively charged electrons. ♦ The configuration of atoms and molecules determines the properties of the materials.	**D 10.** Describe the general structure of the atom, and explain how the properties of the first 20 elements in the Periodic Table are related to their atomic structures. **D 11.** Describe how atoms combine to form new substances by transferring electrons (ionic bonding) or sharing electrons (covalent bonding). **D 12.** Explain the chemical composition of acids and bases, and explain the change of pH in neutralization reactions.

Properties of Matter – How does the structure of matter affect the properties and uses of materials? **9.5 – Due to its unique chemical structure, carbon forms many organic and inorganic compounds.** ♦ Carbon atoms can bond to one another in chains, rings and branching networks to form a variety of structures, including fossil fuels, synthetic polymers and the large molecules of life.	**D 13.** Explain how the structure of the carbon atom affects the type of bonds it forms in organic and inorganic molecules. **D 14.** Describe combustion reactions of hydrocarbons and their resulting by-products. **D 15.** Explain the general formation and structure of carbon-based polymers, including synthetic polymers, such as polyethylene, and biopolymers, such as carbohydrate.
Science and Technology in Society – How do science and technology affect the quality of our lives? **9.6 - Chemical technologies present both risks and benefits to the health and well-being of humans, plants and animals.** ♦ Materials produced from the cracking of petroleum are the starting points for the production of many synthetic compounds. ♦ The products of chemical technologies include synthetic fibers, pharmaceuticals, plastics and fuels.	**D 16.** Explain how simple chemical monomers can be combined to create linear, branched and/or cross-linked polymers. **D 17.** Explain how the chemical structure of polymers affects their physical properties. **D 18.** Explain the short- and long-term impacts of landfills and incineration of waste materials on the quality of the environment

Enrichment Content Standards for High School Science

High School Earth Science	
Content Standards	**Supportive Concepts**
Energy in the Earth System Energy enters the Earth system primarily as solar radiation and eventually escapes as heat.	▪ The sun is a major source of energy for Earth and other planets. ▪ Some of the solar radiation is reflected back into the atmosphere and some is absorbed by matter and photosynthetic processes. ▪ Different atmospheric gases absorb the Earth’s thermal radiation. ▪ The greenhouse effect may cause climatic changes.

High School Chemistry	
Content Standards	**Supportive Concepts**
Atomic and Molecular Structure The periodic table displays the elements in increasing atomic number and shows how periodicity of the physical and chemical properties of the elements relates to atomic structure.	▪ The nucleus of the atom is much smaller than the atom, yet contains most of its mass. ▪ The quantum model of the atom is based on experiments and analyses by many scientists, including Dalton, Thomson, Bohr, Rutherford, Millikan and Einstein. ▪ The position of an element in the periodic table is related to its atomic number. ▪ The periodic table can be used to identify metals, semimetals, non-metals and halogens. ▪ The periodic table can be used to identify trends in ionization energy, electronegativity, the relative sizes of ions and atoms, and the number of electrons available for bonding. ▪ The electronic configuration of elements and their reactivity can be identified based on their position in the periodic table.
Chemical Bonds Biological, chemical and physical properties of matter result from the ability of atoms to form bonds from electrostatic forces between electrons and protons and between atoms and molecules.	▪ Atoms combine to form molecules by sharing electrons to form covalent or metallic bonds or by exchanging electrons to form ionic bonds. ▪ Chemical bonds between atoms in molecules such as H2, CH4, NH3, H2CCH2, N2, Cl2, and many large biological molecules are covalent. ▪ Salt crystals, such as NaCl, are repeating patterns of positive and negative ions held together by electrostatic attraction. ▪ The atoms and molecules in liquids move in a random pattern relative to one another because the intermolecular forces are too weak to hold the atoms or molecules in a solid form. ▪ Lewis dot structures can provide models of atoms and molecules. ▪ The shape of simple molecules and their polarity can be predicted from Lewis dot structures. ▪ Electronegativity and ionization energy are related to bond formation. ▪ Solids and liquids held together by Van der Waals forces or hydrogen bonds are affected by volatility and boiling/melting point temperatures.

Conservation of Matter and Stoichiometry The conservation of atoms in chemical reactions leads to the principle of conservation of matter and the ability to calculate the mass of products and reactants.	▪ Chemical reactions can be described by writing balanced equations. ▪ The quantity one mole is set by defining one mole of carbon 12 atoms to have a mass of exactly 12 grams. ▪ One mole equals 6.02×10^{23} particles (atoms or molecules). ▪ The molar mass of a molecule can be determined from its chemical formula and a table of atomic masses. ▪ The mass of a molecular substance can be converted to moles, number of particles, or volume of gas at standard temperature and pressure. ▪ Hess's law is used to calculate enthalpy change in a reaction.
Reaction Rates Chemical reaction rates depend on factors that influence the frequency of collision of reactant molecules.	▪ The rate of reaction is the decrease in concentration of reactants or the increase in concentration of products with time. ▪ Reaction rates depend on factors such as concentration, temperature and pressure. ▪ Equilibrium is established when forward and reverse reaction rates are equal. ▪ Catalysts play a role in increasing the reaction rate by changing the activation energy in a chemical reaction.

High School Physics

Content Standards	Supportive Concepts
Heat and Thermodynamics Energy cannot be created or destroyed although, in many processes, energy is transferred to the environment as heat.	▪ Heat flow and work are two forms of energy transfer between systems. ▪ The work done by a heat engine that is working in a cycle is the difference between the heat flow into the engine at high temperature and the heat flow out at a lower temperature. ▪ The internal energy of an object includes the energy of random motion of the object's atoms and molecules. The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object. ▪ Most processes tend to decrease the order of a system over time, so that energy levels eventually are distributed more uniformly.

Electric and Magnetic Phenomena Electric and magnetic phenomena are related and have many practical applications.	▪ The voltage or current in simple direct current (DC) electric circuits constructed from batteries, wires, resistors and capacitors can be predicted using Ohm's law. ▪ Any resistive element in a DC circuit dissipates energy, which heats the resistor. ▪ The power in any resistive circuit element can be calculated by using the formula Power = I^2R. ▪ Charged particles are sources of electric fields and are subject to the forces of the electric fields from other charges. ▪ Magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources. ▪ Changing magnetic fields produce electric fields, thereby inducing currents in nearby conductors. ▪ Plasmas, the fourth state of matter, contain ions, or free electrons or both and conduct electricity.

APPENDIX D
VIRTUAL HIGH SCHOOL - NUCLEAR PHYSICS: SCIENCE, TECHNOLOGY & SOCIETY
COURSE DESCRIPTION AND OBJECTIVES

Course Title:	Nuclear Physics: Science, Technology & Society
Discipline:	Science - Physics
Grade Level:	10, 11, 12
Level:	Standard
Offering:	Repeated Semester (Fall: 25 Seats; Spring: 25 Seats;)
Prerequisites:	The student should have good math and writing skills and a basic understanding of atomic structure. It would also be helpful if the student has some experience with graphing calculators.
Accredited by:	Certified by NCAA for initial-eligibility (VHS School Code: 221356); Middle States Commission on Secondary Schools; Northwest Accreditation Commission

Description: The focus of this course is the scientific, technological, and societal implications arising from nuclear physics. Students have an opportunity to explore, in-depth, a topic that has played a major role in the science, technology, politics, philosophy, and everyday life of the past century. The student's primary goal during the course is to answer the question: "What should an informed citizen know about nuclear issues?" The student has some flexibility choosing the areas they wish to concentrate on.

The science topics in the course include the history of discovery, types of nuclear reactions, interactions between radiation and matter, the standard model of subatomic matter and current research. Although some math is used to provide better understanding of the concepts covered, math problems are not the primary focus of the course.

The technology portion includes the design and function of particle detectors, particle accelerators, nuclear reactors, nuclear bombs and nuclear waste facilities. Current and future uses of radiation in industry and medicine are also investigated.

The society portion of the course is the one where many students concentrate their efforts. The weekly discussions on controversial nuclear topics are always interesting. They provide opportunities to look back at the politics behind weapons development and use, the Cold War, nuclear proliferation, and the atomic energy industry. Discussions during the course will include topics that have made recent headlines; such as food irradiation, nuclear reactors in space, Radon mitigation, the demise of the Super-Conducting Super-Collider, the theft of nuclear secrets, and nuclear test ban treaties.

WEEK 1 Objectives:
- Students will begin working together, creating a learning community
- Students will become familiar with the VHS learning environment and will understand the course expectations

WEEK 2 Objectives:
- Students will review the concepts of 'the Scientific Method' and inquiry
- Students will report on the discovery of radioactivity (who, what, when, how)
- Students will be directed to websites to obtain information

WEEK 3 Objectives:
- Students will understand the concept of "inverted priorities" and be able to give examples
- Students will understand the types of radioactive decay and be able to predict the products of those reactions
- Students will be able to solve half-life problems

WEEK 4 Objectives:
- Students will begin doing independent internet research
- Students will be able to describe the source of nuclear energy
- Students will be able to calculate the energy produced in different types of radioactive decays
- Students will begin working in groups

WEEK 5 Objectives:
- Students will begin to understand the effect of radiation on matter
- Students will describe the differences between radiation detectors (Photographic film, fluorescent screens, Geiger counters, Bubble chambers, Cloud chambers)
- Students will begin to investigate the effects of radiation on living organisms and government's role in protecting its citizens from exposure

WEEK 6 Objectives:
- Students will investigate the responsibility of the scientific community and how the scientific community works without borders in most circumstances
- Students will be able to describe the events that led to the first controlled fission reaction

WEEK 7 Objectives:
- Students will examine and add to a time-line of events that led to the first use of atomic weapons
- Students will understand the difference between a controlled nuclear fission reaction of a power plant and an uncontrolled fission reaction in a bomb

WEEK 8 Objectives:
- Students will examine both the positive and negative aspects of nuclear power
- Students will understand the concept of risk assessment

WEEK 9 Objectives:
- Students will understand the difference between low level nuclear waste and highly radioactive waste

- Students will investigate US and state strategies for dealing with low level nuclear waste
- Students will begin reading about the effect of large dose exposure to radiation

WEEK 10 Objectives:
- Students will investigate and report on nuclear weapons test treaties
- Students will understand the reactions that produce nuclear fusion and where they occur

WEEK 11 Objectives:
- Students will understand the difference between atomic bombs and hydrogen bombs
- Students will investigate and report on nuclear proliferation

WEEK 12 Objectives:
- Students will investigate elementary particle research (who, what , where, why, how)

WEEK 13 Objectives:
- Students will understand concepts relating to fiscal responsibilities
- Students will be able to describe the basics of the Standard Model

WEEK 14 Objectives:
- Students will research nuclear issues that are currently in the news
- Students will investigate and report on the frontiers of nuclear and particle physics
- Students will be able to relate elementary particle research to the beginning of the universe

WEEK 15 Objectives:
- Students will organize the material covered throughout the semester
- Students will help create a high school curriculum for a unit on nuclear physics
- Students will compare their curriculum to state and national standards in Science

Learning Objectives:

Students will:

1. Demonstrate an understanding of radioactive decay, nuclear fission and nuclear fusion.

2. Research and discuss the history of nuclear discoveries.

3. Describe the standard model of subatomic matter.

4. Report on current research at worldwide nuclear research facilities.

5. Participate in on-line research and data analysis.

6. Explain the design and function of devices that make use of nuclear reactions.

7. Use scientific principles in discussions of future nuclear technologies.

8. Use research data to do risk assessments and cost assessments.

9. Research and report on the politics of nuclear advancements.

10. Participate in open-minded debates on the benefits and costs related to current nuclear applications.

11. Develop skills in the use of graphing calculators.

12. Help determine topics that should be included in high school science curricula.

ATTACHMENT 1

THE ECONOMIC IMPACT OF NUCLEAR POWER GENERATION IN CONNECTICUT

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June 2011

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EXECUTIVE SUMMARY

The Connecticut Academy of Science and Engineering's (CASE) Energy Alternatives and Conservation Study (December 2006) conducted on behalf of the Connecticut General Assembly suggested further study regarding advances in nuclear power technologies to inform the leadership of the state in making decisions about the future of nuclear power for Connecticut in the 21st century and beyond. Deliberations within the Connecticut Energy Advisory Board (CEAB) determined that an independent and unbiased study would be in the best interest of Connecticut citizens regarding a decision to promote nuclear technology. As a result, the CEAB contracted with CASE to conduct a study on key topics of interest regarding advances in nuclear power technologies and a variety of issues of public interest regarding nuclear power. In turn, CASE commissioned economists at the Department of Economic and Community Development and the Connecticut Economic Resource Center, Inc. to perform a portion of the larger study.

The present study determines the economic impacts related to the construction and operation of new and replacement nuclear power plants and the decommissioning of a retiring power plant. In addition, the study assesses the economic impact of constructing and operating a new or replacement natural gas combined cycle gas turbine (CCGT) power plant of identical electrical output to determine the relative net economic benefit of each plant. The changes in direct, indirect and induced jobs, personal income, value added and net state revenue comprise the analysis results.

The economic and fiscal benefits from replacing an existing nuclear plant at Millstone with either a new nuclear or a CCGT plant are short-term employment gains and short-term state GDP and net state revenue spikes. The replacement scenarios are essentially large construction projects whose economic effects dissipate quickly as construction is completed. There is no change in the wholesale price of electricity because baseload capacity does not increase in the region and there are no changes in Dominion's employment, procurement or electricity sales as the new plants commence operation because we assume the existing workforce and procurement pattern and electricity demand remain intact. Table ES-1 summarizes the annual economic and fiscal results for the replacement of a nuclear plant at Millstone with either an AP 1000 nuclear plant or a CCGT plant. The build time for the nuclear plant is five years and for the CCGT plant two years. The sixth year in the case of replacement by a nuclear plant and third year in the case of replacement by a CCGT plant represents a greatly compressed decommissioning phase. For purposes of this analysis, the beginning of economic modeling "time" is 2009 and the end of modeling time is 2050. The differences in economic impact are primarily due to the difference in construction costs between the two plants. In the CCGT replacement case, we include the cost of extending a natural gas pipeline to the Millstone plant site.

Table ES-1: Economic Impact of Replacing a Nuclear Plant with a Nuclear or CCGT Plant at Millstone

Economic Variable		2009	2010	2011	2012	2013	2014
New Total employment	Nuclear	7,993	20,320	24,756	19,249	6,021	12,087
	CCGT	NA	NA	NA	8,685	8,368	13,679
New Construction Jobs	Nuclear	5,708	14,660	18,194	14,636	5,365	9,922
	CCGT	NA	NA	NA	6,263	6,187	10,245
New State GDP (mil nominal $)	Nuclear	$460.5	$1,214.9	$1,495.1	$1,161.2	$313.4	$725.5
	CCGT	NA	NA	NA	$543.5	$531.1	$889.9
New Output (Sales) (mil nominal $)	Nuclear	$780.5	$2,051.6	$2,516.2	$1,948.9	$530.0	$1,207.3
	CCGT	NA	NA	NA	$917.4	$894.6	$1,474.7
New Personal Income (mil nominal $)	Nuclear	$393.6	$1,055.8	$1,400.3	$1,225.8	$556.5	$902.2
	CCGT	NA	NA	NA	$472	$507.80	$867.20
Net New State Revenue (mil nominal $)	Nuclear	$77.78	$190.7	$218.66	$147.7	$0.53	$72.67
	CCGT	NA	NA	NA	$87.65	$77.71	$131.5

Source: The REMI model and the authors' calculations.

In the case in which we add baseload capacity at Millstone, we assume Dominion's workforce and procurement expands incrementally. For the cases in which a new nuclear or CCGT merchant plant is constructed at the Connecticut Yankee site, we assume there is a merchant owner/operator different from Dominion that adds jobs and establishes a procurement pattern with Connecticut suppliers commensurate with the scale of the operation. However, the new direct jobs and procurement added in each case are not net new to Connecticut because the jobs and procurement are absorbed from retiring marginal units displaced by new baseload capacity.

The "no net new" premise arises from assuming that the displaced marginal units are in Connecticut. If displaced marginal units are elsewhere, there will be net new job creation and net new procurement in Connecticut making the economic impacts larger. Thus, this assumption is the most conservative and defensible. In addition, this assumption implies there are no net new sales of electricity in the region, as we assume regional demand is constant. Each new or replacement unit at least receives its levelized cost of electricity (LCOE) otherwise it will shut down in the long run. The LCOE represents the constant (level) wholesale price generators receive over the life of a power plant that is necessary to cover all operating expenses, including taxes, and provide an acceptable return to investors.

Adding baseload capacity confers long-term benefits in the form of a reduced wholesale price for electricity in the region and that in turn increases employment, business-to-business activity and taxes in the economy as a whole. In these cases, we consider the construction and operation of the plants by merchant owners and operators from 2009 through 2050 in the Connecticut economic model. We omit siting and permitting costs and assume these tasks have been accomplished before this hypothetical analysis begins; further, we assume there are identical costs for connecting the plants to the grid at each site.

Table ES-2 displays summary results of adding a nuclear or a CCGT plant at either the Millstone campus or the Connecticut Yankee site. The differences in the results are due primarily to the difference in construction costs between the two plants. We include the cost of extending a natural gas pipeline to the CCGT plant sites. The baseline forecast for the Connecticut economy is the no-build or status quo forecast against which the changes due to new economic activity are measured.

Table ES-2: Economic Impact of Adding a Nuclear and CCGT Plant at Millstone or Connecticut Yankee

	Annual Average Change from Baseline (2009-2050)			
Economic Variable	Add Nuclear Plant at Millstone or CT Yankee		Add CCGT Plant at Millstone or CT Yankee	
Total New Employment (Persons)	2,420		1,333	
New Construction (Jobs)	957		254	
	Ann. Avg. Change	NPV	Ann. Avg. Change	NPV
New Gross Domestic Product (mil nominal $)	$516.6	$7,594.8	$471.1	$5,768.4
New Output (mil nominal $)	$845	$12,576.3	$773.6	$9,581.7
New Personal Income (mil nominal $)	$363.6	$6,154.1	$247.6	$3,291.8
Net New State Revenue (mil nominal $)	$27.4	$586	$18.6	$306.2

Source: The REMI model and the authors' calculations. NPV is net present value.

The annual average changes in employment, state gross domestic product (GDP), output (sales in all sectors), personal income and net new state revenue from the baseline or status quo forecast show that building new electrical generating capacity in a region creates jobs, taxes and new purchases of goods and services from the regional economy. This occurs because building new capacity reduces the regional wholesale market price for electricity, making the region relatively more competitive in addition to supporting short-term construction jobs.

Replacing retiring units with additional baseload capacity or adding new capacity changes the composition of generating assets in the region and in the case of adding baseload capacity, reduces the wholesale price to load-serving entities (Connecticut Light & Power and United Illuminating are examples of load serving entities [LSEs]).[1] The reduction in the wholesale price of electricity to Connecticut users and the relatively large but short-term construction phases are the drivers of net new economic activity in Connecticut.

The hypothetical CCGT plant increases the regional demand for natural gas and may strain the existing gas delivery infrastructure and adversely affect natural gas prices during periods of peak demand in Connecticut. Further, the addition of a CCGT plant increases CO_2 emissions and makes compliance with Connecticut's Renewable Energy Portfolio Standard (RPS)[2] and Connecticut's commitment to the Regional Greenhouse Gas Initiative (RGGI)[3] CO_2 reduction schedule more difficult. Finally, adding a CCGT increases the New England region's already disproportionate demand for natural gas and renders Connecticut more vulnerable to natural gas price volatility. On the other hand, adding new nuclear capacity increases fuel diversity in the region and mitigates the effects of natural gas price volatility as well as security considerations related to gas supply interruption. In addition, nuclear plants emit no CO_2 in the production of electricity but do entail CO_2 emissions in construction, the fuel cycle and certain operational aspects. We discuss quantitative aspects of fuel diversification in Appendix A. We present an overview of the carbon market in the Northeast in Appendix B. In particular, the Regional Greenhouse Gas Initiative collected $860 million through auctions and direct sales from September 2008 through March 2011; of this amount, RGGI returned 91.5% to the ten member states. From the total proceeds ($860 million), member states used 63.4% on average to improve end-use energy efficiency and accelerate the deployment of renewable energy technologies. In 2009, Connecticut used 97.5% of its RGGI proceeds to improve end-use energy efficiency and accelerate the deployment of renewable energy technologies.

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1 The "New England Electricity Scenario Analysis: Exploring the economic, reliability, and environmental impacts of various resource outcomes for meeting the region's future electricity needs" report performed the analysis to support this result. The report was released August 2, 2007 by ISO New England. It is available at www.iso-ne.com/committees/comm_wkgrps/othr/sas/mtrls/elec_report/scenario_analysis_final.pdf. See footnote 29 as well.

2 Renewable Portfolio Standards are state standards for load-serving entities to provide a portion of their energy from specific renewable technologies that increase each year. Connecticut, Maine, Massachusetts, and Rhode Island have RPSs, and New Hampshire recently established one. Vermont is pursuing an alternative approach and is requiring that renewable resources be used to serve all growth in that state's electricity use. The definition of RPS requirements varies by state. The North Carolina State University's Web site, Database of State Incentives for Renewables and Efficiency (the DSIRE Database, 2007), provides information on state RPS programs.

3 The Regional Greenhouse Gas Initiative is a 10-state CO_2 cap-and-trade program developed and implemented in the Northeast. Under RGGI, the Northeast region must cap its emissions by 2014 on the basis of recent historical emissions and reduce this level by 10% by 2018. By 2018, the six New England states will be allocated 50.2 million tons of carbon allowances from the RGGI cap, which covers other states in the Northeast region (i.e., New York, New Jersey, Maryland, and Delaware). See Appendix B.

INTRODUCTION

The Connecticut Academy of Science and Engineering's (CASE) *Energy Alternatives and Conservation Study* (December 2006) conducted on behalf of the Connecticut General Assembly suggested further study regarding advances in nuclear power technologies to inform the leadership of the state in making decisions about the future of nuclear power for Connecticut in the 21st century and beyond. Deliberations within the Connecticut Energy Advisory Board (CEAB) determined that an independent and unbiased study regarding a decision to promote nuclear technology would be in the best interest of Connecticut citizens. As a result, the CEAB contracted with CASE to conduct a study on key topics of interest regarding advances in nuclear power technologies and a variety of issues of public interest regarding nuclear power. In turn, CASE commissioned economists at the Department of Economic and Community Development and the Connecticut Economic Resource Center, Inc. to perform a portion of the larger study.

The present study determines the economic impacts related to the construction and operation of a new nuclear power plant and the decommissioning and demolition of an existing power plant as applicable for the scenarios considered. The changes in direct, indirect and induced jobs, personal income, value added, and output or sales comprise the analysis results. In addition, the study assesses the economic impact of constructing and operating a natural gas combined cycle gas turbine (CCGT) power plant of identical electrical output (1,000 MWe) to determine the relative net economic benefit of each plant.

The principal analysis in this study is an economic model of the life cycle of a nuclear and a natural gas-fired baseload generating plant of approximately 1,000 MWe. The analysis is a net energy analysis and accounts for all phases including planning, construction, operation, decommissioning and waste disposal and/or safe storage. The plants under consideration are scalable to determine a range of cost-benefit margins based on a variety of cost and operating parameter assumptions. Because of the different cost structures associated with the decommissioning of a nuclear power plant relative to a CCGT plant, the analysis includes a complete life cycle for each plant. For purposes of this analysis, we consider the life of each plant to be 40 years including operation and decommissioning.[4] We examine the consequences of a 60-year life cycle for a nuclear plant as well.

We consider several scenarios regarding new power plant construction in which each derives from the principal analysis and is adapted to each of the scenarios below.

1. ***Replacement generating capacity of an existing Millstone Unit:*** This scenario involves the replacement of existing generating capacity with a new unit on the Millstone site in the event of the retirement of one of the existing two nuclear power plant units on the site. This option would involve decommissioning and demolition of the unit to be retired and construction of a new unit.

[4] In reality, current practice is not to decommission the nuclear plant for many years after shutdown to allow radioactive decay of irradiated materials. Thus, decommissioning might not occur for 20 or more years after shut-down.

2. ***Additional generating capacity:***

    a. ***Construction of an additional nuclear power plant unit on the Millstone site:*** This scenario involves the construction on the Millstone site of a new nuclear power plant unit of a size similar to the two units currently in operation on the site to provide additional electricity generating capacity in Connecticut.

    a. ***Construction of an additional nuclear power plant on a site other than the Millstone Power Station site:*** This scenario involves the construction of a new nuclear power plant of similar size to units currently in operation at the Millstone site at a site to be determined, such as the Connecticut Yankee site located in Haddam Neck, to provide additional electricity generating capacity in Connecticut.

    a. ***Construction of one or more new "modular" nuclear power plants*** to be constructed at a site to be determined with a generating capacity of approximately 100 - 200 MW.

SMALL NUCLEAR REACTORS

The present study does not determine the economic and fiscal costs and benefits of small modular reactors (SMRs) that might be constructed at sites other than at the Connecticut Yankee site or the Millstone campus. While there are several small modular reactor designs and projects in various stages of development around the world,[5] we have no reliable information on specific costs and other operating parameters that are necessary to calculate the levelized cost of electricity (LCOE) for such plants.LCOE represents the constant (level) wholesale price generators receive over the life of a power plant that is necessary to cover all operating expenses and taxes and provide an acceptable return to investors.There is renewed interest in SMRs because their capital costs and construction times are expected to be significantly lower than typical baseload nuclear plants.[6]Further, because such plants can begin producing power sooner, they can begin returning their smaller capital investment sooner.In addition, SMRs can be installed in places where oil- or coal-fired plants are retired, reducing certain costs and taking advantage of existing infrastructure. SMRs may produce products other than electricity such as hydrogen (especially using the high-temperature gas reactors) and desalinated water, as well as central heat (steam) for their neighborhoods.

The revival of interest in smaller and simpler units for generating electricity from nuclear power and for process heat (see footnote 6) is driven both by a desire to reduce capital costs and to provide power in locations distant from large grid systems. The technologies involved are quite diverse. In 2010, the American Nuclear Society convened a special committee to examine licensing issues with SMRs in the United States, where dozens of land-based small reactors were built from the 1950s through the 1980s, proving the safety and security of light water-cooled,

[5] See "The Commercial Outlook for U.S. Small Modular Nuclear Reactors," U.S. Department of Commerce, International Trade Administration.Available at http://trade.gov/publications/pdfs/the-commercial-outlook-for-us-small-modular-nuclear-reactors.pdf.

[6] See "Administration to Push for Small 'Modular' Reactors," The New York Times, February 12, 2011.Available at www.nytimes.com/2011/02/13/science/earth/13nuke.html.

gas-cooled and metal-cooled SMR technologies. The committee had considerable involvement from SMR proponents along with the Nuclear Regulatory Commission, Department of Energy laboratories and universities. Notwithstanding, there is insufficient information to perform an economic impact analysis for SMRs in the present study.

BASIC ASSUMPTIONS

For purposes of this study, we assume the baseload CCGT or nuclear plant would be built on the Millstone campus or at the existing Connecticut Yankee site.Because of the uncertainty and variability of siting and permitting costs, we omit the siting and permitting processes and their associated costs and time despite their potential importance and the differences in these costs between the two power plant types.We therefore assume siting and permitting have been accomplished before this hypothetical analysis begins.In any case, the economic and fiscal costs and benefits of siting and permitting are small relative to those of the construction and operation of the plants.

For the CCGT plant, we assume that an existing gas pipeline would need to be extended to either assumed site and we build in such costs for the economic impact analysis.The two assumed sites should obviate the need for new grid interconnect infrastructure and we assume interconnect costs would be roughly equal for either type of plant.Building a 1,000 MWe CCGT plant may affect gas prices in the region because Connecticut (and New England) is at the end of the gas pipeline network in the United States.If the additional demand for gas for the hypothetical CCGT is not offset by increased gas supply, gas users in Connecticut may see higher prices, thus mitigating the potential wholesale price reduction resulting from adding new baseload capacity from a CCGT plant.We discuss the effects of high natural gas prices on the region below.

Building new electrical generating capacity in a region affects the regional wholesale market for electricity and in turn creates jobs, taxes and new purchases of goods and services from the regional economy.Replacement units are more efficient; they are typically natural gas units andare typically not baseload units.However, for the present analysis, we assume the CCGT plant is a baseload unit, that is, the CCGT plant operates at its rated capacity all the time (nuclear units are always baseload units).The hypothetical CCGT plant therefore increases the regional demand for natural gas and may strain the gas delivery infrastructure and adversely affect natural gas prices during periods of peak demand in Connecticut.The addition of a CCGT plant increases CO_2 emissions and makes compliance with Connecticut's Renewable Energy Portfolio Standard (RPS; see footnote 1) and Connecticut's commitment to the Regional Greenhouse Gas Initiative (RGGI; see footnote 2) CO_2 reduction schedule more difficult. Finally, adding a CCGT increases the region's already disproportionate demand for natural gas and renders Connecticut more vulnerable to natural gas price volatility.On the other hand, adding new nuclear capacity increases fuel diversity in the region and mitigates the effects of natural gas price volatility as well as security considerations related to gas supply interruption. In addition, nuclear plants emit no CO_2 in the production of electricity, but do entail CO_2 emissions in construction, the fuel cycle and certain operational aspects.We discuss quantitative aspects of fuel diversification in Appendix A.We present an overview of the carbon market in the Northeast in Appendix B.

In the cases in which we add baseload capacity, we assume Dominion's workforce and procurement expands incrementally.For the cases in which a nuclear or CCGT merchant plant is constructed at the Connecticut Yankee site, we assume there is a merchant owner/ operator different from Dominion that adds jobs and establishes a procurement pattern with Connecticut suppliers commensurate with the scale of the operation.However, the new direct jobs and procurement added in each case are not net new to Connecticut because the jobs and procurement are absorbed from retiring marginal units displaced by new baseload capacity. The "no net new" premise arises from assuming that the displaced marginal units are in Connecticut.If displaced marginal units are elsewhere, there will be net new job creation and net new procurement in Connecticut making the economic impacts larger.Thus, this assumption is the most conservative and defensible.In addition, this assumption implies there are no net new sales of electricity in the region as we assume regional demand is constant.Each new or replacement unit at least receives its levelized cost of electricity (LCOE), otherwise it will shut down in the long run.The LCOE represents the constant (level) wholesale price generators receive over the life of a power plant that is necessary to cover all operating expenses including taxes and provide an acceptable return to investors.

Adding baseload capacity confers long-term benefits in the form of a reduced wholesale price for electricity in the region that in turn increases employment, business-to-business activity and taxes in the economy as a whole.In these cases, we consider the construction and operation of the plants by merchant owners and operators from 2009 through 2050 in the Connecticut economic model.

Replacing retiring units with additional baseload capacity or adding new capacity changes the composition of generating assets in the region and, in the case of new baseload capacity, reduces the wholesale price to load-serving entities (Connecticut Light & Power and United Illuminating are examples of load serving entities [LSEs]; see footnote 1). The reasons follow from the explanation of the regional electrical energy market below.

THE ELECTRICAL ENERGY MARKET[7]

The independent, regulated, corporate entity (the independent system operator) responsible for overseeing and administering New England's wholesale electricity markets is ISO New England. These markets work together to ensure the constant availability of electricity from the bulk power grid for the six states' 6.5 million households and businesses and 14 million people. Generators may receive payments from one or more of these wholesale markets. The wholesale electricity markets and market products in New England are as follows:

- **Day-Ahead Energy Market**—allows market participants to secure prices for electric energy the day before the operating day and to hedge against price fluctuations that can occur in real time; facilitates electric energy trading.
- **Real-Time Energy Market**—coordinates the dispatch of generation and *demand resources* to meet the demand for electricity and to meet reserve requirements.[8]

[7] The regional market for electricity is complex and we provide a brief overview in this report. An accessible description of the markets and the history of ISO-NE is "Wholesale Electricity Markets" by ISO-NE (available at http://www.iso-ne.com/img/wem.pdf). A comprehensive description is the "2009 Annual Markets Report" from ISO New England, May 18, 2010. Available at www.isone.com/markets/mktmonmit/rpts/other/amr09_final_051810.pdf.

[8] Demand resources are installed measures (i.e., products, equipment, systems, services, practices, and strategies) that result in additional and verifiable reductions in end-use demand on the electricity network during specific performance hours.

- **Forward Capacity Market (FCM)**—ensures the sufficiency of installed capacity, which includes demand resources, to meet the future demand for electricity.
- **Financial transmission rights (FTRs)**—allows participants to hedge against the economic impacts associated with transmission congestion and provides a financial instrument to arbitrage differences between expected and actual day-ahead congestion.

Ancillary services:

- **Regulation Market**—compensates participants whose resources are controlled by the ISO using automated signals to increase or decrease output moment by moment to balance the variations in instantaneous demand and the system frequency because demand varies second to second and the system frequency must be kept at a constant rate.
- **Forward Reserve Market (FRM)**—compensates generators for the availability of their *unloaded* operating capacity that can be converted into electric energy within 10 to 30 minutes when needed to meet system contingencies, such as unexpected outages.[9]
- **Real-time reserve pricing**—is ISO's mechanism to implement *scarcity pricing* that compensates participants with on-line and *fast-start* generators for the increased value of their electric energy when the system or portions of the system are short of reserves.[10] It provides efficient price signals when redispatch is needed to provide additional reserves to meet requirements.
- **Voltage support**—compensates resources for maintaining voltage-control capability, which allows system operators to maintain transmission voltages within acceptable limits.
- **Other services and products**—The ISO procures and compensates participants for other services and products as required by the ISO's *Open Access Transmission Tariff* (OATT).

In what is termed a *multi-settlement system*, each of these markets produces a separate but related financial settlement. The Day-Ahead Energy Market produces financially binding schedules for the sale and purchase of electricity one day before the operating day. However, electricity supply or demand for the operating day can change for a variety of reasons including generator reoffers of their supply into the market, real-time hourly *self-schedules* (i.e., choosing to be on line and operating at minimum output level regardless of the price of electric energy), self-curtailments, transmission or generation outages, and unexpected real-time system conditions.

Physically, real-time operations balance instantaneous changes in electricity supply and demand to ensure that wholesale customers receive the electric energy they demand from the system and that adequate reserves are available to operate the transmission system within

[9] Unloaded operating capacity is operational capacity that is not generating electric energy but that could convert to generating energy. A contingency is the sudden loss of a generation or transmission resource. A first contingency (N-1) is when the first power element (facility) of a system is lost, which has the largest impact on system reliability. A second contingency (N-1-1) is the loss of the facility that would have the largest impact on the system after the first facility is lost.

[10] Fast-start resources are resources that are able to respond quickly to system contingencies that remove equipment from service. An example is a gas turbine powered by jet fuel.

its limits. Financially, the Real-Time Energy Market settles the differences between the day-ahead scheduled amounts of load and generation and the actual real-time load and generation. Participants either pay or receive the real-time locational marginal price (LMP) for load or generation in megawatt-hours (MWh) that deviates from their day-ahead schedule.

Locational marginal pricing is a way for wholesale electric energy prices to reflect the value of electric energy efficiently at different locations based on the patterns of load and generation, and the physical limits of the transmission system. Wholesale electricity prices are identified at 900 pricing points on the New England regional bulk power grid. LMPs differ among these locations because transmission and reserve constraints prevent the next cheapest megawatt (MW) of electric energy from reaching all locations of the grid. Despite that, during periods when the cheapest megawatt can reach all locations, the marginal cost of physical transmission losses entails different LMPs across the system.

Forward Capacity Market

The Forward Capacity Market is a long-term wholesale market that assures resource adequacy locally and systemwide by compensating generation and demand resources for fixed capacity costs not covered through the other wholesale markets. This market promotes economic investment in supply and demand resources where they are needed most. Capacity resources may be new or existing resources and include supply from power plants, import capacity or the decreased use of electricity through demand resources. To purchase sufficient qualified resources to satisfy the region's future needs and allow sufficient time to construct new capacity resources, Forward Capacity Auctions (FCAs) are held each year approximately three years in advance of when the capacity resources must provide service. Capacity resources compete in the annual FCA to obtain a commitment to supply capacity in exchange for a market-priced capacity payment.

Forward Reserve Market

To maintain system reliability, all bulk power systems, including ISO New England, need reserve capacity to be able to respond to contingencies such as those caused by unexpected outages. *Operating reserves* are the unloaded capacity of generating resources, either offline or online, that can deliver electric energy within 10 or 30 minutes (some demand-side resources can provide "reserves" by reducing load requirements to satisfy certain contingencies). ISO operating procedures require reserve capacity to be available within 10 minutes to meet the largest single system contingency (N-1) that results from an unexpected outage of the largest generator in the system. Additional reserves must be available within 30 minutes to meet one-half of the second-largest system contingency (N-1-1). The ISO identifies local second-contingency-protection resources (LSCPRs) to meet the second-contingency requirements in import-constrained areas of New England.

In general, capacity equal to between one-fourth and one-half of the 10-minute reserve requirement must either be synchronized to the power system or be *10-minute spinning reserve* (TMSR), while the rest of the 10-minute requirement may be *10-minute nonspinning reserve* (TMNSR). The entire 30-minute requirement may be served by either *30-minute operating reserve* (TMOR) or by the higher quality 10-minute spinning reserve or nonspinning reserve. In addition to the systemwide requirements, 30-minute reserves must be available to meet the local second contingency in import-constrained areas (Fairfield County is an example).

In the New England system, participants with resources that provide reserves are compensated both through the locational Forward Reserve Market (FRM), which offers a product similar to a capacity product, and through real-time reserve pricing. The FRM obligates participants to provide reserve capacity in real time through a competitive, intermediate-term, forward-market auction. When the ISO dispatches resources in real time and sets LMPs, the process co-optimizes the use of resources for providing electric energy and real-time reserves. When resources are dispatched to a lower level in real time to provide reserve capacity rather than electric energy, a positive real-time reserve price for the product is set, recognizing the resource's opportunity cost of providing reserve rather than energy.

The Forward Reserve Market intends to attract investments in, and compensate for, the type of resources that provide the long-run, least-cost solution to satisfy offline reserve requirements. The locational FRM compensates participants with resource capacity located within specific subareas for making the type of electric energy market offers that would make them likely to be unloaded and thus available to provide energy within 10 or 30 minutes. Typically, these resources are fast-start units that run infrequently throughout the year (i.e., they have low capacity factors). However, the FRM also compensates resources that commit to be on line without Net Commitment-Period Compensation (NCPC) and that have upper portions of their dispatch ranges that typically are unloaded.

It is convenient to separate the wholesale markets into the electrical energy market and the others (capacity, reserve and ancillary services). The energy market pays all generators participating in the day-ahead and real-time markets the price bid by the marginal unit just satisfying the last unit of forecast demand. These payments may not cover all costs that generators face and the generators may participate in other markets to recoup their average total (fixed plus variable) costs. Because baseload units, especially nuclear units, have low fuel costs relative to inframarginal natural gas units, they typically bid zero in the energy markets. As baseload capacity is added, it displaces marginal (higher priced generation) units and reduces the wholesale electricity price in the region. Because nuclear power is relatively inexpensive to generate, adding nuclear baseload capacity drives down the prices for capacity and reserve otherwise provided by units that have higher fuel costs. In some jurisdictions, nuclear power qualifies as green or low-carbon power and nuclear generators may be eligible for renewable energy certificates (RECs) that further depress the prices for all generation products.[11] Fossil fuel units may be taxed for their CO_2 emissions that increases their variable costs of generation.

ECONOMIC IMPACT MODELING ASSUMPTIONS AND STRATEGY

The economic model requires a timeline of costs and benefits to estimate the impact of a project on the regional economy.[12] For the hypothetical buildout of a nuclear or a CCGT plant, we assume each is a merchant plant such that the private sector bears all risk and reaps most of the benefit. In the "merchant model," the nuclear or CCGT plant delivers power into a competitive wholesale market without an assured rate of return. A nuclear or CCGT plant built by a

11 A Renewable Energy Certificate represents the environmental attributes of 1 MWh of electricity from a certified renewable generation source for a specific state's RPS. Providers of renewable energy are credited with RECs, which are usually sold or traded separately from the electric energy commodity.

12 We use the REMI economic and fiscal model of Connecticut provided by Regional Economic Models, Inc. of Amherst, MA. Appendix C provides an overview of the structure of the model.

regulated utility with construction costs approved and passed along to customers has greater certainty and could probably be financed at a lower cost of capital. This would reflect the fact that some of the construction, completion, operating and price risks are shared between the shareholders in the regulated utility and the customers of the regulated utility. In the merchant model, shareholders bear all risk.

For the case in which we add new baseload capacity, electricity users realize benefits from reduced wholesale electricity costs (see footnotes 3 and 29). In the case of a nuclear plant addition, the region's residents also benefit from the lack of emission of CO_2, SOx and NOx. In the case of a CCGT plant, electricity users experience additional CO_2 emission and the cost of emitting additional CO_2, whether it is taxed or not. This is because ratepayers absorb the costs of the current RGGI cap and trade system (see footnote 2) and of the effects of global warming even as they benefit from lower costs of electricity. Further, in the case of the CCGT plant and for purposes of this study, we assume that new natural gas infrastructure would need to be built to reach either assumed CCGT site and that there would be no adverse effect of the new plant on the gas supply for other gas users in the state.

If we displace higher cost marginal units with the addition of new baseload capacity, total sales of electricity may or may not increase in the ISO-NE region depending on the responsiveness of users to price changes and other factors related to the costs of doing business in the region. In fact, in the region, the instantaneous revenue lost by the displaced marginal units (some of which may be in Connecticut) exactly equals the revenue gained by the new baseload units because baseload units receive revenue based on the marginal units' bids. In the cases in which we add new baseload capacity and displace higher cost units, the new marginal price in the region will settle lower than before displacement. This is why there is a savings to ratepayers, as ISO-NE documents (see footnotes 3 and 29).

In the cases in which we add new CCGT or nuclear baseload capacity at Millstone or Connecticut Yankee, we assume the jobs displaced from the retiring marginal units in the ISO-NE region are absorbed by either new baseload plant in Connecticut. That is, the labor released from retiring plants migrates to new job opportunities in Connecticut created by the new plant's operation. In addition, we assume that the goods and services the displaced units previously purchased in the ISO-NE region are now purchased by the new Connecticut baseload plant in equal measure in the ISO-NE region. This "no net new" premise arises from assuming that the displaced marginal units are in Connecticut. If displaced marginal units are elsewhere, there will be net new job creation and net new procurement in Connecticut making the economic impacts larger. Thus, this assumption is the most conservative and defensible. *The actual number of net new jobs in and the net new purchases from the Connecticut economy created as a result of new plant construction is unknown.* In addition, this assumption implies there are no net new sales of electricity in the region as we assume regional demand is constant. Each new or replacement unit receives at least its levelized cost of electricity, otherwise it will shut down in the long run (see below).

We assume that the number and type of jobs released from retiring marginal plants are roughly equivalent to the number and type required in either new baseload plant. A reasonable modeling approach to such displacement is to construct the plant and reduce the cost of electricity to all Connecticut electricity users for the life of the plant. Thus, for purposes of this analysis, there are no employment changes, no changes in procurement and no new electricity sales in the utilities industry in Connecticut. The benefits of adding baseload capacity are exclusively construction of the plant and the subsequent wholesale electricity price reduction to users in the ISO-NE region and Connecticut in particular.

Using the direct inputs of construction expenditure and electricity price reduction (the drivers of economic and fiscal impact), the economic model for the state determines net new employment in each sector across the state and net new purchases from and taxes paid by all sectors based on historical relationships between sales and employment in the utilities sector and sales and purchases by the utilities sector from other sectors. The model determines and we report changes from a baseline or no-build (status quo) forecast of the Connecticut economy. For the cases in which we replace existing generating resources, we assume there would be no net new employment and no change in the purchases of goods and services or taxes because the jobs and procurement would transfer to and accrue from the retiring marginal generating assets in equal measure. The cost structure of the new plants may be lower than for the plants replaced and we cite the cost structures for new baseload plants based on studies cited below.

We assume that each plant receives its LCOE as the minimum revenue stream over the operating life of the plant that is required to avoid shutting down in the long run.[13] LCOE represents the constant (level) wholesale price generators receive over the life of a power plant that is necessary to cover all operating expenses, including taxes, and provide an acceptable return to investors. The calculation of the levelized cost of electricity provides a uniform way to compare the wholesale cost of energy across technologies because it takes into account the installed system price and associated costs such as financing, land, insurance, transmission, operation and maintenance and depreciation, among other expenses. For fossil-fueled plants, carbon emission costs can be taken into account as well. The calculation of the LCOE is the net present value of total life cycle costs of the power plant divided by the quantity of energy produced over the plant's life. Du and Parsons (2009) explain the detailed LCOE calculations and underlying assumptions for a 1,000 MWe CCGT, coal-fired and nuclear plant and implement them in a companion spreadsheet.[14] Du and Parsons (2009) provide the detailed source data and assumptions to support the Deutch, et al. (2009) report[15] that was an update of the Ansolabehere, et al. (2003) report.[16]

Overnight costs, all-in costs and busbar cost are three cost concepts that receive attention in the literature. Overnight costs are a hypothetical estimate of what it would cost if all the parts of the facility could be assembled and put together instantaneously. This cost concept isolates the raw material, manufacturing of components and labor costs. Overnight cost usually includes engineering-procurement-construction (EPC) costs and owner's costs,[17] but is net of financing

[13] It may be possible to cover the plant's average variable costs and not its average fixed costs in the short run; however, this situation cannot continue for long or the plant will shut down.

[14] Du, Yangbo and John E. Parsons (2009). "Update on the Cost of Nuclear Power," Center for Energy and Environmental Policy Research, 09-004, May. Available at http://web.mit.edu/ceepr/www/publications/working-papers.html.

[15] Deutch, J. M., Forsburg, C. W., Kadak, A. C., Kazimi, M. S., Moniz, E. J. and John E. Parsons (2009). "Update of the MIT 2003 Future of Nuclear Power," MIT Energy Initiative. Available at web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.

[16] Ansolabehere, S. Deutch, J., Driscoll, M., Gray, P. E., Holdren, J. P., Joskow, P. l., Lester, R. k., Moniz, E. J. and Neil E. Todreas (2003). "The Future of Nuclear Power: An Interdisciplinary MIT Study." Available at: http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf.

[17] Owner's costs include other infrastructure – transmission upgrades, cooling towers, water intake and treatment systems, administrative buildings, warehouses, roads, switchyards, as well as project management and development costs, permitting, taxes, legal, staffing and training.

costs and does not account for general (nominal) price inflation or real price escalation. Including finance costs yields "all-in" costs (sometimes called installed costs).

Other costs in addition to the cost of installing the facility must be incurred to generate electricity. Fuel, operation and maintenance and additional (incremental) capital costs must be recovered, while provisions must be made to dispose of nuclear waste and to ultimately decommission the nuclear facility. Combining these with the installed costs yields the busbar cost – the cost of delivering electricity to the point of interconnection with the grid. This cost of generation is the real world cost that generators present to the public utility commission for collection from ratepayers or LSEs. In constant, level dollar terms over the life of the plant, busbar cost is the LCOE. Further, in order to deliver electricity to the consumer, transmission and distribution costs are incurred. Finally, the consumer's electric bill reflects these latter and additional charges such as federally mandated congestion, system benefit and state debt reduction charges.

The LCOE of nuclear and CCGT plants calculated using the Du and Parsons (2009) model depends critically on several key operating parameters and financing factors. The most important LCOE element is the overnight cost and how it is treated financially. Studies cited in this report show that capital costs account for about three-quarters of the cost of nuclear-generated electricity. Financial parameters have a large impact on nuclear costs because nuclear reactors are capital-intensive and take a relatively long time to construct (four to six years versus two years for a CCGT plant). Return on investment and capital cost recovery are significant variables affecting the LCOE of a nuclear plant while the price of natural gas is the significant driver of the LCOE of a CCGT plant.

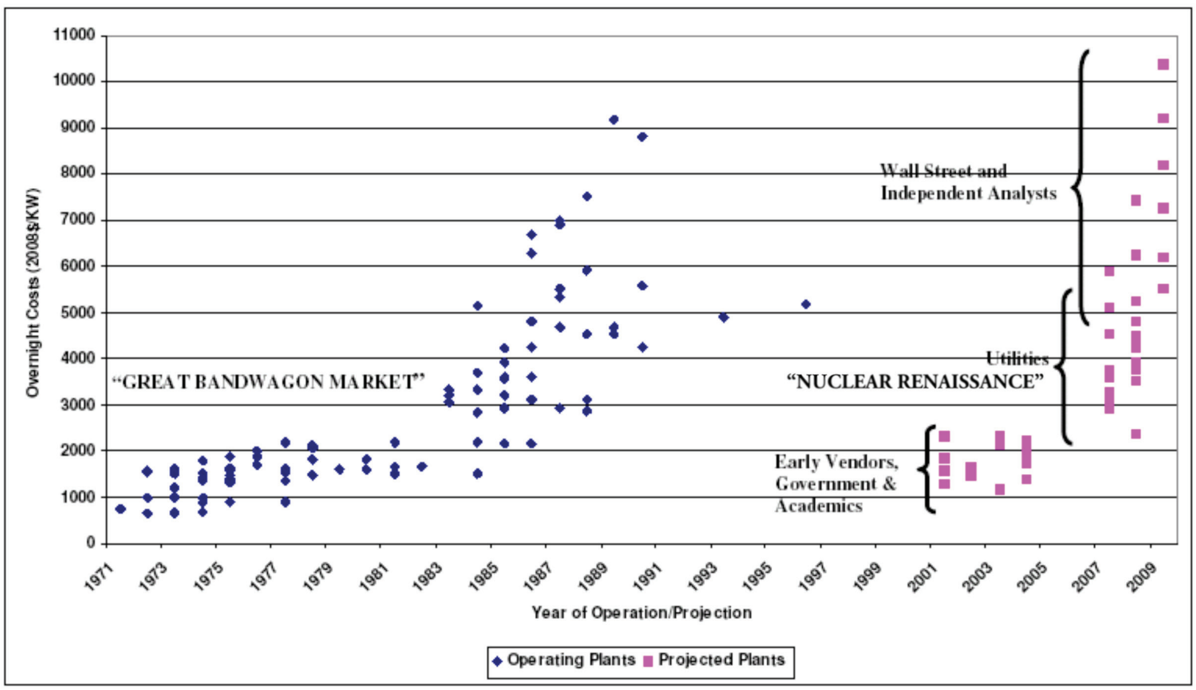
Plant characteristics are an important part of cost analysis with key parameters being plant life, capacity and performance. Operation and maintenance costs are the next most important cost category, followed by fuel costs. The ultimate impact of nuclear waste disposal and decommissioning costs has yet to be determined, in part because they have not yet been fully realized with permanent storage facilities and fully decommissioned large reactors. For the present study, we use a nuclear plant decommissioning cost based on Deutch, et al. (2009). Below, we perform a sensitivity analysis for each cost and operational parameter in the LCOE calculation.

LEVELIZED COST OF ELECTRICITY STUDIES

We cite several studies below as evidence of the wide variation in component and financing costs that determine the levelized cost of electricity and therefore the minimum revenue stream necessary for a plant to operate. In the present study, we do not consider the several incentives that might be available from the federal, state and local governments that reduce the cost of bringing (in particular) nuclear plants online because we have no idea what they are or might be for a given proposal. The costs and operational parameters used to determine the nuclear and CCGT plants' LCOE for this study appear below.

Several papers document the costs associated with constructing and operating fossil and non-fossil generating sources. In addition to the two MIT papers mentioned earlier, the University of Chicago studied the economics of nuclear power and gas- and coal-fired technologies as a nuclear plant's principal baseload competitors.[18] Using several sources for its cost components, the University of Chicago study estimates that the LCOE for new nuclear plants will range from $0.047/kWh to $0.071/kWh. Cooper (2009) reviews several studies that estimate various cost components and displays the wide range of overnight (Figure 1) and busbar (Figure 2) costs that emanate from these studies.[19] Cooper's (2009) bibliography contains the citation for each data point in Figures 1 and 2.

Cooper's (2009) review of prior studies shows that the busbar cost of combined cycle gas plants ranges from 67% to 113% of nuclear busbar cost (Figure 2). Cooper's table, showing estimates of nuclear overnight, all-in and busbar costs, illustrates their variability by study (Table 1 below; note busbar costs in Table 1 are expressed in 2008 dollars per megawatt hour).



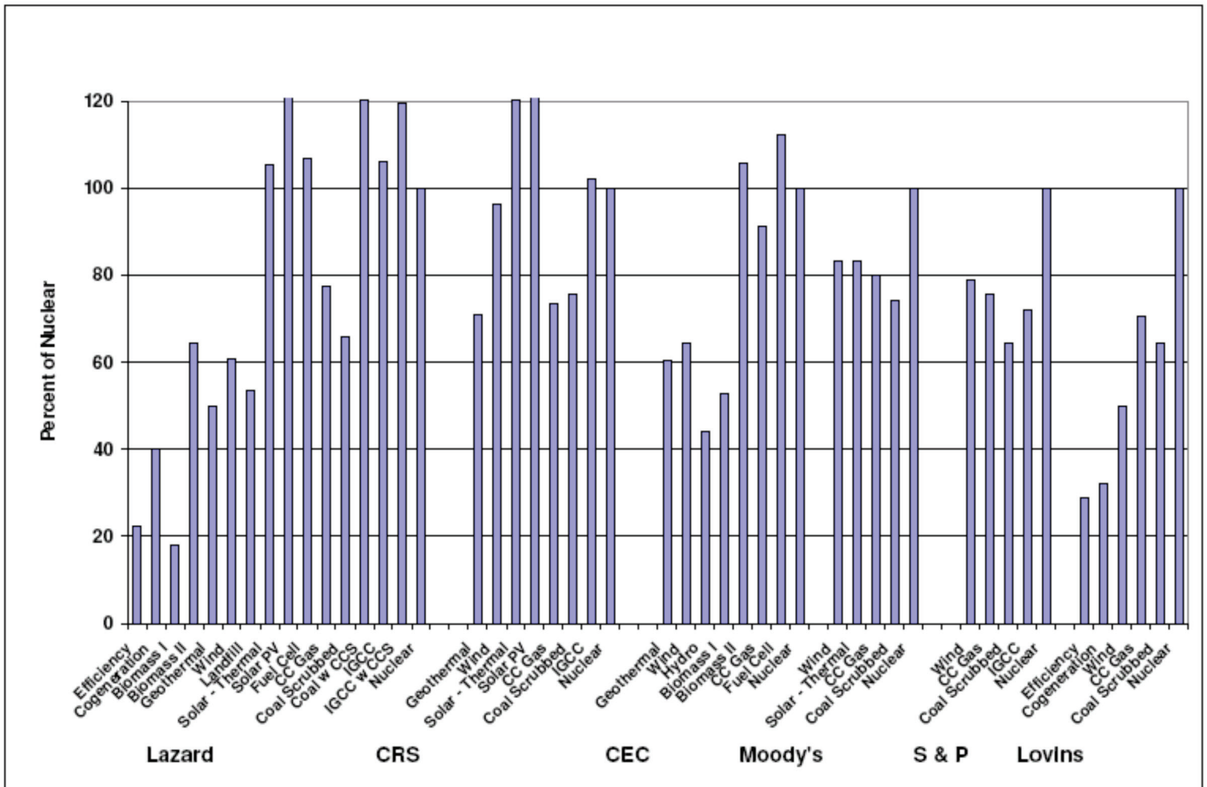
Sources: Koomey and Hultman, 2007, Data Appendix; University of Chicago 2004, p. S-2, p. S-8; University of Chicago estimate, MIT, 2003, p. 42; Tennessee Valley Authority, 2005, p. I-7; Klein, p. 14; Keystone Center, 2007, p.42; Kaplan, 2008 Appendix B for utility estimates, p. 39; Harding, 2007, p. 71; Lovins and Shiekh, 2008b, p. 2; Congressional Budget Office, 2008, p. 13; Lazard, 2008, Lazard, p. 2; Moody's, 2008, p. 15; Standard and Poor, 2008, p. 11; Severance, 2009, pp. 35-36; Schlissel and Biewald, 2008, p. 2; Energy Information Administration, 2009, p. 89; Harding, 2009. PPL, 2009; Deutch, et al., 2009, p. 6. See Bibliography for full citations.

Source: Cooper 2009

FIGURE 1: OVERNIGHT COST OF COMPLETED NUCLEAR REACTORS COMPARED TO PROJECTED COSTS OF FUTURE REACTORS

[18] Tolley, G. S. and Donald W. Jones (2004). "The Economic Future of Nuclear Power," August. Available at http://ebookee.org/The-Economic-Future-Of-Nuclear-Power-A-Study-Conducted-At-The-University-Of-Chicago-2004_130639.html.

[19] Cooper, M. (2009). "The Economics of Nuclear Reactors: Renaissance or Relapse?" Institute for Energy and the Environment, Vermont Law School, June. Available at http://www.vermontlaw.edu/Documents/Cooper%20Report%20on%20Nuclear%20Economics%20FINAL%5B1%5D.pdf.



Sources: See Figure 1-1.

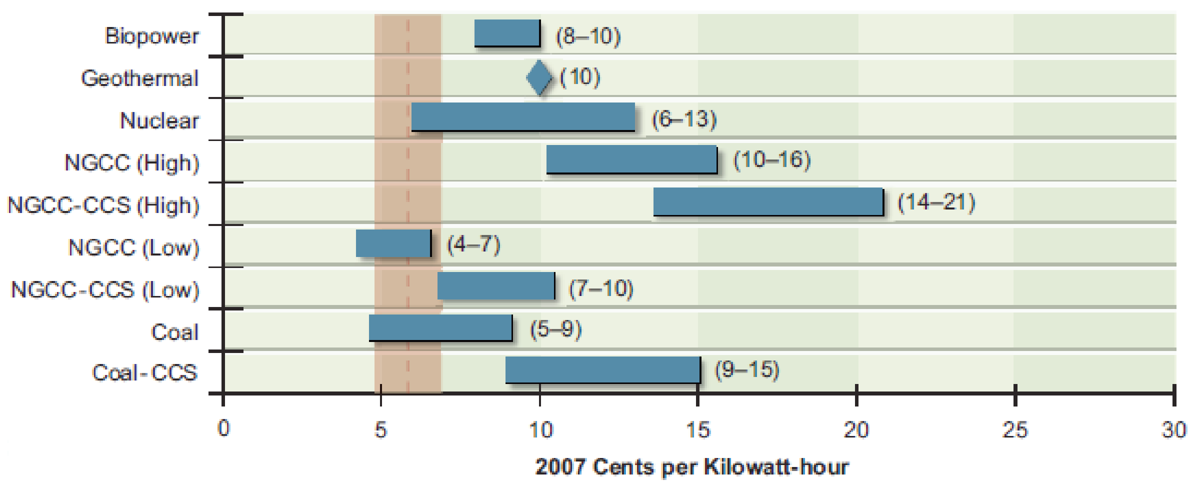
FIGURE 2: BUSBAR COSTS OF ALTERNATIVE ELECTRICAL ENERGY TECHNOLOGIES BY STUDY (NUCLEAR = 100 PERCENT)

TABLE 1: ESTIMATES OF NUCLEAR OVERNIGHT, ALL-IN AND BUSBAR COSTS, 2001 – 2008

Original Estimate	Date of Estimate	Source of Estimate	Overnight Cost 2008$/ kW			All-in Cost 2008$/kW			Busbar Costs (2008$/ mWh)		
			Low	Mid	High	Low	Mid	High	Low	Mid	High
SAIC	2001	U of C	2300	2300	2300				75	81	89
SAIC	2001	U of C	1840	1840	1840				69	61	63
SAIC	2001	U of C	1570	1570	1570				53	56	63
SAIC	2001	U of C	1295	12995	1295				45	52	74
Scully	2002	U of C	1434	1434	1674				41	46	51
Sandia	2002	U of C	2131	2131	2131				68		95
EIA	2003	U of C	215	2015	2217				72		78
EIA	2003	U of C	1241	1563	1784				49		61
MIT	2003	MIT	1175	2350					65	79	
U of C	2004	U of C	1380	1725	2070				61	71	82
TVA	2005	TVA		1853							
CEC	2007	CEC		3021			3840			106	
Keystone	2007	Keystone	3018		3018	3653		4092	85		114
Harding	2007	Harding		3329		4349		4655	96		125
South Texas 3&4	2007	CRS	2931	3214	3754						
Turkey Point 3&4	2007	CRS	3179	3179	4644						
Calvert 3	2007	CRS		5778							
Levy 1&2	2008	CRS		4260							
Summer 2&3	2008	CRS		4387							
Vogtle	2008	GA PUC		4381			6447				
Callaway 1	2008			4250			6125				
Duke	2008	Lovins		4800							
S&P	2008	S & P		4100							
DOE Loans	2008	DOE					6528				
EIA	2008	EIA		3400							
CRS	2008	CRS		3900						83	
CBO	2008	CBO		2358						74	
Lazard	2008	Lazard	3750		5250	5750		7550	100		126
Moody's	2008	Moody's		6250			7500			151	
Severance	2008	Severance	6233	7440		8858	10553		250	300	
MIT II	2009	MIT		4092						86	
Bell Bend	2009	PPL			9375						
Harding - Medium	2009	Harding 09	5524	7263	9217				137	173	212
Harding - High	2009	Harding 09	6189	8184	10383				150	190	235

Source: Cooper 2009

A 2009 National Research Council (NRC) report modeled the levelized cost of the various technologies that we display in Figure 3.[20] The cost ranges in Figure 3 arise from several factors including various assumptions about financing, capital costs, capacity factor and fuel costs, among others. For nuclear energy, the range is from $0.06/kWh to $0.13/kWh. The low end of the range corresponds to plants that secure low-cost financing through the DOE's loan guarantee program. As indicated in the 2009 NRC report, natural gas could be the lowest- or the highest-cost option, depending on the price of the fuel that has a cost range from $0.04/kWh to $0.16/kWh (and up to $0.21/kWh if gas prices are high and carbon capture and sequestration (CCS) technology is added). The NRC report states: "These levelized costs are higher than the current average cost of wholesale electricity [shown as a shaded, vertical bar in Figure 3], but they are likely to be comparable to future costs of electricity from other sources, particularly if fossil fuel plants are required to store CO_2 or pay a carbon fee."



Source: NRC 2009

FIGURE 3: LEVELIZED COST OF ELECTRICITY FOR NEW BASELOAD SOURCES

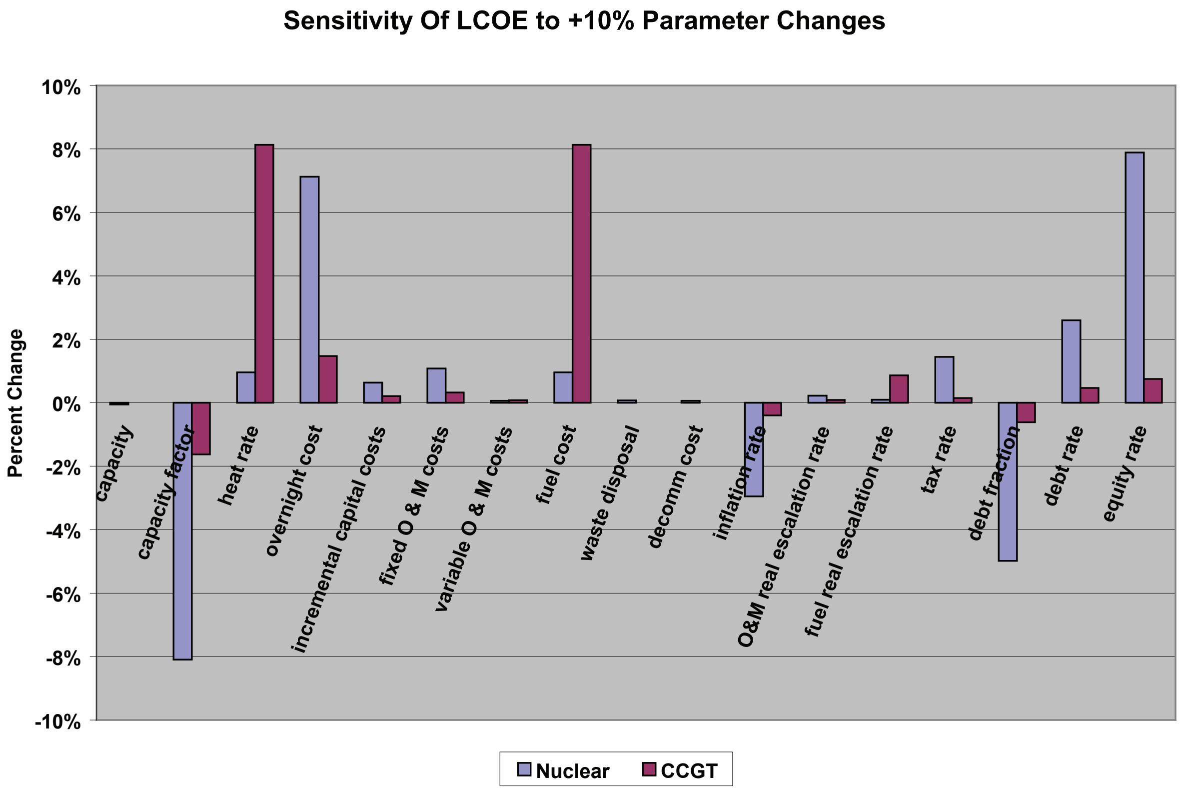
LEVELIZED COST OF ELECTRICITY SENSITIVITY ANALYSIS

To illustrate the sensitivity of LCOE to variation in its determinants, we increase each cost and operational parameter by 10% from the base case values (see below), while holding the other components' values and financing parameters fixed, and calculate, using the Du and Parsons (2009) model, the resulting change in LCOE for the two plants under consideration. Figure 4 shows the sensitivity of the LCOE for a 1,000 MWe CCGT and nuclear plant to small and positive changes in component costs. The LCOE sensitivity analysis is roughly symmetrical to small reductions in component costs.

We notice in Figure 4 that there are certain costs and financing parameters to which the LCOE of each type of plant is quite sensitive. In particular, a nuclear plant's LCOE declines by 8.1% if its capacity factor[21] increases by 10% relative to a 1.6% decline in the LCOE of a CCGT plant.

[20] Available at http://sites.nationalacademies.org/energy/energy_053920.

[21] Capacity factor is the ratio of the electric energy a generating unit produced for a certain period to the electric energy it could have produced at full operation during the same period.



Source: Du and Parsons (2009) and the authors' calculations.

FIGURE 4: SENSITIVITY OF THE LEVELIZED COST OF ELECTRICITY

This occurs because of the close correlation between the price and consumption of natural gas and the capacity factor and the smaller correlation between the price and consumption of nuclear fuel and the nuclear capacity factor. As the capacity factor increases, significantly more gas is required to generate the needed power relative to a negligible increase in nuclear fuel requirement. Moreover, nuclear fuel represents a significantly smaller part of the marginal cost of generation than does natural gas. Therefore, a 10% increase in capacity factor—for instance, from 90% to 99%—significantly reduces the LCOE of a nuclear plant without significantly increasing its fuel costs, while the same capacity factor increase for a CCGT plant raises its fuel costs noticeably and reduces the LCOE modestly.

The CCGT LCOE is quite sensitive to the heat rate that reflects the efficiency with which a unit of fuel is converted to electric energy. A 10% increase in the heat rate for a CCGT plant raises its LCOE by 8.1%, while for a nuclear plant a similar increase raises its LCOE by 0.85%. This reflects the close correlation of fuel and its cost to plant efficiency described above.

The LCOE for nuclear plants is quite sensitive to overnight cost because it is a larger part of the overall cost that must be recovered for a nuclear plant than it is for a CCGT plant. Increasing the inflation rate reduces the LCOEs for nuclear and CCGT plants. If the inflation rate increases by 10%, the LCOE for a CCGT plant decreases by 0.4% while for a nuclear plant, the LCOE declines by almost 3%. This is due to the inverse relationship between inflation and LCOE. The difference between the magnitudes of the decline is due to the higher real fuel escalation factor for natural gas (0.7%) than for nuclear (0.5%). The inflation rate multiplies the real fuel escalation rate raised to the power of the project year to yield the nominal cost escalation factor for fuel.

A 10% increase in the debt fraction significantly reduces the LCOE for a nuclear plant (-5.01%) while having little effect on the LCOE of a CCGT plant (-0.61%). The debt fraction affects the weighted average cost of capital (WACC) as we show in the equation for WACC.

$$WACC = DebtFrac * DebtReturn * (1 - Tax) + (1 - DebtFrac) * EquityReturn$$

For given tax rates and rates of return on debt and equity, an increase in the debt fraction corresponding to a decrease in the equity fraction reduces the WACC if the return on debt for nuclear multiplied by the net tax rate on nuclear is less than the return on equity for nuclear. A smaller WACC increases the discount rate that nominally reduces the quantity of energy produced over the plant's life. The discount rate is given by $Discount_i = 1/(1 + WACC_i)$, where i is the ith year of the plant's life. Conversely, a larger WACC decreases the discount rate that nominally increases the quantity of energy produced over the plant's life. Because the quantity of energy produced over the plant's life is proportional to fuel cost, the impact of an increase in the debt fraction reduces the nuclear LCOE more than it reduces the LCOE of a CCGT plant.

The effects of changes in the rates of return on debt and equity are similar for both plants: a 10% increase in either return rate increases the LCOE of each plant. However, the increases are significantly larger for a nuclear plant than for a CCGT plant (2.6% and 0.47% respectively for debt and 7.9% and 0.75% for equity). For a given tax rate, an increase or decrease in the rates of return on debt and equity unequivocally increases the WACC.[22] In turn, a larger WACC decreases the discount rate that nominally increases the quantity of energy produced over the plant's life. Because the quantity of energy produced over the plant's life is proportional to fuel cost, the impact of an increase in either rate of return affects the nuclear LCOE more than it affects the LCOE of a CCGT plant. Note that the difference between the nuclear plant's assumed return on equity (ROE) and the CCGT plant's ROE reflects the risk premium for investors in nuclear plant building.

Capacity, incremental capital costs, variable and fixed O & M costs as well as waste disposal and decommissioning costs are relatively insensitive to small (10%) changes in component costs and financing parameters. The effects of a large change in component costs and financing parameters may not be proportional to the effects of a small change (the model is nonlinear) and we restrict our attention to the case of small changes. As noted, it appears that the effects of small negative changes on LCOE are approximately symmetrical with small positive changes in component costs and financing parameters. Table 2 provides the detailed component cost changes from the Du and Parsons' (2009) base case and their effects on the LCOE of the nuclear and CCGT plants.

[22] This is because the partial change of *WACC* with respect to the return on debt is positive, as is the partial change of *WACC* with respect to the return on equity.

TABLE 2: SENSITIVITY OF SMALL CHANGES IN COMPONENT COSTS ON THE LCOE OF A NUCLEAR AND CCGT PLANT (40-YEAR ECONOMIC LIFE CASE)

	Sensitivity				
	Nuclear			CCGT	
Base case LCOE in 2007¢/kWh	**7.99**	**% Δ in LCOE**		**6.50**	**% Δ in LCOE**
10% change in capacity	7.98	-0.05%		6.50	0.00%
10% change in capacity factor	7.34	-8.09%		6.40	-1.63%
10% change in heat rate	8.07	0.96%		7.03	8.13%
10% change in overnight cost	8.56	7.13%		6.60	1.47%
10% change in incremental capital costs	8.04	0.63%		6.51	0.21%
10% change in fixed O & M costs	8.08	1.08%		6.52	0.32%
10% change in variable O & M costs	7.99	0.06%		6.51	0.08%
10% change in fuel cost	8.07	0.96%		7.03	8.13%
10% change in waste disposal	7.99	0.08%		NA	NA
10% change in decomm cost	7.99	0.06%		NA	NA
10% change in inflation rate	7.75	-2.95%		6.48	-0.40%
10% change in O&M real escalation rate	8.01	0.23%		6.51	0.09%
10% change in fuel real escalation rate	8.00	0.09%		6.56	0.87%
10% change in tax rate	8.10	1.44%		6.51	0.15%
10% change in debt fraction	7.59	-4.98%		6.46	-0.61%
10% change in debt rate	8.20	2.60%		6.53	0.47%
10% change in equity rate	8.62	7.89%		6.55	0.75%

Source: Du and Parsons (2009) and the authors' calculations.

NUCLEAR AND CCGT CONSTRUCTION AND OPERATIONAL COST ASSUMPTIONS

Du and Parsons (2009) use the cost and parameter values appearing below in their LCOE model (with the exception of the nuclear capacity factor that we increase to 90% for this study). The following assumptions yield a LCOE of $0.079/kWh for a nuclear plant and $0.065/kWh for a CCGT plant:

- Two potential sites exist for the construction of a nuclear power plant or a CCGT plant (Connecticut Yankee and Millstone).
- There is an unregulated electricity market, 1,000 MWe nuclear and gas-fired plants.
- An open, once-through nuclear fuel cycle with spent fuel stored onsite in SAFSTOR mode is used.
- Each plant is owned and operated by a merchant generating company

AP 1000 advanced pressurized water reactor:

40-year economic life (see below for a 60-year economic life LCOE estimate)
Capacity factor: 90% (increased from Du and Parsons [2009] study with new information)
Heat rate: 10,400 Btu/kWh
Overnight cost in 2007 dollars: $4,000/kWe
O&M fixed costs: $56.44/kW/yr
O&M variable costs: 0.42 mills/kWh
O&M real escalation rate: 1%/yr
Incremental capital costs: $40/kW/yr
Fuel costs: $0.67/mmBtu
Inflation rate: 3%/yr
Real fuel escalation rate: 0.5%/yr
Tax rate: 37%
Construction period: 5 years

Financing:
- Equity return: 15% nominal net of income taxes
- Debt return: 8% nominal
- Inflation: 3% annual
- Income Tax rate (applied after expenses, interest & tax depreciation): 37%
- Equity: 50%
- Debt: 50%
- Weighted Avg. cost of capital: 10%
- Depreciation: 15-year MACRS schedule[23]

Waste fee: 1 mill/kWh
Decommissioning cost: $700 million in 2007 dollars
Construction schedule: startup year - 5=10%, year - 4=25%, year - 3=31%, year - 2=25%, year - 1=10%

Natural Gas CCGT:

40-year economic life
Capacity factor: 85%
Heat rate: 6,800 Btu/kWh
Overnight cost in 2007 dollars: $850/kWe
Incremental capital costs: $10.20/kWh/yr
O&M fixed costs: $12.65/kW/yr
O&M variable costs: 0.41 mills/kWh
O&M real escalation rate: 1%/yr
Fuel cost: $7.00/mmBtu
Inflation rate: 3%/yr

[23] The Modified Accelerated Cost Recovery System (MACRS) is the current tax depreciation system in the United States. Under this system, the capitalized cost (basis) of tangible property is recovered over a specified life by annual deductions for depreciation. The lives are specified broadly in the Internal Revenue Code. The IRS publishes detailed tables of lives by classes of assets. The deduction for depreciation is computed under one of two methods (declining balance switching to straight line or straight line) at the election of the taxpayer, with limitations.

Real fuel cost escalation rate: 0.5%/yr
Tax rate: 37%
Construction period: 2 years, half in each year

Financing:
- Equity return: 12% nominal net of income taxes
- Debt return: 8% nominal
- Inflation: 3%/yr
- Income Tax rate: 37%
- Equity: 40%
- Debt: 60%
- Weighted Avg. cost of capital: 7.8%
- Depreciation: 15-year MACRS schedule (identical to the nuclear plant)

Carbon intensity: 14.5 kg-C/mmBtu
Carbon Cost: $0/tCO_2$ (see below for other assumptions)
Construction schedule: startup year - 2=50%, year - 1=50%

We can vary individual costs and operational parameters to illustrate a variety of LCOE scenarios. For example, if we assume a 60-year operational life for the nuclear plant, the LCOE drops to \$0.076/kWh or by \$0.003/kWh. To illustrate the uncertainty in the future price of natural gas, we increase the real escalation rate for the price of natural gas to 1.64% from 0.5% in the base case.[24] This yields a CCGT LCOE of \$0.079/kWh, identical to the base case LCOE for nuclear (with a 40-year economic life). In contrast to our assumed higher escalation rate, the RGGI reference case analysis estimates that the delivered price of natural gas into the ten-state, northeast region will escalate from \$4.30/mmBtu in 2010 to \$8.10/mmBtu in 2030 or a price growth rate of 3.2% per year.[25]

The imposition of a carbon charge, whether a tax or cap and trade cost, has the same effect as the high escalation of the price of natural gas. We note that using the Du and Parsons' (2009) model, a \$41.17 tax or surcharge per ton CO_2 equalizes the LCOE for nuclear and CCGT plants at \$0.079/kWh. This contrasts with the current RGGI price of \$1.90 per ton CO_2. Using \$1.90/tCO_2, the LCOE for CCGT increases to \$0.0657/kWh relative to \$0/tCO_2. Table 3 summarizes the alternate versus the Du and Parsons parameter values we alter for comparison purposes only. The LCOE value has no effect on the economic impact analysis because we assume the merchant operator receives at least its LCOE, otherwise it would shut down in the long run. Recall there are no net new electricity sales in the region.

[24] The high escalation rate represents an increase of 113% in year 40 over the price in year one, while the base case escalation rate represents a 22% increase.
[25] This represents a compound annual growth rate (CAGR). Slide 36 in the "RGGI Reference Case Results and Assumptions," November 5, 2010. Available at: http://www.rggi.org/docs/RGGI_Reference_Case_110510.pdf.

Also see slide 11 in "DRAFT Sensitivity Case Results and Assumptions," November 5, 2010. Available at: http://www.rggi.org/docs/RGGI_Sensitivity_Cases_110510.pdf. If we start at \$7/mmBtu, the price growth rate drops to 0.73% CAGR.

TABLE 3: ALTERNATIVE PARAMETER VALUES AND CORRESPONDING LCOEs

	Parameter Value		LCOE ($/kWh)	
Parameter	Alternate	Du & Parsons	Alternate	Du & Parsons
Nuclear Economic Life	60 years	40 years	$0.076	$0.079
Gas Real Escalation Rate	1.64%	0.5%	$0.079	$0.0650
CO_2 Tax ($t/$CO_2$)	$41.17	$25	$0.079	$0.074
	$1.90	$25	$0.0657	$0.074
	NA	$0	NA	$0.0650

NATURAL GAS PRICING

If the price of natural gas increases for any reason, all users everywhere will feel the effects because there is a "national price" subject to variation in delivery costs. To the extent that Connecticut and New England experience higher natural gas prices only because of our distance from sources, we assume that as the price of natural gas rises, Connecticut will experience no additional cost premium for delivery.[26] Therefore, assuming there is a national price for natural gas, Connecticut gas users will not be at a greater disadvantage than users in other states as the national price of natural gas rises.[27] Consequently, the high natural gas price escalation case confers no relative competitive disadvantage on the state. Two effects of a high escalation of the price of natural gas are that nuclear power would become more competitive with CCGT power in terms of their relative LCOEs and that users would seek to reduce their penalty for using gas by seeking lower cost alternatives as well as by reducing their usage.

ADDING BASELOAD CAPACITY

Irrespective of a higher price for natural gas, increased baseload capacity confers local benefit by displacing higher-priced generating resources in the region. This effect is quantified in the June 2006 ISO-NE report, "Electricity Costs White Paper."[28] This report shows that adding 1,000 MWe of baseload capacity to the grid reduces wholesale costs by 5.7% for users in New England. The ISO-NE report assumes that new baseload resources include low-fuel-cost technologies such as renewables, clean coal and nuclear that displace higher-cost, marginal power plants. The ISO-NE report considers that a moderately efficient marginal gas unit has a heat rate of 8,500 Btu/kWh, while the CCGT unit we consider in this study has a heat rate of 6,800 Btu/kWh that is 25% more efficient and may be reasonably considered to qualify as baseload power. If wholesale costs represent approximately 50% of the retail cost to consumers

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26 There are in fact pipeline improvements in progress and the increasing Marcellus shale gas availability makes the high escalation case less probable. See the Northeast Gas Association presentations from its 2011 Market Trends Forum, April 13, 2011 at http://66.241.193.5/index.php?option=com_content&task=view&id=228&Itemid=96.

27 The exception to this situation is one in which there are regional differentials in carbon costs because of regional cap and trade or carbon taxes. This is the case with the RGGI (see footnote 5); however, at the current cost of $1.90 per ton of CO_2, there is little competitive disadvantage to New England's gas prices relative to the rest of the country. We assume natural gas delivery costs set New England apart.

28 Available at: www.iso-ne.com/pubs/whtpprs/elec_costs_wht_ppr.pdf. See footnote 1 as well.

as the June 2006 ISO-NE report suggests, then the realized savings to all sectors of the New England economy from adding 1,000 MWe to the New England grid are roughly 2.85%. In particular, electricity costs to Connecticut ratepayers decline by 2.85%.

For modeling purposes in the present study, we assume the electricity price reduction affects the industrial, commercial and household sectors equally. Therefore, each sector will experience an annual reduction in its cost of electricity of 2.85% over the assumed 40-year operating life of each plant irrespective of the type of baseload capacity added to the ISO-NE grid. It is not possible to determine the dollar savings to Connecticut ratepayers over the economic life of either plant because the 2006 ISO-NE study quantifies the savings in dollar terms for the entire region.

Because we assume displaced marginal units are in Connecticut, there is no net new job creation, procurement or electricity sales in the state. If displaced marginal units are elsewhere, there will be net new job creation and net new procurement in Connecticut making the economic impacts larger. Thus, this assumption is the most conservative and defensible. Each new or replacement unit receives at least its levelized cost of electricity; otherwise, it will shut down in the long run.

REPLACEMENT SCENARIOS: GENERAL MODELING ASSUMPTIONS

In these cases, we assume a 1,000 MWe AP 1000 nuclear unit or a 1,000 MWe CCGT plant replaces an equivalent amount of existing nuclear power generation at Millstone. We assume Dominion owns and operates either new plant. There is no net new addition to grid baseload capacity and no net new employment or procurement of goods and services from the Connecticut economy because we assume that the existing workforce remains in place and that Dominion's historical purchasing pattern does not change.[29] We assume workers at Millstone receive the utilities' industry average compensation and live in Connecticut.[30]

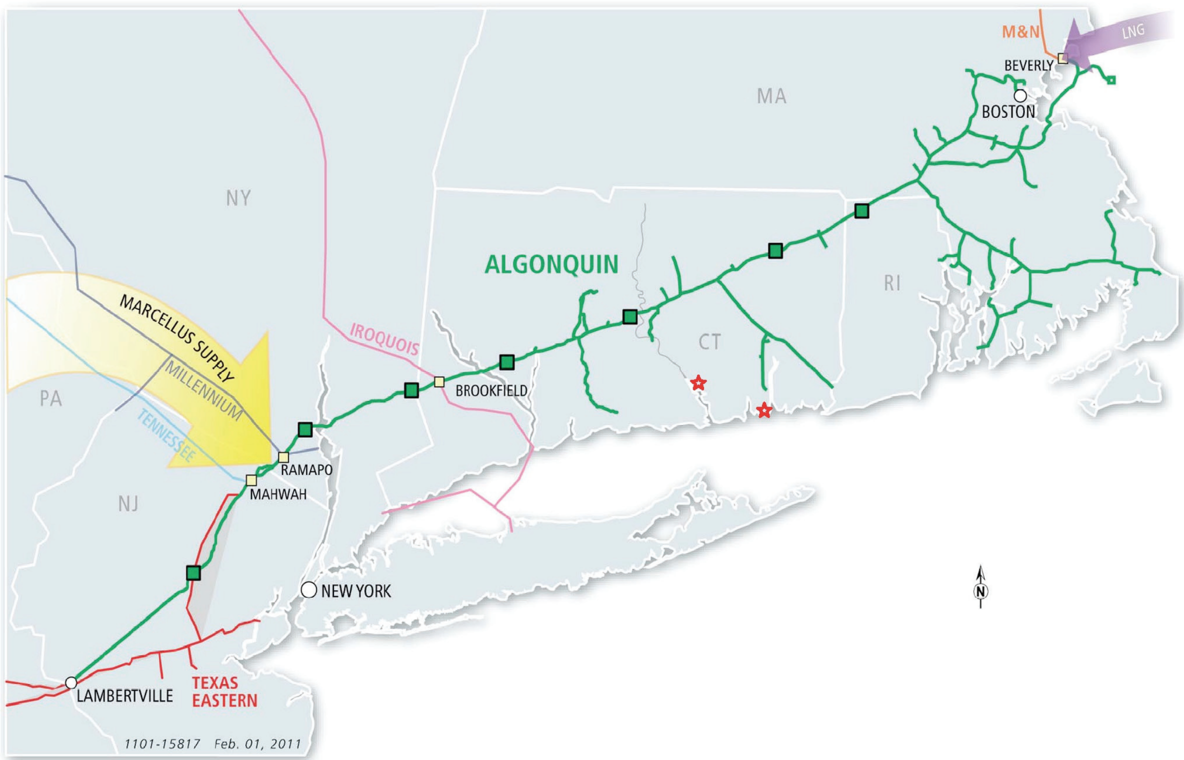
In one scenario, the economic benefit to the region is the construction of the new nuclear plant and the decommissioning of a retiring nuclear unit. We assume construction began in 2009 and lasts for five years and that decommissioning of the existing plant begins in 2014 when the new unit is at full power. The Connecticut economic model simulation horizon begins in 2009 and ends in 2050. For purposes of this analysis, we begin the simulations in 2009 and end them in 2050 the last year available for model results. We assume as in Du and Parsons (2009) that the vendor engineering, procurement, and construction (EPC) overnight cost is $3.333 billion (in 2007 dollars) and that construction outlays are 10%, 25%, 31%, 25% and 10% of this total cost over the five-year construction period. Including owner's costs and using a 3% inflation rate, nominal, annual construction expenditure is $405 million, $1,093 million, $1,391 million, $1,159 million and $456 million for a total construction cost of $4,504 million. We assume the cost to decommission the retiring nuclear plant is $887 million commencing in 2014 ($700 million

29 See the 2003 Nuclear Energy Institute study of Millstone at http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/economicbenefitsstudies/millstone and the March 25, 2011 study by Chmura Economics & Analytics, "The Economic Impact of the Millstone Power Station in Connecticut," (www.chmuraecon.com).

30 If some workers live in other states, we adjust the impact according to the wages and salaries flowing out of state. In this case, household consumption takes place outside Connecticut and the benefit of net new Connecticut employment is reduced.

inflated at 3% per year; see footnote 4). We assume there is no added cost for spent fuel storage because existing resources can accommodate existing, new and decommissioned unit spent fuel storage. We assume as well that there is no net change in the plant's property value for local taxation.

Alternatively, a new 1,000 MWe CCGT unit replaces an equivalent amount of existing nuclear power at the Millstone campus. We assume Dominion owns and operates the new plant. As above, there is no net new addition to baseload capacity and no net new employment or purchasing of goods and services from the Connecticut economy because we assume that the existing workforce remains in place and that Dominion's regional and historical purchasing pattern does not change.[31] The economic benefit to the region is the construction of the new CCGT plant and the decommissioning of a retiring nuclear unit. In addition, we assume that a gas pipeline extension will be built from the existing closest terminus of the Algonquin pipeline to the Millstone campus or to the Connecticut Yankee site (red stars in Figure 1 below).



Source: Spectra Energy (http://www.spectraenergy.com/Operations/US-Transmission/Pipeline-Assets/Algonquin-Gas-Transmission

FIGURE 1: ALGONQUIN PIPELINE IN CONNECTICUT

We assume CCGT plant construction begins in 2012 and lasts for two years and that decommissioning of an existing Millstone nuclear plant begins in 2014 when the new CCGT

31 It is conceivable that total employment at the Millstone campus could decline because the CCGT may not require the operation and maintenance workforce that a nuclear plant does. We assume for purposes of this study that employment does not decline because we have no credible quantitative evidence for a net job loss.

unit is at full power. We assume as in Du and Parsons (2009) that the vendor EPC overnight cost is $850 million (in 2007 dollars) and that construction outlays are equal (in constant 2007 dollars) over the two-year construction period. Including owner's costs and using a 3% inflation rate, nominal, annual construction expenditure is $493 million and $507 million for a total construction cost of $1,000 million. We assume as well that there is no net change in the property value for local taxation.

We assume the cost to decommission the retiring nuclear plant is $887 million commencing in 2014 ($700 million inflated at 3% per year; but see footnote 4). We assume there is no added cost for spent nuclear fuel storage because existing resources can accommodate existing, new and decommissioned spent fuel storage. We assume the natural gas pipeline extension cost is approximately $5 million per mile[32] and the distance from the closest pipeline terminus to the Millstone campus or Connecticut Yankee site is approximately 10 miles. We assume construction of the pipeline extension takes two years and over this period, $25 million is expended in 2012 and 2013. Adding a CO_2 emitting plant makes Connecticut's compliance with its RPS and the RGGI more difficult and increases the region's vulnerability to natural gas price fluctuations; we do not quantify these effects.

For the scenario in which the price of natural gas escalates at 1.64% per year relative to 0.5% per year in the base case (other CCGT cost and financing assumptions remain identical to the base case), the merchant operator receives additional revenue but produces no additional output. The increased natural gas price may translate into higher bid prices in the electricity market, but marginal units will still bid higher than the CCGT baseload plant and we assume the CCGT merchant operator (Dominion) will cover its average total cost with proceeds from other markets; otherwise, it will shut down in the long run.

Higher natural gas prices in the region produce no changes in the merchant's income taxes because we assume its profits remain unchanged as costs and revenues increase in lockstep. There will be no changes in the merchant's employment, wages, procurement or property taxes due to higher gas prices because as a baseload unit, it must commit to deliver its power regardless of the fuel cost. Because New England uses natural gas to produce most of its electricity (about 52%), wholesale and retail prices of electricity correlate highly and positively with natural gas prices.[33] However, adding a CCGT baseload unit increases the region's CO_2 emission and its vulnerability to natural gas price fluctuations, reduces its fuel diversity and drives up the demand for gas, potentially competing for residential, commercial and industrial uses. As explained above, we assume the high escalation of the price of natural gas confers no relative competitive disadvantage on the state. A higher natural gas price translates into higher wholesale cost that will likely be passed to consumers because (gas-fired) marginal units dictate the price received by all generators. Finally, adding another CO_2-emitting plant makes Connecticut's compliance with its RPS and the RGGI more difficult.

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32 Estimates range from $1 million to $10 million from the Algonquin and Iroquois pipelines and Southern Connecticut Gas. We use the mean value.

33 ISO-NE Annual Markets Report 2009, footnote 13 on page 4, discussion bottom of page 6 and Figure 1-3, page 7.

Adding Generating Capacity at the Millstone Campus

In these cases, we model the addition of a CCGT or an AP 1000 nuclear reactor to the Millstone campus. We assume Dominion owns and operates these plants. Recall that adding baseload capacity displaces marginal production. Therefore, in each subcase, there is no net new addition to the ISO-NE generating capacity (only the composition of the region's generating resources changes). Further, there are no changes in employment or purchases of goods and services from the Connecticut economy, though the existing Millstone workforce expands incrementally by absorbing the workers released from retiring marginal units in the region.

Further, we assume that Dominion's regional and historical purchasing pattern increases incrementally; however, the composition of bulk purchases changes significantly in the case of a CCGT plant addition. The incremental procurement increase is absorbed from what was given up by the displaced units in the region (we assume displaced units are primarily gas fired and displaced marginal units are in Connecticut). We assume the skills and competencies of the workforce released from displaced marginal units transfer to the operation and maintenance of the new CCGT or AP 1000 plant at Millstone (and we assume cross-training occurs). We assume, therefore, there is no net new employment in the state. The CCGT plant addition would increase Connecticut's natural gas consumption. The economic benefit to the region is the construction and operation of the new nuclear or CCGT plant and the reduction in the wholesale electricity price as described above. For modeling purposes, we assume workers at Millstone receive the utilities' industry average compensation and live in the state (see footnote 31).

For the addition of a nuclear plant, we assume construction began in 2009 and lasts for five years and that decommissioning begins in 2054 (see footnote 4) when the new unit reaches the end of its (assumed 40-year) economic life. We assume as in Du and Parsons (2009) that the vendor EPC overnight cost is $3.333 billion (in 2007 dollars) and that construction outlays are 10%, 25%, 31%, 25% and 10% of this total cost over the five-year construction period. Including owner's costs and using a 3% inflation rate, nominal, annual construction expenditures are $405 million, $1,093 million, $1,391 million, $1,159 million and $456 million for a total construction cost of $4,504 million. Using a three percent inflation rate, the cost to decommission the unit rises from the Du and Parsons (2009) assumed 2007 cost of $700 million to $4,924 million in nominal dollars commencing in 2054 (see footnote 4; note that the decommissioning cost is included in the LCOE for the nuclear plant). We assume there is no added cost for spent fuel storage because existing resources can accommodate existing, new and decommissioned spent fuel storage.

Alternatively, a new 1,000 MWe CCGT unit complements the existing nuclear reactors at the Millstone campus. We assume construction begins in 2012 and lasts for two years and that operation commences in 2014. We assume as in Du and Parsons (2009) that the vendor EPC overnight cost is $850 million (in 2007 dollars) and that construction outlays are equal (in constant 2007 dollars) over the two-year construction period. Including owner's costs and using a 3% inflation rate, nominal, annual construction expenditure is $493 million and $507 million for a total construction cost of $1,000 million. In addition, we assume a gas pipeline will need to extend to the Millstone campus from the existing Algonquin pipeline (Figure 1). We assume the cost is approximately $5 million per mile and the distance from the closest pipeline terminus to the Millstone campus is about 10 miles. We assume construction of the pipeline extension takes two years and over this period, $25 million is expended in equal increments.

The scenario in which the price of natural gas escalates at 1.64% per year relative to 0.5% per year in the base case (other cost and financing assumptions remain identical to the base case) is described above. As described above, we assume the high escalation of the price of natural gas confers no relative competitive disadvantage on the state.

Adding Generating Capacity at the Connecticut Yankee Site

In this case, we model the addition of a CCGT or an AP 1000 nuclear reactor to the Connecticut Yankee site. In each subcase, there is no net new addition to grid generating capacity and no net new employment and goods and services purchases from the Connecticut economy (recall adding baseload displaces marginal units, their workers and procurement, which are absorbed by the new plants). We assume a merchant other than Dominion owns and operates either plant at the Connecticut Yankee site. *The only difference between locating either plant at the Connecticut Yankee site and the Millstone campus is ownership.* In the case of a plant addition at Millstone, we assume Dominion owns the new plant and incrementally increases its employment and procurement that it absorbs from the displaced marginal units. In this scenario, Dominion's employment does not change and the Connecticut Yankee merchant hires sufficient workers from the displaced marginal plants' pool of workers to operate and maintain the new plant. For modeling purposes, we assume workers at the Connecticut Yankee site receive the utilities' industry average compensation and live in Connecticut (see footnote 31).

The economic benefit to the region is the construction of the new CCGT or AP 1000 nuclear plant and a reduction in the wholesale price of electricity. The construction schedules, costs and financing parameters for each plant are identical to the scenarios for additions at Millstone given above. For the addition of a CCGT at the Connecticut Yankee site, we assume a gas pipeline will need to extend to the site from the existing Algonquin pipeline (see Figure 1). We assume the cost is approximately $5 million per mile and the distance from the closest pipeline terminus to the Connecticut Yankee site is about 10 miles. We assume construction of the pipeline extension takes two years and over this period, $25 million is expended in each year. The scenario in which the price of natural gas escalates at 1.64% per year relative to 0.5% per year in the base case (other cost and financing assumptions remain identical to the base case) is as explained above.

ECONOMIC IMPACT RESULTS: REPLACEMENT SCENARIOS

In the cases in which a nuclear or CCGT plant replaces equivalent capacity at the Millstone campus, the benefit accruing to the region is exclusively new construction and decommissioning activity. We assume there are no changes in revenue received by Dominion or in its employment or procurement. Table 4 summarizes the direct impacts of construction expenditures. Decommissioning represents expenditure for that purpose in one year that actually spans many years.

TABLE 4: CONSTRUCTION, DECOMMISSION AND PIPELINE EXPENDITURES FOR REPLACEMENT SCENARIO (IN NOMINAL MILLION $)

	2009	2010	2011	2012	2013	2014	Total
Nuclear plant construction & nuclear decommission	$405	$1,093	$1,391	$1,159	$456	$887	$5,391
CCGT plant construction & nuclear decommission				$493	$507	$887	$1,887
Pipeline construction				$25	$25		$50
Total CCGT				$518	$532	$887	$1,937

Source: Du and Parsons (2009) for construction and decommissioning costs. See footnote 33 for pipeline costs.

Table 5 illustrates the economic impacts for the case in which a new nuclear plant replaces an existing nuclear plant at Millstone in terms of changes in employment, output (sales), state gross domestic product (GDP) and net state revenue.[34] These changes from the economic model's baseline forecast arise from the ripple or multiplier effects of the direct impacts in Table 4 and accrue to the state as a whole. The benefit of replacement accrues for the duration of construction and decommissioning (see footnote 4). Thereafter, the employment, output and tax revenue and expenditure effects dissipate quickly as the region returns to its pre-construction baseline level of economic activity. We therefore show no economic effects beyond 2014 because we collapse the decommissioning period into one year to capture its economic effect. The actual timing and amount of decommissioning outlays is unknown.

[34] Net state revenue is the revenue from all domestic (in-state) sources less expenditure for all domestic uses.

Table 5: Economic Impact of Nuclear Plant Replacement by a Nuclear Plant at Millstone

Economic Variable	2009	2010	2011	2012	2013	2014
Total new employment	7,993	20,320	24,756	19,249	6,021	12,087
New Private Non-Farm Employment	7,569	19,257	23,484	18,291	5,721	11,510
New Construction Jobs	5,708	14,660	18,194	14,636	5,365	9,922
New Manufacturing Jobs	125	299	327	209	2	75
New Wholesale Trade Jobs	135	334	395	298	85	171
Retail Trade	348	895	1,082	852	280	514
New Finance & Insurance Jobs	47	103	90	14	NA	NA
New Real Estate, Rental and Leasing Jobs	104	240	236	79	NA	NA
New Professional & Technical Services Jobs	191	464	519	321	NA	71
New Administrative & Waste Services Jobs	155	378	427	280	NA	100
New Educational Services Jobs	27	71	91	76	NA	48
New Health Care and Social Assistance Jobs	305	754	879	630	NA	359
New Arts, Entertainment & Recreation Jobs	42	105	126	95	NA	53
New Accommodation & Food Services Jobs	131	340	427	348	NA	220
New Other Services, except Public Administration Jobs	211	522	608	434	NA	225
New State GDP (mil nominal $)	$460.5	$1,214.9	$1,495.1	$1,161.2	$313.4	$725.5
New Output (mil nominal $)	$780.5	$2,051.6	$2,516.2	$1,948.9	$530.0	$1,207.3
New Personal Income (mil nominal $)	$393.6	$1,055.8	$1,400.3	$1,225.8	$556.5	$902.2
New State Revenues (mil nominal $)	$51.07	$123.40	$155.99	$132.90	$60.03	$99.89
New State Expenditures (mil nominal $)	-$26.72	-$67.30	-$62.68	-$14.80	$59.50	$27.21
Net New State Revenue (mil nominal $)	$77.78	$190.70	$218.66	$147.70	$0.53	$72.67

Source: The REMI model.

Total employment includes full- and part-time people who work in firms and those who are independent contractors, sole proprietors or otherwise self-employed, as well as federal, state and local government workers. Private, non-farm employment includes full- and part-time payroll jobs in firms and no agricultural or public sector jobs. Subsequent rows represent changes in the number of full- and part-time jobs in other sectors of the state economy. In 2013 and 2014, several sectors have insignificant job growth that we indicate by "NA." For reference, Connecticut total employment in 2010 was 1,723,900 people on average throughout the year and the state's non-farm employment averaged 1,609,000 jobs throughout 2010. Over the analysis period (2009 through 2014), the reported employment changes range from 0.26% to 1.22% for total and non-farm employment with respect to employment forecasts in the economic model.

Over the analysis period (2009 through 2014), changes in state GDP, personal income and output (sales of all sectors) range from 0.12% to 0.66% for GDP (for reference, Connecticut GDP in 2009 was $220.4 billion) and from 0.2% to 0.72% for personal income (for reference, Connecticut personal income in 2009 was $194.5 billion) with respect to employment forecasts in the economic model. State revenue changes range from 0.24% to 0.68% (for reference, FY 2009 state revenue derived from domestic sources was approximately $12 billion) with respect to employment forecasts in the economic model. State expenditure changes from the baseline forecast turn negative (that is, state expenditure is less than forecast absent the construction project) as employment increases and people reduce their need for social insurances and transfers. However, as employment grows, people migrate to the state in search of work and the demand for public services increases that in turn increases public expenditure even as tax revenues increase.

Table 6 shows the economic impacts for the case in which a new CCGT plant replaces an existing nuclear plant at Millstone in terms of changes in employment, output (sales), state gross domestic product (GDP) and net state revenue. These changes from the economic model's baseline forecast arise from the ripple or multiplier effects of the direct impacts in Table 4 and accrue to the state as a whole. The economic benefit of replacement accrues for the duration of construction (2009 through 2013). In 2014, the retiring plant is decommissioned and there is a spike in construction-related expenditure for that purpose as we collapse the multi-year decommissioning period into one year (see footnote 4) for modeling purposes. Thereafter, the employment, output and tax effects dissipate quickly as the region returns to its pre-construction baseline economic activity. We therefore show no economic effects beyond 2014 because we collapse the decommissioning period into one year to capture its economic effect. The actual timing and amount of decommissioning outlays is unknown.

Table 6: Economic Impact of Nuclear Plant Replacement by a CCGT Plant at Millstone

Economic Variable	2012	2013	2014
New Total employment	8,685	8,368	13,679
New Private Non-Farm Employment	8,250	7,948	13,013
New Construction Jobs	6,263	6,187	10,245
New Manufacturing Jobs	121	104	161
New Wholesale Trade Jobs	137	127	201
New Retail Trade Jobs	373	352	563
New Transportation & Warehousing Jobs	11	6	7
New Information Jobs	22	18	27
New Finance & Insurance Jobs	48	30	41
New Real Estate, Rental and Leasing Jobs	113	79	114
New Professional & Technical Services Jobs	206	176	270
New Administrative & Waste Services Jobs	164	142	222
New Health Care and Social Assistance Jobs	327	296	491
New State GDP (mil nominal $)	$543.60	$531.23	$862.80
New Output (mil nominal $)	$917.12	$895.18	$1,429.11
New Personal Income (mil nominal $)	$472.00	$507.80	$843.20
New State Revenues (mil nominal $)	$50.45	$51.08	$84.36
New State Expenditures (mil nominal $)	-$37.20	-$26.62	-$42.65
Net New State Revenue (mil nominal $)	$87.65	$77.71	$127.01

Source: The REMI model.

Total employment includes full- and part-time people who work in firms and those who are independent contractors, sole proprietors or otherwise self-employed, as well as federal, state and local government workers. Private, non-farm employment includes full- and part-time payroll jobs in firms and no agricultural or public sector jobs. Subsequent rows represent changes in the number of full- and part-time jobs in other private sectors of the state economy. In 2011, several sectors have insignificant job growth that we indicate by "NA." The reported employment changes from the baseline forecast range from 0.36% to 0.59% to 0.64% for total and non-farm employment with respect to employment forecasts in the economic model. The increase above the baseline in total employment in 2013 is smaller than the increases in the earlier years because the construction outlays in 2013 are smaller than in the earlier years. The larger employment increase in 2014 is due to the decommissioning of the retiring nuclear plant for which construction-related expenditure is larger than in 2013. Decommissioning can take up to 20 years and we compress the time into one year to capture the effect. The actual timing and amount of decommissioning outlays is unknown.

Over the analysis period, changes in state GDP, personal income and output (sales of all sectors) range from 0.22% to 0.34% for GDP and from 0.22% to 0.36% for personal income with respect to employment forecasts in the economic model. State revenue changes range from 0.197% to 0.25%. State expenditure changes turn negative (that is, expenditures are less than the baseline forecast) when employment increases and people reduce their need for social insurance and transfers. However, as employment grows, people migrate to the state in search of work and the demand for public services increases that in turn increases public expenditure; note that increased employment produces new tax revenue as well.

For the case in which the price of natural gas escalates at 1.64% per year (or at any other rate), there is no change in the economic impact of the addition of a CCGT plant at the Millstone campus. This is because the price of natural gas rises for all users everywhere (we assume there is a national price for natural gas). To the extent that there are regional differences in gas delivery prices due to transport costs, these price differences would be sustained in the case of a secular price rise. We assume that despite the high escalation rate for the price of natural gas and higher LCOE, the merchant recovers its average total costs from the wholesale market because the price of natural gas rises for marginal producers as well.

Economic Impact Results: Adding a Nuclear Plant to the Millstone Campus or the Connecticut Yankee Site

In these cases, there is net new construction and taxes, but no net new employment and procurement generated as a result of the new plant's construction and operation as explained above. We assume workers live in Connecticut and receive the utilities' industry average compensation. Recall, the only difference between adding a new plant at Millstone and one at the Connecticut Yankee site is ownership.

Table 4 shows the nominal construction costs for the new nuclear plant. As explained above, we reduce the price of electricity for all Connecticut users by 2.85% each year to 2054 because the addition of baseload capacity displaces higher cost marginal units. Finally, the addition to the state's capital stock (plant and equipment) in the amount of construction expenditure each year provides the basis for additional property tax collection.

Table 7 reports the economic impacts for the case in which a new 1,000 MWe nuclear plant complements the existing nuclear capacity at Millstone or is built at the Connecticut Yankee site in terms of the average annual changes in employment, output (sales in all sectors), state gross domestic product (GDP) and net state revenue. These changes from the economic model's baseline forecast arise from the ripple or multiplier effects of the direct impacts in Table 4 as well as increased employment, procurement and a relatively more competitive business environment due to lower electricity costs; these benefits accrue to the state as a whole. Depending on the price elasticity of electricity demand, electricity consumption could increase significantly or not much. We expect the assumed 2.85% electricity price reduction for all ISO-NE users as a result of adding 1,000 MWe of baseload would not increase demand significantly even assuming unit elasticity (the actual elasticity is smaller than unity in absolute value, that is, the demand for electricity is relatively unresponsive to electricity rate changes in the short to medium run).[35]

Total employment includes full- and part-time people who work in firms and those who are independent contractors, sole proprietors or otherwise self-employed, as well as federal, state and local government workers. Private, non-farm employment includes full- and part-time payroll jobs in firms and no agricultural or public sector jobs. Subsequent rows represent changes in the number of full- and part-time jobs in other sectors of the state economy. The reported employment changes range from 0.4% to 1.2% for total and non-farm employment with respect to levels in the economic model's baseline forecast of the Connecticut economy. Table 7 reports the annual average economic changes from the baseline forecast over 42 years. To compare the present case with the case in which we replace a nuclear plant with a new nuclear plant at the Millstone campus, there is a similar number of jobs created in the first five years of construction for either case because construction outlays are identical in each case. The present case averages annual employment, GDP, personal income and net state revenue changes over 42 years. We report net present value for monetary variables using a 5.3% discount rate.

Over the period 2009 through 2050, changes from the baseline forecast in state GDP, personal income and economic output (sales of all sectors) range from 0.06% to 0.67% for GDP and from 0.04% to 0.68% for personal income with respect to forecasts in the economic model. Over the period 2009 through 2050, state revenue changes from the baseline range from 0.13% to 0.67% with respect to forecasts in the economic model. State expenditure changes turn negative when employment increases and people reduce their need for social insurances and government transfers (negative changes mean the simulation result is lower than the baseline forecast for the years in which such changes occur). However, as employment grows, people migrate to the state in search of work and the demand for public services increases that in turn increases public expenditure (that is, it produces changes above the baseline forecast); note that increased employment produces new tax revenue as well.

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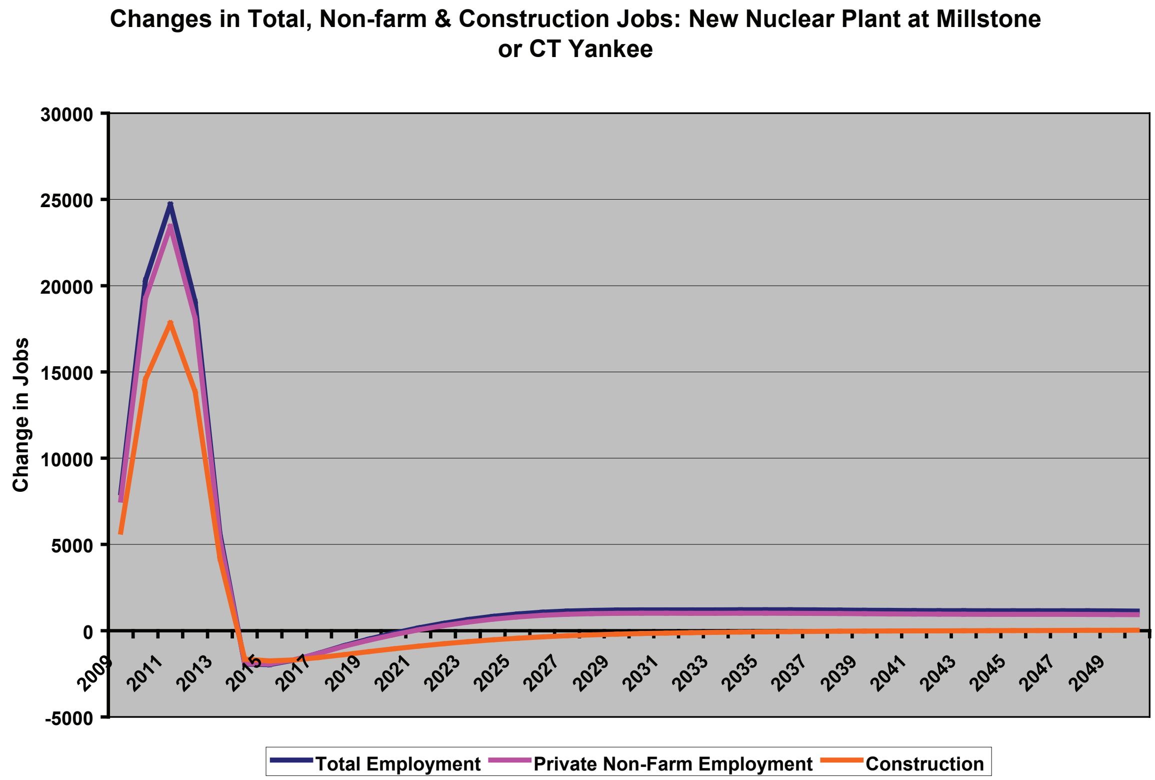
35 Bernstein, M. A. and James Griffin (2005). "Regional Differences in the Price-Elasticity of Demand for Energy," RAND Technical Report. Available at http://www.rand.org/pubs/technical_reports/2005/RAND_TR292.pdf.

Table 7: Economic Impact of Adding a Nuclear Plant at Millstone or Connecticut Yankee

Economic Variable	Annual Average Change from Baseline (2009-2050)	
New Total Employment (Persons)	2,420	
New Private Non-Farm Employment (Jobs)	2,178	
New Utilities (Jobs)	18	
New Construction (Jobs)	957	
New Manufacturing (Jobs)	48	
New Wholesale Trade (Jobs)	81	
New Retail Trade (Jobs)	227	
New Transportation and Warehousing (Jobs)	12	
New Information (Jobs)	25	
New Finance and Insurance (Jobs)	23	
New Real Estate and Rental and Leasing (Jobs)	108	
New Professional and Technical Services (Jobs)	193	
New Administrative and Waste Services (Jobs)	81	
New Educational Services (Jobs)	8	
New Health Care and Social Assistance (Jobs)	178	
New Arts, Entertainment, and Recreation (Jobs)	28	
New Accommodation and Food Services (Jobs)	130	
New Other Services, ex Public Administration (Jobs)	86	
	Ann. Avg. Change	NPV
New Gross Domestic Product (mil nominal $)	$516.6	$7,594.8
New Output (mil nominal $)	$845	$12,576.3
New Personal Income (mil nominal $)	$363.6	$6,154.1
New State Revenue (mil nominal $)	$104.3	$1,501.9
New State Expenditure (mil nominal $)	$76.9	$915.9
Net New State Revenue (mil nominal $)	$27.4	$586

Source: The REMI model and the authors' calculations.

Figure 2 shows the timeline of the changes in total, private non-farm and construction employment from the baseline forecast in terms of full- and part-time jobs created as a result of the construction and operation of the new nuclear plant at the Millstone campus or Connecticut Yankee site. The increase in construction jobs accounts for most of the change in total and private, non-farm job changes during the five-year construction period. These job changes are below the baseline forecast after construction ceases for a few years because there were people who migrated to the state looking for work as the project began. When construction stops, there are people who did not find work during construction and leave the state. In addition,

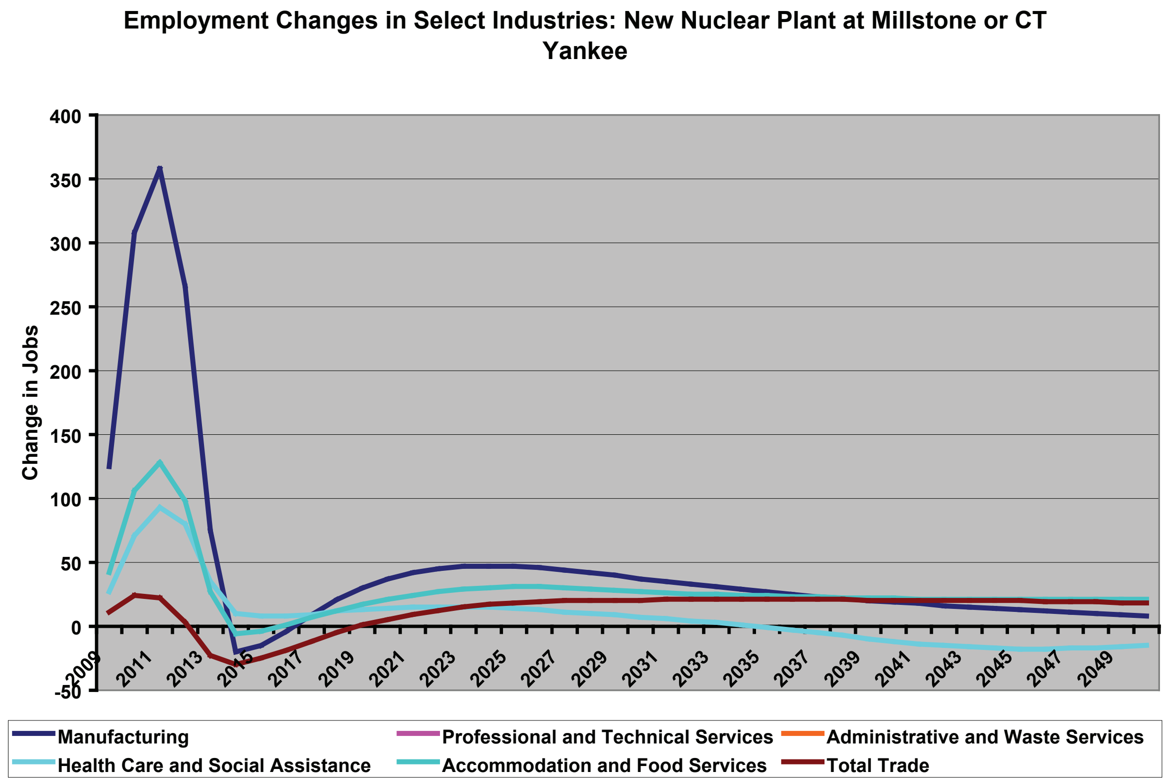


Source: The REMI model.

FIGURE 2: CHANGES IN TOTAL, NON-FARM AND CONSTRUCTION: 2009 - 2050

there were thousands of previously employed construction workers (for example, independent contractors) that leave the state looking for work elsewhere or who are furloughed by their employers (in reality, they move to other construction projects in the region that are unknown to us). This situation occurs in several industries to a lesser extent. After 2025, employment changes (increases) are roughly constant as the new nuclear plant operates until 2054, when decommissioning commences (see footnote 4). The economic model cannot handle time horizons beyond 2050. In addition, actual decommissioning may take 20 years or more beyond the economic life of the plant. This could extend the decommissioning economics to 2094, well beyond reasonable understandings of economic fundamentals that far in the future. Therefore, the analysis simply ceases in 2050 at the horizon of the economic model.

Figure 3 shows the timeline of employment changes in other industries in terms of full- and part-time jobs created as a result of the construction and operation of the new nuclear plant at the Millstone campus. The pattern is similar to the pattern in Figure 2 and for the same reasons. Job changes in trade (wholesale and retail) dominate job changes in the other industries shown in Figure 3. Changes in jobs in the Health Care and Social Assistance industry represent the second largest gain among the industries reported here, while changes in jobs in the Professional and Technical Services industry group represent the third largest gain.



Source: The REMI model

FIGURE 3: EMPLOYMENT CHANGES IN SELECT INDUSTRIES

Economic Impact Results: Adding a CCGT Plant to the Millstone Campus or the Connecticut Yankee Site

In this case, there are net new construction expenditures and taxes, but no net new employment or procurement generated as a result of the new plant's construction and operation as explained above. We assume the workers live in Connecticut and receive the utilities' industry average compensation. The only difference between these cases is ownership.

Table 4 shows the nominal construction costs for the new CCGT plant and the pipeline extension necessary to bring gas to it. As explained above, we reduce the price of electricity for all Connecticut users by 2.85% per year to 2054 because the addition of baseload capacity displaces higher cost marginal units. Depending on the price elasticity of electricity demand, electricity consumption could increase significantly or not much. We expect the assumed 2.85% electricity price reduction for all ISO-NE users as a result of adding 1,000 MWe of baseload would not increase demand significantly even assuming unit elasticity (the actual elasticity is smaller than unity in absolute value, that is, the demand for electricity is relatively unresponsive to electricity rate changes in the short to medium run; see footnote 36). Further, the addition to the state's capital stock (that is, the stock of plant and equipment) in the amount of construction expenditure each year provides the basis for additional property tax collection. Table 8 reports the economic impacts for the case in which a new 1,000 MWe CCGT plant complements the existing nuclear capacity at Millstone or is constructed at the Connecticut Yankee site in terms of the average annual changes from the baseline forecast in employment, output (sales), state gross domestic product (GDP) and net state revenue. These changes from the economic model's baseline forecast arise from the ripple or multiplier effects of the direct impacts in Table 4 as well as increased employment, procurement and a relatively more competitive business environment due to relatively lower electricity costs; these benefits accrue to the state as a whole. In this case, we assume the new gas pipeline is built for $25 million in each plant construction year (2009 and 2010).

Total employment includes full- and part-time people who work in firms and those who are independent contractors, sole proprietors or otherwise self-employed, as well as federal, state and local government workers. Private, non-farm employment includes full- and part-time payroll jobs in firms and no agricultural or public sector jobs. Subsequent rows represent changes in the number of full- and part-time jobs in other sectors of the state economy. Over the 42-year period, employment changes range from 0.03% to 0.46% for total and non-farm employment based on Connecticut employment in the economic model's baseline forecast.

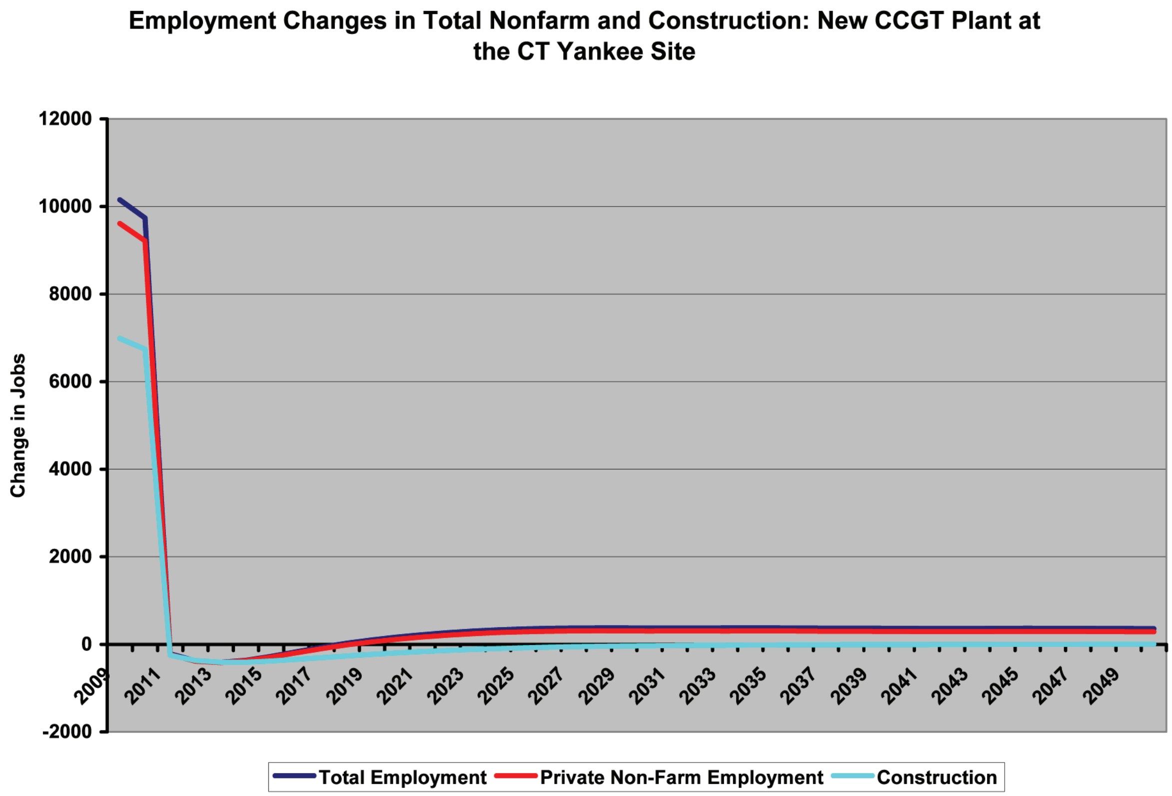
Over the 42-year period, changes in state GDP, personal income and output (sales of all sectors) range from 0.02% to 0.28% for GDP and from 0.02% to 0.27% for personal income with respect to forecasts in the economic model. State revenue changes range from 0.12% to 0.28% with respect to forecasts in the economic model. State expenditure changes may turn negative when employment increases and people reduce their need for social insurances and government transfers (negative changes mean the simulation result is lower than the baseline forecast for the years in which such changes occur). However, as employment grows, people migrate to the state in search of work and the demand for public services increases that in turn increases public expenditure (that is, it produces changes above the baseline forecast); note that increased employment produces new tax revenue as well.

Table 8: Economic Impact of Adding a CCGT Plant at Millstone or to the Connecticut Yankee Site

Economic Variable	Annual Average Change from Baseline (2009-2050)	
New Total Employment (Persons)	1,333	
New Private Non-Farm Employment (Jobs)	1,140	
New Utilities (Jobs)	32	
New Construction (Jobs)	254	
New Manufacturing (Jobs)	24	
New Wholesale Trade (Jobs)	36	
New Retail Trade (Jobs)	117	
New Transportation and Warehousing (Jobs)	15	
New Information (Jobs)	13	
New Finance and Insurance (Jobs)	23	
New Real Estate and Rental and Leasing (Jobs)	124	
New Professional and Technical Services (Jobs)	140	
New Administrative and Waste Services (Jobs)	64	
New Health Care and Social Assistance (Jobs)	122	
New Arts, Entertainment, and Recreation (Jobs)	18	
New Accommodation and Food Services (Jobs)	100	
New Other Services, except Public Administration (Jobs)	60	
	Ann. Avg. Change	NPV
New Gross Domestic Product (mil nominal $)	$471.1	$5,768.4
New Output (mil nominal $)	$773.6	$9,581.7
New Personal Income (mil nominal $)	$247.6	$3,291.8
New State Revenue (mil nominal $)	$84.1	$1,051.8
New State Expenditure (mil nominal $)	$65.5	$745.6
Net New State Revenue (mil nominal $)	$18.6	$306.2

Source: The REMI model and the authors' calculations.

Figure 4 shows the timeline of the changes in total, private non-farm and construction employment in terms of full- and part-time jobs created as a result of the construction and operation of the new CCGT plant at the Millstone campus or the Connecticut Yankee site. The increase in construction jobs accounts for most of the change in total and private, non-farm

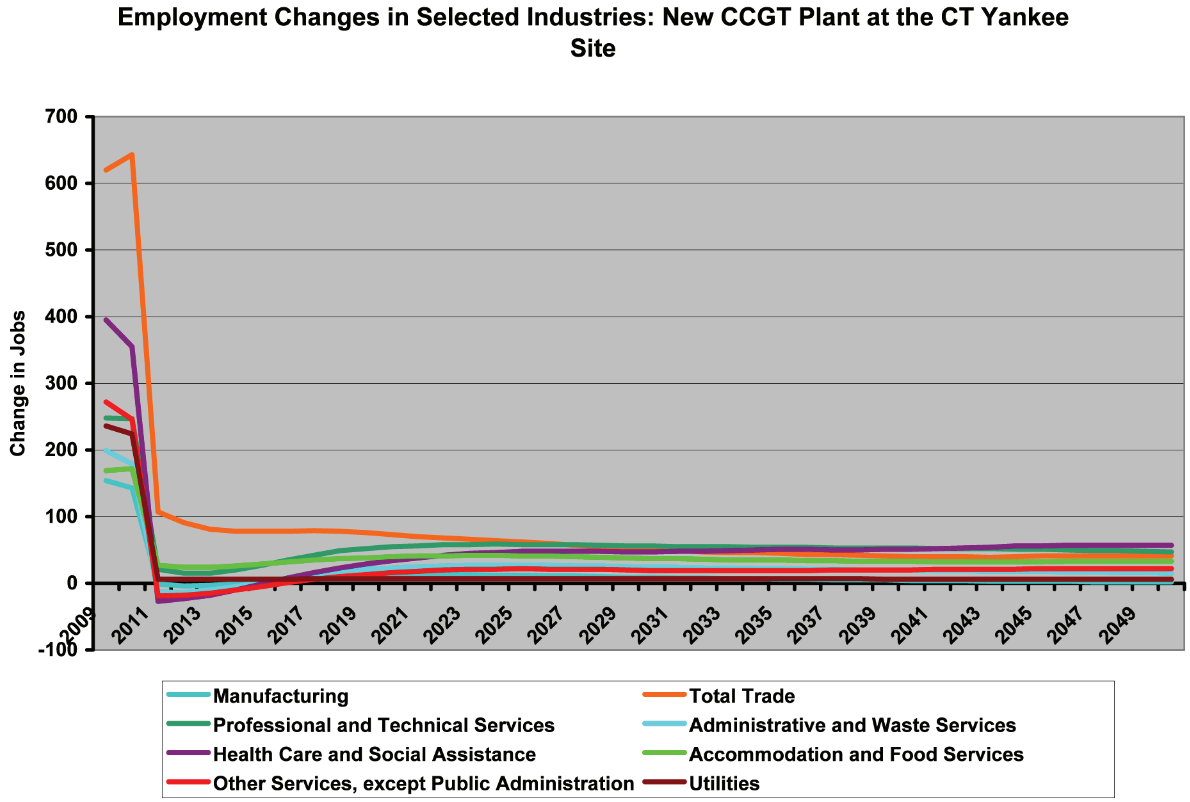


Source: The REMI model

FIGURE 4: CHANGES IN TOTAL, NON-FARM AND CONSTRUCTION JOBS: 2009 - 2050

job changes during the five-year construction period. These job changes are below the baseline forecast after construction ceases for a few years because there were many people who migrated to the state looking for work as the project began. When construction stops, there are people who did not find work during construction and leave the state and there were thousands of previously employed construction workers (for example, independent contractors) who leave the state looking for work elsewhere or are furloughed by their employers. This situation occurs in several industries to a small extent. After 2017, employment changes (that is, increases above the baseline forecast) are roughly constant as the new CCGT plant operates until 2054 when it is decommissioned. The economic model cannot handle time horizons beyond 2050. In addition, actual decommissioning may take several years beyond the economic life of the plant. This could extend the decommissioning economics beyond reasonable understandings of economic fundamentals that far in the future. Therefore, the analysis ceases in 2050 at the horizon of the economic model.

Figure 5 shows the timeline of employment changes in other industries in terms of full- and part-time jobs created as a result of the construction and operation of the new CCGT plant at the Millstone campus. The pattern is similar to the pattern in Figure 4 and for the same reasons. Job changes in trade (wholesale and retail) dominate job changes in the other industries shown in Figure 5. Changes in jobs in the 'Health Care and Social Assistance' industry represent the second largest gain among the industries reported here while changes in jobs in the Professional and Technical Services industry group represent the third largest gain.



Source: The REMI model

FIGURE 5: EMPLOYMENT CHANGES IN SELECT INDUSTRIES

CONCLUSIONS

Replacement Scenarios

The economic and fiscal benefits from replacing an existing nuclear plant at Millstone with either a nuclear or a CCGT plant are short-term employment gains and short-term state GDP and net state revenue spikes. The replacement scenarios are essentially large construction projects whose economic effects dissipate quickly as construction is completed. There is no change in the wholesale price of electricity because baseload capacity is not increased in the region, and there are no changes in Dominion's employment or procurement as the new plants commence operation because we assume the existing workforce and procurement pattern remain intact. Moreover, there are no net new electricity sales in the region and each plant receives at least its LCOE otherwise it would shut down in the long run.

It is helpful to reproduce Table 4 here to understand the different economic responses to the drivers of impact, namely the pattern of construction and decommissioning costs. Decommissioning represents expenditure for that purpose in one year that actually spans many years.

TABLE 4: CONSTRUCTION, DECOMMISSION AND PIPELINE EXPENDITURES FOR REPLACEMENT SCENARIOS (IN NOMINAL MILLION $)

	2009	2010	2011	2012	2013	2014	Total
Nuclear plant construction & nuclear decommission	$405	$1,093	$1,391	$1,159	$456	$887	$5,391
CCGT plant construction & nuclear decommission				$493	$507	$887	$1,887
Pipeline construction				$25	$25		$50
Total CCGT				$518	$532	$887	$1,937

Source: Du and Parsons (2009) for construction and decommissioning costs. See footnote 33 for pipeline costs.

During the five-year construction period for the new nuclear plant commencing in 2009 and the (compressed) one-year decommission of an existing nuclear plant (2014), total employment increases by almost 25,000 (full- and part-time) jobs in 2011 (year three of the construction project); private, nonfarm employment increases by 23,400 (full- and part-time) jobs in 2011; and construction employment increases by 18,194 (full- and part-time) jobs above the baseline forecast or absent the construction. In 2011, state GDP increases by $1.49 billion, output (sales in all sectors) increases by $2.51 billion and net state revenue increases by $218.6 million above the baseline forecast or absent the construction. In 2011, these increases above the baseline forecast represent 1.12% of total employment, 0.66% of state GDP and 0.63% of state revenues.

During the two-year construction period for the new CCGT plant (2012 and 2013) at the Millstone campus and the (compressed) one-year decommission of an existing nuclear plant (2014), total employment increases by 13,679 (full- and part-time) jobs in 2014; private, nonfarm employment increases by 13,013 (full- and part-time) jobs; and construction employment increases by 10,245 (full- and part-time) jobs above the baseline forecast or absent the construction. The construction of an extension to the existing Algonquin Pipeline is represented in these results.

The largest gain in jobs takes place during the decommissioning of the nuclear unit in this case because that represents the largest expenditure (see footnote 4). The lengthy decommissioning process is compressed into one year because we do not know how much is actually expended in each year of the potential 20-year decommissioning phase. In 2014, state GDP increases by $889.9 million, output (sales in all sectors) increases by $1.47 billion and net state revenue increases by $131.5 million above the baseline forecast or absent the construction. In 2014, these increases represent 0.59% of forecast total employment, 0.34% of forecast state GDP and 0.32% of forecast state revenues.

Table 9 summarizes the annual economic and fiscal impacts for the replacement of a nuclear plant at Millstone with either an AP 1000 nuclear plant or a CCGT plant. The differences in economic impact are primarily due to the difference in construction costs between the two plants. In the CCGT replacement case, we include the cost of extending a natural gas pipeline to the plant site.

Table 9: Economic Impact of Replacing a Nuclear Plant with a Nuclear or CCGT Plant at Millstone

Economic Variable		2009	2010	2011	2012	2013	2014
New Total employment	Nuclear	7,993	20,320	24,756	19,249	6,021	12,087
	CCGT	NA	NA	NA	8,685	8,368	13,679
New Construction Jobs	Nuclear	5,708	14,660	18,194	14,636	5,365	9,922
	CCGT	NA	NA	NA	6,263	6,187	10,245
New State GDP (mil nominal $)	Nuclear	$460.5	$1,214.9	$1,495.1	$1,161.2	$313.4	$725.5
	CCGT	NA	NA	NA	$543.5	$531.1	$889.9
New Output (mil nominal $)	Nuclear	$780.5	$2,051.6	$2,516.2	$1,948.9	$530.0	$1,207.3
	CCGT	NA	NA	NA	$917.4	$894.6	$1,474.7
New Personal Income (mil nominal $)	Nuclear	$393.6	$1,055.8	$1,400.3	$1,225.8	$556.5	$902.2
	CCGT	NA	NA	NA	$472	$507.80	$867.20
Net New State Revenue (mil nominal $)	Nuclear	$77.78	$190.7	$218.66	$147.7	$0.53	$72.67
	CCGT	NA	NA	NA	$87.65	$77.71	$131.5

Source: The REMI model and the authors' calculations.

Construction spending for the nuclear plant peaks in 2011, before construction begins on the CCGT. Construction spending on the nuclear plant is more than twice that for the CCGT plant in 2012. In 2013, nuclear plant construction spending declines by more than 50% to $456 million from $1,159 million according to the Du and Parsons (2009) construction schedule. This leads to a reduction in total state employment in 2013 of 13,000 jobs, rebounding to 12,000 jobs in 2014 for the compressed decommissioning period of the retiring nuclear plant at Millstone. In 2015, construction and decommissioning activity stops and there is significant unemployment in the state as workers are furloughed until they can find new work. Many leave the state looking for work elsewhere. The economic model does not know what other work furloughed construction workers may find or when. The model's response to the sudden drop in construction employment is to reduce employment in several sectors as overall demand for products and services declines and to increase social insurance payments. This explains the much smaller increase in net state revenue relative to that estimated for the CCGT case in 2013.

Further, the economic results for the CCGT plant are larger for each reported economic variable in 2014 than the results for the nuclear plant because there is a carryover or inertia effect from the previous years, especially 2013. While total spending increased for the CCGT plant in 2013, it declined significantly for the nuclear plant in 2013 relative to 2012. The model economy in the nuclear case does not recover as quickly as the model economy in the CCGT case despite the fact that spending in 2014 is identical in the two cases. There are more workers looking for jobs in the nuclear case after 2013 than in the CCGT case.

Plant Addition Scenarios

In this analysis, the cases in which we add baseload capacity to the Millstone campus or to the Connecticut Yankee site are identical because they have the same construction costs and operating parameters and absorb the labor and procurement released by retiring marginal plants assumed to be in Connecticut. These cases confer long-term benefits in the form of a reduced wholesale price for electricity in the region and net new employment, business-to-business activity and taxes in the economy as a whole. In these cases, we consider the construction and operation of the plants by merchant owners and operators from 2009 through 2050 in the Connecticut economic model. We omit siting and permitting costs and assume there are identical costs for connecting to the grid at each site. For the cases in which a nuclear or CCGT plant is added to the Millstone site, we assume Dominion's workforce and procurement expands incrementally. For the cases in which a nuclear or CCGT merchant plant is constructed at the Connecticut Yankee site, we assume there is a merchant owner/operator different from Dominion that adds jobs and establishes a procurement pattern with Connecticut suppliers commensurate with the scale of the operation. In each case however, new baseload operations absorb labor and procurement released by displaced marginal plants and there is no net new direct employment at the new plants. In addition, there are no net new electricity sales in the region as we assume demand remains constant. Each plant receives at least its LCOE; otherwise it would shut down in the long run.

For the case in which we add a nuclear plant to either site, the annual average increase above the baseline (no build) forecast for the Connecticut economy for total employment is 2,420 jobs (this includes public and private sector jobs and the self-employed), private, nonfarm employment increases by 2,178 jobs, construction employment increases by 957 jobs and the wholesale and retail sectors' employment increases by 308 jobs. State GDP increases by an average of $516.6 million annually above the baseline forecast, output increases by an average $845 million annually above the baseline forecast and net state revenue increases by $27.4 million on average each year above the baseline forecast. These annual average increases above the baseline forecast of the Connecticut economy represent small fractions of the state's employment, output and GDP.

For the case in which we add a CCGT plant at the Millstone campus or the Connecticut Yankee site, the average annual increase above the baseline forecast in total employment is 1,333 jobs, for private, nonfarm employment the average annual increase is 1,140 jobs, for construction employment the average annual increase is 254 jobs and for wholesale and retail sector employment, the average annual increase is 153 jobs above the baseline forecast. State GDP increases by an average of $471 million annually above the baseline, output increases by an average $773.6 million annually above the baseline and net state revenue increases by $18.6 million on average each year above the baseline forecast. These annual average increases above the baseline forecast of the Connecticut economy represent small fractions of the state's employment, output and GDP.

Table 10 displays summary results of adding a nuclear or a CCGT plant at either the Millstone campus or the Connecticut Yankee site. The differences in the results are due primarily to the difference in construction costs between the two plants. Recall, we add the cost of extending a natural gas pipeline to the CCGT plant site.

TABLE 10: ECONOMIC IMPACT OF ADDING A NUCLEAR AND CCGT PLANT AT MILLSTONE OR CONNECTICUT YANKEE

	Annual Average Change from Baseline (2009-2050)			
Economic Variable	Add Nuclear Plant at Millstone or CT Yankee		Add CCGT Plant at Millstone or CT Yankee	
New Total Employment (Persons)	2,420		1,333	
New Construction (Jobs)	957		254	
	Ann. Avg. Change	NPV	Ann. Avg. Change	NPV
New Gross Domestic Product (mil nominal $)	$516.6	$7,594.8	$471.1	$5,768.4
New Output (mil nominal $)	$845	$12,576.3	$773.6	$9,581.7
New Personal Income (mil nominal $)	$363.6	$6,154.1	$247.6	$3,291.8
Net New State Revenue (mil nominal $)	$27.4	$586	$18.6	$306.2

Source: The REMI model and the authors' calculations.

GLOSSARY OF TERMS AND ABBREVIATIONS

Concept	Definition
10- or 30-Minute Spinning Reserve or Nonspinning Reserve	The entire 30-minute requirement may be served by *30-minute operating reserve* (TMOR) or the higher-quality 10-minute spinning reserve or nonspinning reserve. In addition to the systemwide requirements, 30-minute reserves must be available to meet the local second contingency in import-constrained areas (Fairfield County is an example).
All-in Costs	A cost of construction concept. All-in costs include all construction related costs and financing. (They are the same as Installed Costs.) (See overnight costs for a different measure of construction-related costs.)
BTU	British Thermal Unit, i.e., the heat required to raise 1 lb. of water by 1 degree Fahrenheit
BTU/kWhr	BTUs of thermal input required to produce 1 kilowatt-hour of electricity
Busbar Cost	The cost of delivering electricity to the point of interconnection with the electric grid. This cost of generation is the real world cost that is presented to the public utility commission for collection from ratepayers. In constant, level dollar terms over the life of the plant, busbar cost is the LCOE
Cap and Trade Carbon Market	A cap and trade market is a policy created market developed by governing or regulatory authorities to address the unwanted and socially costly by-product of carbon in from the burning of fossil fuels for electricity generation. A cap and trade market aims to bring economic incentives to bear to reduce carbon emissions by establishing a cap on an acceptable level of carbon emissions and then allowing allocations for permissions to burn carbon to be traded in an open market. The cost of the allocations is determined by the relative scarcity of the allocations, which reflects the demand for electricity.
Capacity Factor	Ratio of actual annual plant electrical production and maximum annual production capability
Carbon Tax	An environmental tax that is levied on the carbon content of fuels. It is a form of carbon pricing. Carbon atoms are present in every fossil fuel (coal, petroleum, and natural gas) and are released as carbon dioxide (CO_2) when they are burnt. A carbon tax can be implemented by taxing the burning of fossil fuels—coal, petroleum products such as gasoline and aviation fuel, and natural gas in proportion to their carbon content. Carbon taxes offer a potentially cost-effective means of reducing greenhouse gas emissions. From an economic perspective, carbon taxes are a type of Pigovian tax. They help to address the problem of emitters of greenhouse gases not facing the full (social) costs of their actions. http://en.wikipedia.org/wiki/Carbon_tax.
CAGR	Compound annual growth rate. The growth rate of values equally spaced in time. $CAGR = \left({Value_n}/{Value_1} \right)^{1/n}$
Day-Ahead Energy Market	A market to secure prices for electric energy the day before the operating day. This market allows for hedging against price fluctuations that can occur in real time; facilitates electric energy trading.

Demand Resources	Measures (i.e., products, equipment, systems, services, practices, and strategies) that result in additional and verifiable reductions in end-use demand on the electricity network during specific performance hours.
Financial Transmission Rights	Allow participants to hedge against the economic impacts associated with transmission congestion and provides a financial instrument to arbitrage differences between expected and actual day-ahead congestion
Forward Capacity Auction	Purchase sufficient qualified resources to satisfy the region's future needs and allow sufficient time to construct new capacity resources. Held each year approximately three years in advance of when the capacity resources must provide service. Capacity resources compete in the annual FCA to obtain a commitment to supply capacity in exchange for a market-priced capacity payment
Forward Capacity Market	A primary wholesale market managed by ISO NE to ensure the sufficiency of installed capacity, which includes demand resources, to meet the future demand for electricity
Forward Reserve Market	An ancillary function of the ISO NE wholesale electricity market designed to maintain system reliability in the relatively short term. This component focuses on ensuring reserve capacity to be able to respond to contingencies such as those caused by unexpected outages. *Operating reserves* are the unloaded capacity of generating resources, either offline or online, that can deliver electric energy within 10 or 30 minutes (some demand-side resources can provide reserves). ISO NE operating procedures require reserve capacity to be available within 10 minutes to meet the largest single system contingency (N-1) that result from an unexpected outage of the largest generator in the system. Additional reserves must be available within 30 minutes to meet one-half of the second-largest system contingency (N-1-1).
Forward Reserve Auction	Compensates generators for the availability of their *unloaded* operating capacity that can be converted into electric energy within 10 or 30 minutes when needed to meet system contingencies, such as unexpected outages
Fuel Real Escalation Rate	The rate at which the fuel price increases in real terms irrespective of the general inflation rate. The nominal cost escalation rate is the real rate multiplied by the general inflation rate.
Gigawatt	One billion watts
Heat Rate	Power plant efficiencies are typically defined as the amount of heat content in (Btu) per the amount of electric energy out (kWh), commonly called a heat rate (Btu/kWh). http://www.npc.org/Study_Topic_Papers/4-DTG-ElectricEfficiency.pdf
Installed Costs	A cost of construction concept. All-in costs include all construction-related costs and financing. (They are the same as All-In Costs) (See overnight costs for a different measure of construction related costs.)
kWe-hr	Kilowatt-hour of electricity

Levelized Cost of Electricity	The minimum revenue stream over the operating life of the plant needed to avoid shutting down in the long run. LCOE represents the constant (level) wholesale price generators receive over the life of a power plant that would be necessary to cover all operating expenses and taxes and provide an acceptable return to investors. The calculation of the levelized cost of electricity provides a common way to compare the cost of energy across technologies because it takes into account the installed system price and associated costs such as financing, land, insurance, transmission, operation and maintenance and depreciation, among other expenses. Carbon emission costs can be taken into account as well. The calculation of the LCOE is the net present value of total life cycle costs of the power plant divided by the quantity of energy produced over the plant's life.
Locational Marginal Pricing (LMP)	A way for wholesale electric energy prices to reflect the value of electric energy efficiently at different locations on the grid based on the patterns of load, generation and the physical limits of the transmission system. Wholesale electricity prices are identified at 900 pricing points on the New England regional bulk power grid. LMPs differ among these locations because transmission and reserve constraints prevent the next-cheapest megawatt (MW) of electric energy from reaching all locations of the grid
MACRS	The Modified Accelerated Cost Recovery System (MACRS) is the current tax depreciation system in the United States. Under this system, the capitalized cost (basis) of tangible property is recovered over a specified life by annual deductions for depreciation. The lives are specified broadly in the Internal Revenue Code. The IRS publishes detailed tables of lives by classes of assets. The deduction for depreciation is computed under one of two methods (declining balance switching to straight line or straight line) at the election of the taxpayer, with limitations.
Megawatt	One million watts
MMBTU	Million British thermal units
NOX	Atmospheric oxides of nitrogen
NPV	Net present value represents a stream of payments or receipts discounted to the present. $NPV = \sum_{i=1}^{n} \frac{cashflow_i}{(1+r)^i}$, where *r* is the discount rate.
O&M Fixed Costs	Consists primarily of plant operating labor. It is highly dependent on the operating cycle of the plant.
O&M Real Escalation Rate	The rate at which O&M costs increase in real or irrespective of the general inflation rate. The nominal cost escalation rate is the real rate multiplied by the general inflation rate.
O&M Variable Costs	Variable O&M includes periodic inspection, replacement, and repair of system components (i.e., filters, desulfurizer, etc.), as well as consumables.
Once-through fuel cycle	Fuel used in only one cycle; there is no reprocessing and subsequent use.

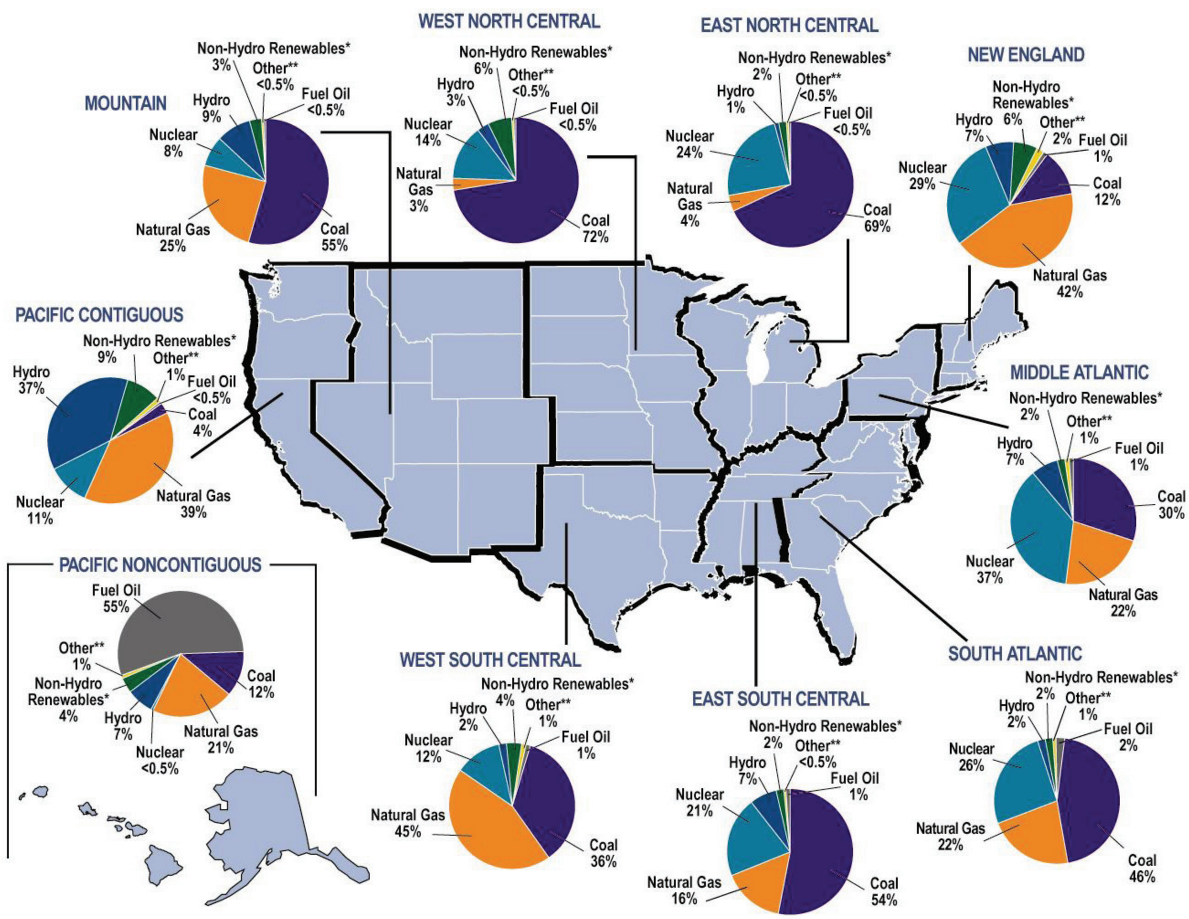
Overnight costs	The hypothetical estimate for cost for the complete construction of an electricity-generating unit assembled instantaneously. By removing the costs of financing and inflation this cost concept isolates the raw material, manufacturing of components and labor costs. Overnight cost includes engineering-procurement-construction (EPC) costs and owner's costs. It is net of financing costs and does not account for inflation. (See All-in Costs)
Reactor	Device utilizing nuclear chain reaction for power production
Real-Time Energy Market	The real-time energy market coordinates the dispatch of generation and *demand resources* to meet the demand for electricity and to meet reserve requirements. Financially, a real-time energy market settles the differences between the day-ahead scheduled amounts of load and generation and the actual real-time load and generation. Participants either pay or are paid the real-time locational marginal price (LMP) for load or generation in megawatt-hours (MWh) that deviates from their day-ahead schedule.
Real-Time Reserve Pricing	An ancillary function related to ISO NE market mechanisms that implements scarcity pricing to compensate participants of online and fast-start generators at above established market rates when the system or portions of the system are short of reserves. It provides efficient price signals when unexpected additional electricity is required.
Regional Economic Models, Inc.	The REMI model is based on a national *input-output* (I/O) model based on data the US Department of Commerce (DoC) developed and continues to maintain. Such models focus on the inter-relationships between industries and provide information about how changes in specific variables—whether economic variables such as employment or prices in a certain industry or other variables such as population—affect factor markets, intermediate goods production, and final goods production and consumption. The REMI Connecticut model takes the US I/O "table" results and scales them according to traditional regional relationships and current conditions, allowing the relationships to adapt at reasonable rates to changing conditions.
Regulation Market	An ancillary function of the ISO NE electricity market that compensates participants whose resources are controlled by the ISO NE using automated signals to increase or decrease output moment by moment to balance the variations in instantaneous demand and the system frequency; demand varies second to second, and the system frequency must kept at a constant rate.
Reprocessing	Processing of spent fuel to recover its fissile material
Return on Debt	The cost of debt capital is the return demanded by investors in the firm's debt; this return largely is related to the interest the firm pays on its debt.
Return to Equity	Equity investors incur an opportunity cost in owning the equity of the firm and demand a rate of return comparable to what they could earn by investing in securities of comparable risk.
RGGI	The Regional Greenhouse Gas Initiative is a ten-state CO_2 cap-and-trade program developed and implemented in the Northeast. Under RGGI, the Northeast region must cap its emissions by 2014 on the basis of recent historical emissions and reduce this level by 10% by 2018. By 2018, the six New England states will be allocated 50.2 million tons of carbon allowances from the RGGI cap, which covers other states in the Northeast region (i.e., New York, New Jersey, Maryland, and Delaware).

RPS	Renewable Portfolio Standards are state standards for load-serving entities to provide a portion of their energy from specific renewable technologies that increases each year. Connecticut, Maine, Massachusetts, and Rhode Island have RPSs, and New Hampshire recently established one. Vermont is pursuing an alternative approach and is requiring that renewable resources be used to serve all growth in that state's electricity use. The definition of RPS requirements varies by state. The North Carolina State University's Web site, *Database of State Incentives for Renewables and Efficiency* (the DSIRE Database, 2007), provides information on state RPS programs.
SAFSTOR	A method of decommissioning in which a nuclear facility is placed and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use. During SAFSTOR the de-fuelled plant is monitored for up to sixty years before complete decontamination and dismantling of the site, to a condition where nuclear licensing is no longer required. During the storage interval, some of the radioactive contaminants of the reactor and power plant will decay, which will reduce the quantity of radioactive material to be removed during the final decontamination phase. US NRC (http://www.nrc.gov/reading-rm/basic-ref/glossary/safstor.html)
Spent fuel	Fuel removed from reactors at end of its useful life; typically stored in water pools for cooling for ~10 years or more
Spent Fuel Dry Storage	Fuel stored after about ten years in shielded concrete casks
Unloaded Operating Capacity	Operational capacity that is not generating electric energy but that could convert to generating energy. Unloaded operating capacity is designed to address the contingency of a sudden loss of a generation or transmission resource. ISO NE based on FERC standards requires two contingencies be considered. The first contingency (N-1) would be the loss from the system of the power generating facility that would have the largest impact on the system. A second contingency (N-1-1) is the loss of the facility that would have the largest impact on the system after the first facility is lost
Voltage Support	An ancillary function of the ISO NE system that compensates resources for maintaining voltage-control capability, which allows system operators to maintain transmission voltages within acceptable limits.
Weighted Average Cost of Capital	The overall cost of capital is a weighted-average of the cost of its equity capital and the after-tax cost of its debt capital. See the equation on page 23.

APPENDIX A
(ECONOMIC IMPACT STUDY)

FUEL DIVERSITY

Fuel diversity refers to variety in the fuel mix used to generate electricity in a region. Greater fuel diversity is considered advantageous to an electricity system because it may strengthen the system against fuel supply shocks. For example, using a mix of fuel can provide a hedge against a price increase or sudden disruption in the supply of one particular fuel. This intuitively appealing argument is regularly used to advocate for greater fuel diversity.



Source: Edison Electric Institute, May 2010.[36] *Includes generation by agricultural waste, landfill gas recovery, municipal solid waste, wood, geothermal, non-wood waste, wind, and solar. ** Includes generation by tires, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.

FIGURE A1: FUEL DIVERSITY ACROSS U.S. REGIONS

Figure A1 shows the wide variety in the fuel mix used to generate electricity across the United States. In New England, natural gas dominates electricity production (42%), followed by nuclear (29%) and coal (12%).

36 http://www.eei.org/ourissues/ElectricityGeneration/FuelDiversity/Documents/map_fuel_diversity.pdf.

QUANTIFYING FUEL DIVERSITY

While achieving greater fuel diversity is a worthy goal, quantifying fuel diversity is not straightforward. If the analytical means exist to quantify the costs and benefits of increased fuel diversity, they can be used to gauge the value of different fuel "mixes" to arrive at an optimal fuel combination such that the optimal mix minimizes risks associated with supply disruption and/or price shocks of one or more constituent fuels used in the region. Two methods referred to in the literature to quantify fuel diversity are indices and analytical tools from the financial literature, such as portfolio theory and real options theory.[37]

The most widely referenced index to measure fuel diversity is the Shannon-Weiner index, shown below, where Δ_a specifies a particular index of diversity, and p_i denotes the proportional representation of option *i* in the portfolio under scrutiny (see footnote 37).

$$\text{Shannon-Weiner Index: } \Delta_a = \sum_{i=1}^{I} - p_i \ln(p_i)$$

The higher the value of the index, the greater the diversity of the system. While this can be used to rank the diversity of a given set of portfolios, it will not tell us which portfolio (i.e., fuel mix) is optimal.

Portfolio theory attempts to value the benefits of fuel diversity. In finance, portfolio management is used to reduce risk and maximize returns over time. This motive is what makes it applicable to fuel diversification. The focus in energy planning is not on finding a single lowest cost source, but on finding an efficient, or optimal, generating portfolio. An efficient portfolio is one that has the largest possible return for a given level of risk.

In portfolio theory, a range of optimal portfolios are calculated using historical measures of returns, risk (standard deviation of returns), and the correlation coefficients between the different assets to be used in the portfolio. Each optimal portfolio represents the maximum return possible with the lowest level of risk achievable from the particular combination of assets in the portfolio. Taken together, these optimal portfolios form an *efficient frontier* of diversification choices. The goal of portfolio theory is not to provide one optimal diversification option, but a range from which an investor (or, in this case, a region or generating company) will make a choice based on its preferences and risk aversion.

Bar-Lev and Katz (1976) pioneering empirical study of fuel diversity utilizing portfolio theory analyzes the fuel mix in nine regions of the United States. They calculate the efficient frontier for each region and compare it to actual utility operations.[38] Other studies include Awerbuch (2000)[39] that evaluates the US gas-coal generation mix and Awerbuch and Berger (2003)[40]

[37] Roques, Fabien A., *Analytic Approaches to Quantify and Value Fuel Mix Diversity*, July 2008. http://www.wip.tu-berlin.de/typo3/fileadmin/documents/infraday/2008/papers/_17ad_roques_paper.pdf.

[38] Bar-Lev, D., and Katz, S. (1976). "A Portfolio Approach to Fossil Fuel Procurement in the Electric Utility Industry," *Journal of Finance*, 31(3): 933-47.

[39] Awerbuch, S. (2000). "Investing in Photovoltaics: Risk, Accounting and the Value of New Technology," *Energy Policy*, 28(14): 1023-1035.

[40] Awerbuch, S. and M. Berger (2003). http://www.awerbuch.com/shimonpages/shimondocs/iea-portfolio.pdf.

that uses portfolio theory to identify the optimal European technology mix. Humphreys and McClain (1998)[41] demonstrate how the energy mix in the United States could be chosen given the goal to reduce the risks to the domestic economy of unanticipated energy price shocks. The general conclusion of the application of portfolio theory to valuing diversity suggests intuitively that more diverse generation portfolios are in general associated with lower risks for the same returns.[42]

FUEL DIVERSITY AND NUCLEAR GENERATION IN NEW ENGLAND

Additional nuclear generation is not expected to change the region's disproportionate dependence on natural gas as the primary generator of electricity. ISO New England's 2007 study[43] shows that adding 5,400 MWe of new capacity from a single non-gas-fired technology or resource type (such as nuclear, renewables, imports or energy efficiency) does not change this dependence. The addition of 1,000 MW from the nuclear power plant modeled in this study is therefore unlikely to have a significant impact on the region in terms of the primary goal of fuel diversity, which is to insulate the region from natural gas supply shocks and price volatility.

[41] Humphreys, H. and K. McClain (1998). "Reducing the Impacts of Energy Price Volatility through Dynamic Portfolio Selection," *The Energy Journal*, 19(3): 107-131.

[42] Roques, Fabien A. (2008). "Analytic Approaches to Quantify and Value Fuel Mix Diversity," July 2008. http://www.wip.tu-berlin.de/typo3/fileadmin/documents/infraday/2008/papers/_17ad_roques_paper.pdf.

[43] ISO New England, Inc., 2007. New England Electricity Scenario Analysis, August 2007. http://www.iso-ne.com/committees/comm_wkgrps/othr/sas/mtrls/elec_report/scenario_analysis_final.pdf.

APPENDIX B
(TO ECONOMIC IMPACT STUDY)
THE CARBON MARKET IN THE NORTHEAST: THE REGIONAL GREENHOUSE GAS INITIATIVE

The release of carbon dioxide (CO_2) from electrical generation facilities that burn fossil fuel creates a negative externality. An externality results when the cost of production does not account for all costs associated with production, and represents a market failure. It is negative because the production of the good (electricity) imposes costs on society with byproducts such as CO_2, SOx, NOx and mercury that many people accept as important contributors to climate change and atmospheric pollution. To address the market failure created from this negative externality, governments can price carbon dioxide using one or a combination of at least three approaches:

- Tax carbon emissions
- Develop an emissions trading market (A cap and trade market)
- Provide subsidies to producers of electricity that do not burn fossil fuels

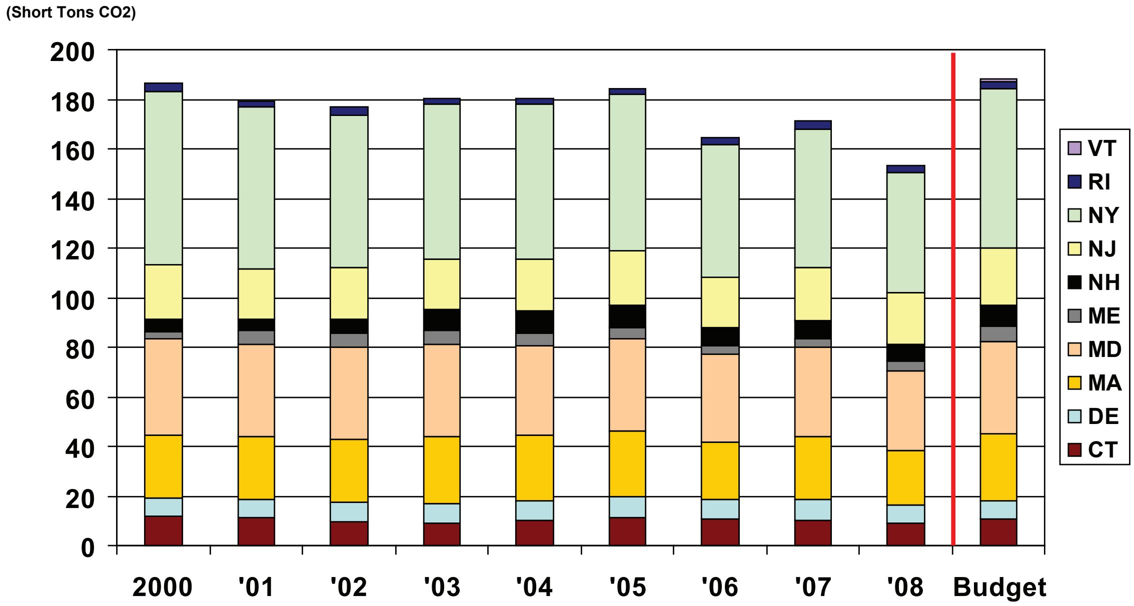
Another option that governments can pursue to address the problem would be to fully regulate or own the production of electricity. This approach implies that the government would be able to predetermine the acceptable level of CO_2 emissions through the choice of fuel sources, applications of different technologies and generating facilities. However, under current economic theory and in the US policy environment, this approach is unacceptable because it removes most if not all price information from the production process and is thus assumed to be inefficient relative to an approach that includes pricing of electricity production based on market signals.

Before reviewing the Regional Greenhouse Gas Initiative (RGGI), a cap and trade market that has been established in the northeastern United States, two factors that are critical to addressing CO_2 emissions should be noted. Both relate to the ability to correctly price the return on an investment in the building of a new power plant. One factor limiting the ability to price the investment arises from the difficulty of pricing related to the potential direction of government policy. Policies related to emissions from the plant that are established by governing authorities need to be perceived by the investing entities as being likely to be in place for a long enough period of time for them to choose the appropriate fuel source and method of generation. Given that the period for the return on the construction of power plants can easily be 40 or 50 years, it is a significant challenge for a government to establish the perception of a credible policy that would extend this far into the future. An additional factor that impacts the investment decision is the expected change in scientific knowledge and technical applications as they apply to electricity production. The net result is that the correct price signals on the most appropriate type of generating facility to build will incorporate significant risk that could reduce the appropriate level of investment. The implication is that to provide the investment necessary for stability or growth in the energy market, it may be logical to develop alternative business models.

A Cap and Trade initiative for CO_2 emissions began in 2005 for ten northeastern US states. These states joined to form the Regional Greenhouse Gas Initiative, or RGGI. RGGI was the first market-based regulatory program in the United States designed to reduce greenhouse gas emissions. The ten states include:

- Connecticut
- Delaware
- Maryland
- Massachusetts
- Maine
- New Hampshire
- New Jersey
- New York
- Rhode Island
- Vermont

The RGGI market is a carbon auction structured as a cap and trade program for CO_2 emissions from power plants with at least 25 MWe production capacity. RGGI placed a cap on carbon production in 2009 and in 2014 the cap will be reduced annually by 2.5% until 2018, when carbon production would be capped at 10% below the initial cap. The initial cap or budget for CO_2 was established in part based on the observed production of CO_2 from regional plants from 2000 through 2008. Each member state determined a CO_2 budget with an aggregate allocation of slightly more then 188 million short tons of CO_2. This budget is about 7% more than the average output observed for those ten states from 2000 through 2008. It is about one percent higher than the output observed in 2000, the year with the highest output and 13% higher than the average observed from 2006 to 2008 (the three years closest to the start of the implementation of the auction in 2009.) The trend for the CO_2 production from 2000 to 2008 and the budget used for the initial cap for each of the ten states appear in Figure B1. The total allocation of the budget and the amount budgeted by each of the ten states in RGGI appear in Figure B1 as well.

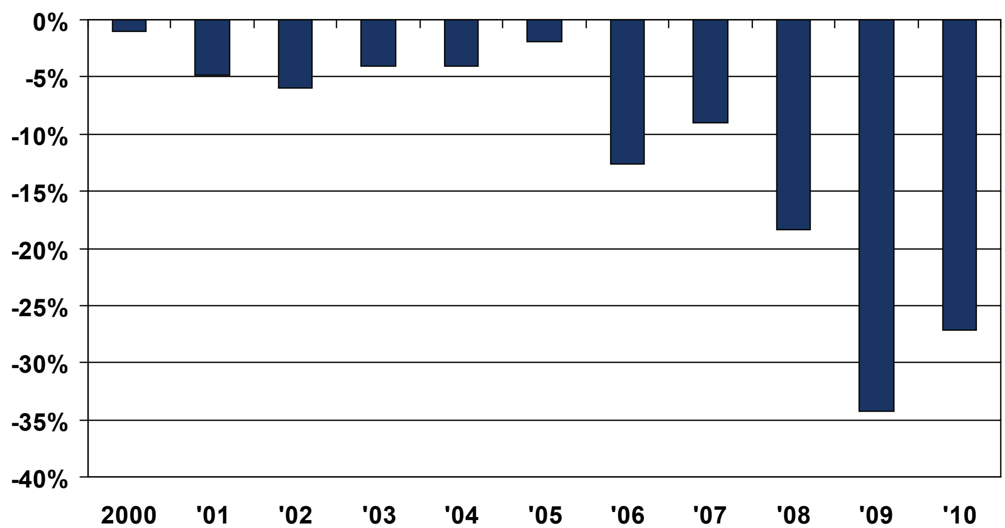


Source: RGGI, Inc. http://www.rggi.org/design/overview/cap

FIGURE B1: TREND OF CO_2 PRODUCTION 2000 TO 2008 AND 2009-2013 BUDGET

For clarification, the budget was developed based on observed CO_2 emissions from electricity production rather than the production of electricity. The difference is that the budget does not take into account the import or export of electricity from the region or the production of electricity from existing facilities with capacities larger than 25 MW that do not produce carbon (nuclear, wind, hydro, solar).

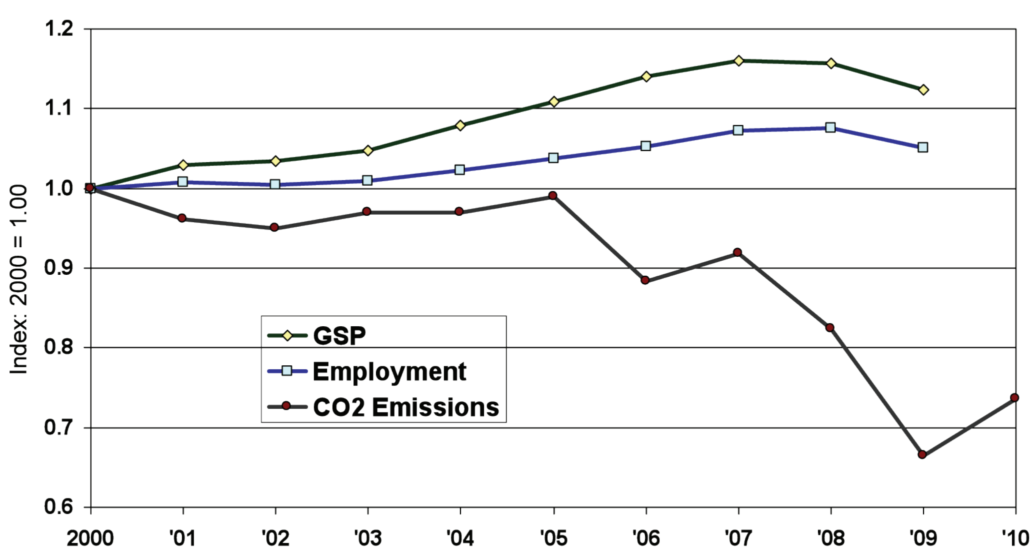
Figure B1 shows that the trend in CO_2 emissions declined from 2005 through 2008. This downward trend continues through 2009 in Figure B2. RGGI CO_2 emissions in 2009 were slightly less than 124 million short tons —34% below the 2009 budget of 188 million tons and 19% below 2008 emissions. Figure B2 shows that CO_2 emissions in 2010 increased by about 10% from the previous year (13 million short tons) but were still 27% below the budgeted trading cap set for the RGGI states in that year.



Source: RGGI, Inc. http://www.rggi.org/design/overview/cap

FIGURE B2: PERCENT OF CO_2 PRODUCTION BELOW 2009 BUDGET, 2000 TO 2010

A reduction in economic activity in the Great Recession undoubtedly explains part of the reduction CO_2 emissions from 2008 through 2010. However, Figure B3, which shows the indexed growth in Gross State Product (GSP), Employment and CO_2 since 2000, suggests other factors are involved. The aggregate indices for the ten states in RGGI show CO_2 emissions declined in 2005, rebounded slightly in 2006, and then declined significantly the following two years, while the economic indices continued to climb for at least two years beyond the 2005 decline in CO_2 emissions.



Source: US Bureau of Economic Analysis and RGGI, Inc.

FIGURE B3: TREND IN ECONOMIC ACTIVITY AND CO_2 EMISSIONS IN RGGI STATES

A study prepared by the New York State Energy Research and Development Authority (NYSERDA) for RGGI, Inc. estimated that the variation in electricity demand due to the economy accounted for approximately a 9.2% drop in the demand for electricity.[44] The report estimates that, due to the economy, electricity usage decreased by 2,957 GWh in 2009 compared to 2005 usage. The actual change in electricity requirements and the breakdown of the factors that contributed to the change between 2005 and 2009 appear in Table B1.

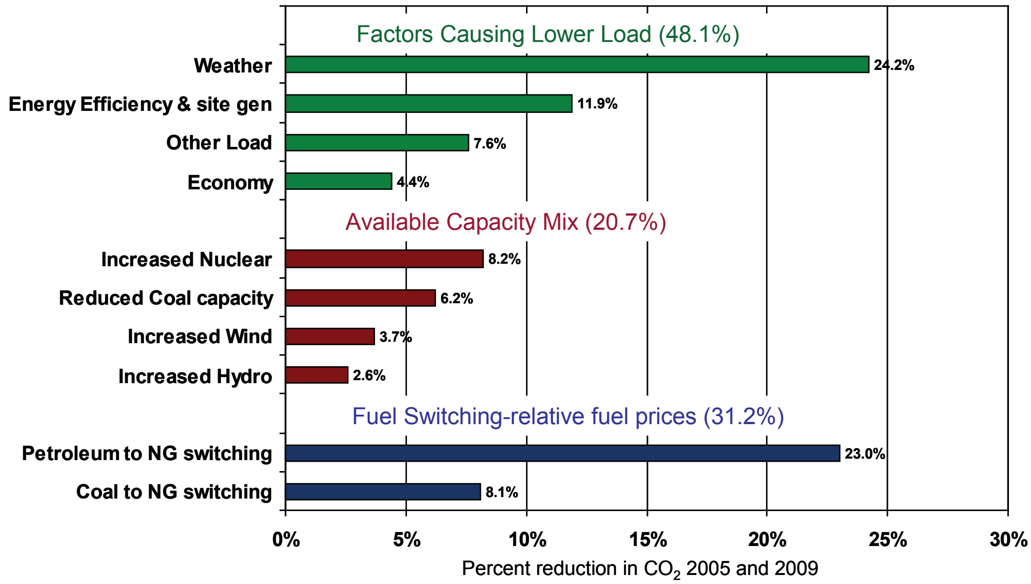
TABLE B1: ACTUAL RGGI REGION ELECTRICITY REQUIREMENTS AND BREAKDOWN OF COMPONENTS OF CHANGE, 2005 AND 2009

Required Electricty	**GWh**	**Change**
2005 Actual usage	477,655	
2009 Actual usage	445,518	
Change	32,137	-6.7%
Cause of Lower Electricity Requirements	**Estimate**	**Share of Change**
Weather	16,160	50.3%
Energy Efficiency & Customer-Sited Generation	7,967	24.8%
Economy	2,957	9.2%
Other Load Impacts	5,054	15.7%

Source: RGGI, Inc
http://www.rggi.org/docs/Retrospective_Analysis_Draft_White_Paper.pdf

The four factors identified in Figure B4 that caused the 6.7% decline in electricity requirements when comparing 2005 to 2009 accounted for 48.1% of the total decline in CO_2 emissions between those years. Figure B4 shows those four factors and the other six factors evaluated in this report that caused a reduction of CO_2 emissions between those years, and the percent change in CO_2 they caused. Because the factors causing a change in the load represented 48.1% of the total change in CO_2, the impact in CO_2 due to the secular economic activity changes was 4.4%. The most important factors comparing the changes in CO_2 emissions between 2005 and 2009 were the weather (24.2%) and the switch in fuel use from petroleum to natural gas (23.0%).

44 "Relative Effects of Various Factors on RGGI Electricity Sector CO_2 Emissions: 2009 Compared to 2005," Draft White Paper –11/2/10. Prepared by: New York State Energy Research and Development Authority. http://www.rggi.org/docs/Retrospective_Analysis_Draft_White_Paper.pdf



Source: RGGI, Inc. NY State Energy Research and Development Authority
http://www.rggi.org/docs/Retrospective_Analysis_Draft_White_Paper.pdf

FIGURE B4: ESTIMATED FACTORS CAUSING CO_2 EMISSIONS TO DECREASE FROM 2005 TO 2009 IN THE RGGI REGION

The net effect on the initial cap for the 2009 to 2013 period set for the states in the RGGI region is likely to be above an amount that would impinge on the electricity generators' production of CO_2 through that period. Because the cap on carbon is set at a level above the demand for CO_2 generation, the ability to infer the impact of the RGGI carbon market on the economics associated with greenhouse gas emissions and electricity production appears to be marginalized. This may not be true through 2018, when the RGGI cap will be 10% lower and demand for electricity may well increase in the region. In fact, given that it will reduce the ability to produce CO_2 by 10% by 2018 and the level observed for 2010 was still 17% below the 2018 reduced cap, it may not impinge on CO_2 emissions by the end of the 2018 expected end date for the current plan. Important observations gleaned from the analysis by NYSERDA as they apply to understanding the impact of a carbon market on include the difficulties of predicting the impact of

- factors such as the weather and changes to the economy
- changes in technology and modes of production of electricity
- changes in efficiencies in use, onsite generation and transmission networks.

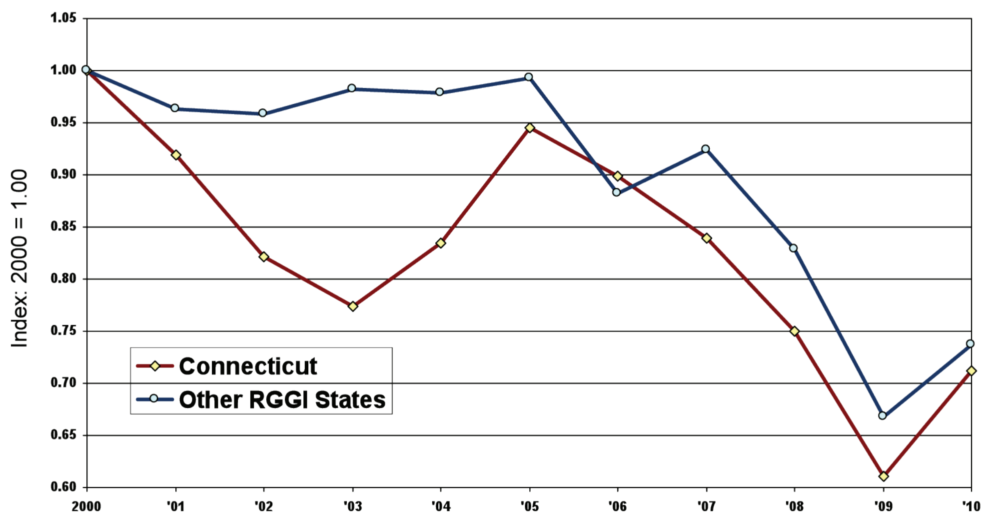
Among member states, Connecticut's major electricity generators produced an average of 10.4 million tons of CO_2 between 2000 and 2008. Over these nine years, Connecticut produced 93.2 million tons, accounting for nearly 6% of the total 1,577 tons from the ten states in RGGI during those years. The average CO_2 produced for each of the states from 2000 to 2008, the total produced, the distribution among the RGGI states of that production, and the budget established for each state and its distribution appear in Table B2.

TABLE B2: CO_2 PRODUCTION 2000-2008 AND BUDGET 2009 FOR RGGI STATES

State	Average* 2000 to 2008	Total 2000 to 2008 Absolute*	Total 2000 to 2008 Distribution	Final Budget* 2009 Absolute*	Final Budget* 2009 Distribution
RGGI Total	175.2	1,576.6	100%	188.1	100.0%
Connecticut	10.4	93.2	5.9%	10.7	5.7%
Delaware	7.8	70.3	4.5%	7.6	4.0%
Massachusetts	25.2	226.6	14.4%	26.7	14.2%
Maryland	36.3	326.4	20.7%	37.5	19.9%
Maine	4.5	40.3	2.6%	5.9	3.2%
New Hampshire	7.1	63.8	4.0%	8.6	4.6%
New Jersey	21.0	189.2	12.0%	22.9	12.2%
New York	60.2	541.9	34.4%	64.3	34.2%
Rhode Island	2.7	24.7	1.6%	2.7	1.4%
Vermont	0.0	0.1	0.0%	1.2	0.7%

Millions of short tons CO^2

An index of Connecticut's production of CO_2 and that of the other states in the region appears in Figure B5. Connecticut's trend shows a fairly significant decline, dropping to 77% by 2003 based on the production seen in 2000 followed by a strong rebound. By 2005 it was back to nearly 95% of the level in 2000 before dropping steadily down to only 61% of the 2000 level by 2009. Aggregate CO_2 production for the rest of the region was relatively stable throughout the early 2000s before dropping in tandem with Connecticut. The region appears to bottom out in 2009 with a production of only 67% of the CO_2 produced in 2000. New York's trend in CO_2 production from 2000 through 2010 strongly correlates with Connecticut's (0.85), while Maine (0.56) and New Hampshire (0.57) appear to be the most independent of the other states in the region.



Source: RGGI

FIGURE B5. TREND IN CO_2 PRODUCTION FOR CONNECTICUT AND OTHER RGGI STATES

After each state determined the 2009 budget, or cap, for CO_2 emissions, they developed policies to distribute the allowances to produce CO_2 emissions. Table B3 shows the allocation summary for allowances distributed in 2009 where each allowance represents the permission to produce one short ton of CO_2 emission as a byproduct from the production of electricity.

Table B3: Distribution of Allocation Allowances as Determined by Each State

	2009 CO2 Allowance Budget	Sold at Auction	Sold at Fixed Price	Total Sold	Distributed from Set-aside Accounts	Remaining to be Distributed from State Accounts	Retired	Total
TOTAL	188,076,976	86.92%	3.08%	90.00%	3.59%	4.83%	1.58%	100%
Connecticut	10,695,036	84.11%	1.29%	85.39%	1.99%	12.00%	0.79%	100%
Delaware	7,559,787	50.42%	0.00%	50.42%	33.61%	0.00%	15.97%	100%
Massachusetts	26,660,204	98.59%	0.00%	98.59%	0.00%	1.41%	0.00%	100%
Maryland	37,503,983	85.32%	0.00%	85.32%	0.00%	14.68%	0.00%	100%
Maine	5,948,902	84.68%	0.00%	84.68%	0.00%	15.32%	0.00%	100%
New Hampshire	8,620,460	71.00%	0.00%	71.00%	29.00%	0.00%	0.00%	100%
New Jersey	22,892,730	74.07%	24.70%	98.77%	0.00%	1.23%	0.00%	100%
New York	64,310,805	93.97%	0.00%	93.97%	2.33%	1.09%	2.61%	100%
Rhode Island	2,659,239	99.00%	0.00%	99.00%	0.00%	1.00%	0.00%	100%
Vermont	1,225,830	99.00%	0.00%	99.00%	0.00%	1.00%	0.00%	100%

Source: http://www.rggi.org/design/overview/allowance_allocation

Table B3 shows that 84.11% of Connecticut's 10.7 million allowances (one allowance represents one short ton CO_2) were sold in the RGGI, Inc. auctions as of May 20, 2010 and 1.29% had been sold at a fixed price ($2.00) directly to a regulated CO_2 source. For all states, nearly 87% of the allocations were sold at the auctions, and slightly more than 3% were sold at a fixed price. New Jersey is the only state, other than Connecticut, to sell allocations at a fixed price to regulated electricity producers. In addition to their allocations being sold, either at auction or at a fixed price, states can decide to distribute allocations from set aside accounts or to retire them. Connecticut chose to distribute nearly 2% directly to regulated sources, while Delaware distributed slightly more than a third of all of its allocations directly to regulated sources. New Hampshire distributed 29% and New York 2.3% directly to CO_2 sources. Twelve percent of Connecticut's 2009 allocations had not been distributed at the time of publication of Table B3. This compares to 4.8% of the allocations for the ten states not distributed at the time of Table B3 publication. Finally, 1.58% of the allocations from the states' budgets for 2009 were retired. This retirement reduces the supply of allocations in the market. If that reduction were to result in a constrained supply, the cost of the allocations would have increased. However, as noted above, the budget for 2009 significantly exceeded the required capacity for CO_2 emissions.

The first data column in Table B3 shows that the distribution of the 2009 allocation of the total budgeted allowance to the auction was nearly 87% of all allocations in the region. This auction provides the "trade" aspect of the cap and trade model used by the RGGI and thus allows for the potential establishment of a regional market price for CO_2 based on the demand for electricity in the region. The auctions, which are managed by RGGI, Inc. the nonprofit corporation created by the states to support the development and implementation of the initiative, are held quarterly online.[45] The first auction was September 25, 2008. The allocations

[45] Regional Greenhouse Gas Initiative, Inc. (RGGI, Inc.) is a 501(c)(3) non-profit corporation created to support development and implementation of the Regional Greenhouse Gas Initiative (RGGI). RGGI is a cooperative effort among ten states – Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont – to reduce greenhouse gas emissions. RGGI, Inc. has no regulatory or enforcement authority. All such sovereign authority is reserved to each Participating State. http://www.rggi.org/rggi.

sold at the auctions can be used for CO_2 emissions anytime in a specified three-year period. The first two auctions, occurring in September and December 2008, sold allocations for CO_2 emissions for the 2009 to 2011 period. Starting with the March 2009 auction, allocations for CO_2 emissions were sold for the 2012 to 2014 period.

As of the March 2011 auction, there have been nearly 346 million allowance transactions through the auction for the 2009 to 2011 period and nearly 17 million for the 2012 to 2014 period. Figure B6 shows the number of allocations for the 2009 to 2011 period sold in each auction and the price for each auction. The first RGGI auction, in September 2008, resulted in 12.56 million allowances sold for $3.07 per allowance. In total, these transactions—which produced nearly $35.6 million in proceeds—were equivalent to emissions of 12.56 million short tons of CO_2 in the 2009 to 2011 period. Although it is possible for an individual or company to buy these transactions in the auction, slightly more than 80% were bought by the electric generators classified as compliance entities.[46]

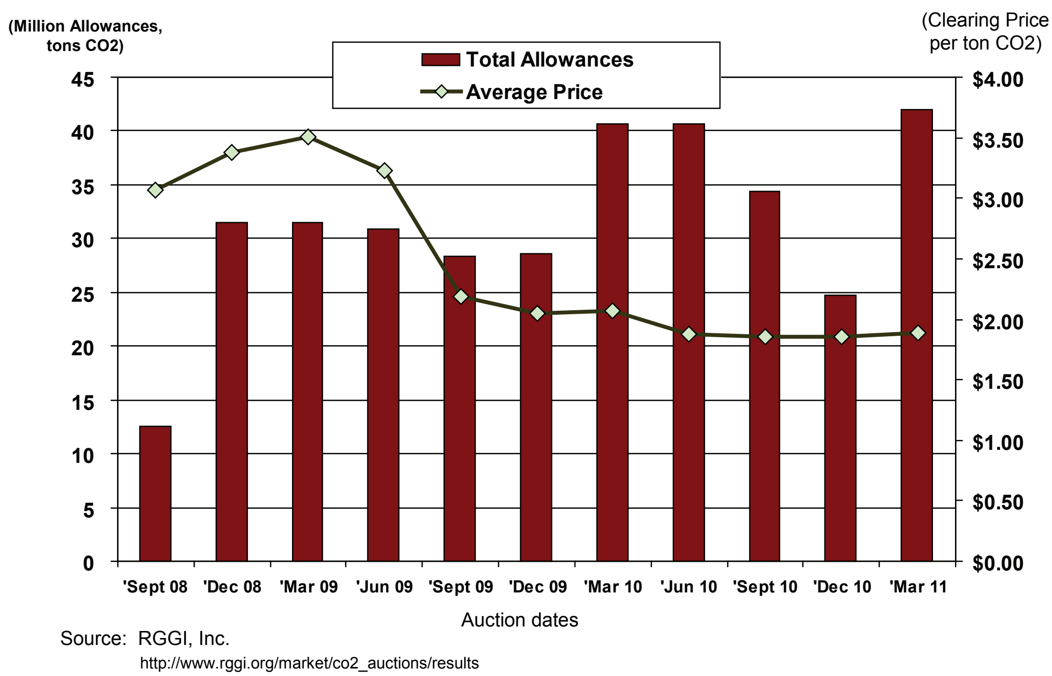


FIGURE B6: ALLOCATIONS SOLD AND TRANSACTION PRICES FOR 2009 TO 2011 ALLOCATIONS

Since the September 2008 auction, the quantity of allocations sold has increased substantially. Subsequent to a price increase in the next two auctions to $3.51 per ton of CO_2, the price declined eventually to the minimum of $1.86 for the September and December 2010 auctions before increasing to $1.89 in the March 2011 auction.

Total proceeds from the 11 auctions for the 2009 to 2011 allocations held through March 2011 were slightly more than $826 million. For the 2012 to 2014 period, total proceeds from the nine auctions are nearly $34.7 million. For comparison, the first auction for the 2009 to 2011 period occurred three months before the start of the period (in September 2008) and it resulted in $38.6

46 *Market Monitor Report for Auction 1*. Prepared for RGGI, Inc. on behalf of the RGGI Participating States. Prepared by: Potomac Economics, October 16, 2008, p.5. http://www.rggi.org/docs/Auction_1_MM_Report.pdf.

million based on a sale of 12.6 million allocations. However, to date, the nine auctions for the 2012 to 2014 period have resulted in nearly 17 million allocations sold and total revenues of $34.7 million. Figure B7 shows the cumulative proceeds from the 11 auctions are $860 million through the March 2011 auction.

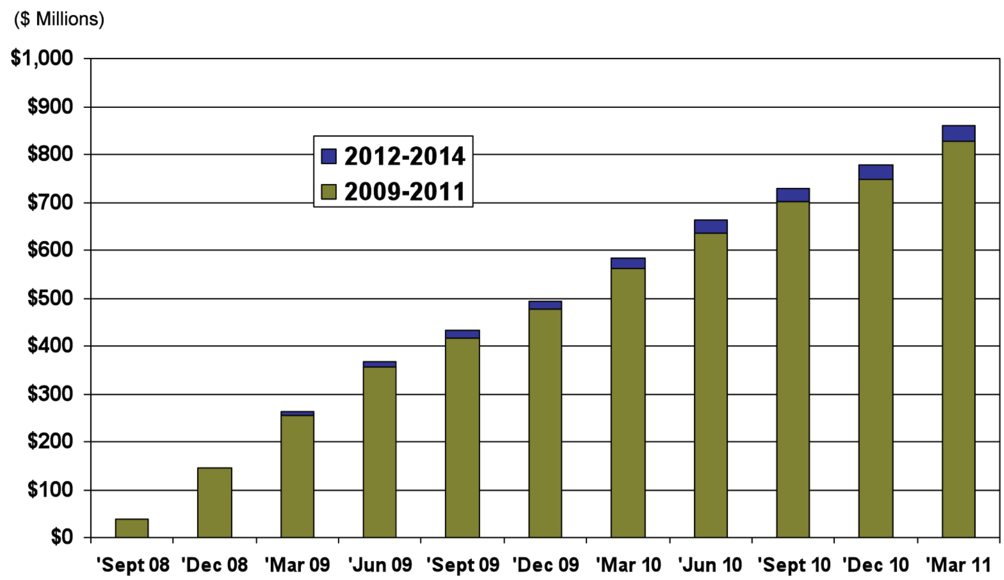
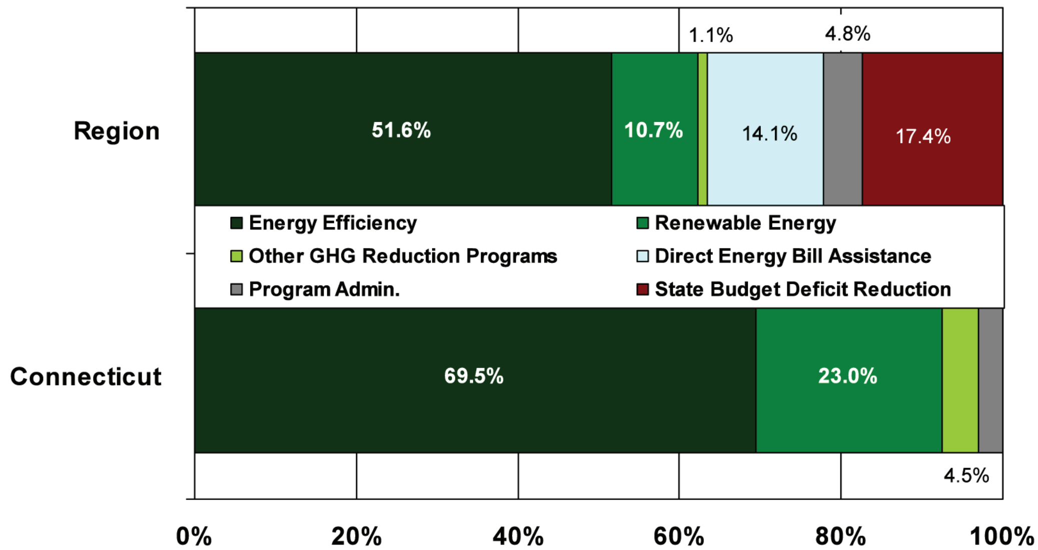


FIGURE B7: CUMULATIVE PROCEEDS FROM ELEVEN RGGI AUCTIONS

RGGI distributes the proceeds from the auctions to the states based on their contributions to the auctions. A memorandum of understanding among the RGGI states developed in 2005 commits each state to a minimum of 25% of the distribution of the proceeds from the allowances to the benefit of the consumers in the states. The states have exceeded this minimum—in fact, overall, they are investing slightly more than 63% to improve end-use energy efficiency and accelerate the deployment of renewable energy technologies. Figure B8 shows the overall distribution for the ten RGGI states and for Connecticut from the auction proceeds.

Figure B8 shows that Connecticut has allocated approximately 97% of its total proceeds in assorted energy programs. These funds have supported the expansion of the energy efficiency and renewable energy programs overseen by the Energy Conservation Management Board (ECMB) and the Connecticut Clean Energy Fund (CCEF). A comprehensive overview of these activities is available in the February 2011 report Investment of Proceeds from RGGI CO_2 allowances.[47] Connecticut used 3% of the proceeds for program administration.

[47] The full title of this report is "*Investment of Proceeds from RGGI CO_2 Allowances Benefits of Regional Greenhouse Gas Initiative. (RGGI)-funded programs in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.*" It is available at http://www.rggi.org/docs/Investment_of_RGGI_Allowance_Proceeds.pdf.



Source: RGGI, Inc. http://www.rggi.org/docs/Investment_of_RGGI_Allowance_Proceeds.pdf

FIGURE B8: ALLOCATION OF AUCTION PROCEEDS BY CATEGORIES, 2009

The 2009 to 2011 vintage for allowances for CO_2 emissions suggest that overall there will be 564 total allowances initially available to electricity producers in the ten states. If Connecticut, Delaware and New York retire the same number of allowances in 2010 and 2011 as they retired in 2009, 8.9 million allowances will be retired, leaving 555 million total allowances in the region. Of those 555 million allowances, an estimated 490 million allowances would be sold in the online RGGI market from September 2008 through the December 2011 auctions. Another 17 million allowances could be expected to be sold at a fixed price again if the states continue distributing their allowances in 2010 and 2011 as they did in 2009, as we show in Table B3. The final set, an estimated 47.5 million allowances, would be distributed in various ways over the three years. Through the March 2011 auction, nearly 346 million allowances have been sold. Thus, if the states distribute the allowances in 2010 and 2011 as they did in 2009, the overall supply of allowances for the 2009 to 2011 period would be approximately 555 million. In 2009 and 2010, 260 million allowances were used. If the growth in CO_2 production continues for 2011 at the rate observed from 2009 to 2010, another 152 million allowances would be required. Thus, the total requirement for CO_2 allowances in the RGGI states would be up to 415 million, resulting in approximately 140 million excess allowances (or 25%). These estimates appear in Table B4.

Table B4: Estimated Available and Required CO_2 Allowances

	Allocations of short tons CO2
Total Sold in Auction So far	345,929,119
3 year estimates	
Total sold at auction	490,451,149
Total sold fixed	17,377,411
Total sold	507,825,352
Total Distributed (& remaining)	47,549,219
Retired	8,910,902
Total in region for use	555,374,570
Total estimated requirements	412,504,803
Difference	142,869,767

Source: RGGI, Inc

Changes in state regulations in 2010 and 2011, as well as changes in participating states, will likely affect the allowances. One observation is that unless CO_2 production increases significantly in the 2012 to 2014 period, the CO_2 cap established by the RGGI states and its reduction by 2.5% per year from 2014 to 2018, increasing to a 10% reduction in 2018, is not likely to influence the market price for carbon.

This observation does not mean that the RGGI has failed. The RGGI collected $860 million through auctions and direct sales from September 2008 through March 2011; of this amount, RGGI returned 91.5% to member states. From the cumulative proceeds ($860 million), member states used 63.4% on average to improve end-use energy efficiency and accelerate the deployment of renewable energy technologies as depicted in Figure B8. In 2009, Connecticut used 97.5% of its RGGI proceeds to improve end-use energy efficiency and accelerate the deployment of renewable energy technologies. It is possible that charging the average price of $2.37 per ton of CO_2 altered consumers' selection of electricity generators in the regional electric market with a positive environmental impact from the reduction of green house gas emissions.

APPENDIX C
(TO ECONOMIC IMPACT STUDY)
THE REMI MODEL

The Connecticut REMI model is a dynamic, multi-sector, regional economic model developed and maintained for the Department of Economic and Community Development by Regional Economic Models, Inc. of Amherst, Massachusetts. This model provides detail on all eight counties in the State of Connecticut and any combination of these counties. The REMI model includes the major inter-industry linkages among 466 private industries, aggregated into 67 major industrial sectors. With the addition of farming and three public sectors (state and local government, civilian federal government, and military), there are 70 sectors represented in the model for the eight Connecticut counties.[48§]

The REMI model is based on a national input-output (I/O) model that the US Department of Commerce (DoC) developed and continues to maintain. Modern input-output models are largely the result of groundbreaking research by Nobel laureate Wassily Leontief. Such models focus on the inter-relationships between industries and provide information about how changes in specific variables—whether economic variables such as employment or prices in a certain industry or other variables such as population—affect factor markets, intermediate goods production, and final goods production and consumption.

The REMI Connecticut model takes the US I/O "table" results and scales them according to traditional regional relationships and current conditions, allowing the relationships to adapt at reasonable rates to changing conditions. Listed below are some salient structural characteristics of the REMI model:

- REMI determines consumption on an industry-by-industry basis, and models real disposable income in Keynesian fashion, that is, with prices fixed in the short run and GDP (Gross Domestic Product) determined solely by aggregate demand.
- The demand for labor, capital, fuel, and intermediate inputs per unit of output depends on relative prices of inputs. Changes in relative prices cause producers to substitute cheaper inputs for relatively more expensive inputs.
- Supply of and demand for labor in a sector determine the wage level, and these characteristics are factored by regional differences. The supply of labor depends on the size of the population and the size of the workforce.
- Migration—which affects population size—depends on real after-tax wages as well as employment opportunities and amenity value in a region relative to other areas.
- Wages and other measures of prices and productivity determine the cost of doing business. Changes in the cost of doing business will affect profits and/or prices in a given industry. When the change in the cost of doing business is specific to a region, the share of the local and US market supplied by local firms also is affected. Market shares and demand determine local output.

48 [§] The seminal reference is George I. Treyz (1993), Regional Economic Modeling: A Systematic Approach to Economic Forecasting and Policy Analysis, Kluwer Academic Publishers, Boston.

- "Imports" and "exports" between states are related to relative prices and relative production costs.
- Property income depends only on population and its distribution adjusted for traditional regional differences, *not* on market conditions or building rates relative to business activity.
- Estimates of transfer payments depend on unemployment details of the previous period, and total government expenditures are proportional to population size.
- Federal military and civilian employment is exogenous and maintained at a *fixed* share of the corresponding total US values, unless specifically altered in the analysis.
- Because each variable in the REMI model is related, a change in one variable affects many others. For example, if wages in a certain sector rise, the relative prices of inputs change and may cause the producer to substitute capital for labor. This changes demand for inputs, which affects employment, wages, and other variables in those industries. Changes in employment and wages affect migration and the population level, which in turn affect other employment variables. Such chain reactions continue in time across all sectors in the model. Depending on the analysis performed, the nature of the chain of events cascading through the model economy can be as informative for the policymaker as the final aggregate results. Because REMI generates extensive sectoral detail, it is possible for experienced economists in this field to discern the dominant causal linkages involved in the results.

The REMI model is a structural model, meaning that it clearly includes cause-and-effect relationships. The model shares two key underlying assumptions with mainstream economic theory: *households maximize utility* and *producers maximize profits*. In the model, businesses produce goods to sell to other firms, consumers, investors, governments and purchasers outside the region. The output is produced using labor, capital, fuel and intermediate inputs. The demand for labor, capital and fuel per unit output depends on their relative costs, because an increase in the price of one of these inputs leads to substitution away from that input to other inputs. The supply of labor in the model depends on the number of people in the population and the proportion of those people who participate in the labor force. Economic migration affects population size and its growth rate. People move into an area if the real after-tax wage rates or the likelihood of being employed increases in a region.

Supply of and demand for labor in the model determine the real wage rate. These wage rates, along with other prices and productivity, determine the cost of doing business for each industry in the model. An increase in the cost of doing business causes either an increase in price or a cut in profits, depending on the market supplied by local firms. This market share combined with the demand described above determines the amount of local output. The model has many other feedbacks. For example, changes in wages and employment impact income and consumption, while economic expansion changes investment and population growth impacts government spending.

MODEL OVERVIEW

Figure C1 is a pictorial representation of the model. The Output block shows a factory that sells to all the sectors of final demand as well as to other industries. The Labor and Capital Demand block shows how labor and capital requirements depend on both output and their relative costs. Population and Labor Supply contribute to final demand and to wage determination in the product and labor market. The feedback from this market shows that economic migrants respond to labor market conditions. Demand and supply interact in the Wage, Price and Profit block. Once prices and profits are established, they determine market shares, which along with components of demand, determine new output or sales in all sectors

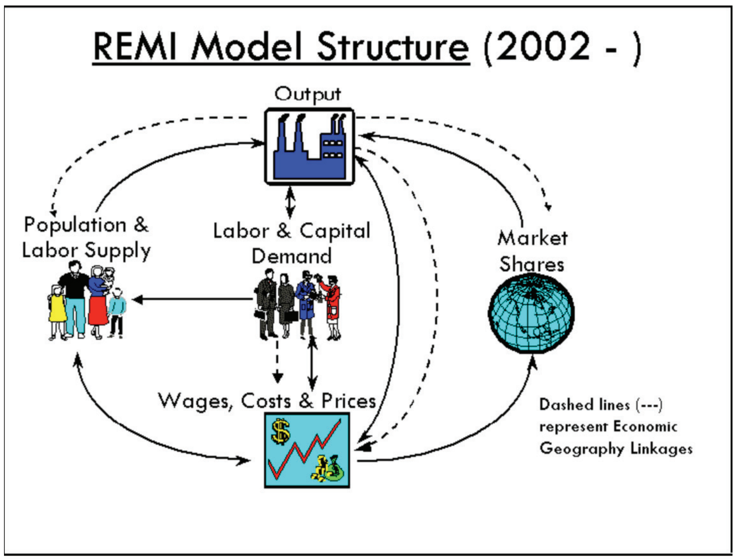


FIGURE C1

The REMI model brings together the above elements to determine the value of each of the variables in the model for each year in the baseline forecasts. The model includes each inter-industry relationship that is in an input-output model in the Output block, but goes well beyond the input-output model by including the relationships in all of the other blocks shown in Figure C1.

In order to broaden the model in this way, it is necessary to estimate key relationships econometrically. This is accomplished by using extensive data sets covering all areas of the country. These large data sets and two decades of research effort have enabled REMI to simultaneously maintain a theoretically sound model structure and build a model based on all the relevant data available. The model has strong dynamic properties, which means that it forecasts not only what will happen, but also when it will happen. This results in long-term predictions that have general equilibrium properties. This means that the long-term properties of general equilibrium models are preserved without sacrificing the accuracy of event timing predictions and without simply taking elasticity estimates from secondary sources.

UNDERSTANDING THE MODEL

In order to understand how the model works, it is critical to know how the key variables in the model interact with one another and how policy changes are introduced into the model. To introduce a policy change, one begins by formulating a policy question. Next, select a baseline forecast that uses the baseline assumptions about the external policy variables and then generate an alternative forecast using an external variable set that includes changes in the external values, which are affected by the policy issue.

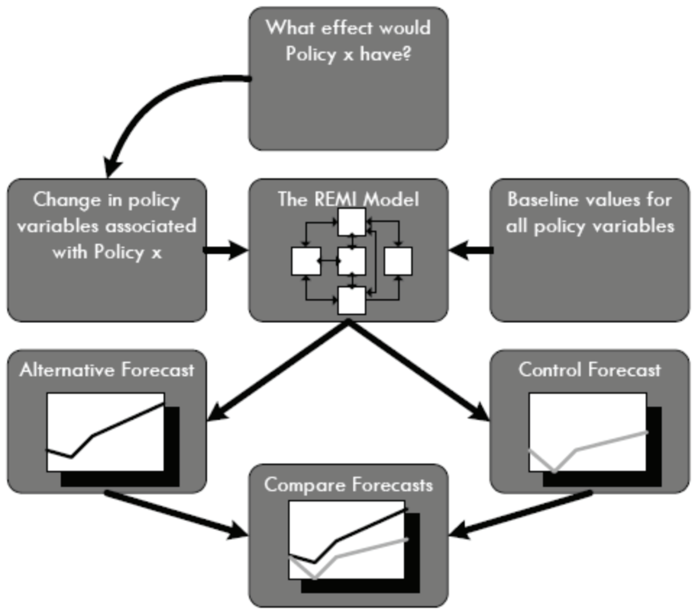


FIGURE C2

Figure C2 shows how this process would work for a policy change called Policy X. In order to understand the major elements in the model and their interactions, subsequent sections examine the various blocks and their important variable types, along with their relationships to each other and to other variables in the other blocks. The only variables discussed are those that interact with each other in the model. Variables determined outside of the model include

- variables determined in the US and world economy (e.g., demand for computers)
- variables that may change and affect the local area, but over which the local area has no control (e.g., an increase in international migration)
- variables that are under control of local policy (e.g., local tax rates).

For simplicity, the last two categories are called policy variables. Changes in these variables are automatically entered directly into the appropriate place in the model structure. Therefore, the diagram showing the model structure also serves as a guide to the organization of the policy variables (see Figure B3).

OUTPUT BLOCK

The Output Block variables are

- State and Local Government Spending
- Investment
- Exports
- Consumption
- Real Disposable Income

These variables interact with each other to determine output and depend on variable values determined in other blocks as follows:

Variables in the Output Block	Variables Outside of the Output Block that are Included in its Determinants
State and Local Government Spending	Population
Investment	Optimal Capital Stock (also the actual capital stock)
Output	Share of Local Market (The proportion of local demand supplied locally, called the Regional Purchase Coefficient)
Exports	The Regional Share of Interregional and International Trade
Real Disposable Income	Employment, Wage Rates and the Consumer Expenditure Price Index

LABOR AND CAPITAL DEMAND BLOCK

The Labor and Capital Demand block has three types of key variables:

- Employment - determined by the labor/output ratio and the output in each industry, determined in the Output block.
- Optimal Capital Stock - depends on relative labor, capital and fuel costs and the amount of employment.
- Labor/Output Ratio - depends on relative labor, capital and fuel costs.

Simply put, if the cost of labor increases relative to the cost of capital, the labor per unit of output falls and the capital per unit of labor increases.

POPULATION AND LABOR SUPPLY BLOCK

The model predicts population for 600 cohorts segmented by age, ethnicity and gender. This block also calculates the demographic processes: births, deaths and aging. The model deals with different population sectors as follows:

- Retired migrants are based on past patterns for each age cohort 65 and over.
- International migrants follow past regional distributions by country of origin.
- Military and college populations are treated as special populations that do not follow normal demographic processes.
- Economic migrants are those who are sensitive to changes in quality of life and relative economic conditions in the regional economies. The economic variables that change economic migration are employment opportunity and real after-tax wage rates.

This block allows the determination of the size of the labor force by predicting the labor force participation rates for age, ethnicity and gender cohorts, which are then applied to their respective cohorts and summed. The key variables that change participation rates within the model are the ratio of employment to the relevant population (labor market tightness) and the real after-tax wage rates.

WAGE, PRICE AND PROFIT BLOCK

Variables contained within the Wage, Price and Profit block are:

- Employment Opportunity
- Wage Rate
- Production Costs
- Housing Price
- Consumer Price Deflator
- Real Wage Rate
- Industry Sales Price
- Profitability

The wage rate is determined by employment opportunity and changes in employment demand by occupation for occupations that require lengthy training. The housing price increases when population density increases. The Consumer Expenditure Price Index is based on relative commodity prices, weighted by their share of US nominal personal consumption expenditures. The model uses the price index to calculate the real after-tax wage rate for potential migrants that includes housing price directly, while the price index used to deflate local income uses the local sales price of construction. Wage rates affect production costs, as well as other costs, and they in turn determine profitability or sales prices, depending on whether the type of industry involved serves mainly local or external markets. For example, a cost increase for all local grocery stores results in an increase in their prices, while an increase in costs for a motor vehicle factory reduces its profitability of production at that facility but may not increase their prices worldwide.

MARKET SHARES BLOCK

The Market Shares Block consists of:

- Share of Local Market
- Share of External Market

An increase in prices leads to some substitution away from local suppliers toward external suppliers. In addition, a reduction in profitability for local factories leads to less expansion of these factories relative to those located in areas where profits have not decreased. These responses occur because the United States is a relatively open economy where firms can move to the area that is most advantageous for their business.

THE COMPLETE MODEL

Figure C3 illustrates the entire model and its components and linkages. This diagram is helpful in understanding the complex relationships shared by variables within the various blocks discussed above, as well as their relationships to variables in other blocks.

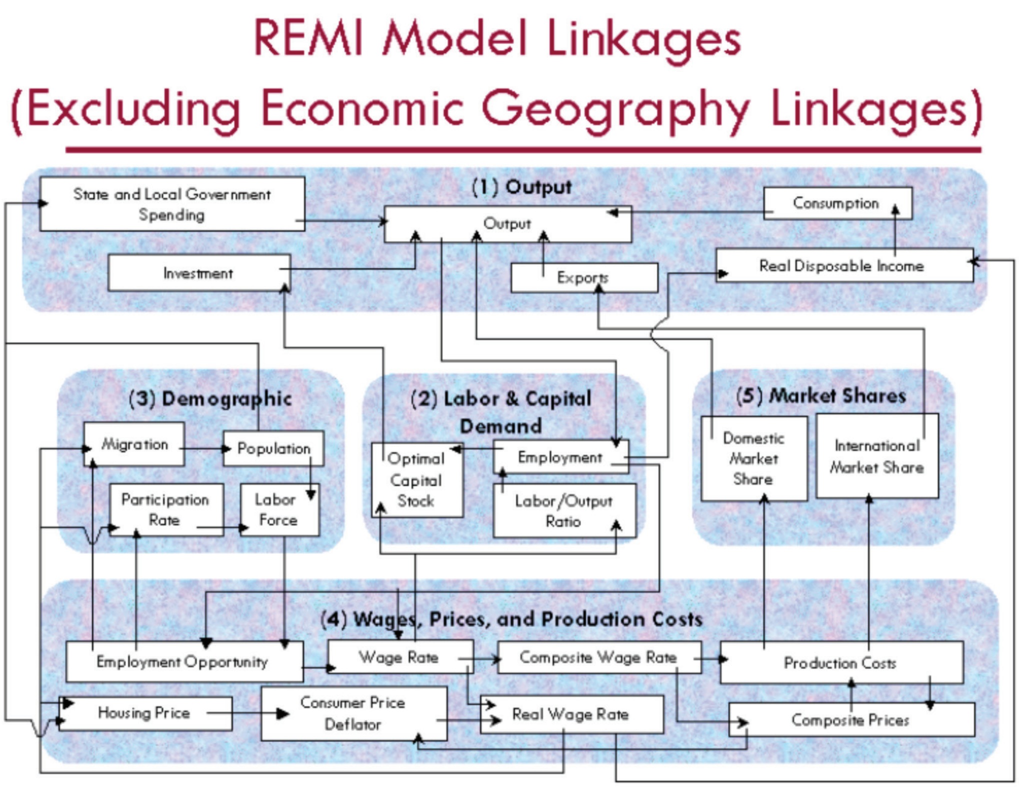


FIGURE C3

ATTACHMENT 2

ASSESSING CONNECTICUT RESIDENTS' OPINIONS OF NUCLEAR POWER PHONE SURVEY RESULTS DECEMBER 2010

EXECUTIVE SUMMARY

The Connecticut Academy of Science and Engineering (CASE) commissioned the Connecticut Economic Resource Center, Inc. (CERC) to assess Connecticut residents' opinions of nuclear power on behalf of the Connecticut Energy Advisory Board (CEAB). The survey was designed to assess the attitudes of the general population in Connecticut regarding nuclear energy, particularly as it relates to cost, environment and safety. The methodology selected to gauge the sentiments of the public was a rigorous, unbiased survey; a telephone survey was deemed to be the best approach because the results could be gleaned in a timely manner. The results from the phone survey, presented below, will be used by the CASE study committee as guidance in the development of the study's findings and recommendations and by the CEAB in developing energy plans for Connecticut for the future.

The 600 survey completions of residents who were at least 18 years old were evenly distributed among Fairfield County, Hartford & New Haven counties, New London County and the rest of the state. The survey had a confidence level of 95%, with a confidence interval at the county level of 8% and confidence interval at the state level of 4%.

Questions were developed around the following sets of issues and were sorted randomly to control for position bias:

- General electric energy and climate change awareness
- Where residents find information about electric energy issues
- Actions taken to reduce electric energy usage
- Impressions of electric energy sources (fossil fuels, renewable/green, nuclear)
- Attitudes of nuclear energy issues
- Degree to which respondents agreed or disagreed with building additional power plants
- Demographics questions for comparisons (such as education attainment and income)

This survey, which assessed residents' opinions about electric energy and nuclear power issues, identified some interesting findings, including the following:

- The majority of respondents incorrectly thought that fossil fuels accounts for most of the electricity generated in Connecticut (see Figure 8 for details).
- Many respondents did not understand the activities of a nuclear power plant facility

(Figures 19, 20), or that there is an operating nuclear power plant in Connecticut (Figure 21).

- Respondents were generally very concerned about climate change issues (Figure 5) and the need to reduce the state's reliance on fossil fuels for generating electricity (Figure 11).
- Most respondents were not thinking about nuclear power as a potential source of electricity (Figure 22).
- Respondents favored green/renewable energies over fossil fuels and nuclear (Figures 14-16, 18).
- Reducing property taxes was not seen as an incentive for locating a nuclear power plant facility (Figure 17).
- Building a new nuclear power plant facility was more favorable to those with graduate school experience and degrees (Figure 22).

Possible next steps include:

- Educating the general public about electric energy issues and Connecticut's situation. Information like this is generally read by the public on the Internet, and in newspapers, books and magazines. Education will assist the public in making informed decisions about future power generation in Connecticut and whether importing or generating electricity within the state boundaries is preferred.
- Assess the opinions of residents who fully understand that Connecticut has been operating nuclear power plants for many years, and whether they were in favor of expanding nuclear power generation. By better understanding misconceptions, fears or opinions, electricity generation decision makers can determine the type and focus of general public education that is needed, as well as gain an understanding of the public's preferences for energy sources to generate electricity.
- Assessing the opinions of residents who live near Millstone or the former nuclear power plant site in East Haddam to gauge their opinions of expanding nuclear power generation.

ASSESSING CONNECTICUT RESIDENTS' OPINIONS OF NUCLEAR POWER PHONE SURVEY RESULTS REPORT: DECEMBER 2010

The Connecticut Academy of Science and Engineering (CASE) commissioned the Connecticut Economic Resource Center, Inc. (CERC) to assess Connecticut residents' opinions of nuclear power on behalf of the Connecticut Energy Advisory Board (CEAB). The survey was designed to assess the attitudes of the general population in Connecticut regarding nuclear energy, particularly as it relates to cost, environment and safety. The methodology selected to gauge the sentiments of the public was a rigorous, unbiased survey; a telephone survey was deemed to be the best approach because the results could be gleaned in a timely manner. The results from the phone survey, presented below, will be used by the CASE study committee as guidance in the development of the study's findings and recommendations and by the CEAB in developing energy plans for Connecticut for the future.

Approach

Using random digit dialing and computer-assisted-telephone-interview (CATI) software, the polling contractor, Horizon Research Group, made more than 4,400 calls to obtain 600 survey completions. The project fieldwork began on October 8th and concluded on October 27th, 2010. Respondents were contacted Monday through Friday between 4:00 pm and 9:00 pm, and Saturday between 10:00 am and 4:00 pm. The survey took approximately 10 minutes for each respondent to complete. Figure 1 denotes the final call disposition.

No answer / busy	732
Answering machine / voice mail	1,845
No blocked calls / privacy manager	493
Fax / Modem	36
Disconnected	243
Language Barrier	15
Call Back / Decision Maker Not Available	177
Initial Refusal / Refused At Introduction	253
Terminated During Interview	19
Completed Interview	600
Total	4,413

FIGURE 1: 600 SURVEYS COMPLETED OF CONNECTICUT RESIDENTS

The 600 survey completions of residents who were at least 18 years old were evenly distributed among Fairfield County, Hartford & New Haven counties, New London County and the rest of the state. The survey had a confidence level of 95%, with a confidence interval at the county level of 8% and confidence interval at the state level of 4%.

Questions were developed around the following sets of issues and were sorted randomly to control for position bias:

- General electric energy and climate change awareness
- Where residents find information about electric energy issues
- Actions taken to reduce electric energy usage
- Impressions of electric energy sources (fossil fuels, renewable/green, nuclear)
- Attitudes of nuclear energy issues
- Degree to which respondents agreed or disagreed with building additional power plants
- Demographics questions for comparisons (such as education attainment and income)

Survey Findings

All of the respondents were at least 18 years old and evenly distributed among counties. A range of ages and both genders were represented. Figure 2 shows the details of the respondents by county, age and gender.

		Age					Gender	
	Total	18-29	30-44	45-54	55-64	65+	Male	Female
Base	600	15	159	150	112	143	257	343
Fairfield County	150	1	39	36	33	38	63	87
Hartford & New Haven Counties	150	4	37	38	29	35	67	83
New London County	150	4	46	30	21	42	65	85
All other counties	150	6	37	46	29	28	62	88

FIGURE 2: THE RESPONDENTS WERE EVENLY DISTRIBUTED AMONG COUNTIES WITH REPRESENTATION AMONG AGE AND GENDER.

When asked to state the most important environment issue currently facing the United States, one-third of the respondents mentioned future energy demands. Figure 3 shows that future energy demands, climate change, and air quality/smog were the most common issues.

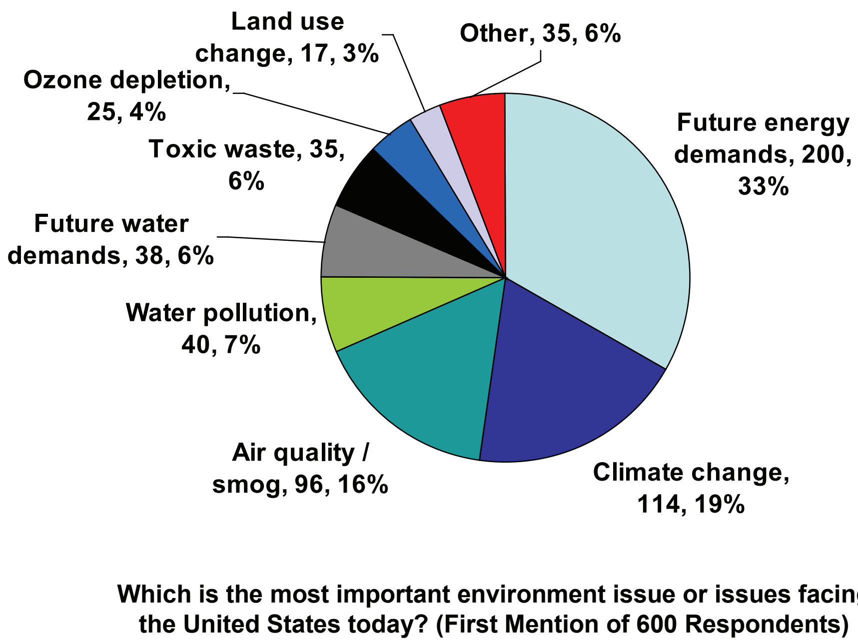


FIGURE 3: FUTURE ENERGY DEMANDS WERE FIRST ON THE MINDS OF ONE-THIRD OF THE RESPONDENTS

There was no statistical difference in the mentions among the counties or age groups. However, men more than women tended to think of future energy needs, while women more than men thought of water pollution. In addition to mentioning one environment issue facing the United States, respondents were asked if there were others on their minds. Up to three mentions were recorded; 1,496 mentions were noted of the 600 respondents. Figure 4 shows that the issues that topped the first mention list were consistent when all of the mentions were included.

	# Total Mentions	% Total
Future energy demands	350	23%
Climate change	244	16%
Air quality / smog	204	14%
Water pollution	143	10%
Toxic waste	128	9%
Ozone depletion	110	7%
Future water demands	106	7%
Land use change	82	5%
Overpopulation	33	2%
Other	96	6%

FIGURE 4: TOTALS OF 1ST, 2ND, AND 3RD MENTIONS (600 RESPONDENTS, 1,496 MENTIONS)

Next, the respondents were asked to what degree they thought the climate change situation was serious, if any. The climate change situation was thought to be serious or very serious by 59% of respondents. By adding the respondents that also thought the situation was somewhat serious, the share of the total jumped to 88%. Figure 5 also shows that 72% of 30-44 year-old respondents thought the situation was serious or very serious, while 50% of respondents 65 years or more thought the same.

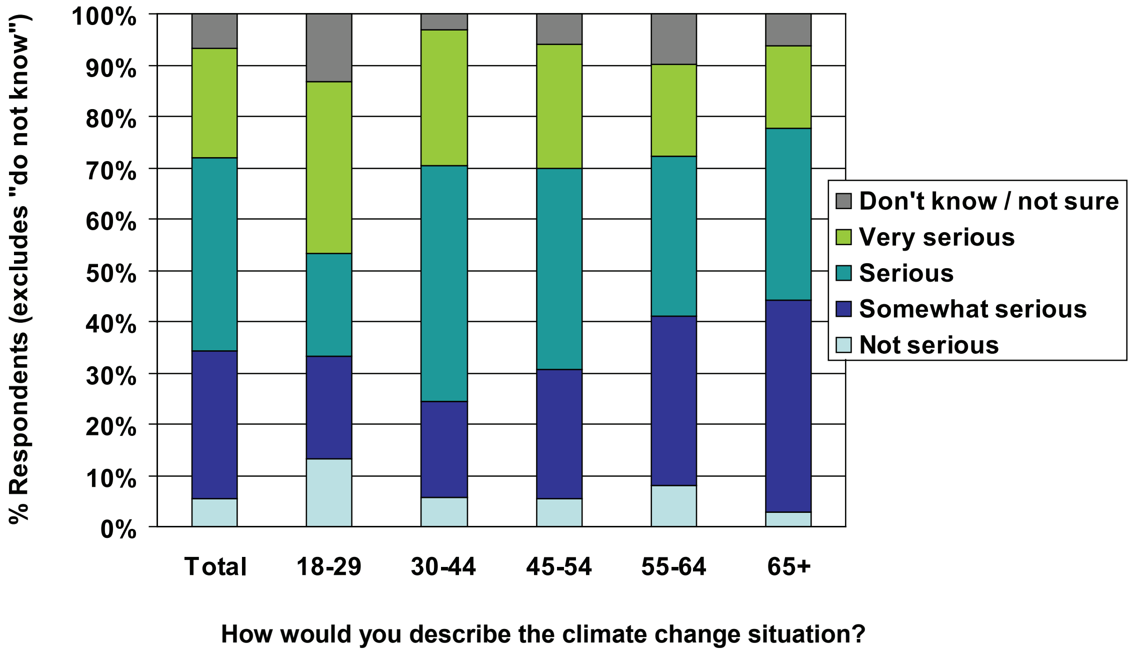


FIGURE 5: THE CLIMATE CHANGE SITUATION WAS THOUGHT TO BE SERIOUS OR VERY SERIOUS BY 59% OR RESPONDENTS.

The distribution of opinions by county and gender were similar to the total average shown in the above figure.

Respondents were asked what came to mind when thinking about US electric energy issues. Since respondents were allowed to mention more than one issue, the 600 respondents produced 1,083 responses. Energy prices was the most noted mention, with 31% of all the responses, followed by environmental issues with 18% and petroleum dependency with 14%. Nuclear energy was mentioned 6% of the time (Figure 6).

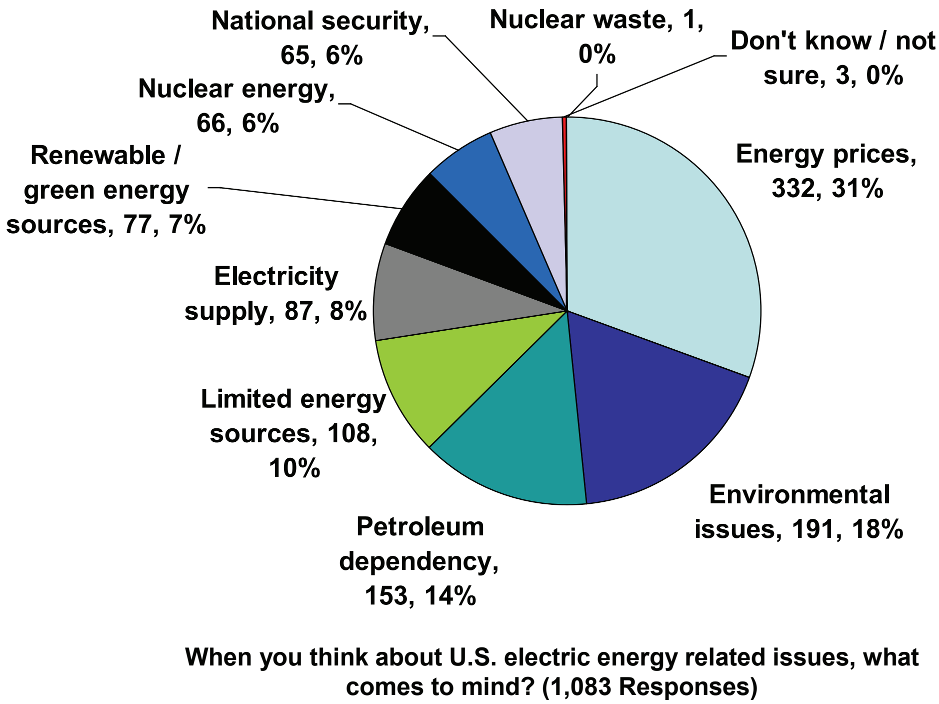


FIGURE 6: THE PRICE OF ENERGY WAS THE TOP US ELECTRIC ENERGY ISSUE.

Although not shown in the figure above, it should be noted that energy prices were mentioned by a larger share of Fairfield County residents than the total average, and men mentioned prices more often than women. Limited energy sources and renewable/green sources were mentioned less often by residents over the age of 65.

Next, respondents described the energy issues of the United States and then of Connecticut. Figure 7 shows that respondents viewed the national and state energy issues similarly. It is interesting to note that 10% did not know how to rate Connecticut's situation, compared with 5% for the United States. 78% thought the US situation was very serious or serious, while 71% thought the same of Connecticut.

Although not shown in the figure, younger respondents saw the problem as more serious than the older respondents.

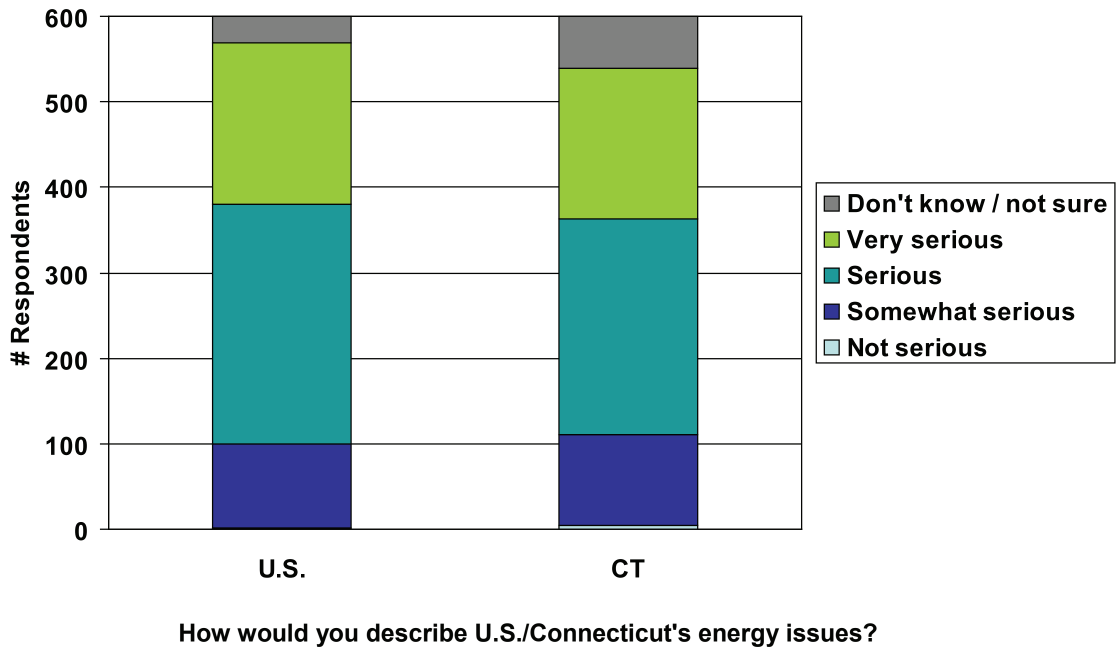


FIGURE 7: RESPONDENTS VIEWED NATIONAL AND STATE ENERGY ISSUES SIMILARLY.

Almost 70% of the respondents thought that fossil fuels accounted for most of the electricity generated in Connecticut, as shown in Figure 8. It is interesting to note that 18% did not know how to answer the question. Although not shown in the figure, more men (20%) selected nuclear than women (6%), and more women (22%) than men (12%) did not know.

According to 2008 Energy Information Administration data, 51% of the electricity generated was from nuclear power, 27% from natural gas and 14% from coal. Fossil fuels account for the majority of the electricity generating capacity but not the electricity generated. The respondents were incorrect in believing that fossil fuels account for most of the electricity generated in the state.

The next question asked if the respondent had ever looked for information about electric energy issues. Ninety-eight of the 600 respondents, only 16%, had searched for that type of information. Figure 9 shows the sources from which those respondents had obtained the information with the Internet, newspapers and books/magazines topping the list. Although not shown in the figure, more men (24%) than women (11%) had looked for the information; and more 45-64 year-olds (19%) than 65+ year-olds (11%) had searched.

These 98 respondents were also asked how they would prefer to obtain information about electric energy issues with the Internet, newspapers and books/magazines still topping the list. Men (51%) preferred books/magazines to women (24%).

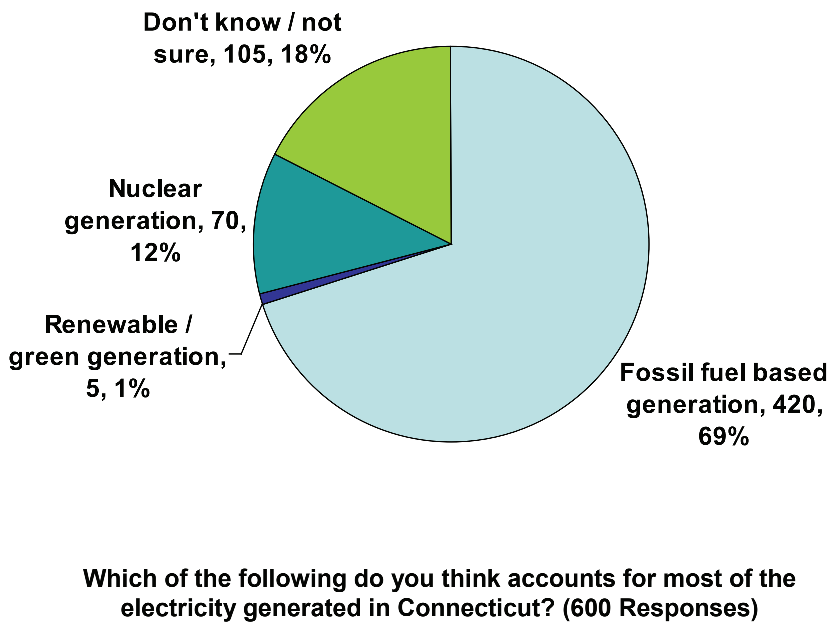


FIGURE 8: THE MAJORITY OF RESPONDENTS INCORRECTLY THOUGHT THAT FOSSIL FUELS ACCOUNTED FOR MOST OF THE ELECTRICITY GENERATED IN CONNECTICUT.

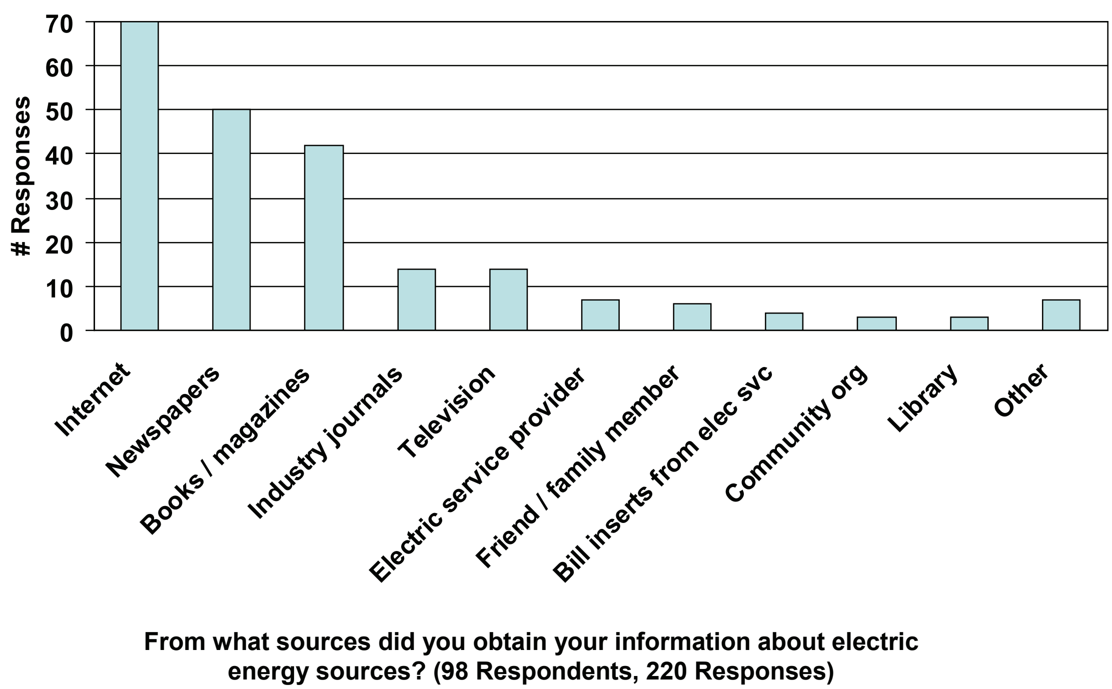


FIGURE 9: THE INTERNET, NEWSPAPERS, BOOKS AND MAGAZINES WERE THE MOST POPULAR SOURCES FOR ELECTRIC ENERGY INFORMATION.

The Internet, newspapers, books and magazines were also the preferred sources for the information among the 502 respondents who had not yet conducted any research.

What actions had been taken by the respondents regarding energy issues? Using energy efficient light bulbs was the most likely action taken, as seen in Figure 10.

More 30-44 year olds than 55-64 and 65+ year olds had replaced conventional light bulbs with energy efficient ones. In addition, more respondents in the rest of the state, rather than Fairfield or New London counties, had replaced the light bulbs. The respondents in the 65+ age group had less of a tendency to seal air leaks or add more insulation, or to purchase "energy star" qualified products, than the other age groups. The younger age groups were also more inclined to participate in a community recycling program than the older respondents.

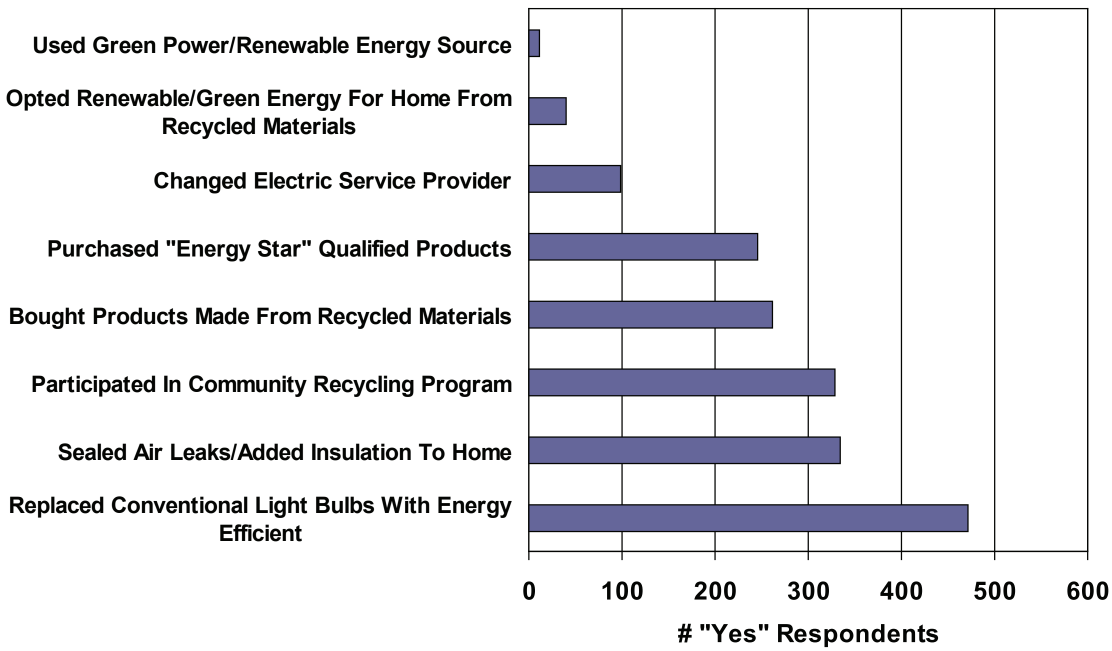


FIGURE 10: USING ENERGY EFFICIENT LIGHT BULBS WAS THE MOST LIKELY ACTION TAKEN.

When asked what other actions were taken, the most frequent response was to conserve electricity or to install timers (75 respondents noted doing this). Installing new windows was also mentioned by 36 respondents.

The next series of questions asked the respondents to think about the current use of fossil fuels. Figure 11 shows the result of whether the respondents believed that Connecticut should reduce its reliance on fossil fuels. More than half thought it was very or extremely important to reduce fossil fuel reliance.

Although not shown in the figure, it was "extremely important" to reduce fossil fuel reliance to more younger people (e.g., 28% among 30-44 year olds), compared to 17% among 55-64 year olds and 13% among 65+ year olds.

How should Connecticut reduce its reliance on fossil fuels? Figure 12 shows that 166 respondents did not know how to answer this question, followed by a series of renewable/ green energy options. Five respondents noted using nuclear energy (these five responses were classified in the "other" category).

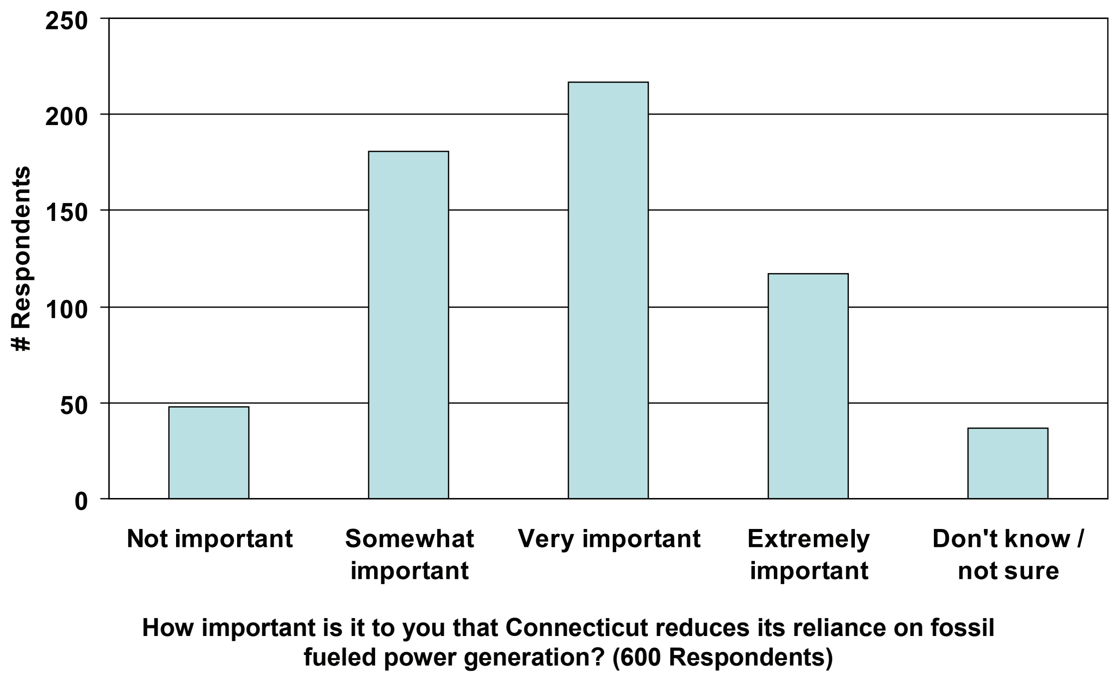
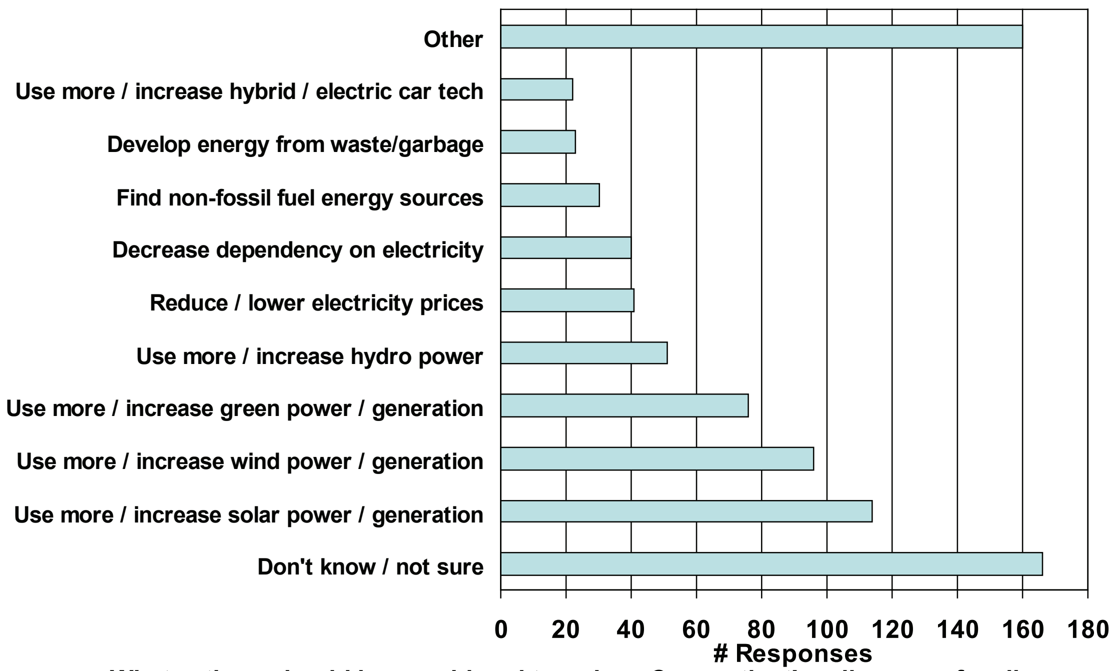


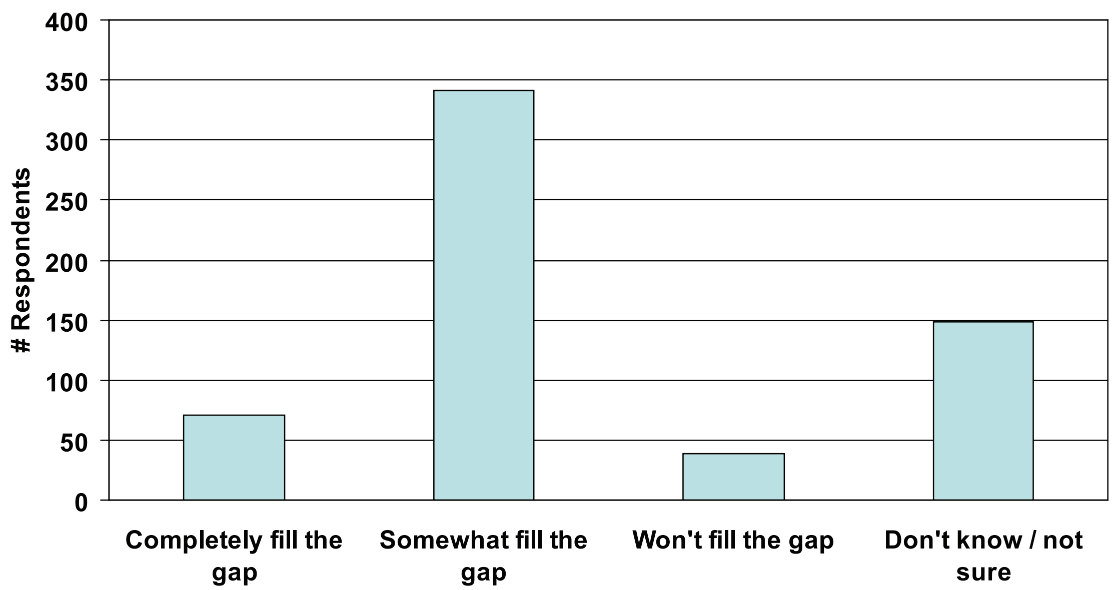
FIGURE 11: IT WAS VERY OR EXTREMELY IMPORTANT THAT CONNECTICUT REDUCE ITS RELIANCE ON FOSSIL FUELS TO 334, OR 56%, OF RESPONDENTS.



What actions should be considered to reduce Connecticut's reliance on fossil fueled power generation? (515 Respondents, 819 Responses)

FIGURE 12: BESIDES NOT KNOWING HOW TO REDUCE CONNECTICUT'S RELIANCE ON FOSSIL FUELS, RENEWABLE POWERS WERE MOST OFTEN CITED.

Almost 350 respondents thought that renewables could somewhat fill the gap in reducing Connecticut's reliance on fossil fuels, with another 150 respondents not sure (Figure 13).



To what extent do you think that renewables alone can fill in the gap in order to reduce Connecticut's reliance on fossil fueled electric power generation? (600 Respondents)

FIGURE 12: BESIDES NOT KNOWING HOW TO REDUCE CONNECTICUT'S RELIANCE ON FOSSIL FUELS, RENEWABLE POWERS WERE MOST OFTEN CITED.

The next series of questions asked the respondent to compare fossil fuel, renewable/green and nuclear based generation regarding a number of issues.

First, the respondents were asked how favorable or unfavorable each type of electric energy source was in contributing to reliable and secure supplies of power in the future. Almost half of the respondents thought that nuclear was not favorable (although there was a significant difference between Fairfield County and New London County – 52% not favorable versus 41%. It can also be noted in Figure 14 that renewable/green based generation was seen as extremely favorable by 230 of the 600 respondents.

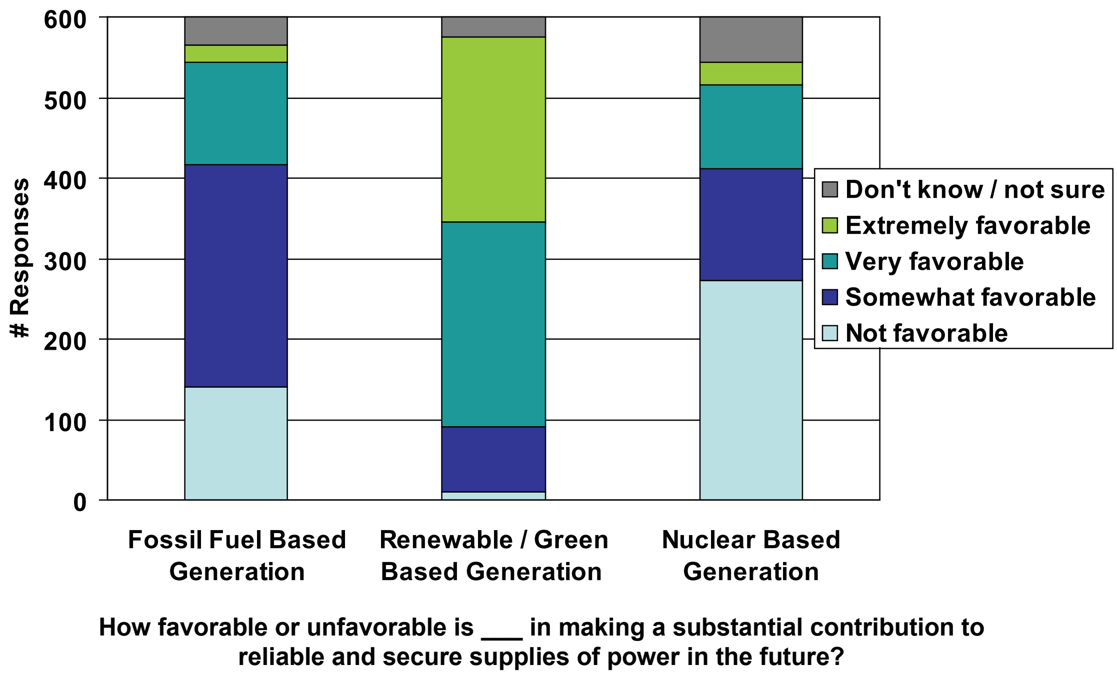


FIGURE 14: RENEWABLE/GREEN BASED GENERATION WAS SEEN MOST FAVORABLY.

Next, each of the respondents was asked how expensive it was to produce power from each source. As Figure 15 shows, fossil fuels were seen to be very expensive by 314 of the 600 respondents. Only 103 respondents thought that nuclear based generation was very expensive although 187 did not know how to answer the question.

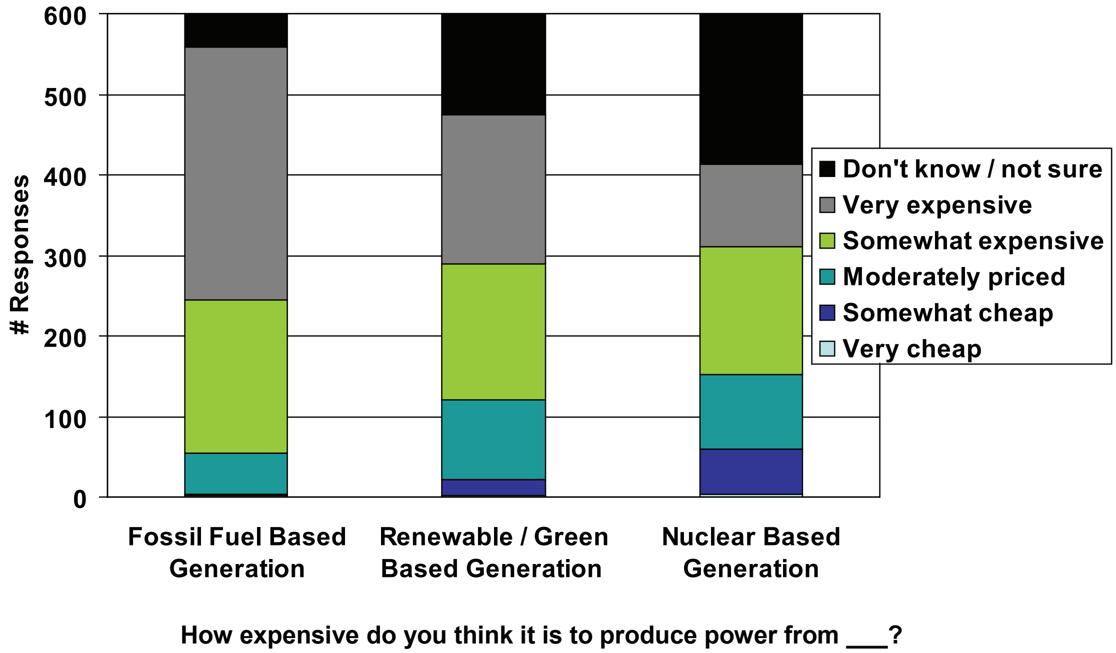


FIGURE 15: FOSSIL FUELS WERE SEEN AS THE MOST EXPENSIVE, ALTHOUGH ONE-THIRD OF RESPONDENTS DID NOT KNOW HOW TO RATE THE COST OF NUCLEAR BASED GENERATION.

When asked whether Connecticut should increase, maintain or reduce usage of the three electric energy sources, respondents overwhelmingly wanted to increase usage of renewable/green based generation. Only eight respondents wanted to increase the use of fossil fuels, while 75 would increase nuclear based generation. Almost 200 respondents did not want to use nuclear based generation at all.

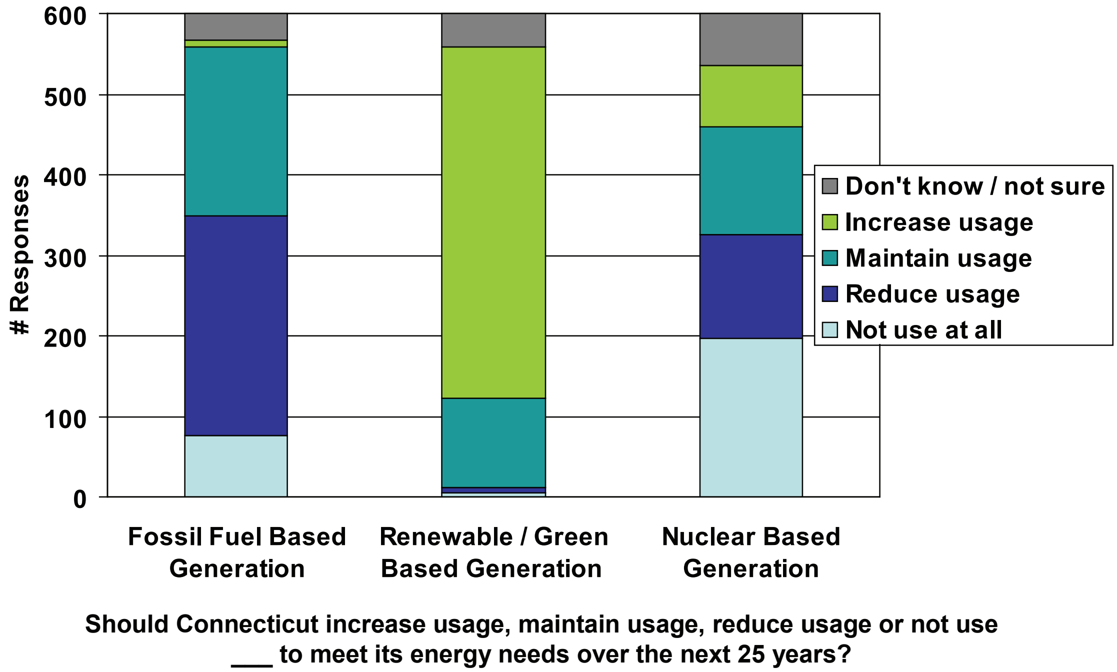


FIGURE 16: RESPONDENTS WANTED TO INCREASE USAGE OF RENEWABLE/ GREEN BASED GENERATION.

Respondents were asked how they would feel about having a power plant built nearby – within five miles of their homes. Would their feelings change if their property taxes were reduced? Figure 17 shows the results of both of these questions, in which the opinions of the respondents did not change much even when the property tax incentive was presented.

Although not presented in the figure, it is interesting to note that:

- The younger respondents, 30-44 years and 45-54 years, were more strongly opposed to a new fossil fuel power plant than the older respondents, 55-64 years and 65+ years. Building a new fossil fuel power plant was supported or strongly supported by 28% of respondents.
- The same age pattern applied regarding a new renewable/green power plant, while 63% supported or strongly supported it.
- Residents in Fairfield County opposed a new nuclear plant more than all the other regions, while New London County and the rest of the state supported a new nuclear plant more than Fairfield County and Hartford/New Haven counties. Building a new nuclear power plant was supported or strongly supported by 19% of respondents.

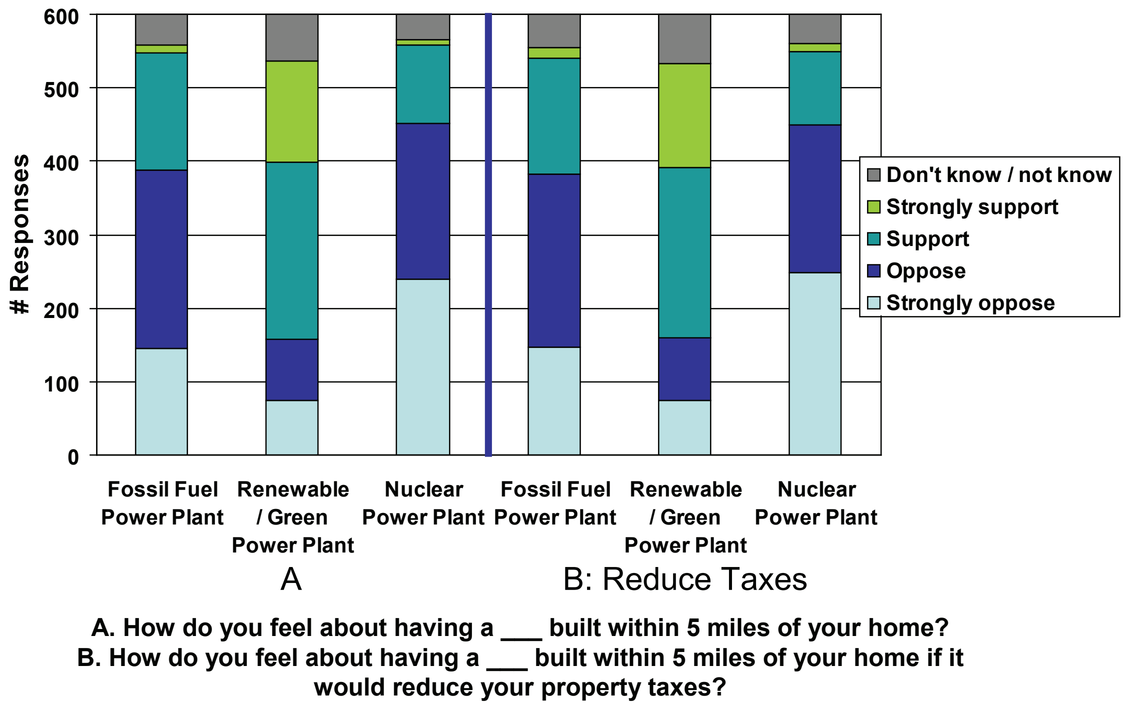


FIGURE 17: REDUCING PROPERTY TAXES DID NOT CHANGE MANY RESPONDENTS' MINDS ABOUT LOCATING A POWER PLANT NEARBY.

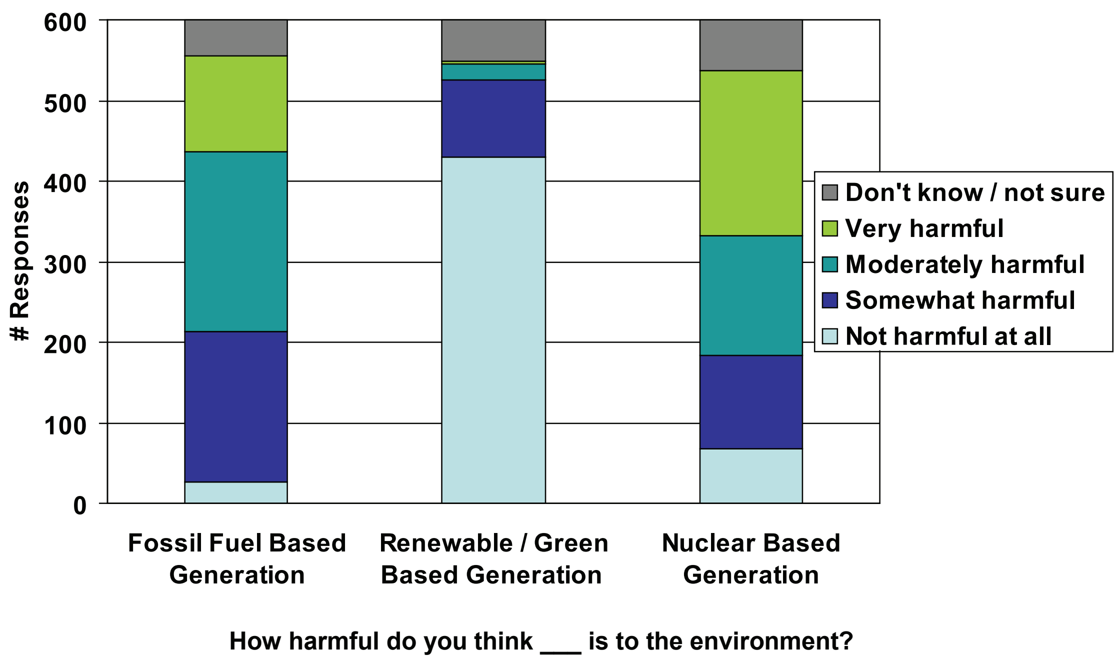
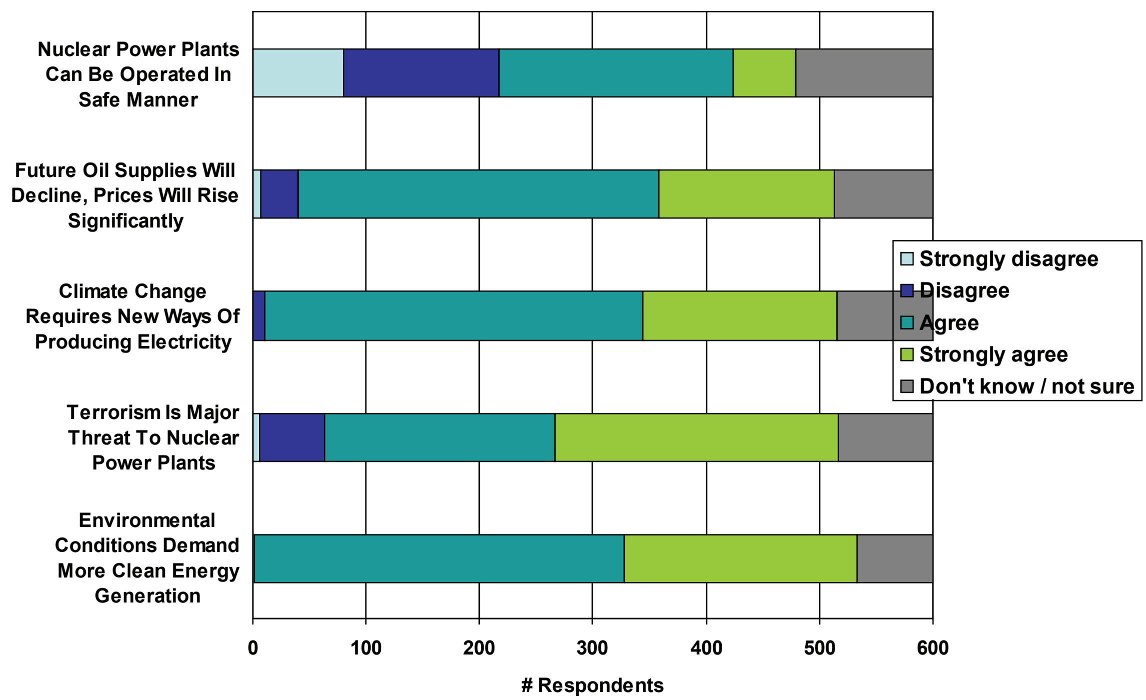


FIGURE 18: RENEWABLE/GREEN BASED GENERATION WAS SEEN AS THE LEAST HARMFUL OF THE THREE OPTIONS.

Figure 18 shows that the majority of the respondents did not think that renewable/green based generation was at all harmful to the environment; while 118 respondents thought that fossil fuels were very harmful and 205 thought the same about nuclear.

New London County respondents saw nuclear generation as less harmful than those in Hartford/New Haven counties.

The next set of questions asked the respondents whether they agreed or not with a series of statements. The majority of the respondents agreed about the statements regarding environmental issues: oil prices will rise in the future because of declining supply, climate change requires new ways of producing electricity, and environmental conditions demand more clean energy generation. Most also agree that terrorism is a major threat to nuclear power plants. Regarding nuclear power plants being operated in a safe manner, more than 100 respondents did not know how to answer the question, and more than 200 disagreed or strongly disagreed with the statement (Figure 19). Although not in the figure, New London County respondents agreed (41%) or strongly agreed (5%) that nuclear power plants could be operated in a safe manner versus Fairfield County (20% and 13% percent, respectively).



Based upon what you know or may have heard, please tell me if you agree or disagree with the following (1 of 2).

19: VIRTUALLY EVERYONE AGREED THAT ENVIRONMENTAL CONDITIONS DEMAND MORE CLEAN ENERGY GENERATION.

Figure 20 is a continuation of statements with which the respondents either agreed or disagreed. It is interesting to note how many respondents did not know how to respond to the following statements:

- Nuclear waste can be stored safely for many years (311 not sure how to respond)
- Nuclear material is sufficiently protected against misuse (298 not sure)
- It is very unlikely there would be a serious accident at a nuclear power plant in the next ten years (277 not sure)
- The disposal of radioactive waste is under control (237 not sure)
- Nuclear proliferation is a major threat to national security (227 not sure)
- Geopolitical instability in the Mideast is a significant challenge to the energy future of the United States (205 not sure)
- National security depends on reducing the use of oil (202 not sure)

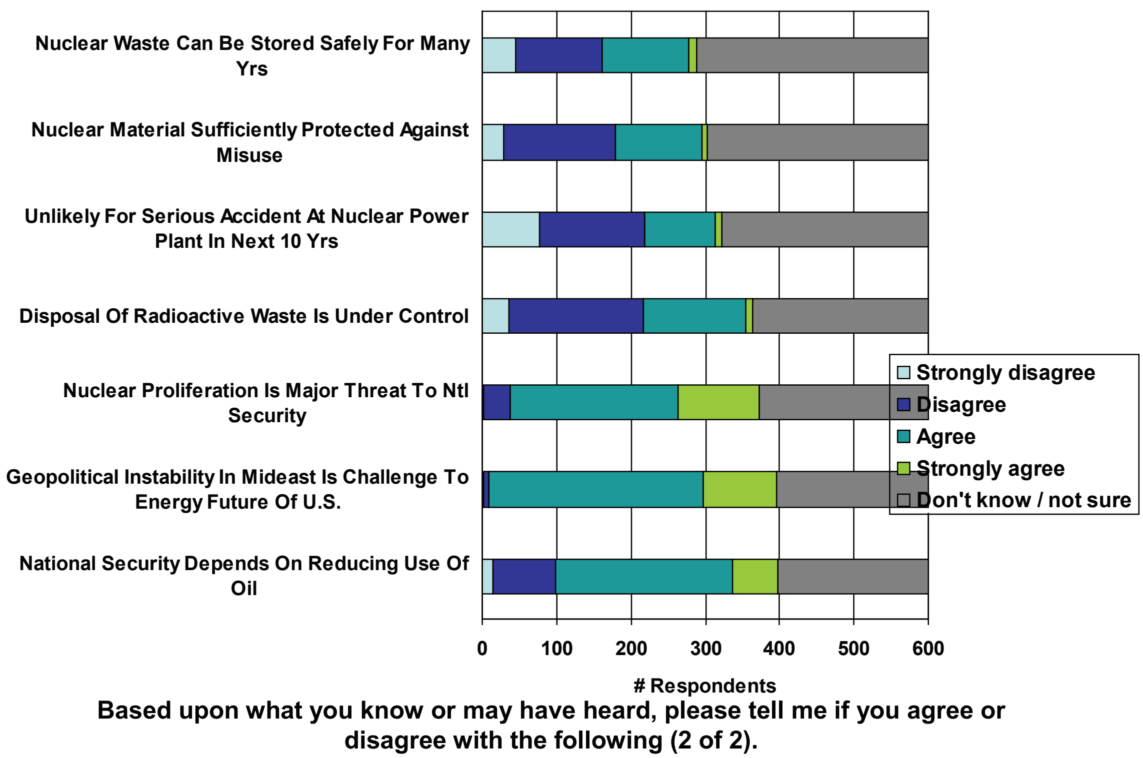


FIGURE 20: MANY RESPONDENTS WERE UNSURE ABOUT NUCLEAR ISSUES.

The next question asked: "Based upon what you know or may have heard, are there any operating nuclear power plants located in Connecticut?" Of the 600 respondents, 314 said yes, 158 said no, and 128 were not sure.

Of the 314 respondents who said there were operating nuclear power plants in the state, 230 respondents said there was one, 49 respondents thought there were two, six respondents thought there were three or four, and 29 respondents did not know.

Next, the 314 respondents were asked where the operating nuclear power plants were located. Figure 21 shows that 54% mentioned either Waterford, Millstone or Niantic. Another 20% were not sure where the power plants were located.

Some of the municipalities mentioned in the "other" category include East Haddam (3 responses), Groton (3), Bridgeport (3), Norwalk (2), Old Saybrook (2), Enfield (1), Middlebury (1), Milford (1), New Haven (1), Windsor (1), Watertown (1), Noank (1), and Portland (1).

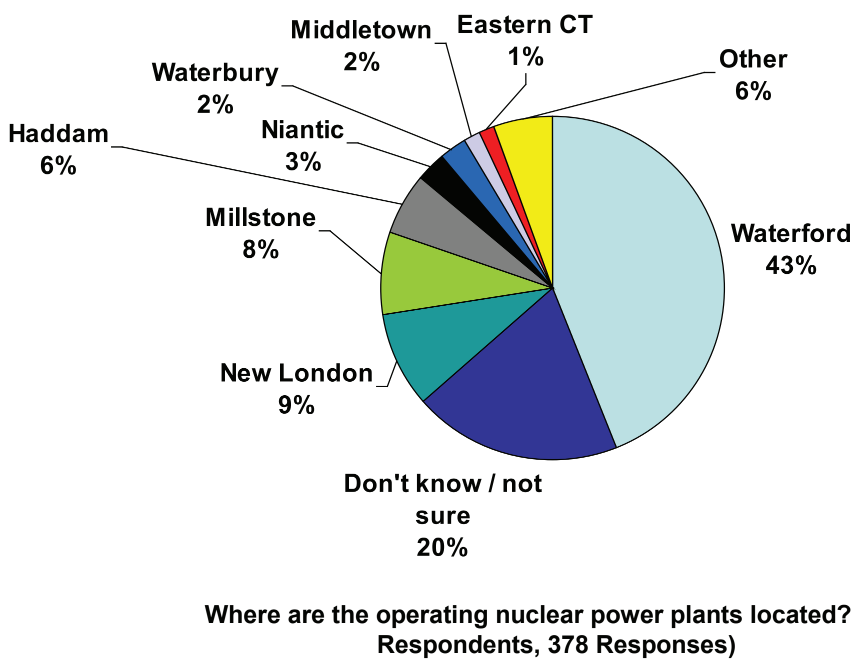


FIGURE 21: WATERFORD WAS THE MOST OFTEN MENTIONED LOCATION FOR AN OPERATING NUCLEAR POWER PLANT IN THE STATE.

Figure 22 shows results from the next question, which asked whether Connecticut should build a new nuclear power plant facility for additional electric capacity.

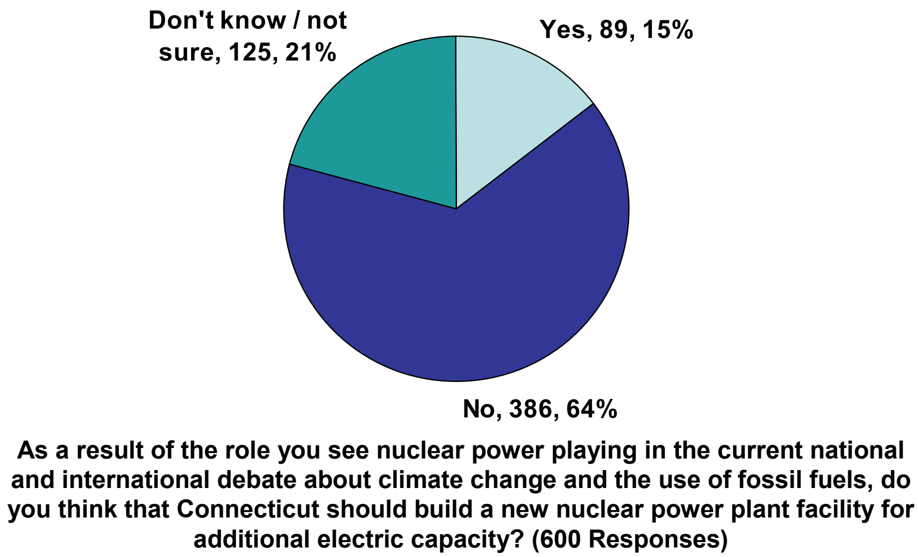


FIGURE 22: MOST RESPONDENTS DID NOT THINK THAT CONNECTICUT SHOULD BUILD A NEW NUCLEAR POWER PLANT FACILITY.

64% of all the respondents did not think that Connecticut should build a new nuclear power plant facility. However, the results varied somewhat by demographics and interests:

- Those who thought the climate change situation is very serious were mostly against building a new nuclear power plant facility. The "very serious" respondents had more of an opinion (fewer "don't know" responses) and 76% said no to building a new nuclear facility. For the "serious" respondents, 65% said no to building a new facility. As for the other responses to the climate change situation, 58% said no to building a new facility.
- The nuclear energy-conscious were more positive about building a new facility than the rest of the respondents (25% for building a new facility and 30% not sure). The respondents who were more nuclear energy-conscious were among those who mentioned it when asked: "When you think about US electric energy related issues, what comes to mind?"
- Those who thought it is very or extremely important for Connecticut to reduce its fossil fuel reliance tended to not want to build a new nuclear plant. The "yes" percentages between these two groups were virtually the same. However, more that selected "extremely" or "very important" regarding Connecticut reducing its fossil fuel use had an opinion about building a nuclear facility. Of the "extremely" and "very important"

respondents, 69% selected no to building a new facility versus 59% of the others.

- Respondents with graduate work or degrees were more supportive of a nuclear facility than other respondents. Of the respondents with some graduate work or a degree, 40% were in favor of building a new facility.
- Income levels did not correlate much with opinions of a new nuclear facility, although respondents with lower incomes were generally more opposed.

Conclusions

This survey, which assessed residents' opinions about electric energy and nuclear power issues, identified some interesting findings:

- The majority of respondents incorrectly thought that fossil fuels accounts for most of the electricity generated in Connecticut.
- Many respondents did not understand the activities of a nuclear power plant facility, or that there is an operating nuclear power plant in Connecticut.
- Respondents were generally very concerned about climate change issues and the need to reduce the state's reliance on fossil fuels for generating electricity.
- Most respondents were not thinking about nuclear power as a potential source of electricity.
- Respondents favored green/renewable energies over fossil fuels and nuclear.
- Reducing property taxes was not seen as an incentive for locating a nuclear power plant facility.
- Building a new nuclear power plant facility was viewed more favorably by those with graduate school experience and degrees.

Possible next steps include:

- Educating the general public about electric energy issues and Connecticut's situation. Information like this is generally read by the public on the Internet, and in newspapers, books and magazines. Education will assist the public in making informed decisions about future power generation in Connecticut and whether importing or generating electricity within the state boundaries is preferred.
- Assessing the opinions of residents who fully understand that Connecticut has been operating nuclear power plants for many years, and whether they were in favor of expanding nuclear power generation. By better understanding misconceptions, fears or opinions, electricity generation decision makers can determine the type and focus of general public education that is needed, as well as gain an understanding of the public's preferences for energy sources to generate electricity.
- Assessing the opinions of residents who live near Millstone or the former nuclear power plant site in East Haddam to gauge their opinions of expanding nuclear power generation.

APPENDIX A
(TO ATTACHMENT 2: PHONE SURVEY)

PHONE SURVEY QUESTIONS

CERC
Nuclear Power Survey
Final – September 23, 2010

Hello, my name is _____________ and I am calling from Horizon Research Group, an independent market research firm. May I please speak with an adult (over age 18) member of your household who has the next upcoming birthday?

REPEAT INTRODUCTION ONCE APPROPRIATE RESPONDENT IS ON LINE AND CONTINUE:

We are conducting a survey for the Connecticut Academy of Science and Engineering on behalf of the Connecticut Energy Advisory Board on environmental and energy issues and would like to include your views. This is a professional market research interview, not a sales call. The survey will take approximately 10 minutes. Any information you provide will be kept strictly confidential and used for research purposes only. In addition, your identity will remain anonymous. Are you willing to participate in this survey? (OBTAIN CONSENT AND CONTINUE)

Interviewer____ Date________________

==

Environmental Concerns

1. Which is the most important environmental issue or issues facing the United States today? (ACCEPT UP TO THREE MENTIONS – PROBE AND CLARIFY FULLY)

(DO NOT READ, EXCEPT TO CLARIFY)	1ST Mention	2ND Mention	3RD Mention
a. Future water demands	01	01	01
b. Biodiversity protection	02	02	02
c. Carbon footprint	03	03	03
d. Habitat protection	04	04	04
e. Air quality / smog	05	05	05
f. Urban sprawl	06	06	06
g. Future energy demands	07	07	07
h. Endangered species	08	08	08
i. Land use change	09	09	09
j. Toxic waste	10	10	10
k. Ozone depletion	11	11	11
l. Acid rain	12	12	12
m. Climate change	13	13	13
n. Water pollution	14	14	14
o. Overpopulation	15	15	15
p. Destruction of ecosystems	16	16	16
Other (PLEASE SPECIFY)	________	________	________

2. How would you describe the climate change situation? Would you say that the climate change situation is (READ CHOICES IN ORDER)?

Very serious	4
Serious	3
Somewhat serious, or	2
Not serious	1
Don't know / not sure (DO NOT READ)	8

3. When you think about US electric energy related issues, what first comes to mind? (PROBE & CLARIFY FULLY – ACCEPT MULTIPLE RESPONSES)

   <u>(DO NOT READ, EXCEPT TO CLARIFY)</u>
   Petroleum dependency.. 01
   Energy prices 02
   National security
   Renewable/green energy sources... 03
   Electricity supply 04
   Limited energy sources... 05
   Nuclear energy.. 06
   Environmental issues.. 07
   Other (PLEASE SPECIFY)____

4. How would you describe the nation's electric energy issues? Would you say that the nation's energy issues are (READ CHOICES IN ORDER)?

   Very serious 4
   Serious 3
   Somewhat serious, or.. 2
   Not serious 1
   Don't know / not sure ....(DO NOT READ).................................. 8

5. How would you describe Connecticut's electric energy issues? Would you say that Connecticut energy issues are (READ CHOICES IN ORDER)?

   Very serious 4
   Serious 3
   Somewhat serious, or.. 2
   Not serious 1
   Don't know / not sure ....(DO NOT READ).................................. 8

6. Which of the following do you think accounts for most of the electricity generated in Connecticut? (READ CHOICES IN ORDER)

   Fossil fuel-based generation 1
   Renewable/green generation.. 2
   Nuclear generation.. 3
   Don't know / not sure ....(DO NOT READ).................................. 8

7. Have you ever looked for information about electric energy sources?

   Yes 1
   No ....(GO TO Q10)............................. 2
   Don't know / not sure ....(GO TO Q10)............................. 3
   Refused ....(GO TO Q10)............................. 4

8. From what source did you obtain your information about electric energy sources? (PROBE & CLARIFY FULLY – ACCEPT MULTIPLE RESPONSES)

DO NOT READ, EXCEPT TO CLARIFY)

Website / Internet 01
Radio 02
Television 03
Online social networking, such as ....
Facebook, MySpace and YouTube................04
Other (SPECIFY)________________________
____

Newspapers 07
Scientific journals...05
Industry journals...06
Books, magazines 08
....

(IF **WEBSITE OR INTERNET** IS MENTIONED, PROBE FOR SPECIFIC WEBSITE, INCLUDING SOCIAL NETWORKING SITES
IF **TELEVISION** IS MENTIONED, PROBE FOR SPECIFIC STATION OR CHANNEL
IF **RADIO** IS MENTIONED, PROBE FOR SPECIFIC STATION, CALL LETTERS, CHANNEL OR FORMAT)

9. How would you prefer to obtain your information about electric energy sources? (PROBE & CLARIFY FULLY – ACCEPT MULTIPLE RESPONSES)

DO NOT READ, EXCEPT TO CLARIFY)

Website / Internet 01
Radio 02
Television 03
Online social networking, such as ....
Facebook, MySpace and YouTube................04
Other (SPECIFY)________________________
____

Newspapers 07
Scientific journals...05
Industry journals...06
Books, magazines ....
....

(IF **WEBSITE OR INTERNET** IS MENTIONED, PROBE FOR SPECIFIC WEBSITE, INCLUDING SOCIAL NETWORKING SITES
IF **TELEVISION** IS MENTIONED, PROBE FOR SPECIFIC STATION OR CHANNEL
IF **RADIO** IS MENTIONED, PROBE FOR SPECIFIC STATION, CALL LETTERS, CHANNEL OR FORMAT)

NOW TO Q11

10. If you were to seek out information about electric energy sources, what resource would you prefer to use? (PROBE & CLARIFY FULLY – ACCEPT MULTIPLE RESPONSES)

DO NOT READ, EXCEPT TO CLARIFY)

Website / Internet 01
Radio 02
Television 03
Online social networking, such as ....
Facebook, MySpace and YouTube................04
Other (SPECIFY)________________________
____

Newspapers 07
Scientific journals...05
Industry journals...06
Books, magazines ....
....

(IF **WEBSITE OR INTERNET** IS MENTIONED, PROBE FOR SPECIFIC WEBSITE, INCLUDING SOCIAL NETWORKING SITES
IF **TELEVISION** IS MENTIONED, PROBE FOR SPECIFIC STATION OR CHANNEL
IF **RADIO** IS MENTIONED, PROBE FOR SPECIFIC STATION, CALL LETTERS, CHANNEL OR FORMAT)

11. Have you taken any of the following actions within the past 12 months? (READ & ROTATE LIST)

(READ & ROTATE LIST)	Yes	No	DK
b. Changed my electric service provider	1	2	3
c. Replaced conventional light bulbs with energy efficient light bulbs	1	2	3
d. Purchased "energy star" qualified products	1	2	3
e. Sealed air leaks / added more insulation to home	1	2	3
f. Used green power / renewable energy source like solar or wind energy	1	2	3
g. Participated in community recycling program	1	2	3
h. Bought products made from recycled materials	1	2	3
i. Opted to buy renewable/green energy for my home	1	2	3

12 What other action / actions did you take? (PROBE & CLARIFY FULLY – ACCEPT MULTIPLE RESPONSES)

____

____

13. How important is it to you that Connecticut reduces its reliance on fossil-fueled power generation (i.e., coal, oil or natural gas generated power)? Would you say that it is (READ CHOICE IN ORDER) that Connecticut reduces its reliance on fossil-fuelled power generation?

Extremely important		4
Very important		3
Somewhat important, or		2
Not important	(GO TO 15)	1
Don't know/ not sure	(DO NOT READ – GO TO Q15)	8

14. What actions should be considered to reduce Connecticut's reliance on fossil-fueled power generation (i.e., coal, oil or natural gas generated power)? (PROBE & CLARIFY FULLY – ACCEPT MULTIPLE RESPONSES)

____

____

15. To what extent do you think that renewables alone can fill the gap in order to reduce Connecticut's reliance on fossil-fueled electric power generation? Would you say that renewables alone can (READ CHOICES IN ORDER) in order to reduce Connecticut's reliance on fossil-fueled power generation?

Completely fill the gap		1
Somewhat fill the gap, or		2
Won't fill the gap		3
Don't know / not sure	(DO NOT READ)	8

16. I am going to read a list of electric energy sources. After I read each source please tell me whether the energy source is extremely favorable, very favorable, somewhat favorable, or not favorable in making a substantial contribution to reliable and secure supplies of electric power in the future? How favorable or unfavorable is (READ & ROTATE LIST) in making a substantial contribution to reliable and secure supplies of power in the future?

(REFER TO HELP SHEET FOR DEFINITION OF ENERGY TERMS AS NEEDED)

(READ & ROTATE)	Extremely Favorable	Very Favorable	Somewhat Favorable	Not Favorable	DK
a. Fossil fuel-based generation	4	3	2	1	8
b. Renewable/green-based generation	4	3	2	1	8
c. Nuclear-based generation	4	3	2	1	8

17. I am going to read the same list of energy sources we just discussed. This time I would like you to think about the costs of producing different sources of power and tell me how expensive you think it is to produce power from each energy source. Would you say that it is very expensive, somewhat expensive, moderately priced, somewhat cheap or very cheap to produce power from (READ & ROTATE)?

(REFER TO HELP SHEET FOR DEFINITION OF ENERGY TERMS AS NEEDED)

(READ & ROTATE)	Very Expensive	Somewhat Expensive	Moderately Priced	Somewhat Cheap	Very Cheap	DK
a. Fossil fuel-based generation	5	4	3	2	1	8
b. Renewable / green-based generation	5	4	3	2	1	8
c. Nuclear-based generation	5	4	3	2	1	8

18. In order to meet Connecticut's energy needs over the next 25 years, companies and government agencies need to start planning today. I will read the same list of energy sources we have been discussing. After I read each energy source please tell me how Connecticut should meet this demand. Should Connecticut increase usage, maintain usage, reduce usage or not use (READ & ROTATE) at all?

(REFER TO HELP SHEET FOR DEFINITION OF ENERGY TERMS AS NEEDED)

(READ & ROTATE)	Increase Usage	Maintain Usage	Reduce Usage	Not Use At All	DK
a. Fossil fuel-based generation	4	3	2	1	8
b. Renewable/green-based generation	4	3	2	1	8
c. Nuclear-based generation	4	3	2	1	8

19. Now I am going to read a list of different kinds of power plants which may help meet new electricity demand. After I read each kind of power plant please tell me how you feel about having that type of power plant built within 5 miles of your home. Would you strongly support, support, oppose or strongly oppose having a new (READ & ROTATE) built within 5 miles of your home? (REFER TO HELP SHEET FOR DEFINITION OF POWER PLANTS AS NEEDED)

(READ & ROTATE)	Strongly Support	Support	Oppose	Strongly Oppose	DK
a. Fossil fuel-based generation	4	3	2	1	8
b. Renewable/green-based generation	4	3	2	1	8
c. Nuclear-based generation	4	3	2	1	8

20. How would you feel about having each type of power plant built within 5 miles of your home if it would reduce your property taxes? Would you strongly support, support, oppose or strongly oppose having a new (READ & ROTATE) built within 5 miles of your home if it would reduce your property taxes? (REFER TO HELP SHEET FOR DEFINITION OF POWER PLANTS AS NEEDED)

(READ & ROTATE)	Strongly Support	Support	Oppose	Strongly Oppose	DK
a. Fossil fuel-based generation	4	3	2	1	8
b. Renewable/green-based generation	4	3	2	1	8
c. Nuclear-based generation	4	3	2	1	8

21. Using the same list of electric energy sources we previously discussed, please tell me whether you think the energy source is very harmful, moderately harmful, somewhat harmful or not harmful at all to the environment. How harmful do you think (READ & ROTATE) is to the environment?

(REFER TO HELP SHEET FOR DEFINITION OF ENERGY TERMS AS NEEDED)

(READ & ROTATE)	Very Harmful	Moderately Harmful	Somewhat Harmful	Not Harmful At All	DK
a. Fossil fuel-based generation	4	3	2	1	8
b. Renewable/green-based generation	4	3	2	1	8
c. Nuclear-based generation	4	3	2	1	8

Nuclear

22. Has the current national and international debate about climate change and the use of fossil fuels influenced your opinion about nuclear power as an option for Connecticut?

Yes	1
No	2
Don't know / not sure	3

23. Based upon what you know or may have heard, please tell me whether you strongly agree, agree, disagree or strongly disagree with the following statements: (READ & ROTATE)?

(READ & ROTATE)	Strongly Agree	Agree	Disagree	Strongly Disagree	DK
a. Nuclear power plants can be operated in a safe manner	4	3	2	1	9
b. Terrorism is a major threat to nuclear power plants	4	3	2	1	9
c. The disposal of radioactive waste is under control	4	3	2	1	9
d. Nuclear material is sufficiently protected against misuse	4	3	2	1	9
e. Nuclear waste can be stored safely for many years	4	3	2	1	9
f. It is very unlikely that there will be a serious accident at a nuclear power plant in the next 10 years	4	3	2	1	9
g. Future oil supplies will decline and prices will rise significantly	4	3	2	1	9
h Climate change requires new ways of producing electricity	4	3	2	1	9
i. Nuclear proliferation is a major threat to national security	4	3	2	1	9
j. Geopolitical instability in the Mideast is a significant challenge to the energy future of the United States	4	3	2	1	9
k. National security depends on reducing the use of oil	4	3	2	1	9
l. Environmental conditions demand more clean energy generation	4	3	2	1	9

24. Based upon what you know or may have heard, are there any operating nuclear power plants located in Connecticut?

Yes 1
No .... (GO TO Q27) 2
Don't know / not sure .... (GO TO Q27) 3

25. How many operating nuclear power plants are located in Connecticut?

______________________________ (RECORD NUMBER)

26. Where are the operating nuclear power plants located? (RECORD TOWN(S) BELOW – CAPTURE AS MANY LOCATIONS AS TOTAL NUMBER OF MENTIONS IN Q25)

____

____

27. As a result of the role you see nuclear power playing in the current national and international debate about climate change and the use of fossil fuels, do you think that Connecticut should build a new nuclear power plant facility for additional electric capacity?

Yes 1
No 2
Don't know / not sure 3

These last few questions will help us to better organize the responses to our survey. Remember, all information is confidential.

A. How old are you?

(DO NOT READ, EXCEPT TO CLARIFY)
18 to 29 1
30 to 44 2
45 to 54 3
55 to 64 4
65 or over 6
Refused 7

B. What is the highest level of education you have completed?

(DO NOT READ, EXCEPT TO CLARIFY)
Less than high school 1
High school graduate or GED 2
Trade school graduate 3
Some college 4
Associate's degree 5
Bachelor's degree 6
Post graduate work 7
Post graduate degree 8
Refused 9

C. What is your residential zip code?

____________________ (RECORD 5 DIGIT ZIP CODE)

D. What would you estimate your 2010 total household income to be? (READ CHOICES IN ORDER)

Less than $25,000 1
$25,000 to $49,999 2
$50,000 to $74,999 3
$75,000 to $99,999 4
$100,000 to $149,999 5
Over $150,000 6
Don't know / not sure ....(DO NOT READ).......... 7
Refused ....(DO NOT READ).......... 8

E. RECORD GENDER FROM OBSERVATION:

Male 1
Female 2

Thank you very much for your time.

APPENDIX B
(TO ATTACHMENT 2: PHONE SURVEY)

DEFINITIONS FOR ENERGY SOURCES FOR TELEPHONE SURVEY

CERC

Nuclear Power Survey Interviewer Help Sheet

Definitions for Energy Source

Fossil fuel-based generation

Energy resources derived from fuel that was formed in the earth in prehistoric times from remains of living-cell organisms including oil, coal, natural gas or their by-products. Fossil fuels are considered finite resources that cannot be replenished once they are extracted and burned.

Nuclear-based generation

Energy resources derived from splitting heavy atoms (fission) or joining light atoms (fusion). A nuclear energy plant uses a controlled atomic chain reaction to produce heat. The heat is used to make steam to run conventional turbine generators.

Renewable / green-based generation

Energy resources derived from solar, wind, geothermal, hydro and wood as well as some experimental / less-developed sources such as tidal power, sea currents and ocean thermal gradients. Resources constantly renew themselves and are regarded as practically inexhaustible.

APPENDIX B
(TO ATTACHMENT 2: PHONE SURVEY)

NUCLEAR POWER SURVEY DATA TABLES

These data tables are available on the CASE website at
www.ctcase.org/reports/nuclear/surveydata

MAJOR STUDIES OF THE ACADEMY

2010

- Environmental Mitigation Alternatives for Transportation Projects in Conecticut
- The Design-Build Contracting Methodology for Transportation Projects: A Review of Practice and Evaluation for Connecticut Applications
- Peer Review of an Evaluation of the Health and Environmental Impacts Associated with Synthetic Turf Playing Fields

2009

- A Study of the Feasibility of Utilizing Waste Heat from Central Electric Power Generating Stations and Potential Applications
- Independent Monitor Report: Implementation of the UCHC Study Recommendations

2008

- Preparing for Connecticut's Energy Future
- Applying Transportation Asset Management in Connecticut
- A Study of Weigh and Inspection Station Technologies
- A Needs-Based Analysis of the University of Connecticut Health Center Facilities Plan

2007

- A Study of the Feasibility of Utilizing Fuel Cells to Generate Power for the New Haven Rail Line
- Guidelines for Developing a Strategic Plan for Connecticut's Stem Cell Research Program

2006

- Energy Alternatives and Conservation
- Evaluating the Impact of Supplementary Science, Technology, Engineering and Mathematics Educational Programs
- Advanced Communications Technologies
- Preparing for the Hydrogen Economy: Transportation
- Improving Winter Highway Maintenance: Case Studies for Connecticut's Consideration
- Information Technology Systems for Use in Incident Management and Work Zones
- An Evaluation of the Geotechnical Engineering and Limited Environmental Assessment of the Beverly Hills Development, New Haven, Connecticut

2005

- Assessment of a Connecticut Technology Seed Capital Fund/Program
- Demonstration and Evaluation of Hybrid Diesel-Electric Transit Buses
- An Evaluation of Asbestos Exposures in Occupied Spaces

2004

- Long Island Sound Symposium: A Study of Benthic Habitats
- A Study of Railcar Lavatories and Waste Management Systems

2003

- An Analysis of Energy Available from Agricultural Byproducts, Phase II: Assessing the Energy Production Processes
- Study Update: Bus Propulsion Technologies Available in Connecticut

2002

- A Study of Fuel Cell Systems
- Transportation Investment Evaluation Methods and Tools
- An Analysis of Energy Available from Agricultural Byproducts, Phase 1: Defining the Latent Energy Available

2001

- A Study of Bus Propulsion Technologies in Connecticut

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web: www.ctcase.org

Connecticut Academy of Science and Engineering

The Connecticut Academy is a non-profit institution patterned after the National Academy of Sciences to identify and study issues and technological advancements that are or should be of concern to the state of Connecticut. It was founded in 1976 by Special Act of the Connecticut General Assembly.

Vision

The Connecticut Academy will foster an environment in Connecticut where scientific and technological creativity can thrive and contribute to Connecticut becoming a leading place in the country to live, work and produce for all its citizens, who will continue to enjoy economic well- being and a high quality of life.

Mission Statement

The Connecticut Academy will provide expert guidance on science and technology to the people and to the State of Connecticut, and promote its application to human welfare and economic well being.

Goals

- Provide information and advice on science and technology to the government, industry and people of Connecticut.

- Initiate activities that foster science and engineering education of the highest quality, and promote interest in science and engineering on the part of the public, especially young people.

- Provide opportunities for both specialized and interdisciplinary discourse among its own members, members of the broader technical community, and the community at large.

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