The Role of Nuclear Energy in Reducing CO_2 Emissions in The Northeastern United States

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Introduction and Findings

Nine states in the Northeast aim to reduce carbon dioxide (CO_2) emissions from the electric generation sector through the Regional Greenhouse Gas Initiative (RGGI). The Northeastern states already enjoy some of the lowest CO_2 emission rates in the country in part because nuclear energy is the most widely used source of power in the region, and nuclear energy does not emit CO_2 or other greenhouse gases.

As state governments in the Northeast discuss a mandatory cap on CO_2 emissions from the electric power sector, the affect that such a program will have on the diversity of the electric generation portfolio should be considered. This assessment does just that. Commissioned by the Nuclear Energy Institute and prepared by Polestar Applied Technology, Inc., this assessment explores how different CO_2 emission goals can affect the sources of electricity in the Northeast.

Findings:

1. Nuclear Power Plants Must Keep Producing Electricity

This assessment shows that continued operation of the region's 15 nuclear power plants and construction of new nuclear power plants will be needed to achieve the 2020 CO_2 reduction targets under consideration by RGGI. Even the most modest goal considered in this analysis – holding CO_2 emissions constant at the 2005 level while preserving fuel diversity – requires renewal of the operating licenses for the region's nuclear plants (see Scenario 1).

Retirement of a typical nuclear power plant would require construction of four natural gas plants and the early closure of two coal/oil plants just to keep CO_2 emissions at current levels. This would diminish fuel diversity by increasing reliance on natural gas and reducing the use of both nuclear power and coal- or oil-fired facilities. Without nuclear energy, the only way to reduce CO_2 emissions in the Northeast involves relying on natural gas generation for over 50 percent of the region's power. Moving above this threshold will likely create economic and security risks.

2. New Nuclear Power Plants Can Ease CO_2 Reductions

This assessment also shows that one or two new nuclear power plants would help achieve CO_2 reduction targets while maintaining fuel diversity in the region. Building new baseload, non-CO_2 emitting nuclear plants would allow continued operation of efficient fossil units even under an aggressive goal of reducing emissions to 10 percent below 1990 levels without any energy efficiency gains (see Scenario 6). In addition, new nuclear plants could help maintain the region's fuel diversity by ensuring that natural gas plants represent no more than half of the region's generating capacity.

3. RGGI Will Require Major Change to the Electric Supply Infrastructure

The analysis also demonstrates that a regional cap-and-trade program for CO_2, like the one under discussion, would:

1. force major restructuring of the electric generation infrastructure in the RGGI region, including construction of significant amounts of new renewable and natural gas-fired generation,

2. potentially place unsustainable demands on natural gas supply and transportation infrastructure (due to the large amounts of new gas-fired generating capacity required to meet CO_2 reduction targets), and

3. compromise the RGGI region's fuel diversity.

The amount of new construction would be unprecedented. Increasing renewable generation from 4 percent today to 15 percent by 2020 would require construction of 12,800 megawatts (MW) of new renewable energy capacity. This number is high because the capacity factor – a measure of availability – of renewable resources is limited. To get to 12,800 MW would mean building two projects each year like the Cape Wind facility that has encountered substantial political and civic opposition in the region.

To meet the most modest goal analyzed, maintaining CO_2 emissions at the 2005 level under a 10 percent conservation target (of future growth in electricity demand), could require 12,800 MW of renewable generation and 5,000 MW of new natural gas fired generation – approximately 10 new plants. At the same time, many reliable, efficient and economic coal-fired and oil-fired plants would be forced to close prematurely (see Scenario 1).

Even if it is possible to *build* the new gas-fired plants needed to reach the CO_2 reduction goals (up to 21 new plants through 2020 in Scenario 6), it might not be possible to *fuel* them. Natural gas production in the U.S. and Canada has reached a plateau, and natural gas demand is expected to exceed supply in the U.S. by 2020, resulting in an 11 percent shortfall.[i] Even if fuel supplies were sufficient, existing pipeline capacity and/or LNG facilities in the region would have to be substantially expanded to transport the needed gas.

Using estimated overnight construction costs, which do not include inflation or financing, up to $15 billion of capital investment would be required to achieve the CO_2 emissions reductions goals that RGGI is considering.[ii]

Background

Regional Greenhouse Gas Initiative

In 2003, RGGI was formed by nine Northeastern states "to discuss the design of a regional cap-and-trade program initially covering carbon dioxide emissions from power plants in the region."[iii] The states participating in RGGI include Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont. Maryland, Pennsylvania and the District of Columbia are observing. Specifically, RGGI's goal is to develop a multi-state cap-and-trade program covering greenhouse gas (GHG) emissions. The initial goal is to develop a program to reduce carbon dioxide emissions from power plants in the participating states, while maintaining energy affordability and reliability. After the cap-and-trade program for power plants is implemented, the states may consider expanding the program to other kinds of sources.

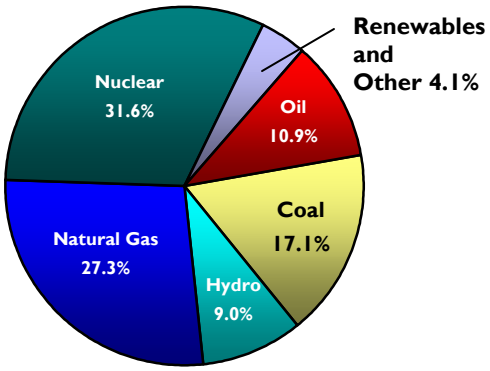
RGGI has commissioned modeling of both the impact on the electric sector and the region's overall economy. CO_2 reduction targets being modeled range from 5 percent

to 35 percent below 1990 levels to be achieved by 2020. RGGI must identify a regional CO_2 emission cap as well as a system for apportioning the allowances to each state.

RGGI recommendations were presented to state energy and environmental officials at the end of April, 2005. Discussion among those officials will continue until a regional cap-and-trade framework is agreed upon. Then each state must implement the program individually.[iv]

Nuclear Energy in the Northeast

RGGI Area Generation 2003



Nuclear energy does not emit CO_2 or other greenhouse gases in the production of electricity.[v] Fortunately for the Northeast, nuclear energy is the largest source of electricity. Fifteen nuclear plants in the nine RGGI states produce 31.6 percent of the region's electricity.[vi]

Nine of those fifteen plants have operating licenses that will expire before 2020. Those operating licenses can be renewed, and the plants can keep generating emission-free electricity after a rigorous examination by the Nuclear Regulatory Commission ensures that the plants continue to meet strict federal environmental and safety standards. If the nuclear plants in the Northeast do not seek license renewals, the power they generate would likely be replaced by fossil fired generation, because nuclear is a baseload, inexpensive source of electricity that runs about 90 percent of the time. Renewable generation, the only other source of non-emitting generation, is more expensive and cannot run continuously. On average renewables run 40 percent of the time or less.

Expiration of U.S. Nuclear Regulatory Commission Licenses

Reactor	State	License Expiration
Millstone 2	Connecticut	July 2015*
Millstone 3	Connecticut	November 2025*
Pilgrim	Massachusetts	June 2012
Seabrook	New Hampshire	October 2026
Hope Creek	New Jersey	April 2026
Oyster Creek	New Jersey	April 2009
Salem 1	New Jersey	August 2016
Salem 2	New Jersey	April 2020
Ginna	New York	September 2029
Indian Point 2	New York	September 2013
Indian Point 3	New York	December 2015
James Fitzpatrick	New York	October 2014
Nine Mile Point 1	New York	August 2009*
Nine Mile Point 2	New York	October 2026*
Vermont Yankee	Vermont	March 2012

*License renewal application has been submitted to the Nuclear Regulatory Commission.
Data current as of March 2005.

Methodology and Supporting Data

Overview of the Analysis

This analysis considered three CO_2 emission reduction goals, or caps, to be achieved by 2020[vii] by electric generators collectively in the nine RGGI states:

1. maintaining CO_2 at 2005 levels,
2. 5 percent below 1990 emissions, and
3. 10 percent below 1990 emissions.

For each CO_2 emission goal, two electricity demand growth scenarios were considered, a 1.2 percent annual growth rate and an overall 10 percent reduction in new growth through 2020 due to increased efficiency and conservation. The first, a 1.2 percent annual demand growth, is the average demand growth observed in the region for the past decade. The second scenario effectively assumes a lower growth rate of about 1.1 percent annually, which is the aim of energy efficiency and conservation programs.

Scenario 1 is the most modest CO_2 reduction target modeled combining both 10 percent energy conservation with the goal of maintaining CO_2 emissions at 2005 levels. Scenario 6 is the most rigorous target modeled in this analysis, with a goal of reducing CO_2 to 10 percent below 1990 levels without any conservation.

Finally, three nuclear power scenarios were assessed:

1. no additional nuclear power plants renew their operating licenses,[viii]
2. all nuclear power plants renew their operating licenses, and
3. all nuclear plants renew their licenses and two new nuclear plants are built in the region.

Two additional constraints were placed on the generating capacity mix: renewable facilities grow to 15 percent of the region's electricity supply (an aggressive goal), and natural gas generation cannot exceed 50 percent of the region's electricity supply. Today, renewable energy sources supply less than about 4 percent of electricity (see pie chart on page 2, where "Other" is not renewable) and natural gas, about 27 percent.

Methodology

Using generation data from the Energy Information Administration (EIA), a simple, mathematical model was derived to calculate the amount of electricity produced by each fuel-type given assumed demand growth under the constraints of generation limitations and CO2 emission levels. To avoid unnecessary complexity and to follow the RGGI approach of controlling only in-region generators, imports and exports of electricity from non-RGGI states and Canada were not considered. The analysis instead focused on the generation internal to New England, New York, New Jersey and Delaware.

Assumptions

Three key factors must be taken into account in determining a reasonable mix of future electricity generation to balance the "three-legged stool" of: achieving CO_2 emissions reductions; meeting growing electricity demand; and complying with electricity grid reliability standards.

1. **CO_2 emission reduction goals:** As noted earlier, the analysis was performed based on a range of emission reduction goals, all are under consideration by RGGI. It is important to note that RGGI area's 2005 CO_2 emission levels are actually slightly below 1990 levels, even though electricity production has increased by 17 percent over the same period, because nuclear plant performance and output has increased and more efficient, less CO_2 – emitting, gas-fired power plants have been built. [ix]

2. **Electricity generation growth:** Over the past 12 years, electricity generation in the RGGI region has grown at ~1.2 percent per year. This actual growth proved to be consistent with projections by the three ISOs that are operating within the RGGI region. Obviously, one way to reduce CO_2 emissions is from additional conservation measures. To reflect this, the analysis considered a scenario with future growth reduced by 10 percent (a substantial reduction from conservation programs not yet established).

3. **Reliability constraints**: It was assumed that future renewable generating resources will primarily be wind-based. The operation of these facilities is intermittent, and both the American Wind Association and the U.S. Department of Energy have stated that reliable grid operations begins to be compromised if renewable generation represents more than 15 percent of total generation. Because wind plants often run intermittently, they typically have a capacity factor of 25 to 40 percent compared to 80 to 90 percent for fossil and nuclear-fueled power plants.[x]

Currently, the RGGI region is dependent upon natural gas fired power plants for ~ 30 percent of its generation capacity and obviously this dependence would increase with a commitment to reduce CO_2 emissions. The practical limits of this dependence can be taken from ISO New England which will soon use natural gas for ~50 percent of its generation – a level that could reduce "grid reliability" given the lack of flexibility that delivery pipelines provide during peak demand periods. This analysis therefore assumed that natural gas generation would be limited to no more than 50 percent of the RGGI region's generation capacity. Also, new nuclear plant construction was limited to two, 800 MW[xi] facilities somewhere in the RGGI region, an assumption consistent with projections by the Nuclear Energy Institute.

Conservatively, existing hydro generation was not considered as part of "renewables" and was assumed to continue at its current generation capacity through 2020. Conversely, other forms of renewables, such as existing wood chip and biomass facilities, were counted as part of the 15 percent generation limit cited above.

And, finally, setting an emission reduction goal to be achieved by 2020 is only credible if it is based on technologies that are available today. Accordingly, the analysis excluded potential technologies, such as fuel cells, as well as awaited breakthroughs in the efficiency of both solar and wind renewable technologies.

Power Plant Capital Cost Estimates and Capacity Factors/Emission Factors[xii]

Generation Type	Capacity Factor (%)	Size (MW)	Overnight Capital Cost 2002 Dollars ($/kW)	CO_2 Emissions Factor (Lbs CO_2/KWh)
New Natural Gas	80	500	542	0.98
Existing Natural Gas	80	400	n/a	1.30
Existing Coal/Oil	80	400	n/a	2.0/1.84
New Nuclear	87.5	800	1,928	0
New Renewables (wind --- as solar and biomass have higher costs)	40	400	1,015	0
Nuclear License Renewal	87.5	---	55	0

About Polestar Applied Technology, Inc.

Formed in 1992, by three veterans of the nuclear navy, Polestar Applied Technology, Inc. provides expertise in several areas of nuclear technology and electricity generation: management assessment, engineering, facility decommissioning and environmental remediation as well as safety and risk analysis. Polestar provides consulting services to a diverse base of clients in both the United States and abroad including: the US Department of Energy, regulatory authorities, trade associations and nuclear power plant operators.

The firm also has a broad strategic analysis capability that focuses on business and public policy matters regarding the environmental, economic, engineering and regulatory issues associated with electricity generation. Assessments involving nuclear power have covered: waste storage and transportation, power plant transactions and economic viability, fuel procurement, potential regulatory issues proffered by intervenors and the feasibility of converting a retired commercial facility into natural gas-fired generation plant.

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Scenario 1

Key Assumptions:

CO_2 emission goal for 2020:	Maintain at 2005 level
Electricity demand growth:	~1.1% annually (10% conservation)
Percent renewable generation:	15%
Percent natural gas fired generation:	≤ 50%

Findings:

- RGGI states cannot maintain 2005 CO_2 emission levels, even assuming 10 percent conservation, without continued operation of the region's nuclear power plants, requiring renewal of their operating licenses through this period.
- Two new nuclear plants *and* 10 percent conservation would maintain a balanced fuel mix, allowing almost all existing coal and oil plants to continue operating while still meeting the CO_2 target.
- Conservation would reduce the need for new natural gas fired generation and keep natural gas plants at ~34 percent or less of the electric supply.

Electric Generation Type	**2005 Electricity Generation (Million MWh)**	**2020 Estimated Electricity Mix Assuming 3 Different Nuclear Energy Options (Million MWh)**		
		Full License Renewal	License Renewal & 2 New Nuclear Plants	No Additional License Renewal
Nuclear	100	100	115	CO_2 Reduction Target Unattainable
Coal & Oil	90	70	85	
Hydro	30	30	30	
Natural Gas	105	140	110	
Renewables	15	60	60	
Conservation	n/a	<10	<10	

Scenario 2

Key Assumptions:

CO_2 emission goal for 2020:	Maintain at 2005 level
Electricity demand growth:	1.2% annually
Percent renewable generation:	15%
Percent natural gas fired generation:	≤ 50%

Findings:

- Even with continued operation and license renewal of the region's nuclear plants, maintaining 2005 CO_2 emissions under recent, real demand growth would require both:
  - A four-fold increase in electricity generation from renewable facilities; that additional 45 million MWh of electricity would require approximately two wind farms to be built every year from now to 2020,[xiii] and
  - Half again as much gas fired generation means construction of about 14 new natural gas plants.
- Building two new nuclear power plants would further preserve fuel diversity in the region by reducing the forced shutdown of coal-fired and oil-fired capacity and reducing demand for natural gas.

Electric Generation Type	**2005 Electricity Generation (Million MWh)**	**2020 Estimated Electricity Mix Assuming 3 Different Nuclear Energy Options (Million MWh)**		
		Full License Renewal	License Renewal & 2 New Nuclear Plants	No Additional License Renewal
Nuclear	100	100	115	CO_2 Reduction Target Unattainable
Coal & Oil	90	60	80	
Hydro	30	30	30	
Natural Gas	105	155	125	
Renewables	15	60	60	
Conservation	n/a	0	0	

Scenario 3

Key Assumptions:

CO_2 emission goal for 2020:	5% below 1990 level
Electricity demand growth:	~1.1% annually (10% conservation)
Percent renewable generation:	15%
Percent natural gas fired generation:	≤ 50%

Findings:

- This goal produces results similar to those in Scenario 1 because 2005 emissions from in-region electric generation are already 3 percent below 1990 levels, despite a 17 percent increase in demand over the same period. This emissions reduction achieved during a time of demand growth is due, in part, to:
  - Oil generation, declined from 67 million MWh in 1990 to 33 MWh in 2005 – about a 50 percent decrease,
  - Natural gas generation, which emits less CO_2 per MWh than coal or oil generation, increased 250 percent, and
  - Nuclear power generation, a non-emitting source of power, increased 20 percent.

Electric Generation Type	**2005 Electricity Generation (Million MWh)**	**2020 Estimated Electricity Mix Assuming 3 Different Nuclear Energy Options (Million MWh)**		
		Full License Renewal	License Renewal & 2 New Nuclear Plants	No Additional License Renewal
Nuclear	100	100	115	CO_2 Reduction Target Unattainable
Coal & Oil	90	65	80	
Hydro	30	30	30	
Natural Gas	105	145	115	
Renewables	15	60	60	
Conservation	n/a	<10	<10	

Scenario 4

Key Assumptions:

CO_2 emission goal for 2020:	5% below 1990 level
Electricity demand growth:	1.2% annually
Percent renewable generation:	15%
Percent natural gas fired generation:	≤ 50%

Findings:

- Achieving this goal versus maintaining 2005 emission levels (Scenario 2) results in a relatively small increase in the number of natural gas plants built and coal/oil plants retired. This is because 2005 levels are already 3 percent below 1990 emission levels.

Electric Generation Type	**2005 Electricity Generation (Million MWh)**	**2020 Estimated Electricity Mix Assuming 3 Different Nuclear Energy Options (Million MWh)**		
		Full License Renewal	License Renewal & 2 New Nuclear Plants	No Additional License Renewal
Nuclear	100	100	115	CO_2 Reduction Target Unattainable
Coal & Oil	90	60	75	
Hydro	30	30	30	
Natural Gas	105	160	130	
Renewables	15	60	60	
Conservation	n/a	0	0	

Scenario 5

Key Assumptions:

CO_2 emission goal for 2020:	10% below 1990 level
Electricity demand growth:	~1.1% annually (10% conservation)
Percent renewable generation:	15%
Percent natural gas fired generation:	≤ 50%

Findings:

- Even with conservation, this aggressive goal causes the generation from coal and oil plants to be cut in half, further reducing fuel diversity in the region.

- The difference between aiming for 10 percent below 1990 CO_2 emissions versus 5 percent below the 1990 level (Scenario 3) is the required replacement of seven coal/oil plants (the equivalent of 20 million MWh difference) with either:
  - Six natural gas plants (as shown below), *or*
  - Three nuclear power plants (scenario not shown), *or*
  - A 30+ percent conservation level (scenario not shown).

Electric Generation Type	**2005 Electricity Generation (Million MWh)**	**2020 Estimated Electricity Mix Assuming 3 Different Nuclear Energy Options (Million MWh)**		
		Full License Renewal	License Renewal & 2 New Nuclear Plants	No Additional License Renewal
Nuclear	100	100	115	CO_2 Reduction Target Unattainable
Coal & Oil	90	45	60	
Hydro	30	30	30	
Natural Gas	105	165	135	
Renewables	15	60	60	
Conservation	n/a	<10	<10	

Scenario 6

Key Assumptions:

CO_2 emission goal for 2020:	10% below 1990 level
Electricity demand growth:	1.2% annually
Percent renewable generation:	15%
Percent natural gas fired generation:	≤ 50%

Findings:

- This is the most aggressive CO_2 reduction goal assessed.
- Even with nuclear power plant license renewal, to achieve this goal:
  - Approximately 20 new gas plants must be built, *and*
  - About 18 coal and/or oil plants must be retired, *and*
  - More than 30 renewable generation facilities must be built.
- The increase to 180 million MWh of gas-fired electricity generation causes the region's total natural gas consumption to increase as much as 20 percent.
- Building two nuclear plants:
  - Saves the premature retirement of about a six coal/oil plants,
  - Conserves enough natural gas through reduced natural gas-fired generation to fuel 1.5 million homes per year, and
  - Achieves better fuel diversity.

Electric Generation Type	**2005 Electricity Generation (Million MWh)**	**2020 Estimated Electricity Mix Assuming 3 Different Nuclear Energy Options (Million MWh)**		
		Full License Renewal	License Renewal & 2 New Nuclear Plants	No Additional License Renewal
Nuclear	100	100	115	CO_2 Reduction Target Unattainable
Coal & Oil	90	40	55	
Hydro	30	30	30	
Natural Gas	105	180	150	
Renewables	15	60	60	
Conservation	n/a	0	0	

End Notes

[i] "An Updated Assessment of Pipeline and Storage Infrastructure for the North American Gas Market: Adverse Consequences of Delays in the Construction of Natural Gas Infrastructure", Prepared for the INGAA Foundation, Inc., July 2004.

[ii]Caution should be used in interpreting these values as this effort followed the simple guidelines of assuming 15 percent renewable generation and no more than 50 percent gas fired generation for reconfiguring generating capacity and made no attempt to optimize total capital or operating cost.

[iii] RGGI description from http://www.rggi.org/about.htm.

[iv] For additional information on the Regional Greenhouse Gas Initiative, visit their website, www.rggi.org.

[v] Nuclear energy, like all non-emitting technologies such as wind turbines and hydroelectric generation, does not emit criteria pollutants or greenhouse gases in the direct production of electricity. All of these technologies may produce some emissions during maintenance, while testing back-up generators or arising from other segments of the life cycle. These emissions, in all cases, have been found to be insignificant when compared to air emissions from fossil fuel based generation.

[vi] Pie chart source data comes from the Energy Information Administration.

[vii] Since this analysis was begun, RGGI has added stricter goals to their investigation. RGGI is modeling goals of 15 percent, 25 percent and 35 percent below 1990 level CO2 emissions by 2020. These tighter goals only increase the need to keep the nuclear fleet operating and build new nuclear plants.

[viii] One of the region's 15 nuclear units has already received license renewal. This case assumes that nine others don't. Another five nuclear plants have initial operating licenses that extend beyond 2020.

[ix]The lowest common denominator in determining the generation and consumption of electricity is an ISO Region – as the commodity is fungible and does not observe politically established state borders. In determining CO_2 emissions RGGI considered in-state generation of electricity. That approach is reasonable for New England and New York, which are ISO regions, but it may result in under reporting in New Jersey and Delaware. For instance based on in-state generation only ~50 percent of Delaware's electricity consumption is accounted for in the RGGI analysis – as the remainder is from the PJM ISO which has a considerable amount of coal generation.

[x] *Wind Energy Facts*, American Wind Association. Once wind is generating more than 15 to 20 percent of the electricity that the system is delivering in a given hour, the system operator begins to incur substantial costs because of the need to procure additional equipment that is solely related to the system's increased variability.

[xi] The 800 MW size for a new nuclear plant is not necessarily a real plant capacity size, but was chosen for ease of modeling computation.

[xii] Source: U.S. Department of Energy, Energy Information Administration, Assumptions to *Annual Energy Outlook*, February 2004.

[xiii] To calculate the number of power plants needed to generate electricity, use information from the tables and page 13 with these formulas:

Generation (MWh) / [(8760 hours in a year) x (capacity factor of technology)] = Capacity (MW)

Capacity (MW) / size of typical plant (MW) = number of power plants