Options for a coal-free Massachusetts: Evaluating the Air Quality, Grid, and Workforce Impacts of Replacing the Brayton Point Power Station

MIT Students

Executive Summary

Concerns about the impacts of coal-fired electricity generation on public health, the environment, and the stability of the global climate have prompted calls across the United States to transition away from coal to natural gas and renewable. In 2011-2012, the state of Massachusetts will consider the bill “An Act Relative to a Coal-Free Commonwealth”; if passed, the bill would likely force coal-fired power plants in the state to switch to natural gas or to shut down entirely.

The bill and the debates surrounding this area present critical choices about the nature of our energy supplies. It is crucial to understand the implications of the range of policy options available. In Massachusetts, the complexity of decision-making is augmented by initiatives to increase energy efficiency and introduce offshore wind power generation, as well as by the fluctuating prices of electricity generated from coal alternatives such as natural gas.

This study explores coal-fired electricity generation and its alternatives by synthesizing impact assessments in the areas of air quality/human health, grid economics, and workforce. To mitigate the complexities inherent in analyzing electricity generation throughout Massachusetts, the study focuses on a single coal plant – Brayton Point Power Station. As it is Massachusetts’ largest coal-fired power plant, a study of the possible impacts of retaining or abolishing it will be salient to statewide policy decisions on the issue.

This study examines four possible cases for Brayton Point from now to 2020. The first case is the “business as usual” (BAU) case, where Brayton Point continues to operate as-is until 2020. The second case, natural gas, is analyzed as two sub-cases. “Retrofit” considers the impacts of retrofitting Brayton Point’s coal generators to natural gas combined-cycle generators. “Replace” considers the impacts of demolishing Brayton Point and replacing it with a new, same-capacity natural gas combined-cycle power plant. The “renewables” case replaces Brayton Point with renewable power generation from wind and solar facilities. For all cases, three forecasts for electricity demand from now to 2020 are considered: 1) with no energy efficiency, 2) with energy efficiency leading to a -0.5% decrease in electricity demand (relative to 2010), and 3) with energy efficiency leading to a -1.3% decrease in demand.

Three types of potential impacts are analyzed for each case: air quality/human health, electric grid economics, and workforce. The air quality/human health impact analysis utilizes the AMS/EPA Regulatory Model (AERMOD) to model health impacts from air pollution. Available data are also used to discuss health impacts from toxic chemicals, ecosystem impacts from various forms of pollution, and greenhouse gas emissions. The grid economics impact analysis utilizes electricity market data from ISO New England, the Independent System Operator for the New England electricity grid, to build a model of average electricity system cost. For each of the natural gas cases, the impact on wholesale electricity prices is modeled for different natural gas prices and energy efficiency scenarios. The likely impact of renewables is qualitatively discussed. The workforce impact analysis utilizes available Massachusetts employment data to compare each case. For the renewables case, the Jobs and Economic Development Impact (JEDI) models from the National Renewable Energy Laboratory (NREL) are used to calculate the impacts of replacing Brayton Point with onshore wind and solar PV installations. Data from a study of Massachusetts’ proposed offshore wind power plant, Cape Wind, are also used to estimate the workforce and economy impacts of replacement with offshore wind.

Uncertainties from the assumptions in the models used, and from the input data, are present in all analyses. The grid model assumes that Brayton Point can only be replaced with other base load operating capacity, which makes modeling the natural gas cases possible but complicates renewables modeling. It also assumes that any decreases in yearly demand will have an equal impact across the year, but these decreases may have a more significant impact on the system at times of peak demand. The air quality/health analyses assume specific emission factors but report their range for uncertainty discussions. For employment, the JEDI model default values for inputs like onshore wind turbine size and solar PV system size were assumed to be representative of reality. The offshore wind employment analyses based on the Cape Wind study also assume that Cape Wind is representative of other offshore wind projects.

Our results underline the tradeoffs that will inform any policy decision on the future of coal-fired electricity generation in Massachusetts. For the BAU case, the output from the grid economic model suggests that Brayton Point will produce 9,020,960MWh of electricity output in 2020. The air quality/ health analysis estimates 2020 carbon dioxide emissions from Brayton Point to be 7.7 metric megatons. AERMOD shows that Brayton Point emissions result in an annual mean concentration of 0.20 $\mu g/m^3$ of PM within 10km of the plant. The employment analysis estimates that the 235 current jobs will be retained at Brayton Point. Additionally, the town of Somerset received over 30% of its property tax revenue from Brayton Point in FY 2011.

For the natural gas “retrofit” case, the grid analysis shows that at low gas prices, average wholesale energy price across the energy efficiency scenarios is not significantly different from BAU. However, as gas price increases it becomes expensive to operate the retrofitted natural gas plant. The air quality/human health analysis using AERMOD shows that retrofitting reduces the amount of PM within 10km of the plant from a mean of 0.2 $\mu g/m^3$ to 0.06 $\mu g/m^3$ – resulting in an 84% improvement in health outcomes. Employment-wise, 40-110 O&M jobs will be created, less than under BAU. Property tax revenues will be somewhat higher than under BAU. For the natural gas “replace” case, the grid analysis shows a higher average wholesale energy price than under “retrofit”. For air quality/health AERMOD shows that replacement reduces the amount of PM within 10km of the plant to 0.05 $\mu g/m^3$ or an 87% improvement in health outcomes, and criteria pollutants are also lower than under “retrofit”. Finally, the employment analysis notes that the “replace” case is likely to create an order of magnitude more construction jobs than “retrofit”, and about 40 O&M jobs. Property tax revenues will be much higher than under BAU.

For the “renewables” case, the grid analysis notes that the intermittency of wind power can lead to higher system costs. The air quality/health analyses show that no pollution will be associated with the production of electricity, but there may be life cycle emissions from construction and installation of the renewable facilities. The JEDI models for employment show an increase in construction jobs ranging from 3719 to 4064 and an increase in annual O&M jobs ranging from 228 to 259 depending on the energy efficiency scenario. Property tax revenues for Somerset will be negligible as the town itself is not well-suited to renewables siting and the jobs created will be outside of Somerset’s tax area. Across all cases, energy efficiency measures will also create 831-1666 jobs.

Several case-specific findings stand out: the air quality and health implications of the BAU case remain serious despite mitigation efforts; the grid system cost of the natural gas cases could be high; and although the “renewables” case could have a significant positive impact on air pollution, health, and employment, its potential impacts on grid reliability and cost could pose significant challenges to renewables deployment.

In terms of a “coal-free Massachusetts”, our analyses and the current political situation suggest that the natural gas “retrofit” or “replace” cases are relatively more feasible in the near term than “renewables”. In choosing between “retrofit” and “replace”, one key tradeoff is between grid system cost and environmental and health impacts. Although total grid system cost is slightly lower under the “retrofit” case, the “replace” case has improved air pollution and lower impacts on the global climate. The “retrofit” case will likely create fewer new jobs than the “replace” case because of the lack of need for new construction, but both result in higher property tax values than under the BAU case.

Our analysis is subject to uncertainty and time limitations, and any policy decision might also consider other factors rigorously such as the costs of retrofitting versus replacement. That said, we believe the importance of the grid, air quality, health, and employment issues surrounding coal-fired power generation and its alternatives make this case study model assessment of options for Brayton Point a useful guide to the wider impacts of electric-generation policy in the Commonwealth. It is our hope that it makes a valuable contribution to the current debate about going coal-free.

Contents

Introduction

Coal-fired electricity generation has recently become the target of public health and climate change policy advocates, who argue that the high carbon emissions intensity and "dirty" air pollution emissions of coal fired power plants mean that the path to a sensible and sustainable energy policy must start by shutting down coal power plants. The "coal-free" movement has gained attention in the wider space of national energy policy debates. One state legislature has already taken the lead: in the spring of 2011, the Washington state legislature approved a bill that would phase out the remaining 1400 MW of coal-fired capacity in that state by 2025, and on April 29, 2011 it was signed by Gov. Chris Gregoire, making Washington the first state in the nation to phase out coal. Coal-free electricity generation, however, raises many questions: will its baseload generation be replaced by natural gas, which may be more expensive and cause prices to rise, and the extraction of which may cause significant health impacts associated with hydraulic fracturing? Alternatively, can renewable energy deliver enough electricity to replace coal? These concerns are at the center of the policy debate.

This debate about whether to go coal-free has now reached Massachusetts. In 2011-2012, Massachusetts lawmakers will consider an omnibus bill that would direct companies managing coal-fired installations in the state to file feasibility studies about switching to natural gas or renewable energy generation and would direct the state Public Utilities Commission to conduct a full assessment of the feasibility of shutting down coal within the next two years. By 2020, the bill would charge emitters per pound of hazardous air pollutant emitted and, in implementing the 2008 Global Warming Solutions Act, would mandate that all power plants attain carbon intensities of natural gas or better. The bill also provides funds for workers displaced by coal-plant decommissioning. While the bill does not fully mandate a ban on coal-fired power plants, its provisions would likely force either a switch from coal to natural gas, or the plants to shut down by 2020. "An Act Relative to a Coal-Free Commonwealth" was filed by Representative Lori A. Ehrlich and is supported by advocacy groups such as the Conservation Law Foundation and the Environmental League of Massachusetts. Another advocacy group, Students for a Just and Stable Future, has argued for a faster timeline: phasing out coal by 2015.

In Massachusetts, the coal industry provides 25% of all electricity in Massachusetts, so the bill has attracted the interest of a wide range of stakeholders. As listed in Table 1, they include the coal plant employees, the Massachusetts government, the general public and others.

Table 1. Stakeholders in the issue of a Coal-Free Massachusetts.

Stakeholder	Scale	Potential Effects of Plant Replacement	+ , - , ?
Person near plant	Local	Local air quality improvements	+
Plant employee	Local	Loss of/change in employment	-
Plant owner	Local	Loss of/change in investment	-
Municipal government	Local	Loss of/change in property tax revenue	-
Ratepayers	MA	Possible increase in electricity prices	? / -
ISO-New England	N.E.	Grid reliability from new generation	? / -
Global citizen	Global	Reduction in greenhouse gases	+

The Massachusetts coal-free bill itself needs to be placed in wider perspective. Its legislative fate could inform other state and federal discussions of climate policy, public health issues, and energy policy. In the national context, it could both confirm the recent trend started by TVA and Washington State, and make Massachusetts a trend-setter in relation to the multifaceted issues it involves. Massachusetts is already widely recognized for its environmental leadership as a spearhead of the Regional Greenhouse Gas Initiative (RGGI), which created a ten-state carbon market in the northeast United States.

The bill also raises many questions in relation to its economic, social, technical, and political acceptability. Is removing all coal-fired generation in Massachusetts feasible? What effects will that removal have on the local and state economy, the electric grid, air quality, and health? Will it have a meaningful impact on climate change?

Currently, five coal-fired power plants operate in Massachusetts. This study examines the feasibility of a coal-free Massachusetts by considering the effects of removing a single coal-fired power plant: Brayton Point in Somerset, Massachusetts, which produces roughly 80% of the coal-generated electricity in Massachusetts. Brayton Point was selected because it is New England's largest coal plant, so the effects of its removal should serve as a good guideline to the removal of all coal generating capacity in Massachusetts.

Brayton Point Power Station is a 1537 MW generating facility on the south shore of Massachusetts owned by Dominion Resources, Inc. It is located in Somerset, directly across Mount Hope Bay from the city of Fall River. It is approximately fifteen miles from Providence, Rhode Island and forty miles from the Boston metropolitan area. Coal is delivered to Brayton Point by barge and the low sulfur coal comes largely from Colombia.

Brayton Point utilizes 3 coal-fired generating units, an oil/natural gas unit, and 3 diesel units. Table 2 lists the generating capacities of each unit. Coal makes up 71.2% of Brayton Point's total generating capacity, although the fourth unit is not consistently fired, making >90% of Brayton Point's output from coal.

Table 2. Brayton Point Power Station Descriptive Statistics. Data from (Dominion Resources, Inc. 2011).

Source	Generating Resource	Generating Capacity (MW)	% of total generating capacity	Operation Start Year
Unit 1 - Coal	Coal	243	15.8%	1963
Unit 2 - Coal	Coal	240	15.6%	1964
Unit 3 - Coal	Coal	612	39.8%	1969
Unit 4 - Natural Gas	Natural gas/Oil	435	28.3%	1974
Diesel Generators (3)	Diesel	7.6	0.5%	N/A

Stakeholders and Assessment's Salience, Legitimacy, and Credibility

This study aims for an assessment that is both tractable and policy-relevant. Initial research revealed that the overlapping geographic and political scales of relevant issues - global climate change impacts, US coal imports and production, a New England-wide electricity grid, interstate air quality impacts from fossil fuel burning, a Massachusetts-specific renewable energy portfolio standard and local considerations at the coal-fired plant level – would pose crucial challenges to a salient assessment. We decided that limiting the spatial scope of our assessment would help reduce the number of interacting variables and assumptions while ensuring the assessment remains broadly relevant. The pending Massachusetts Omnibus Bill H02146 for a "Coal-Free Massachusetts" and the fact that Massachusetts is home to the largest coal-fired power plant in New England, Brayton Point Power Station, led to our focus on the question: "What would it mean to decommission, following the provisions of the Coal-Free Massachusetts Bill, the Brayton Point Power Station?"

Our initial research identified stakeholders who might be interested in the outcome of an assessment of the connections between coal-fired power generation, air quality, and climate change. Our contact with these stakeholders shaped and refined our assessment. Dr. Praveen Amar at the New England States Consortium for Air Use Management (NESCAUM), an inter-state scientific agency which studies air quality impacts, highlighted the importance of natural gas pricing and pointed out several relevant studies.

The organization Students for a Just and Stable Future (SJSF) was active in a previous attempt to pass Massachusetts legislation that would mandate 100% renewable electricity generation in-state by 2020. Having failed in this attempt, they have taken a position of "coal-free by 2015". Craig Altemose from SJSF provided key input into the structure and scope of our assessment, touching on the issues of air quality/health, grid/energy, and workforce/economics. Additionally, Eugenia Gibbons at the Environmental League of Massachusetts (ELM) indicated that an assessment of the workforce impacts would make the assessment particularly useful.

After the scope of our assessment had been established, we also contacted the sponsor of the "Coal Free Commonwealth" Bill, State Representative Lori Ehrlich. As a legislator, Lori Ehrlich gave us insight into how information is used in the policy-making process. She described focusing on health impacts over climate impacts when speaking with most local constituents about the dangers of coal-fired power plants, because health is a more immediate and less controversial topic than climate change. She described her sometimes-volatile relationship with labor unions, who do not want to lose jobs at the coal plants and who are concerned that replacement with natural gas will lead to different types of jobs that will go to other workers and not re-trainees. Rep. Ehrlich also described resistance from the municipalities in which coal fired power plants are located, because they receive large portions of their tax revenue from the plants. In short, Rep. Ehrlich gave us a frank description of the obstacles to coal-free politics in Massachusetts. She simultaneously confirmed the salience of our work as a contribution to the policy debate and guided our assessment process.

We understand from our stakeholders, who are all actively involved in discussions about state-coal policy, that a Brayton Point-focused assessment would be a salient contribution to the coal-free policy debate space at the state-level. We believe that, because our assessment does not follow any terms of reference from any particular stakeholder or advocacy group, and because it will be attached unofficially to the MIT-brand name, our assessment will carry a certain amount of credibility and legitimacy respectively.

Cases and Assumptions

The three cases used for our Brayton Point assessment are outlined below. These have been selected because they each represent feasible outcomes given the current legislative discussion and energy developments in the state and represent the range .

Case 1: Business As Usual

This case represents the status quo where Brayton Point continues to operate until 2020. This case is contrary to the goal of H02614, to be coal-free by 2020, but represents a necessary baseline against which alternative options can be assessed. Pollution control options for the Brayton Point plant, such as carbon capture and storage (CCS), are not covered in this study because they are contrary to the goal of the bill. Thus, Case 1 provides an initial assessment of the economic, workforce, and air quality impacts of maintaining Brayton Point generation through 2020.

It is assumed that the levelized cost of generating coal-fired electricity is always below the wholesale market rate for electricity in the grid. This assumption is reasonable given that coal-fired plants generate electricity for around three cents per kilowatt-hour and the wholesale market rate rarely gets that low in a region. H02614 stipulates in Section 142P that a pollution mitigation fee of no less than 20 cents per pound of air pollutant emitted by any major source as defined in 42 U.S.C. section 7412(a) will be established. At 20 cents per pound, such a fee has a negligible influence on the cost of generating coal-fired electricity and is thus excluded from the analysis (It would amount to approximately $250,000). However, at much higher fees the cost of producing coal-fire electricity could become exceedingly expensive, providing further rationale for phasing it out of the state generation profile.

Case 2: Natural Gas

If H02614 is passed into law, the Commissioner of the Department of Energy Resources would be required to submit a plan for replacing all coal-fired generation capacity in Massachusetts, which includes, "an assessment of the potential for replacing or repowering each such coal-fired electric generating facility with a combined cycle natural gas power plant" (H02614 Section 2.iii). Case 2 therefore provides an initial assessment of the economic, workforce, and air quality impacts of replacing the Brayton Point generation facility with a natural-gas power plant. The case is broken into two sub-cases:

Case 2.1: 'retrofit': Convert the 1095MW of coal-fired generation capacity at Brayton Point Units 1-3 to natural gas-fired generation capacity. Brayton Point's coal-fired generation units can be powered by burning coal or natural gas (Dion 2008). Case 2.1 assesses the impacts of converting the 1095 MW of coal-fired generation capacity to natural gas-fired units. For our assessment, we have assumed that both the existing coal units and the new natural gas units would operate with an 85% capacity factor.

Case 2.2: 'replace': Replace the full 1537MW of capacity at Brayton Point with a new combined-cycle natural gas power plant. Case 2.2 assesses the impact of replacing all of Brayton Point's generating capacity with combined cycle natural gas power plants. To model this case, we replace Brayton Point with an equivalent amount combined-cycle natural gas plant in adjusted capacity terms. With Brayton Point's reported 67% capacity factor (Faggert 2009) and assuming an 85% capacity factor for the new plant, the new plant will need to have approximately 1,211MW of generation capacity.

Case 3: Renewables

This case assumes that the mandates of the Class I Renewable Portfolio Standard (RPS) are met, which stipulate that "all retail electricity suppliers must provide a minimum percentage of kilowatt-hours (kWh) sales to end-use customers in Massachusetts from eligible renewable energy resources installed *after* December 31, 1997" which in 2020 is 15% of sales (DSIRE: Database of State Incentives for Renewables and Efficiency 2011). The 2020 Class I RPS sales were estimated assuming that retail sales were equivalent to the total system load with 7% transmission losses, and that on 10.4%[1] of the retail sales were exempt from the Class I RPS.

Navigant Consulting has produced a report that compares the theoretical, technical, and economic potential as well as market penetration of various technologies eligible for the Class I RPS, given three rates of renewables development. The report demonstrated that most of Massachusetts' renewables potential lies in offshore wind (Navigant Consulting 2008). A summary of the report by the MA Department of Energy Resources (MA DOER) presented Class 1 Renewables projects "currently under construction, design, or consideration, if approved and developed":

- 2.2 million MWh from 670 MW of offshore wind at four proposed sites
- 0.2 million MWh is from 100 MW of onshore wind
- 1.0 million MWh is from 140 MW of biomass projects
- up to 0.3 million MWh from the commitment to 250 MW of solar (Department of Energy Resources 2008).

However, as a result of a study on the sustainability of biomass, on May 3, 2011 a draft regulation[2] was filed which would considerably limit the biomass from MA eligible for the Class I RPS. Recognizing the constraints on the resources, the planned biomass projects were excluded from this model. Therefore, in our analysis the shortfall in Class I RPS from the projected projects less biomass is assigned to offshore wind. Assuming a 37% capacity factor of offshore wind, the theoretical potential of offshore wind is 6,270MW or 17.8 million MWh. Under Navigant Consulting's Market-Based Development and Accelerated Development Cases, ~1,500MW and ~2,000MW, respectively, of offshore wind is economically feasible. (Navigant Consulting, 2008). The Class I RPS will change given different energy efficiency projections, as shown in Table 3.

Table 3. 2020 Renewable Portfolio Standard Projections

2020 Projection	Scenario A, 0% Load Growth from 2010	Scenario B, -0.5% Load Growth from 2010	Scenario C, -1.3% Load Growth from 2010
Class I RPS	7,598,806 MWh	7,227,301 MWh	6,666,792 MWh
Offshore Wind	2,190MW; 7,098,806MWh	2,076MW; 6,721,301MWh	1,903MW; 6,166,792MWh
Onshore Wind	100MW; 200,000MWh	100MW; 200,000MWh	100MW; 200,000MWh
Solar PV	250MW; 300,000MWh	250MW; 300,000MWh	250MW; 300,000MWh

[1] 10.4% represents the average percent of Total Retail Sales exempt from Class I RPS from 2003-2009. Total Retail Sales from "Table 8. Retail Sales, Revenue, and Average Retail Price by Sector, 1990 Through 2009." US EIA Massachusetts Electricity Profile. http://www.eia.doe.gov/cneaf/electricity/st_profiles/massachusetts.html. Class I RPS data from "Massachusetts Renewable and Alternative Energy Portfolio Standards: Annual Compliance Report for 2009". November 2010 MA DOER.

[2] 225 CMR 14.00 Renewable Energy Portfolio Standard – Class I. http://www.mass.gov/Eoeea/docs/doer/renewables/biomass/225-cmr-14-00-050311-biomass-draft-reg-with-tracked-changes.pdf

[3] "Massachusetts Renewable and Alternative Energy Portfolio Standards: Annual Compliance Report for 2009". November 2010 MA

Uncertainty is present in the projections for the mix of renewables installed by 2020. First, the assumption that 100% of the Class I RPS will be generated in MA is unlikely considering that only 9.3% was generated in MA in 2009[3]. Also, there are several years of lag time from when an eligible Class I Renewables project is conceived to when it actually supplies the grid. Lastly, though offshore wind has the greatest potential, other forms of renewables may be more cost effective. The mix of renewables only impacts the economic impact analysis.

Energy Efficiency Scenarios

According to the American Council for an Energy-Efficient Economy[4] in Massachusetts the Green Communities Act requires that electric and gas utilities make acquisition of all cost- effective energy efficiency a higher priority than using other resources. The MA DPU approved the 2010-2012 electric and gas energy efficiency plans, which paves the way for achieving the goals set in the Act on January 28th, 2010." They project an "annual electricity savings of 2.4 percent per year going forward", which would be 1.3% less than a reference case due to the 1.1% Business As Usual (BAU) load growth. This target is ambitious and not mandated out until 2020, therefore this assessment considered three different annual electricity savings cases, shown in Table 4.

Table 4. Energy Efficiency Scenarios

Scenario		From 2010	From BAU
A	No load growth from 2010	0.0% annually	-1.1% annually
B	Moderate load reduction from 2010	-0.5% annually	-1.6% annually
C	Target load reduction from 2010	-1.3% annually	-2.4% annually

The current MA plans are closest to Case B (See Appendix D).

Assessment Methodology

As Figure 1 illustrates, our impact assessments of these three cases demonstrate the effect of each case on air quality and human health, the electric grid, and workforce, given three demand reduction scenarios due to energy efficiency.

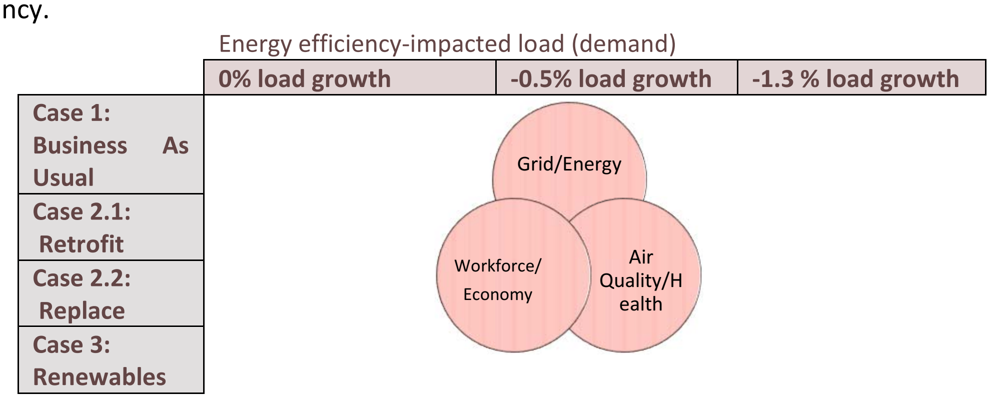

Figure 1. Assessing the Cases.

[3] "Massachusetts Renewable and Alternative Energy Portfolio Standards: Annual Compliance Report for 2009". November 2010 MA DOER

[4] " Massachusetts Utility Policies." American Council for an Energy-Efficient Economy. http://www.aceee.org/sector/state-policy/massachusetts

Assessment A: Grid and Grid Economics

Changes to major power plant infrastructure in Massachusetts can have a profound effect on the economics and reliability of the regional electricity grid, operated by ISO New England. Thus, when debating the ultimate removal of the Brayton Point coal plant from the power producing capacity of the regional electric grid, one has to consider the impact on total system costs and therefore wholesale energy prices. These costs are distributed across all consumers in some variable markup and form the basis of retail electricity rates. The model used in this study to simulate total system cost changes under alternate cases does not assess these distributional impacts as this is outside the scope of the study. However, modeling total system cost and average wholesale energy prices provides valuable insight into the aggregate effect of making electricity infrastructure changes on the New England electric grid, and therefore on all of its consumers.

Grid Economics

ISO New England operates a restructured wholesale market. Power producers submit bids to the ISO on an hourly basis with the price that they are willing to generate energy at, and these bids form the basis of a supply curve. In order to meet hourly demand, ISO New England dispatches power from different power producers in the order of least cost. The wholesale market rate is set based upon the bid price of the last plant dispatched, and every power producer is paid the market price for each unit of energy they produce. Figure 2 shows the relationship between the power load in Massachusetts and the wholesale price of electricity. The “Average Wholesale Price” curve represents the nominal yearly supply curve for all of Massachusetts at varying levels of system load.

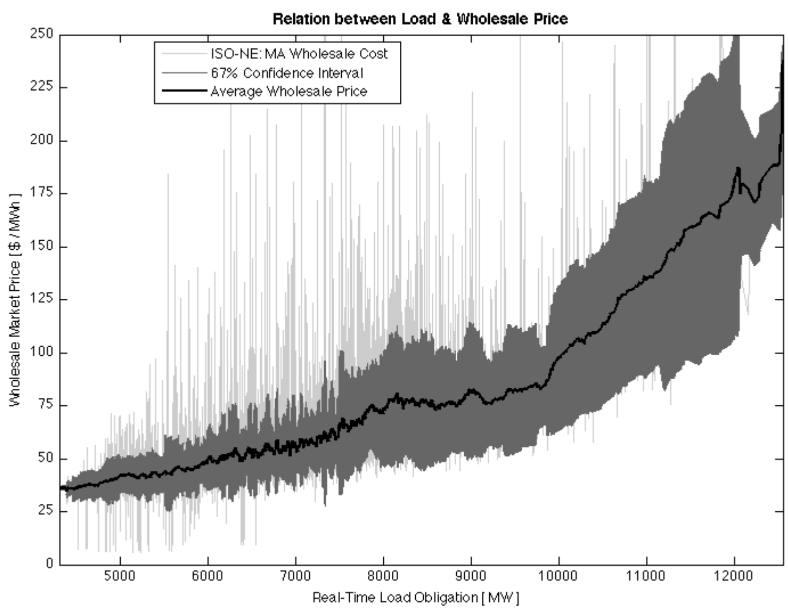

Figure 2: Relationship between System Load and Wholesale Market Price (data source: ISO-NE Data, 2010)

Demand for energy is represented in a load-duration curve, like the one in Figure 3. This curve depicts the distribution of demand for every hour in the year.

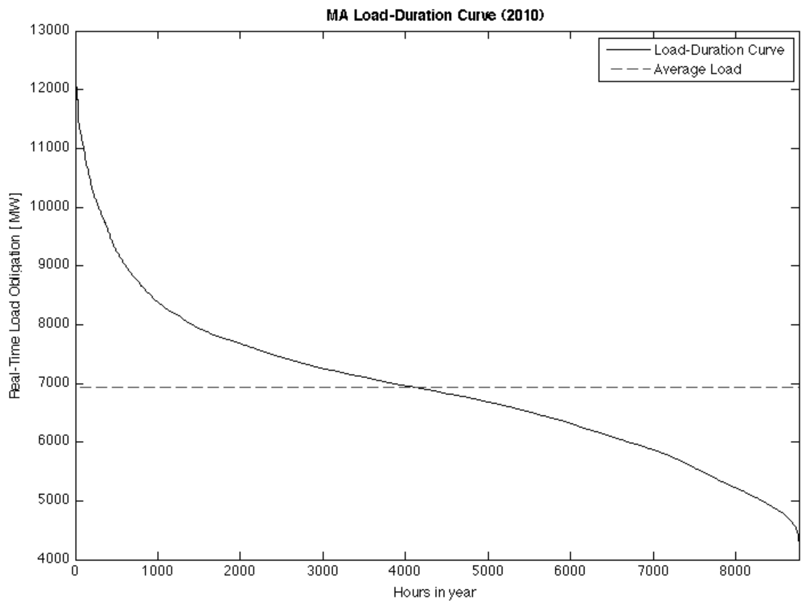

Figure 3: Massachusetts Load-Duration Curve (source: ISO-NE Data, 1/2010 - 12/2010)

Description of the Model

The grid-economics model is a simple economic model of supply and demand, which is based on concepts discussed in (Tester 2006) and reported hourly wholesale market prices and system load from ISO New England (ISO New England 2011). The model uses 2010 wholesale market data to infer a "nominal" yearly supply curve (shown in Figure 2 as "Average Wholesale Price) by applying a simple moving average to the wholesale load-cost data once it has been sorted in order of decreasing load. The uncertainty is this simple moving average is captured and used to help estimate the uncertainty in reported values.

For each hour, load on the system load is forecasted using the load-duration curve, and the wholesale price is determined using the nominal supply curve. The total system cost for that hour is the product of the system load and wholesale price. This process is repeated for all 8760 hours in the year and summed to determine the total system cost in a year. Finally, to facilitate model comparison across different load reduction cases, the average cost of wholesale electricity, expressed in dollars per megawatt-hour ($/MWh) is calculated by dividing the total system cost by the total number of megawatt-hours generated in the year.

With this general framework, effects of removing Brayton Point and adding new generating capacity can be simulated. To simulate the removal of a plant, all points on the supply curve where the market price exceeds the plant's bid price are shifted to the left by the adjusted generation capacity of the plant. Similarly, to simulate the addition of a plant, all points on the supply curve where the market price exceeds the plant's bid price are shifted to the right by the adjusted generation capacity of the plant. For more details on the grid modeling methodology and assumptions, see Appendix A.

Assessment B: Air Quality and Human Health Impacts

At the center of the debate about the future of coal-fired power generation in the Commonwealth of Massachusetts are questions about the impacts of coal combustion on human health and air quality in the immediate areas surrounding coal-fired power plants. The potential harmful impacts of coal combustion for electricity generation can be separated both by scope and categorically. By scope, they can be distinguished as *plant-specific emissions-based health impacts* and *life-cycle emissions.* Plant-specific health impacts refer to impacts that result from the emission of pollutants at the point of the power plant during its normal operation. Life-cycle emissions refer to impacts that result from the extraction, processing, and transport of the fuel and the emissions associated with installation operation. Only annual recurring *life-cycle greenhouse gas emissions* are included in our assessment; "one-off" emissions associated with construction, decommissioning, or land-use change are not included in our assessment. This has enabled more useful direct comparisons across our cases, but all of our life cycle emissions assessments should be understood to be incomplete and narrowly defined. For example, impacts on water quality from hydraulic fracturing for natural gas extraction are very important, but are not estimated in our analysis. A full LCA is beyond the scope of our assessment, but for a comparison of natural gas and coal life cycle impacts in the United States, please see (Jaramillo, Griffin and Matthews 2007)

Our assessment separates plant-specific air quality, pollution and health impacts into four groupings: (a) criteria air pollutant health impacts, (b) toxic chemical release health impacts including coal fly-ash and water pollution, (c) other environmental impacts that affect ecosystems such as thermal pollution, and (d) greenhouse gas emissions. The first three groupings all have a geographic limit to their impact that is localized to the relatively immediate environs of the plant (within about 50 miles), while the last category, greenhouse gas emissions, are global in their scope, and harm can only be calculated or described in marginal terms (per unit of GHG emission). Because of the difficulty in geographically specifying health effects from life cycle emissions other than greenhouse gases (criteria air pollutants may be emitted at many different locations in the extraction and transport processes for example, and thus have variable and indefinable impacts), we have limited our life cycle assessment to the only pollutant having global impacts: greenhouse gas emissions.

PLANT SPECIFIC EMISSIONS

Criteria Pollutants

Significant air-quality-related human health impacts near power plants result from prolonged exposure to criteria air pollutants. To mitigate these impacts, the EPA requires proposals for new sources of pollution to demonstrate compliance with standards established by the Clean Air Acts. These proposals typically use results from regulatory models that simulate the dispersion of these pollutants to the immediate surroundings. In the study by Levy et al., human health impacts were calculated by using one such model (CALPUFF), then by applying concentration-response functions from epidemiological literature that relate pollutant concentrations to the incidence of premature mortalities, hospitalizations, and other health outcomes (Levy, et al. 2000). In this assessment, a similar approach was used to estimate air-quality-related human health impacts for the three cases .

Because particulate matter ("PM") typically causes the strongest air-quality-related impacts, the analysis of the health impacts of criteria pollutants in this assessment only focuses on this pollutant. The AMS/EPA Regulatory Model (AERMOD) was used to simulate the concentrations of PM up to 10 km away from Brayton Point. AERMOD inputs came from a 2009 proposal by Dominion Resources, Inc. to build two cooling towers and a fabric filter/dry scrubber at the plant. Immediately available meteorological data for 1985, 1990, and 1992 were input into AERMOD as well. Once the concentrations of PM in the surrounding area were found for each case, health impacts were estimated using concentration-response functions from the Levy study. Since these functions depend on population in affected areas, 2000 population data were obtained from the Socioeconomic Data and Applications Center (SEDAC) at Columbia University for the area surrounding Brayton Point. The results of this process were the estimated increase in various health outcomes due to the power plant for different cases. Comparisons of the health outcomes among the cases were calculated using these AERMOD results, then applied to estimates of health outcomes from a 2004 report by Abt Associates (Schneider 2004). Emissions of other criteria pollutants, namely sulfur oxide and nitrogen oxide were calculated using EPA and NREL emissions factors on a kg emitted per MWh output basis for natural gas and coal combustion (Spath and Mann 2000).

Toxic Chemicals

Each year, the United States Environmental Protection Agency releases a Toxics Release Inventory (TRI) for all major power plant installations, including organochlorines, acids, and heavy metals that are released to land, air and water from plant operation, including the production and storage of coal fly ash, which may contain known carcinogens. Carcinogenic hexavalent chromium (of Erin Brockovitch fame), and hazardous air pollutants such as lead and mercury are include. Data for Brayton Point *Business As Usual* were obtained from Dominion Resources, Inc. Data for natural gas toxic releases were based on amounts from similar plants in

New England (Mystic Station in Everett, MA) and comparable combined cycle natural gas plants in the mid-west. Renewables operation was assumed not to release toxic chemicals.

Ecosystem Impacts

Impacts to the ecosystem include thermal pollution to adjacent waters. For Brayton Point, thermal pollution to Mount Hope Bay has been a source of major concern over the last several decades. Thermal pollution can lead to fish kills and disrupt the food-web structure of ecosystems (Swanson, Hyun-Sook and Sankaranarayanan 2006). Also of concern to the surrounding ecosystem is the impounding and entrainment of aquatic life in the cooling water intakes used by ocean-side plants, such as Brayton Point. Statistics related to impingement and entrainment are available from a 2002 EPA case study of Brayton Point (Environmental Protection Agency 2002). All of these impacts have been mitigated by the construction of cooling towers at the location in 2008-2009, which have reduced thermal pollution and the use of ocean water for cooling. The results present a qualitative discussion of this issue across cases, as no quantitative data are available to conduct our assessment.

PLANT SPECIFIC AND LIFE CYCLE EMISSIONS

Greenhouse Gases

Coal and natural gas amounts were calculated based on estimated 2020 generation outputs from the grid model in all cases except the Renewables Case. EPA emissions factors for natural gas combustion and sub-bituminous coal combustion were used to estimate quantity for emissions on a kg CO2/MWh output basis. Life cycle emissions factors were taken from NREL Report (Spath and Mann 2000) and (Jaramillo, Griffin and Matthews 2007). Renewables operation emissions factors were obtained from cross-company comparison (European Wind Energy Association 2011).

Assessment C: Workforce and Economy

Often, when determining economic impacts of proposed changes in industry such as decommissioning a power plant, consultants utilize regional economic impact models like "the industry-standard IMPLAN® software Version 3.0 to estimate the direct, indirect and induced economic impacts" (Global Insight 2003, Reiner and Mayeda 2010). These models take into account specifics about the regional economic profile, and calculate impacts using multipliers and macroeconomics, with outputs in dollars.

For this assessment, the intent is to understand specific local impacts rather than broad indirect and induced impacts, therefore different types of information and models were used to estimate the impacts of different cases on construction jobs, operation and maintenance jobs and earnings, and property taxes for the Town of Somerset depending on the case.

Energy Efficiency:

- Jobs: Prior MA estimates and regression across 24 states
- Earnings: Prior MA estimates

Base Case:

- Jobs: Power plant profile, recent regional Employment and Wages Data
- Earnings: Recent regional Employment and Wages Data
- Property Tax: Information from Asst. Tax Assessor, prior financial reports

Natural Gas Cases:

- Jobs: Published jobs per MW multipliers, comparison to similar plants
- Earnings: Comparison to relevant, recent regional Employment and Wages Data

Renewables:

- Jobs: Published jobs per MW multipliers and government-provided Jobs and Economic Development Impact (JEDI) models, comparison to relevant local study
- Earnings: Government-provided Jobs and Economic Development Impact (JEDI) models, comparison to relevant local study

Uncertainty and Transparency in the Assessment

Our assessment projects the economic and emissions reality of Massachusetts in 2020, nine years in the future. As such, it must be regarded as uncertain. Throughout our assessment process and model runs, we have dealt with uncertainty in two ways, which we can describe *formally* and *informally*.

We have formally treated uncertainty in our creation of sub-cases. Because grid economics and electricity generation decisions depend on the overall demand for electricity in the grid system *and* on fuel prices, we have created a matrix of sub-cases on the basis of a range of three “load reduction” assumptions, based in part on MA state projections related to energy efficiency and implementation of the Green Communities Act, and a range of six future prices for natural gas ($4-$9/MMBtu), which reflect the recent volatility of natural gas prices.

Informally, we have had to make assumptions about emissions factors, projections of renewable energy implementation, health impacts per given concentration, etc. Because we believed that providing a range for each and every multiplier would lead to a matrix of results with 1000s of cases, we thought it better to make a formal assumption, while admitting that a range of values are possible. For example, there are a range of literature values for nitrogen oxide emissions per MWh from the combustion of both coal and natural gas. Because we are providing an assessment that is intended to inform public officials and state policymakers, we have informally treated uncertainty by, whenever possible, using data from the Massachusetts state government, the federal government, or respected intergovernmental agencies and organizations. When these sources were not available, we sought literature-based values that a) use high-profile, frequently cited journals and articles and b) mimic our case as closely as possible.

In our assessment process we have run self-constructed, Excel-based models for workforce, environmental, and grid impacts, as well as the models JEDI and AERMOD for workforce and air quality assessments. We have attempted to make all of our assumptions apparent in the presentation of our results, and all contents and model code are available to any consumer of our assessment upon request. In an effort to enhance the credibility of our models, nothing that we have done is proprietary.

Finally, several of the impact assessments have case-specific uncertainties resulting from the models or methods used to analyze those particular cases. Such case-specific uncertainties are detailed in the appendices to this report.

Results

Case 1: Business As Usual

Grid and Grid Economics

Results for this case are integrated with the results for the natural gas retrofit case.

Air Quality and Human Health

The output from the grid economic model suggests that Brayton Point will produce roughly 9,000,000 MWh of electricity output in 2020, regardless of assumption of load reduction (because it is a base-load generation facility). This number compares well with the 8,500-9,100 GWh produced by Brayton Point annually between 2005-2009, indicating that our projected 2020 output is credible (Carbon Monitoring for Action 2010). The criteria pollutant emissions associated with this level of output from coal combustion are shown in Table 5, the toxic releases are shown in Table 6, and the greenhouse gas emissions from both the plant and the life-cycle are shown in Table 7 and Figure 4. The model estimates 2020 carbon dioxide emissions from Brayton Point under BAU to be 7.7 metric megatons of carbon dioxide, which again compares favorably to the 2009 estimate of 7.2 metric megatons projected future emissions reported for Brayton Point on the Carbon Management for Action website (www.camra.org) and is within about 5-10% of other reported values (Carbon Monitoring for Action 2010). This uncertainty likely results from the assumed carbon emission factor for coal (See Appendix B). In aggregate terms of all of these air pollutants and greenhouse gases, except ammonia release and life-cycle methane emissions, the BAU coal combustion has the highest levels of pollution.

Table 5. Criteria Pollutant Emissions Projections for 2020.

* Data reported for $5/MMBtu of natural gas and -0.5 % load reduction.

2020 Emissions Projections	Sulfur Oxides (kt)	Nitrogen Oxide (kt)	Particulate Matter (kt)
Base Case Coal	47.72	15.55	1.82
Natural Gas Case 1*	5.47	1.48	0.18
Natural Gas Case 2*	0.02	0.35	0.06
Renewables Case	0.00	0.00	0.00

Table 6. Toxic Release Inventory Projections for 2020.

	Base Case Coal	Natural Gas Case 1	Natural Gas Case 2
HEAVY METALS	Total (lb)	Total (lb)	Total (lb)
Arsenic	598	0	0
Chromium	1027	0	0
Lead	227	80	68
Mercury	84	0	0
Other Heavy Metals	17558	0	0
TOXIC POPS			
Benzo (GHI) Perylene	0.1	0.04	0.04
Polycyclic Aromatic Compounds	24.2	1.4	1.3
Dioxin (amt in g)	5	0	0
NITROGENOUS POLLUTANTS			
Ammonia	3480	50097	46850
ACIDS			
Hydrochloric Acid	1135642	0	0
Hydrofluoric Acid	63751	0	0
TOTALS	1223140	50099	46852

Table 7. Annual Greenhouse Gas Emissions from Plant and Life Cycle for 2020.

2020 Emissions Projections	Combustion (kt CO_2e)	Extraction and Transportation (kt CO_2e)	Total (kt CO_2e)
Base Case Coal	7735.45	127.11	7862.56
Natural Gas Case 1*	3403.72	831.62	4235.34
Natural Gas Case 2*	2567.36	833.25	3400.61
Renewables Case	0	50.73	50.73

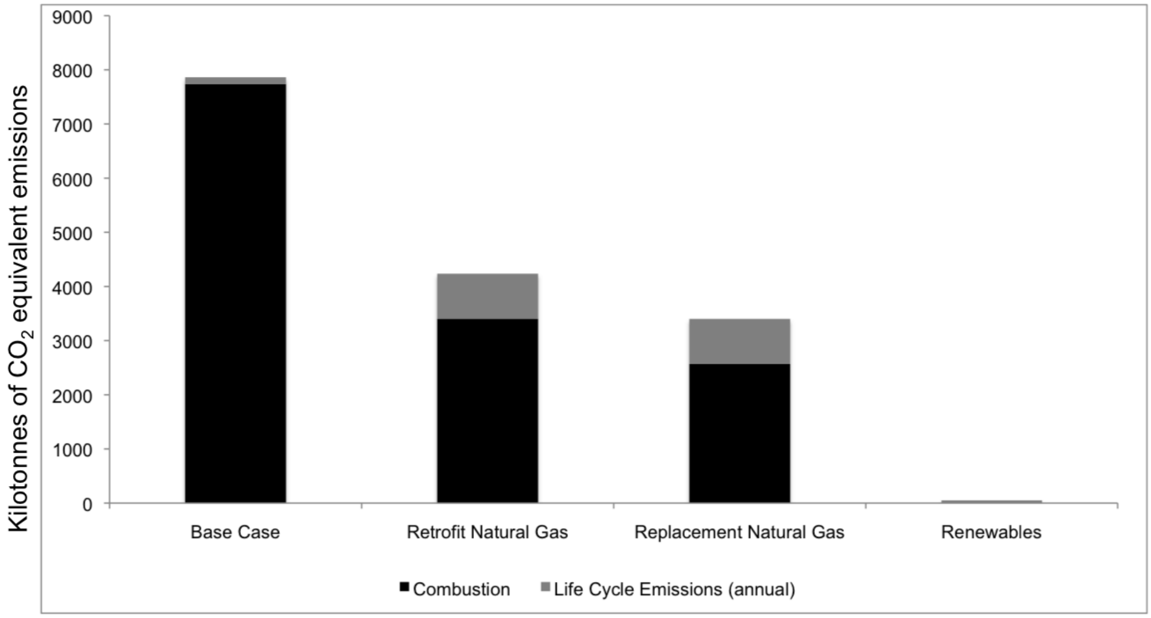

Figure 4. Greenhouse gas emissions associated with fuel combustion (black bars) and life cycle extraction, and transportation (gray bars) in kilotons of carbon dioxide equivalent per year in 2020.

The results of AERMOD for the base case are shown in Figure 5. Annual mean concentrations of PM are highest near the power plant, then disperse outward in preferred directions due to local weather. Following the addition of cooling towers and the fabric filter on Unit 3, Brayton Point emissions result in an annual mean concentration of 0.20 of PM within 10km.

The estimated health impacts for the base case are shown in Table 8 and come from a 2004 study conducted by Abt Associates (Schneider 2004). Aside from causing premature deaths, pollutants from Brayton Point cause a variety of negative health effects. Because of a combination of significant concentrations and high population density, most of the local health effects are seen in the city of Fall River and in surrounding residential areas.

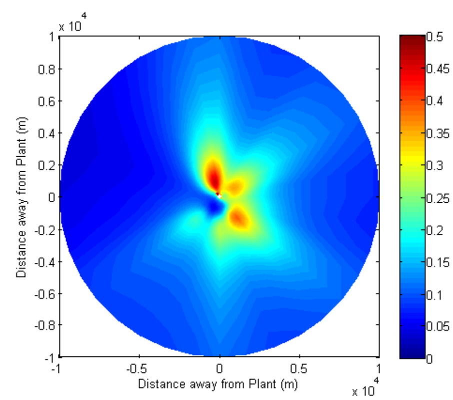

Figure 5. AERMOD results for annual mean concentrations (μg/m3) of PM 10 km away from Brayton Point for base case emissions. The mean concentration is 0.20 μg/m^3.

Table 8. Renewables Case is not shown because of 0 emissions. AERMOD runs indicated that switching to natural gas resulted in an 84% reduction in health outcomes for Case 1 and 87% reduction for Case 2.

Health Outcomes	Base Case Coal	Natural Gas Case 1	Natural Gas Case 2
Deaths	19	3	2
Heart Attacks	35	6	5
Asthma Attacks	300	49	39
Hospital Admissions	16	3	2
Chronic Bronchitis	12	2	2
Asthma ER Visits	11	2	1

Figure 6 removed due to copyright restrictions.

Figure 6. Map displaying spatial distribution of local health effects for the base case along with reference map.

While thermal pollution is also greatest under the Base Case, it has been significantly reduced over the last two years, and compares favorably to similar coal plants. The total net impact of thermal pollution to the Mount Hope Bay ecosystem, according to several recent studies, is not negligible, but is also not deemed to be significant (O'Neill, Englert and Ko 2006). Impingement of fish kills from cooling water intake does less economic harm to the fishing industry than the cost of replacements to the intakes (Environmental Protection Agency 2002).

Economy and Workforce

Brayton Point is estimated to employ 235 people consistently, with additional contractors currently working on the cooling towers and scrubbers projects. Most employees are represented by a local Utility Workers Union of America (UWUA). Contracted electricians for the cooling towers and scrubbers project are represented by IBEW Local 223. Employees in the Power generation and Supply industry in the area, which includes a small natural gas plant, earned average salaries of $112,730 (Executive Office of Labor and Workforce Development 2010).

The MA Executive Office of Labor and Workforce Development projected that in 2016, there would be 0.4% more electricians employed in MA, but 7.4% fewer employees across all utilities.[5] It is not likely that Brayton Plant employees, if dismissed, could find employment at similar utilities in the region.

For FY 2011, Dominion Energy paid $13,437,550 in property taxes to the Town of Somerset for Brayton Point properties, representing 34.2% of the town's property tax revenue and 23.3% of the town's entire tax revenue[6]. The tax assessment of Brayton Point's 306 acres of land and facilities has changed in value over recent years: $525,526,160 in 2006, $549,109,200 in 2007 and an estimated $469,516,073 in 2011. In 2010, another coal-fired power plant in Somerset, Somerset Power Generating Station, closed instead of investing in a costly gasification upgrade. The closure reduced the Town's tax revenue by $577,000; town officials are seeking alternative tax generating uses of the property (Welker 2011).

Case 2.1: Natural Gas "retrofit"

Grid and Grid Economics

Evaluating the average wholesale electricity price under natural gas retrofit involves the consideration of variable natural gas prices, which are known to be quite volatile. Figure 7 displays results from the simulation model. At low gas prices, average wholesale energy price across the demand reduction (energy efficiency) cases is not terribly different from the base case where Brayton Point coal plant remains in operation.

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[5] "Massachusetts Employment Projections Reports through 2016." MA Executive Office of Labor and Workforce Development. http://lmi2.detma.org/lmi/data/Employment%20Projections%202006-2016%20for%20Industries%20and%20Occupations.xls

[6] Information from Town of Somerset Assistant Tax Assessor, Pamela Lee.

However, as gas price increase it becomes exceedingly expensive to operate the retrofitted natural gas plant, and it is therefore not cost-effective to operate the plant at all (in the graph this is why some of the columns are missing). This is largely because the plant simply isn't operating at high utilizations during the course of the year since its bids are more likely to be above the market rate.

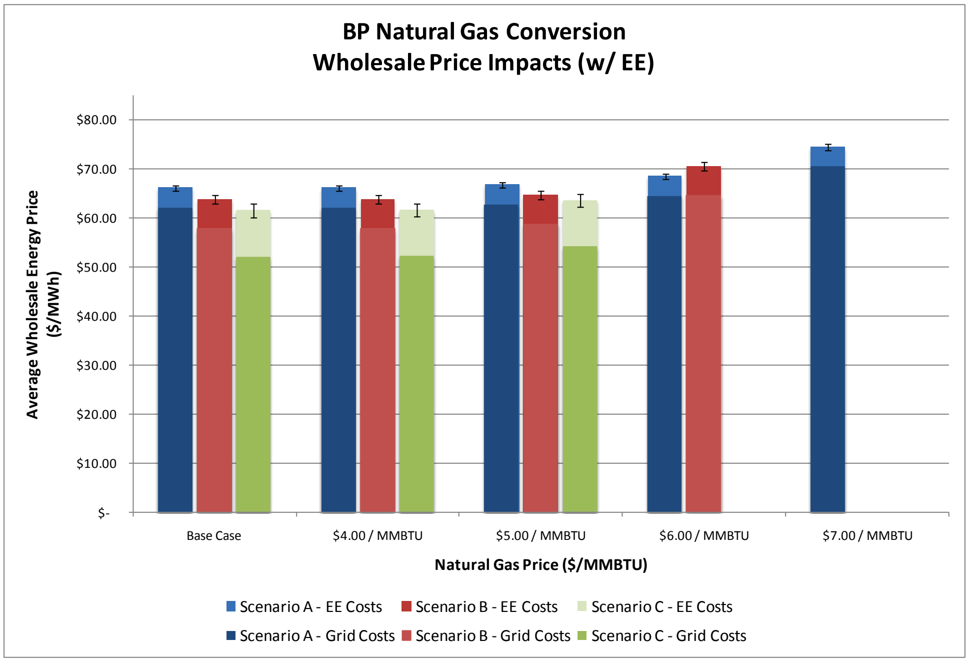

Figure 7: Average wholesale energy price of BP gas retrofit under variable natural gas prices

Air Quality and Human Health

Emissions, and thus public health impacts and associated environmental pollution, from this case come from two sources: the combustion of natural gas in the three converted units at Brayton Point, and the continued emissions from Unit 4, which is assumed to burn oil/gas, as it did previously, with a slight correction factor. As gas prices in the case rise, MWh output from Units 1-3 falls, and thus so do emissions associated with natural gas combustion. The criteria pollutant emissions, toxic releases, and greenhouse gas emissions from a "typical" case ($5/MMBtu and "medium" load reduction in 2020) are shown in Table 5, Table 6, Table 7 and Figure 4 respectively. In the case of criteria pollutant emissions, the bulk of emissions in this case come from Unit 4, which burns oil and natural gas, rather than from Units 1-3 which are assumed to have been converted to just natural gas combustion.

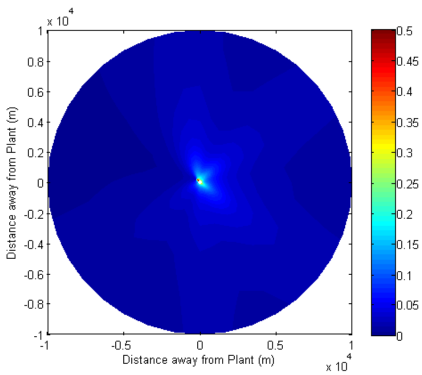

Figure 8. AERMOD results for natural gas case 1 emissions. The mean concentration is 0.06 μg/m^3.

The results of AERMOD for case 2.1 are shown in Figure 8. Switching to natural gas greatly reduces the amount of PM within 10km of the plant, from a mean of 0.2 to 0.06. More significantly, the annual mean concentrations of pollutants over Fall River were greatly reduced, ultimately resulting in less negative health impacts.

The estimated health impacts are shown in Table 7. Switching to natural gas resulted in an 84% reduction in health outcomes, according to calculations of health impacts using AERMOD. For example, the number of premature deaths attributable to Brayton Point emissions decreases from 19 to 3.

Economy and Workforce

Construction Jobs

No data were available to estimate the employment required to convert a coal-fired power plant to a natural gas plant. Clearly, fewer jobs would be required than to build a new plant.

Operation & Maintenance Jobs

With the 1095MW coal-fired units converted to 1095MW of traditional natural gas combustion, between 40[7] and 110 (Kammen 2004) operating and maintenance jobs are anticipated. The nature of natural gas plant operations differs from that of coal plant operations; pipefitters may replace some electricians or other trades. Employees in the Power Generation and Supply industry in neighboring Norfolk County which has several natural gas plants (Energy Information Agency n.d.) earned average salaries of roughly $84,000 in 2011 dollars (Executive Office of Labor and Workforce Development 2011).

Property Taxes

It is assumed that a fully operational plant would be valued somewhat higher than the existing plant due to the upgrades.

Case 2.2: Natural Gas "replace"

Grid and Grid Economics

In this case the full replacement (all 4 Units) of Brayton Point with natural gas combined cycle (NGCC) capability is assessed. Figure 9 displays the simulation results for this case. Compared with standard natural gas replacement in Case 2.1, the average wholesale energy price is lower because the plant operates at higher efficiencies and utilizations despite having higher upfront capital costs. Again, as natural gas price increases, the amount of time during the year that is profitable to produce energy decreases.

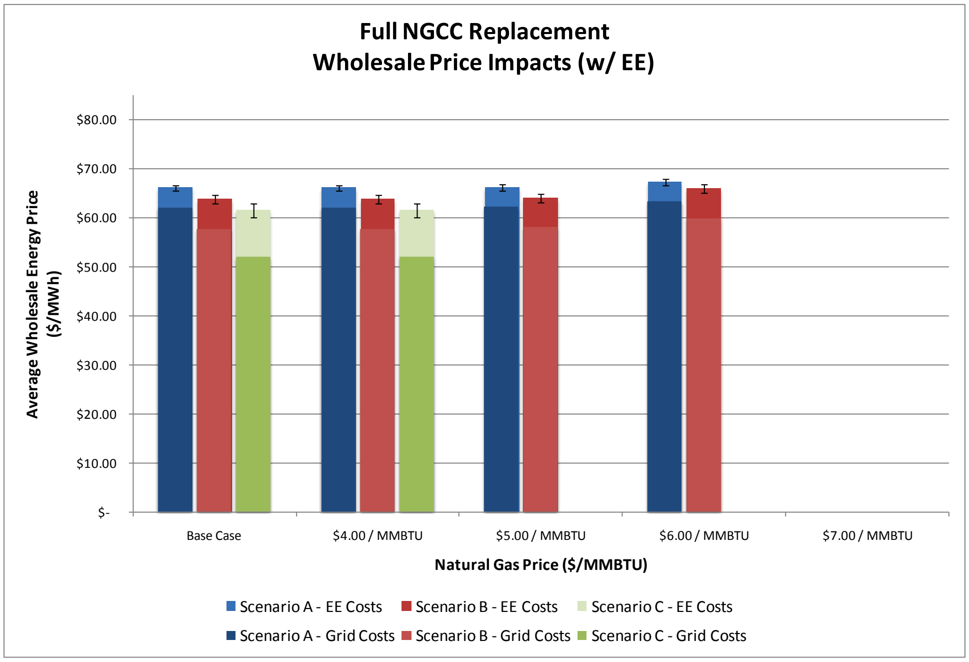

Figure 9: Average wholesale energy price of BP NGCC replacement under variable natural gas prices

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[7] Assuming similar employment patterns to combined cycle natural gas plants.

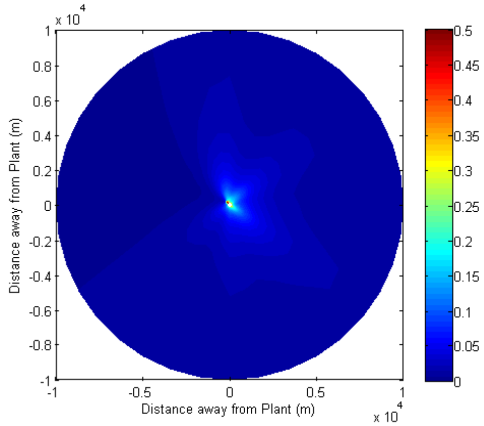

Figure 10. AERMOD results for natural gas case 2 emissions. The mean concentration is 0.05 μg/m^3.

Air Quality and Human Health

In this case, health impacts are from the combustion of combined cycle natural gas to produce an output that is assumed to be replacing Brayton Point (see case discussion). Again the pollution emissions for the "typical" case of $5/MMBtu and "medium" load reduction in 2020 are shown in the tables and figure above. The emissions from this plant, largely because there is no oil-burning Unit 4 and it is a combined cycle plant, are lower than Natural Gas Case 1 across the board, but are similar. The only case in which natural gas emissions are greater than coal is for ammonia, which is produced during the operation of a combined cycle natural gas plant. Because there is less thermal pollution associated with the more efficient operation of a combined cycle natural gas plant, the qualitative impacts on Mount Hope Bay would be reduced under this case compared to the Base Case, as would the fish kills.

While the new-plant construction and old plant decommissioning life cycle emissions that would naturally occur under this case are beyond the quantitative scope of our model assessment and are unlikely to change the overall rankings of greenhouse gas emissions in Figure 4, they are non-zero. Using Spath and Mann's (2000) numbers from a NREL life cycle study, a new natural gas plant is likely to require 110,000 metric tons of concrete, 37,000 tons of steel, 476 tons of iron, and 250 tons of aluminum. Again using numbers from Spath and Mann's 2000 NREL report, emissions associated with decommissioning the old plant and construction of new pipeline and the new plant would be approximately 16 kt CO_2e.

The results of AERMOD for case 2.2 are shown in Figure 10. Switching to natural gas in this case further reduced the amount of PM within 10km of the plant, from an annual mean concentration of 0.2 to 0.05. Switching to this natural gas case resulted in an 87% reduction in health outcomes from the coal case.

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Economy and Workforce

Construction Jobs

Changing the coal-fired plant to be a natural gas combined cycle (NGCC) power plant could involve demolishing existing structures and rebuilding, or replacing the units while keeping structures intact. Assuming that the new 1211MW facility must be constructed, at least 10,290 job-years would be required for just the construction[8]. When the 1580MW Mystic River NGCC Units 8 & 9 were built in Everett, MA, the project "employed several thousand union workers" at peak construction (Energy Vortex n.d.).

Operation & Maintenance Jobs

An exponential trend was found to correlate the jobs in several Dominion Energy NGCC power plants in other states along with Mystic River (Appendix C). 40 jobs are expected for this 1211MW facility. As with Natural Gas Case 1, area salaries in the industry average at $84,000.

Property Taxes

It is assumed that a new fully operational plant would be valued higher than the current coal plant due to the new facility.

[8] 8.5 person-years per MW capacity for Gas Construction. Kammen, Daniel M. et al. "Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?" Renewable and Appropriate Energy Laboratory, Univ. California Berkeley. April 2004.

Case 3: Renewables

Grid and Grid Economics

Calculating total system cost using the model is straightforward when it concerns replacing base load operating capacity, the reason being that these plants can be ramped up when necessary to meet demand at the current market price. Modeling renewable energy generators can be a challenge if the renewable resource is variable and intermittent, such as wind and solar power. In thinking about the future of renewable energy generation in Massachusetts, the focus is primarily on wind due to substantial offshore potential. Unfortunately, a 500 MW offshore wind farm cannot for example be ramped up to its full generation capacity during high demand periods if the wind isn't blowing. While this model relies on increasing supply requirements when load requirement is high, another possible assumption is to model wind availability as negative (or positive) demand on the grid. Such an approach is more complex and operates on finer time scales. Modeling wind capacity increases under alternate energy efficiency cases is therefore outside the scope of this study. Nonetheless, it is evident that the intermittency of wind power will lead to larger total system costs, in addition to the infrastructure and permitting costs required to build and implement offshore (and onshore) wind farms.

Air Quality and Human Health

We are assuming no plant-specific criteria pollution, toxics, or greenhouse gas emissions associated with any of the renewable energies that are anticipated in this case (a combination of on-shore wind, off-shore wind, and solar energy), because there is no active combustion of fuel in the process of electricity generation. There are, however, non-zero impacts on local ecosystems. Off-shore wind energy installations can have significant effects on marine mammal and migratory sea-bird populations, and these effects are anticipated in the ocean areas off the south-coast of Massachusetts. The precise magnitude of the effects, however, would depend on local ecology and bathymetry. Suitability citing for these installations can help mitigate these effects (Winiarski, 2011). Beyond these impacts, viewscapes are altered by wind turbine construction, which may affect property values. Finally, the production of solar panels continues to have high energy intensity.

Life cycle emissions associated with construction and installation are also non-zero. The maintenance and operation associated emissions with on and off shore wind are reflected in Figure 4, for greenhouse gas emissions.

Economy and Workforce

Given the Town of Somerset's regional proximity to potential offshore wind sites, many of the current Brayton Point employees should be able to access those jobs. The accessibility of solar PV and onshore wind jobs will depend on site locations. Many unions are strong supporters of Green Jobs, so these jobs may be union jobs.

<u>Construction Jobs</u>

The number of additional workers employed in the construction of 250MW of new residential solar photovoltaic (PV) facilities and 100MW of onshore wind are calculated. It is assumed that the remaining amount of power required comes from offshore wind. The model used for solar and onshore wind, and the basis for the offshore wind calculations, are discussed in Appendix C.

<u>Operation & Maintenance Jobs</u>

The number of additional workers employed for the annual operation and maintenance of 250MW of new residential solar photovoltaic (PV) facilities, 100MW of onshore wind, and the remainder of offshore wind are calculated. The JEDI model is used to calculate the requirements for solar PV and onshore wind, and the relevant numbers from the Cape Wind study are used to calculate the expected annual workers and earnings. Table 9 and Table 10 summarize the results of the calculations for construction and operation and maintenance workers, respectively.

Table 9. Construction Jobs: These jobs will only persist for the duration of the construction project.

	Capacity (MW)	Source	Jobs	Salary	Earnings (millions)
A: 0% load reduction	100	Onshore Wind	60	$63,849	$3.82
	250	Solar PV	1382	$78,682	$108.8
	2190	Offshore Wind	2621	$30,630	$80.3
	2540	**Sum / Average**	**4064**	**$47,464**	**$192.9**
B: -0.5% load reduction	100	Onshore Wind	60	$63,849	$3.82
	250	Solar PV	1382	$78,682	$108.8
	2076	Offshore Wind	2484	$30,630	$76.1
	2426	**Sum / Average**	**3926**	**$48,052**	**$188.7**
C: -1.3% load reduction	100	Onshore Wind	60	$63,849	$3.82
	250	Solar PV	1382	$78,682	$108.8
	1903	Offshore Wind	2277	$30,630	$69.8
	2253	**Sum / Average**	**3719**	**$49,022**	**$182.3**

Table 10. Operation & Maintenance Jobs: Jobs, Salary and Earnings recur annually.

	Capacity (MW)	Source	Jobs	Salary	Earnings (millions)
A: 0% load reduction	100	Onshore Wind	6	$69,904	$0.42
	250	Solar PV	19	$66,461	$1.3
	2190	Offshore Wind	234	$52,880	$12.4
	2540	**Sum / Average**	**259**	**$54,275**	**$14.1**
B: -0.5% load reduction	100	Onshore Wind	6	$69,904	$0.42
	250	Solar PV	19	$66,461	$1.3
	2076	Offshore Wind	222	$52,880	$11.7
	2426	**Sum / Average**	**247**	**$54,345**	**$13.4**
C: -1.3% load reduction	100	Onshore Wind	6	$69,904	$0.42
	250	Solar PV	19	$66,461	$1.3
	1903	Offshore Wind	203	$52,880	$10.7
	2253	**Sum / Average**	**228**	**$54,463**	**$12.4**

Property Taxes

From the perspective of the Town of Somerset, they would not receive any property taxes if Brayton Point was taken off line. Somerset is not well-suited for profitable wind or solar projects, so it is not a likely choice for such projects to happen without a directive. However, coal fired power plants are capable of burning biomass (Loric 2010). Certain types of biomass are eligible under the Class I RPS, so this may be an alternative use of the power plant in order to continue to generate tax revenue for the town.

Factoring Energy Efficiency into Job Calculations

The three energy efficiency projections (A, B, and C) result in different outlooks for energy efficiency employment. These jobs are additional to those due to specific energy producing technologies. As can be seen in Figure 11, all of the energy efficiency projections could potentially provide at least the same level of employment as the Brayton Point plant currently does except for in years 2011 and 2012. Electricians and related trades may be able to access these jobs. The estimated average salaries would be $68,013 (see Appendix D).

For the base case and natural gas cases, the number of jobs at the coal and natural gas plants is not expected to change significantly under different energy efficiency projections because the plant capacities are fixed. However, the energy efficiency projections do impact the required capacity of renewables to be installed to meet the Class I RPS.

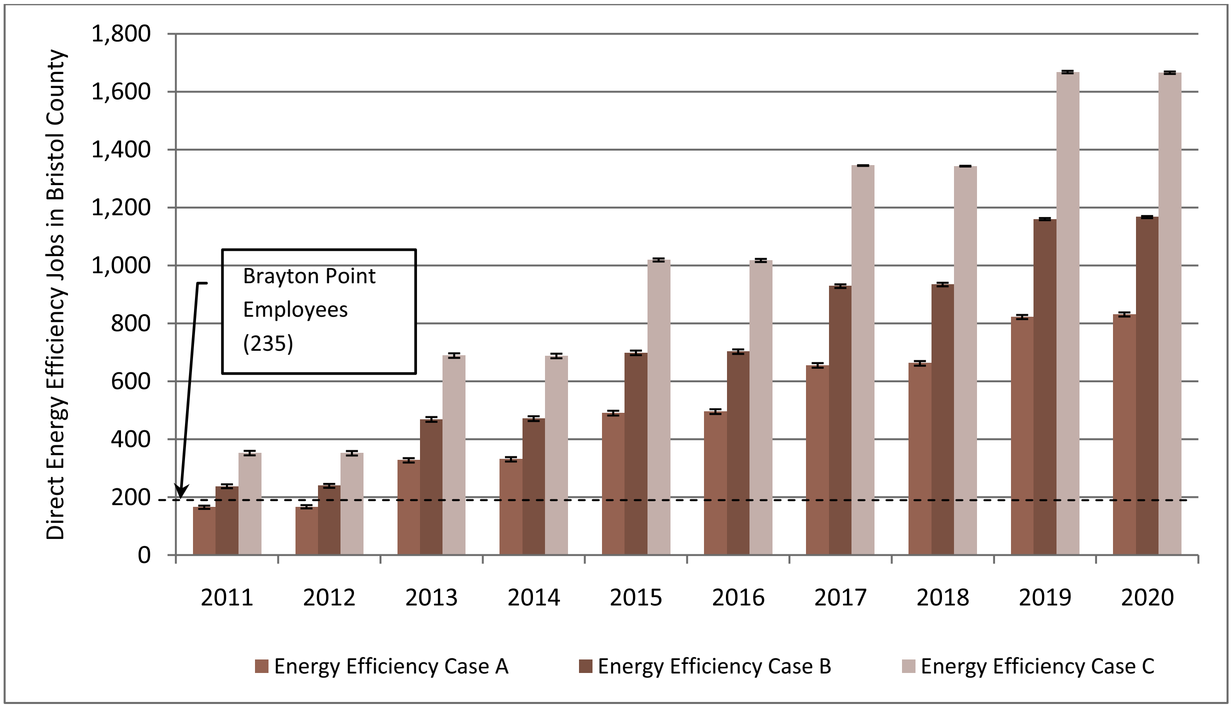

Figure 11. Direct Jobs Created in Bristol County, MA due to Energy Efficiency Programs. Bars represent averages of two calculation methods, error bars represent range of calculate values.

Discussion of Results and Conclusions

Figure 12 shows the magnitude of effects for air quality, electricity cost, and to the workforce across cases and load reduction scenarios. While the grid impacts of renewables were not formally analyzed and thus should not be regarded as "zero," the figure demonstrates the significant reduction in negative health impacts from retrofitting or replacing with natural gas and the significant boon to modeled workforce impacts from renewables. The results from this assessment suggest that natural gas retrofits and/or replacements to Brayton Point can be cost-effective under certain load reduction scenarios, and at significant reductions to harmful emissions.

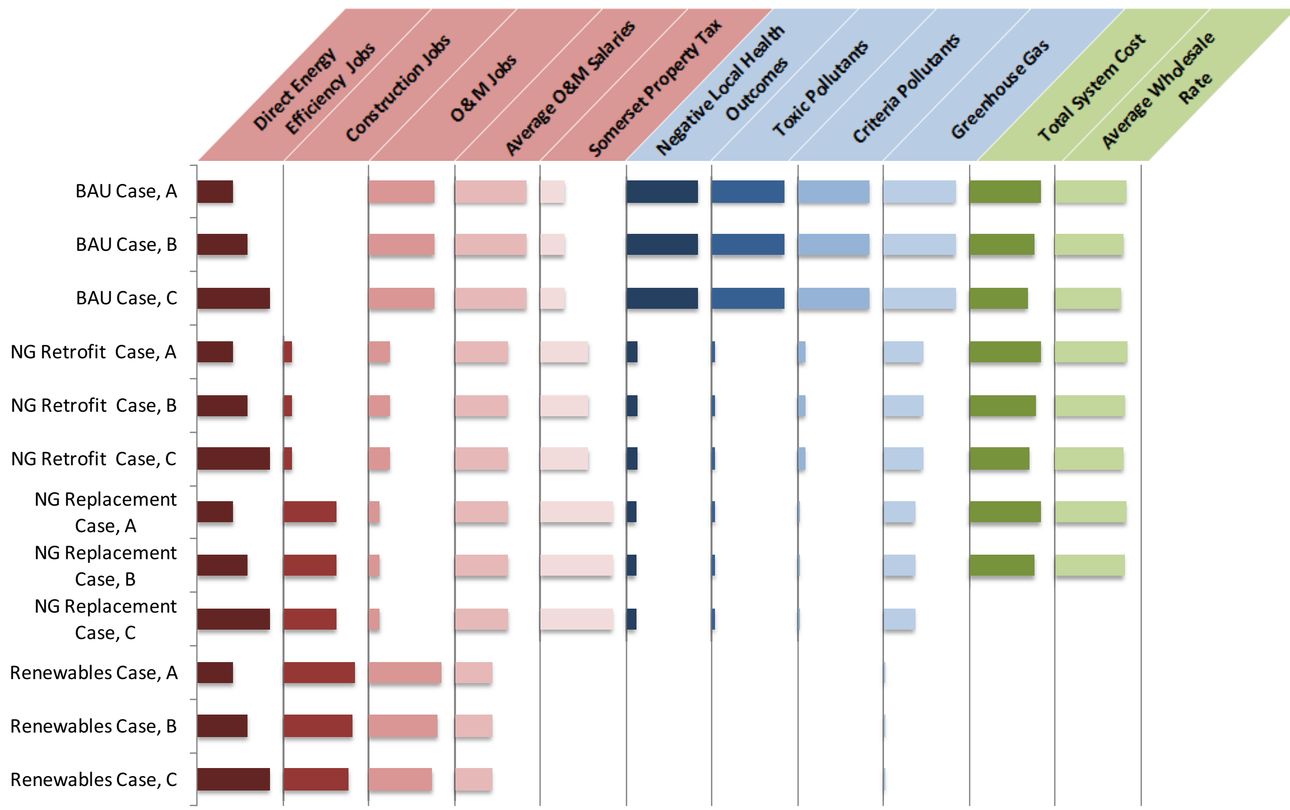

Figure 12. Comparison of results across impact assessments and cases (gas cases assume $5/MMBtu).

Table 11 demonstrates the tradeoffs between the different cases in terms of short term construction jobs and long term O&M jobs, average O&M salaries, and the property tax received by the Town of Somerset. For example, the renewables cases provide considerable jobs in all categories, but with lower average salaries and no property tax to the town, whereas the base case is competitive in all categories except construction jobs. ”Coal” signifies no change in the type of property tax assessment of the coal-fired power plant; “>Coal” signifies that the property tax will be greater; “>>Coal” signifies the property tax will be much greater.

Table 11. Estimated Case Impacts on Bristol County Employees and Somerset Property Tax in 2020.

Case	Energy Efficiency Jobs	Construction Jobs	O& M Jobs	Average O & M Salaries	Somerset Property Tax*
Base Case A	831	None	235	$112,730	Coal
Base Case B	1,167	None	235	$112,730	Coal
Base Case C	1,666	None	235	$112,730	Coal
Natural Gas 1A	831	Hundreds	40 to 110	$84,000	> Coal
Natural Gas 1B	1,167	Hundreds	40 to 110	$84,000	> Coal
Natural Gas 1C	1,666	Hundreds	40 to 110	$84,000	> Coal
Natural Gas 2A	831	Thousands	40	$84,000	>>Coal
Natural Gas 2B	1,167	Thousands	40	$84,000	>>Coal
Natural Gas 2C	1,666	Thousands	40	$84,000	>>Coal
Renewables A	831	4064	259	$57,989	None
Renewables B	1,167	3926	247	$58,039	None
Renewables C	1,666	3719	228	$58,123	None

The grid impact analysis reveals that switching to natural gas under either the retrofit or replacement cases will increase wholesale energy prices; as natural gas prices increase, it will become less profitable to produce energy from natural gas. While it is not possible to perform a full grid impact analysis for the renewables scenario, their integration into the electric grid is likely to be expensive and may also affect grid reliability. Thus, modeling system costs and wholesale energy prices from different renewable scenarios is a subject for further research. The air quality/human health impact analyses show that the health effects are most serious for the Business As Usual case, even though Brayton Point has taken measures to mitigate thermal pollution. The emissions from the natural gas “replace” case are lower than for the “retrofit” case, and the “replace” case also has fewer negative health impacts. Finally, the employment analyses reveal that a significant number of jobs could be added under both the natural gas and renewables cases, but the property tax values may be higher under natural gas because the Brayton Point area is not ideal for many renewable energy generators.

Of the three cases studied, several case-specific findings stand out: the air quality and health implications of the BAU case remain serious despite mitigation efforts; the grid system cost of the Natural Gas cases could be high; and although the Renewables case could have a significant positive impact on air pollution, health, and employment, its potential impacts on grid reliability and cost could pose significant challenges to renewables deployment.

Our analyses suggest that the Natural Gas “retrofit” or “replace” cases are relatively more feasible in the near term. One key tradeoff is between grid system cost and health. Although total grid system cost is slightly lower under the “retrofit” case, the “replace” case has improved air pollution and health impacts. The “retrofit” case will likely create fewer new jobs than the “replace” case because of the lack of need for new construction, but both result in higher property tax values than under the BAU case, a new plant would be assessed much higher than an aging retrofitted plant. The analyses also reveal the importance of considering the interaction between the cases and energy efficiency measures. Energy efficiency measures can significantly affect the system load, and will have separate employment and workforce impacts that interact with the case-specific employment impacts.

It is clear that there is no “silver bullet” solution to phasing out the coal-fired infrastructure at Brayton Point. Therefore, relevant stakeholders need to evaluate tradeoffs across health, economy, and grid reliability metrics. The results from this report can be used as one of many inputs used for informing this decision.

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Appendix A. Grid Modeling Assumptions

The model developed for this study is for the Brayton Point coal plant specifically, and it is assumed that the wholesale price of generating electricity from the plant is always below the market rate, and is therefore always dispatched. This is a reasonable assumption given the relative cheapness of producing power from coal, and in part explains why electricity production from coal is such a lucrative business. Figure 13 provides a graphical representation of the modeling framework. The top graph demonstrates modifying the supply curve by removing Brayton Point and adding a new 1000MW plant that generates power at $50/MWh. The lower graph shows how the load duration curve is adjusted to incorporate energy efficiency improvements.

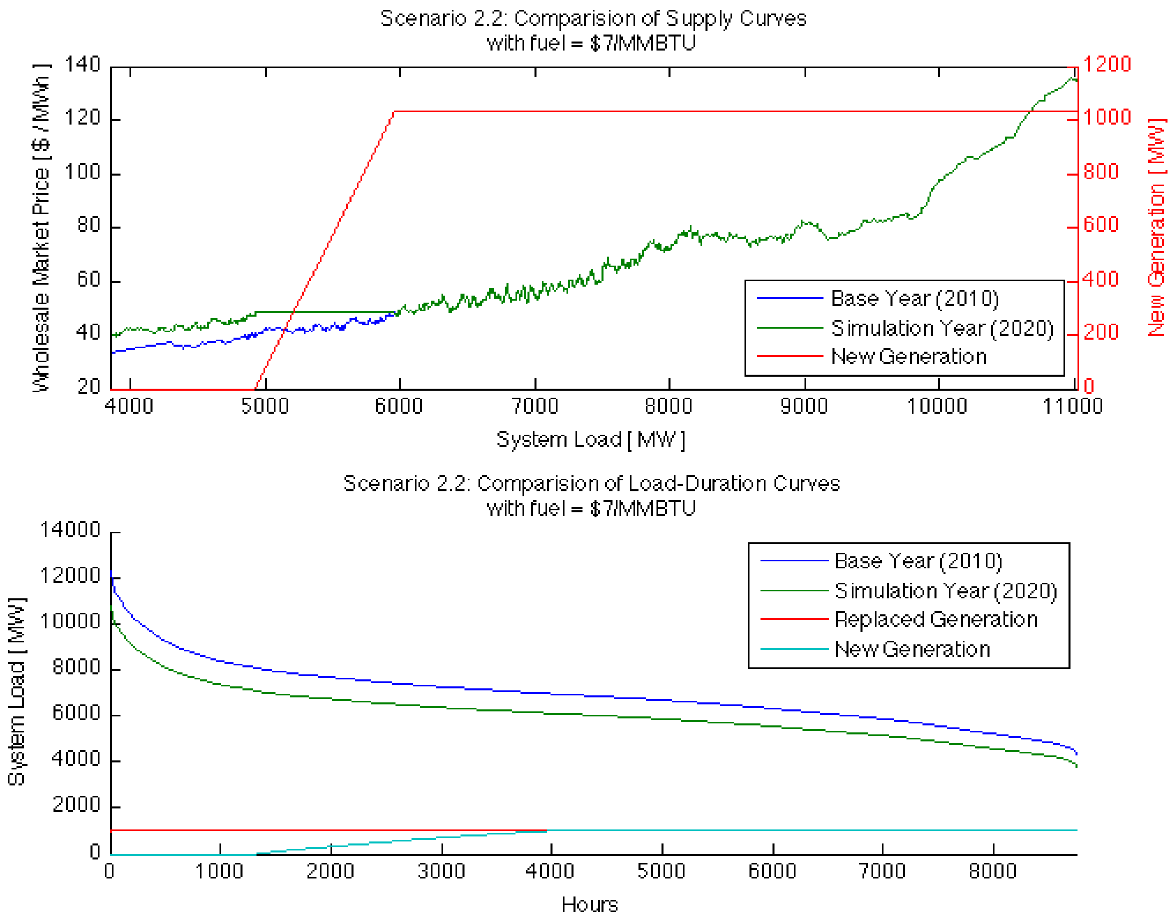

Figure 13: Example of Modeling Outputs

Additional Model Assumptions

- Replacing coal generation from Brayton Point requires an exact replacement of electricity from the new infrastructure. In other words, supply must remain constant.
- New power infrastructure generates power at the same rate regardless of capacity factor. However, the model puts ranges (in terms of standard deviation) on the market price to get an uncertainty range on the final total system cost.
- It is only possible to replace Brayton Point power with other base load operating capacity. The model requires that new power easily be "turned on" which makes modeling infrastructure like wind or solar difficult since their output is probabilistic and intermittent.
- Decreases in yearly demand due to energy efficiency improvements results in demand reductions that are uniform across the entire year. In reality, these decreases would likely have a greater impact during times of peak demand.
- Demand for power cannot grow from year to year. This cannot be modeled accurately in our model, but is also a realistic assumption given the aggressive energy efficiency and demand reduction standards of Massachusetts. Thus, all cases will evaluate only variables decreases in demand growth each year.

Model Limitations

The model is limited in that it can only model base load replacements to Brayton Point's generating capacity. These replacements need to be able to operate at variable utilizations based solely on energy demand fluctuations throughout the course of the year. Thus, modeling renewable energy additions from intermittent sources such as wind and solar is not possible since these generators cannot be ramped up to a certain level when required to do so. The model also cannot take into account demand increase cases because it does not specify whether capacity additions would take the form of base load or peaking power. This decision is complicated by the fact that the model assumes uniform increases (or decreases) in demand over the course of the year while it is clear that this is not the case. Demand increases (or decreases) will likely manifest during hot summer hours as opposed to more temperate spring and fall hours, and the model cannot take this into account explicitly.

Modeling Energy Efficiency Costs:

While rate-payer-funded expenditures on energy efficiency do not directly impact wholesale rates, the expenditures do affect retail rates. In the Commonwealth, a small tariff, called a "system benefit charge" is imposed on retail rates for each unit of energy sold. Revenue from the tariff is used to fund for energy efficiency programs offered by utilities and subsidize energy efficiency services. Historically, Massachusetts's energy efficiency programs have spent between $32.00 and $38.00 for each megawatt-hour of electricity saved through the programs (MA DOER 2007).

Using an avoided cost of $35.00 / MWh saved (with standard deviation of $5.00 / MWh saved), the total cost of the three energy efficiency savings scenarios are estimated. This energy efficiency system cost is added to the grid system cost and then divided by the total generation in each scenario to compute the average wholesale rate. The contribution of energy efficiency expenditures to electricity rates are summarized below in Table 12.

Table 12: Contribution of Energy Efficiency Expenditures to Electricity Rates

EE Scenario	A	B	C
EE Rate Component ($/MWh)	$4.05	$6.05	$9.50

Scenario-Specific Assumptions: Natural Gas

In general, plants set their prices at or slightly above their levelized cost of energy (LCOE), which is the price that a plant must sell energy at in order to recover their capital costs after a predetermined period of time.

$$LCOE = \frac{\sum_{t=0}^{t=N} (I_t + O_t + F_t) \big/ (1+r)^t}{\sum_{t=0}^{t=N} P_t \big/ (1+r)^t}$$

Lumping investment (*I*) and operating (*O*) expenses and assuming:

- Total capital costs $C_0 = I + O$ (investment and operating expense is time-independent);
- constant fuel cost per unit of generation *f* (where $F_t=fP$ and $f=3.412/e$ where *e* is the thermal efficiency of the plant and 3.412 represents the conversion from MMBtu to MWh*)*;
- constant generation in each year *P*;
- investment and operating costs vary across the retrofit and replacement (NGCC) options (see table below)

the LCOE equation reduces to:

$$LCOE = \frac{C_0 + fP \sum_{t=1}^{t=N} 1 \big/ (1+r)^t}{P \sum_{t=1}^{t=N} 1 \big/ (1+r)^t}$$

Applying a 15-year period for analysis ($N = 15$) and 10% discount rate ($r = 0.10$), we arrive at our final formulation for the LCOE:

$$LCOE = f + \frac{C_0}{t^* P}$$

where $t^* = P \sum_{t=1}^{t=N} 1 \big/ (1+r)^t \approx 7.6\ years$

In practice, the plant's operators must estimate the amount of energy the plant will generate each year to set its LCOE. However, the amount of generation ultimately depends upon the bid price that the plant submits to ISO-NE and how that price compares with other generating units in the ISO region. To overcome this circularity, we set the new natural gas plants bid price using the LCOE equation above and ran our model until the estimated generation and the modeled generation converged. The different parameter values for the retrofit and NGCC options are shown in Table 13.

Table 13. Plant-specific parameter values for energy price calculations (IEA 2010)

Plant Type	Retrofit Brayton Point	Replace with NGCC
Capital Cost ($/kW)	300	750
Thermal Efficiency	42%	60%

Figure 14 summarizes the distribution of energy production at Brayton Point under the different cases and energy efficiency scenarios.

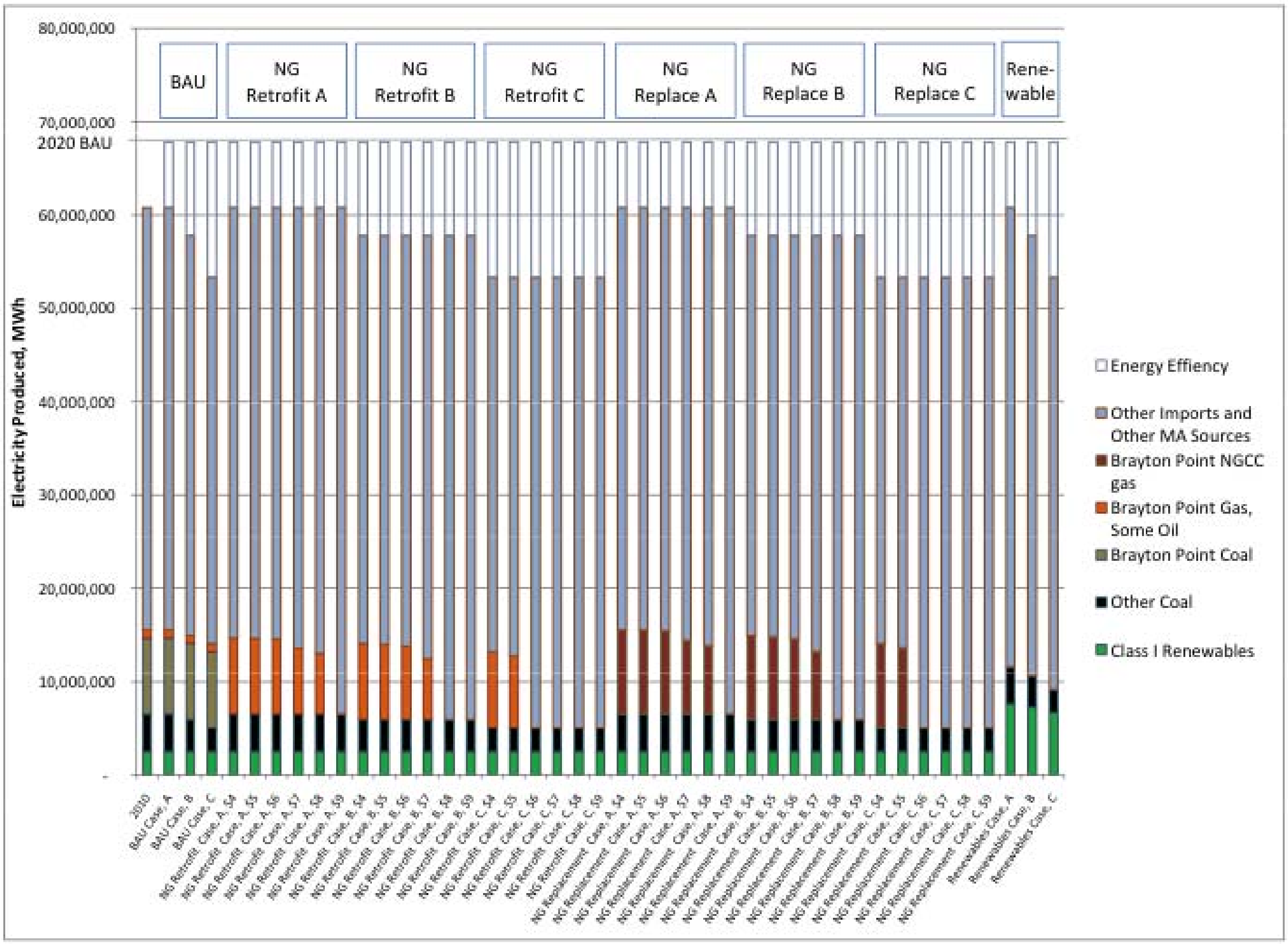

Figure 14. Electricity generation across all cases. Total system generation output is shown for each sub-case with Brayton Point's different contributions highlighted in the colors at the bottom of the stacked graphs.

Appendix B. Air Quality Assumptions

Criteria Pollutant Estimation

The AMS/EPA Regulatory Model (AERMOD) was used to calculate mean annual concentrations of particulate matter in the area surrounding Brayton Point. For each case except renewables, AERMOD was run three times, once for each year of meteorological data (1985, 1990, 1992). The resulting concentrations were then averaged, giving a grid of concentrations at locations away from the plant averaged over three years. The inputs into AERMOD include PM emissions rates, stack height, exit temperature, exit velocity, and stack diameter. These inputs are listed below.

Base Case

Source	PM Emission Rate (g/s)	Stack Height (m)	Exit Temperature (K) [1]	Exit Velocity (m/s)	Diameter (m)
Cooling Tower 1	5.6	151.5	-20	3.39	67.6
Cooling Tower 2	5.6	151.5	-20	3.39	67.6
Unit 1	19.21	107.5	358.2	30	4.4
Unit 2	19.21	107.5	358.2	30	4.4
Unit 3	15.14	107.5	348.2	29.7	5.9
Unit 4	4.17	152.6	466.5	33.8	5.6

Natural Gas Retrofit

Source	PM Emission Rate (g/s)	Tower Height (m)	Exit Temperature (K) [1]	Exit Velocity (m/s)	Diameter (m)
Cooling Tower 1	5.6	151.5	-20	3.39	67.6
Cooling Tower 2	5.6	151.5	-20	3.39	67.6
Unit 1	0.40	107.5	358.2	30	4.4
Unit 2	0.40	107.5	358.2	30	4.4
Unit 3	1.01	107.5	348.2	29.7	5.9
Unit 4	4.17	152.6	466.5	33.8	5.6

Natural Gas Replacement

Source	PM Emission Rate (g/s)	Tower Height (m)	Exit Temperature (K) [1]	Exit Velocity (m/s)	Diameter (m)
Cooling Tower 1	5.6	151.5	-20	3.39	67.6
Cooling Tower 2	5.6	151.5	-20	3.39	67.6
Unit 1	0.5	107.5	358.2	30	4.4
Unit 2	0.5	107.5	358.2	30	4.4
Unit 3	0.5	107.5	348.2	29.7	5.9
Unit 4	0.5	152.6	466.5	33.8	5.6

[1] Negative temperatures are processed by AERMOD as temperatures above ambient temperatures read from weather data.

For the calculation of health outcomes from concentrations of pollutants, the following formula is used.

$$Increase\ in\ Health\ Outcome = Baseline\ Rate \times Population \times \left(1 + concentration\ in\ \mu g/m^3 \times \frac{Percent\ increase\ per\ \mu g/m^3}{100}\right)$$

Baseline rates of health outcomes are listed below and are on a per-person-per-year basis. These rates came from the Levy study, except for premature mortalities, and represent estimates based on surveys of epidemiological studies. Uncertainties in these estimates are discussed in the Levy study and not included for the purpose of this assessment. For premature mortalities, the baseline rate from a report about Particulate Matter in New Jersey was used.

Since increases in health outcomes are linearly scaled with concentrations, the percent change for the different health outcomes from one case to another will be the same. For example, for the base case to natural gas retrofit, health outcomes decreased by 84% across all health outcomes.

Increase in Mortality and Morbidity effects per $\mu g/m^3$ increase in PM concentration (Levy et al. 2000)

Health Outcome	Baseline Rate	Percent increase per $\mu g/m^3$
Premature Mortalities	0.000015	.4
Chronic Bronchitis, age 25+	0.0053	.82
Respiratory hospital admissions, all ages	0.01351	.10
Cardiovascular hospital admissions, age 65+	0.09905	.06
ER visits, asthma, all ages[1]	1,900,000/307,006,550	.43
ER visits, non-asthma, all ages[1]	88,000,000/307,006,550	.08
Asthma attack frequency[2]	0.13	.31
Restricted activity days, age 18+	6.6	.29
Minor Restricted activity days, age 18+	6.3	.44
Upper respiratory symptoms, age 18+	0.037	.68
Upper respiratory symptoms, age < 18	0.016	.16
Lower respiratory symptoms, age < 18	0.004	.31

[1] 1.9 million and 88 million ER visits each year in the U.S. Divided by U.S. population to get ER visits per person per year.

[2] Asthma attack frequency is 13%. Change due to emissions from Brayton Point will just increase this percentage (not take population into account).

The table below summarizes the sources of information for each step of the process to calculate health outcomes.

Information	Details	Source of Information
Meteorological data for 1985, 1990, 1992	Surface observations for T.F. Green Airport Upper-air soundings for Chatham, MA	EPA Support Center for Regulatory Air Modeling, WebMET
Emissions source parameters	Emissions flow rates, heights,	Brayton Point PSD Application

	exit temperatures, exit velocities, and stack diameters	2009
Health outcome baseline rates	Premature mortality rate	Particulate Matter in New Jersey
	Morbidity rates	Levy
Health outcome concentration-response functions	Percent increase in incidence per $\mu g/m^3$ of PM	Levy
Health outcome 2010 base case numbers	2010 Projections of health impacts from Brayton Point	Abt Associates
Population Grid	7.5 arc-second gridded 2000 population of Boston and Providence metropolitan areas	Socioeconomic Data and Applications Center

Several important assumptions were made during the calculation of health outcomes. AERMOD does not simulate important chemistry that leads to the formation of "secondary" PM in the atmosphere. According to the Levy study, secondary PM formed farther than 50km away from Brayton Point can contribute to greater health effects than local PM alone. Related to this assumption, calculations of health effects did not include dense populations in Providence and Boston. Including these major metropolitan areas is expected to increase the estimated health outcomes.

The 2004 Abt Associates study used a proprietary model (REMSAD) that includes chemistry for the formation of secondary PM. The estimates of the health effects of PM for the base case are listed in the results in the report, and estimates for the natural gas cases are found by applying percentage changes found from AERMOD to these estimates. This assumes that percent changes among the cases do not differ for AERMOD versus models that include chemistry.

2000 Population data was used for calculating health outcomes. This analysis assumes that changes in the population to 2020 do not significantly change health outcomes.

AERMOD runs did not include effects of building downwash and topography, though their effects were included in the PSD application. Building downwash is expected to decrease concentrations away from the power plant because pollutants settle near the power plant. Topography also affects concentrations.

Sulfur oxide, nitrogen oxide and particulate emissions for coal were calculated using the reported emissions from the Brayton Point Power Plant in their 2009 PSDA EPA Permit Application (Faggert 2009), assuming 85% capacity facto for Units 1-3. Sulfur dioxide and nitrogen oxide emissions from natural gas were calculated based on Spath and Mann (2000)'s emission factors.

These were:

Sulfur oxides: 2kg/GWh
Nitrogen oxides: 95kg/GWh

Particulate emissions for combined cycle natural gas were assume to emit at 7kg/GWh, based on reported emissions from life-cycle assessments of combined cycle natural power plants.

Toxics Estimation

Data for the Base Case were taken from the 2009 TRI report filed by Dominion for Brayton Point and were unadjusted. Toxic releases for natural gas were estimated in the following manner: whether or not emissions would take place from Brayton Point under Cases 2.1 and 2.2 were assumed to follow the same trend as another Massachusetts natural gas combined cycle plant: Mystic Station in Everett, MA. On this basis, it was assumed that ammonia, lead, polycyclic aromatics and benzoperylene would be emitted by a natural gas plant replacing Brayton Point or by the conversion of the current BP infrastructure to burning natural gas. Ammonia emission were calculated on the basis of the 2009 TRI for two 800MW ombined cycle natural gas plants managed by the TVA. The average rate of emission between these two plants was 0.0075lbs NH_3/MWh. This conversion factor was used to calculate BP ammonium emissions under natural gas replacement. The relative BP natural gas ammonia emissions to reported Mystic Station ammonia emissions was then used linearly to estimate lead, PAC and Benzopyrelene emissions, all of which were low.

Greenhouse Gas Emissions

Combustion Emissions

Emissions factors for coal and combined cycle natural gas combustion were assigned as follows, on the basis of EPA values and literature reviews, including estimates used by the Northwest Planning Council and the IPCC. Both of these values had wide ranges (+/- 15%) in the literature, and the precise emission level would depend on the precise chemical make up of the fuel that Brayton Point is combusting, which is not easily knowable. These numbers correspond nicely to the current Brayton Point annual emissions (within 6%).

Coal: 870 t CO_2/GWh
Natural Gas: 411 t CO_2/GWh for retrofit
Natural Gas: 411 t CO_2/GWh x 0.75 savings for combined cycle efficiency for replacement

Life Cycle Emission

Transportation and extraction emissions estimates for coal, natural gas, and renewables were taken from Jaramillo et al. (2007), Spath and Mann (2000) IPCC good practice guideline estimates. They were as follows:

Coal Extraction: Follow Spath et al. (1999) NREL Report using 1.91 g CH_4/kg coal mined from surface mining and 9g CO_2/KWh from emissions associated with coal extraction.

Coal Transportation: 5.3545 t CO_2/ million ton-miles of coal. Assume distance from Colombia to Somerset, MA to be 2217 miles, and 0.15 t coal/MWh to obtain emissions from coal barge transportation (Jaramillo et al. 2007)

Natural Gas Pipeline Leakage and Operation: Assume 96% of natural gas is CH_4 by weight, 1.07% of NG leaks from pipelines (EPA number, range 1-4%), and GWP of CH_4 is 23x CO_2. Volume of gas delivered is calculated on basis of 1KWh=3413 BTU, and 1 MMBTU=1.030 MCF and density of natural gas of 0.0424 lbs/CF.

Natural gas extraction and transportation emissions associated with pipeline operation were calculated from Spath and Mann (2000)'s life cycle analysis: 124.5 g CO_2e/KWh (which includes pipeline leakage, so this amount is subtracted out to avoid double counting.

Wind: Based on a comparative study of on and off-shore operations by numerous wind energy companies: windenergyknowthefacts.org has estimated 7g CO_2/KWh from onshore wind operation and 8g CO_2/KWh from off-shore operations. The range of estimates is 5g-15g.

Appendix C. Workforce Assumptions

Business As Usual Case:

Number of Employees

On Dominion Energy's website[9], Brayton Point is stated to employ +/- 190 people. In the Town of Somerset's 2006 Comprehensive Financial Annual Report (CFAR), Dominion Energy is stated to employ 190 people, citing the MA Department of Employment and Training. In the Town's 2007 CAFR, Dominion Energy was stated to employ 235 people. After 2007, the town discontinued publication of CAFRs, and this information was not available from the (renamed) MA Executive Office of Labor and Workforce Development (EOLWD). Using government employment data derived from mandatory reporting, jobs in the Power Supply and Generation industry in Somerset have stayed rather constant recently, varying by 54 jobs over the period 2003-2009, suggesting that the number of jobs in the industry has stayed roughly constant. A 2008 newspaper article also suggests roughly 230 employees[10]. Dominion Energy Brayton Point did not respond to a request for a breakdown of employment.

Dominion Energy Brayton Point provided the most jobs in Somerset in 2007, and the 5th ranking number of jobs in 2006. These jobs, however, are not necessarily held by Somerset residents. Other Major employers include nursing homes, retail, millwork and ship building.

Employee Unions

Most employees are represented by a Utility Workers Union of America (UWUA) local. Contracted electricians for the cooling towers and scrubbers project are represented by IBEW Local 223. Doug Nelson[11], business agent with IBEW Local 223 projected that there would be opposition to Brayton Point closing down, from the perspective of lost jobs and concerns about electric grid stability. Nelson also commented that the IBEW members are prepared to work on all types of energy projects, including renewable. His impression about energy efficiency jobs was that they are good temporarily, but are not sustainable.

Natural Gas Case 1:

Employees in the Power Generation and Supply industry in neighboring Norfolk County which has several natural gas plants[12] earned average salaries of roughly $82,000[13] in 2010, which inflates to $84,034.

[9] http://www.dom.com/about/stations/fossil/brayton-point-power-station.jsp
[10] http://www.heraldnews.com/business/x501038221
[11] Phone Conversation with Doug Nelson by Reed Miller on 4/25/11.
[12] "Map of Massachusetts." Energy Information Agency. http://www.eia.doe.gov/state/state-energy-profiles.cfm?sid=MA
[13] "Employment and Wages (ES-202)". 2010 Data for Norfolk County. NAICS 2211 Executive Office of Labor and Workforce Development (EOLWD). http://lmi2.detma.org/lmi/lmi_es_a.asp#IND_LOCATION

Natural Gas Case 2:

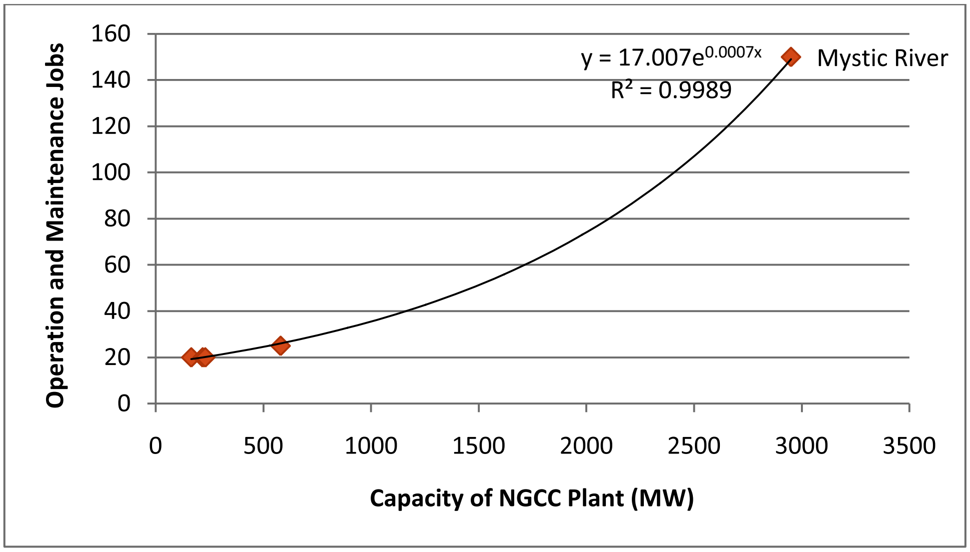

Figure 15. Comparison of Operation and Maintenance Jobs at Existing NGCC Plants and Capacity

Table 14. Comparison of Operation and Maintenance Jobs at Existing NGCC Plants and Capacity

Plant Name	Capacity (MW)	Jobs	Jobs / MW	Data Source
Rosemary	165	20	0.12	http://www.dom.com/about/stations/fossil/rosemary-power-station.jsp
Gordonsville	218	20	0.09	http://www.dom.com/about/stations/fossil/gordonsville-power-station.jsp
BelleMeade	230	20	0.09	http://www.dom.com/about/stations/fossil/bellemeade-power-station.jsp
Bear Garden	580	25	0.04	http://www.dom.com/about/stations/fossil/bear-garden-power-station.jsp
Brayton Point	1211	**40**	0.03	(Future NGCC Plant)
Mystic River	2950	150	0.05	http://www.reuters.com/finance/stocks/companyProfile?symbol=UPR.N

Renewables Case

For the solar PV and onshore wind calculations, the Jobs and Economic Development Impact (JEDI) models from the National Renewable Energy Laboratory (NREL) are used to estimate the total number of new jobs and the resulting earnings (National Renewable Energy Laboratory 2010). As the NREL website notes, JEDI "estimates the number of jobs and economic impacts to a local area that could reasonably be supported by a power generation project" (National Renewable Energy Laboratory 2010). JEDI models are available for onshore wind and solar PV. The inputs to the model are the amount of power we assume is required to be generated by onshore wind, and the number of residential solar PV installations needed to achieve the required amount of power. The default values from JEDI for parameters like onshore wind turbine size and installed system cost are used.

For the offshore wind calculations, the Global Insight report "Economic Impact Analysis of the Cape Wind Off-Shore Renewable Energy Project" is used as a basis to calculate the impact of the required amount of offshore wind (Global Insight 2003). The report provides employment data on the number of workers required to construct the 468MW Cape Wind offshore wind farm. We obtain a ratio for workers/MW from this report, which we use to derive the number of workers required to build the MW of offshore wind necessary to meet the remaining load in Massachusetts. We also obtain earnings per worker from the report, which we use to approximate the earnings of the workers on the required offshore wind farms.

Appendix D. Factoring in Energy Efficiency

Energy Efficiency Jobs in Bristol County

Figure 16 presents the average of two estimates of direct energy efficiency jobs projections for Bristol County, MA. The estimates were remarkably similar. Both methods are based off of the estimated reduced customer electricity demand due to energy efficiency measures, calculated as 93% (factoring in 7% transmission losses) of the difference between Business As Usual (BAU) Total System Load and Energy Efficient Total System Load for each energy efficiency reduction case. As can be seen, Case B most closely reflects MA's actual targets for reduced customer electricity demand due to energy efficiency measures.

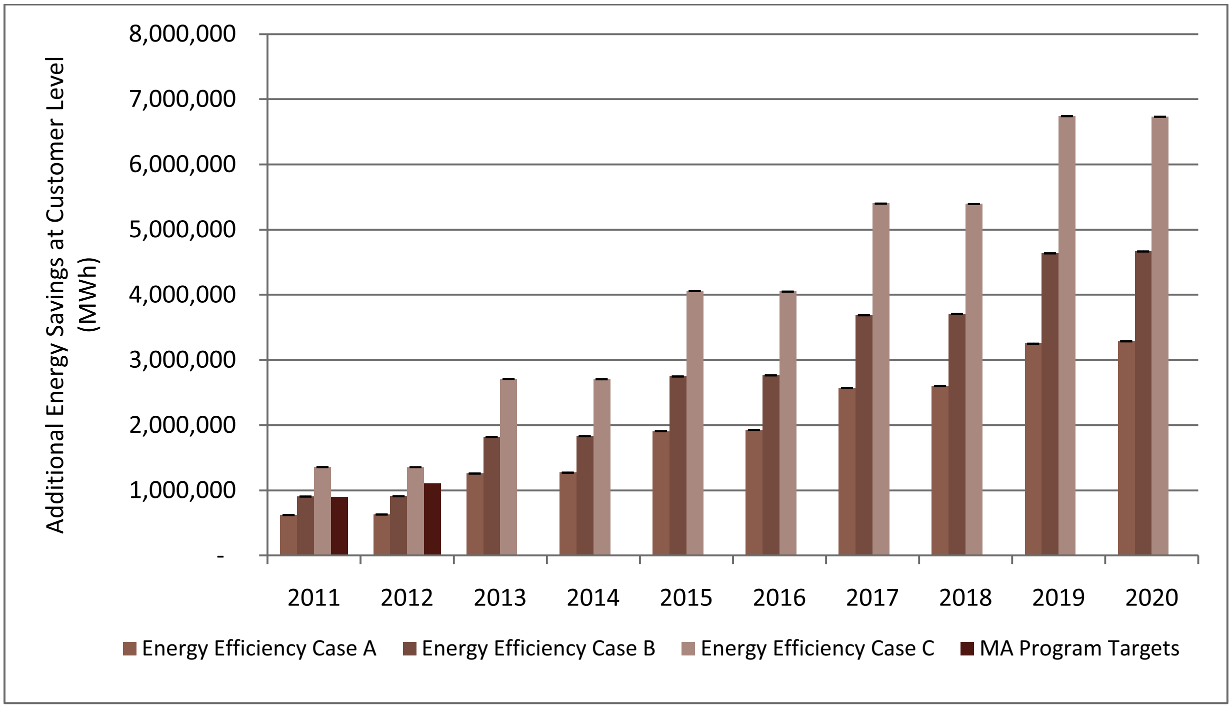

Figure 16. Estimated reduced customer electricity demand due to energy efficiency measures.

Also, MA's Energy Efficiency programs are distributed across residents and economic sectors, so the quantity of programs and related jobs occurring in Bristol County were assumed to proportional to the relative population of Bristol County within MA. According to a US Census estimate[14], Bristol County represented approximately 8.3% of MA's total population in 2009.

MA Division of Energy Resources Calculation Method

The MA DOER completed a report[15] in 2007 summarizing MA's energy efficiency program over the period 2003-2005. It reported the jobs created each year due to energy efficiency measures, and stated that "Job creation happens in jobs directly created in the energy efficiency industry due to investments in energy efficiency measures, where Massachusetts is a major factor nationally. These short-term jobs represent about 30% of the job total and last the length of time needed for the production and installation of the energy efficiency measures."

[14] "State & County QuickFacts: Bristol County, MA." US Census Bureau. http://quickfacts.census.gov/qfd/states/25/25005.html

[15] "Massachusetts Saving Electricity: A Summary of the Performance of Electric Efficiency Programs Funded by Ratepayers Between 2003 and 2005." Executive Office of Energy and Environmental Affairs. MA DOER. April 2007.

Therefore, 30% of the jobs created were assumed to be directly related to the installation and retrofitting required for energy efficiency measures.

Year	Investment (million)	Annual Energy Savings (GWh)	Energy Efficiency Jobs	Direct Energy Efficiency Jobs	Direct Energy Efficiency Jobs per GWh
2003	$166	318	3,166	950	3.0
2004	$174	442	4,075	1,223	2.8
2005	$164	455	3,952	1,186	2.6
Total	**$504**	**1,215**	**11,193**	**3357.9**	**2.8 (average)**

The average Direct Energy Efficiency Jobs per GWh was multiplied by the estimated reduced customer electricity demand and relative population of Bristol County within MA to arrive at the direct energy efficiency jobs in MA. To calculate average salaries, the average salary from the same study was calculated and inflated to 2010 dollars to be consistent with other energy sources.

Year	Disposable Income (millions)	Energy Efficiency Jobs	Energy Efficiency Job Salary	Energy Efficiency Job Salary, 2011USD[16]
2003	$185	3,166	$58,433	$70,966
2004	$233	4,075	$57,178	$67,641
2005	$226	3,952	$57,186	$65,433
Total	**$644**	**11,193**	**$57,599 (average)**	**$68,013**

Note that a more recent study commissioned by the Massachusetts members of the Avoided-Energy-Supply-Component (AESC) Study Group "sponsored an analysis of the economic development impact of the 2010-2012 Massachusetts Joint Statewide Three-Year Electric and Gas Efficiency Plans"[17] which determined that 22.9 person-years was a reasonable jobs multiplier per million dollars of energy efficiency investment. It is difficult to project what the energy efficiency investment will be in 2020 as compared to the energy savings, so that method was not applied.

American Council for an Energy Efficient Economy (ACEEE) Method[18]

The ACEEE regressed the net jobs created by energy efficiency programs based on a sample of 24 studies from various US state energy efficiency programs:

$$\underset{(8.660)}{\text{Net Jobs} = 34.233} * (\text{TBtu Save} * \text{BenefitCost})^{\underset{(15.888)}{0.939}}$$

To compare all of the programs, some of which were measured in GWh and others in TBtu, a conversion factor of 98 GWh/TButu was applied. According to the Massachusetts Joint Statewide Three-Year Electric Energy

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[16] "CPI Inflation Calculator." US Bureau of Labor Statistics. http://www.bls.gov/data/inflation_calculator.htm
[17] Hornby, Rick. "Avoided Energy Supply Costs in New England." 2009 Report. Synapse Energy. http://www.synapse-energy.com/Downloads/SynapseReport.2009-10.AESC.AESC-Study-2009.09-020.pdf
[18] Laitner, "Skip" and Vanessa McKinney. "Postive Returns: State Energy Efficiency Analyses Can Inform US Energy Policy Assessments." June 2008. American Council for an Energy Efficient Economy.

Efficiency Plan[19], the Benefit Cost Ratio (BCR) of the Three-Year plan is 3.27; this BCR, higher than all listed in the sample studies, was used in the calculations. The same 30% direct jobs factor and 8.3% Bristol County factor was applied.

[19] "Massachusetts Joint Statewide Three-Year Electric Energy Efficiency Plan." October 2009. Massachusetts Energy Efficiency Advisory Council. http://www.ma-eeac.org/docs/DPU-filing/ElectricPlanFinalOct09.pdf

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