# Life Cycle Analysis of the Northeast Supply Enhancement Project

MJB & A

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# Contents

# Acronyms

| | |
|---|---|
| \$/MT | Dollar per Metric Ton |
| AFUE | Annual Fuel Utilization Efficiency |
| ASHP | Air-Source Heat Pump |
| $CH_4$ | Methane |
| $CO_2$ | Carbon Dioxide |
| $CO_2$-e | Carbon Dioxide Equivalent |
| COP | Coefficient of Performance |
| Dth/d | Dekatherms per Day |
| EIA | Energy Information Administration |
| G | Gram |
| GHG | Greenhouse Gas |
| GSHP | Ground-Source Heat Pump |
| GWP | Global Warming Potential |
| HHV | Higher Heating Value (Gross Calorific Value) |
| Kg | Kilogram |
| LCA | Life Cycle Assessment |
| LHV | Lower Heating Value (Net Calorific Value) |
| MJ | Megajoule |
| MJB&A | M.J. Bradley & Associates LLC |
| MMBtu | Million British Thermal Units |
| MMDth | Million Dekatherms |
| MWh | Megawatt Hour |
| NESE | Northeast Supply Enhancement Project |
| $N_2O$ | Nitrous Oxide |
| $NO_X$ | Oxides of Nitrogen |
| PM | Particulate Matter |
| SCC | Social Cost of Carbon |
| $SO_2$ | Sulfur Dioxide |

# Acknowledgements

The following study was prepared by Brian Jones, Tom Curry, Robert LaCount, Dana Lowell, and Nicole Pavia of M.J. Bradley & Associates, LLC. (MJB&A) to assess the life cycle greenhouse gas impacts associated with the Northeast Supply Enhancement Project (NESE). It is intended to inform and assist government officials, regulators, energy consumers, and other stakeholders, as they undertake efforts to address the challenges of climate change, while striving to further improve local air quality.

The findings of the life cycle greenhouse gas analysis presented in this report were prepared by MJB&A based on market demand and technology adoption assumptions in the geographic study area. Environmental Defense Fund (EDF) engaged with the MJB&A team to provide technical assistance on certain issues, including the social cost of carbon and methane leakage rates. National Grid and Williams also contributed to this study. The report, and results, reflects the analysis and judgment of the MJB&A authors alone.

Amlan Saha, Dave Seamonds, Alissa Huntington, Luke Hellgren, and Ted Langlois of MJB&A made important contributions to this report.

This report is available at www.mjbradley.com

## About M.J. Bradley & Associates, LLC

M.J. Bradley & Associates, LLC (MJB&A), founded in 1994, is a strategic consulting firm focused on energy and environmental issues. The firm includes a multi-disciplinary team of experts with backgrounds in economics, law, engineering, and policy. The company works with private companies, public agencies, and non-profit organizations to understand and evaluate environmental regulations and policy, facilitate multi-stakeholder initiatives, shape business strategies, and deploy clean energy technologies.

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# Life Cycle Analysis of the Northeast Supply Enhancement Project

This study was prepared by M.J. Bradley & Associates (MJB&A) for National Grid, to provide an independent evaluation of life cycle greenhouse gas emissions associated with operation of the Northeast Supply Enhancement (NESE) Project, as well as the local air emission co-benefits. Environmental Defense Fund (EDF) requested that National Grid undertake such an evaluation to inform regulatory review of the project.

National Grid forecasts growing demand for natural gas in its New York City and Long Island service areas to supply new construction in the commercial and multi-family sectors and to meet requests for lower-emitting fuels to replace heating oil. This analysis compares life cycle emissions of natural gas versus heating oil and electricity to meet demand for space heating, water heating, and other purposes (e.g., cooking and clothes drying). The geographic scope of the analysis covers the service areas of National Grid's downstate New York natural gas utilities–The Brooklyn Union Gas Company (KEDNY) and KeySpan Gas East Corporation (KEDLI).[1] The analysis focuses on the period of 2020 through 2030.

**Key Findings**

- Meeting demand for space heating, water heating, and other purposes using natural gas supplied by NESE (NESE Case) would lower net GHG life cycle emissions compared to meeting the same demand with electricity and heating oil (No NESE Case).
- Under Upstream Scenario 1, cumulative life cycle GHG emissions are reduced 33 to 38 percent in the NESE Case compared to the No NESE Case. Estimated cumulative monetized societal benefits of these reductions range from $212 million to $262 million (2019$) through 2030.[2]
- In addition to reducing life cycle GHG emissions, natural gas supplied by NESE reduces nitrogen oxide ($NO_X$), sulfur dioxide ($SO_2$), and particulate matter (PM) emissions in New York City and on Long Island compared to using electricity and heating oil to meet the same demand.

## Northeast Supply Enhancement Project

The proposed Northeast Supply Enhancement Project will expand and upgrade the existing energy infrastructure in Pennsylvania, New Jersey and New York to provide 400,000 dekatherms per day (Dth/d) of incremental firm natural gas transportation service into downstate New York. National Grid's downstate New York gas distribution utilities—KEDNY and KEDLI—have entered into 15-year contracts for 100 percent of the firm transportation capacity that will be created by the NESE Project. Specifically, KEDNY has agreed to purchase 211,300 Dth/d and KEDLI has agreed to purchase 188,700 Dth/d.

National Grid intends to use the incremental capacity created by the NESE Project to support projected demand growth in its downstate service territories. Over the next ten years, peak day gas demand in the KEDNY and KEDLI territories is expected to grow by more than ten percent due to the continued conversion of oil-fired heating systems to natural gas as well as increased demand from new construction customers.

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[1] KEDNY provides natural gas service to approximately 1.2 million customers in Brooklyn, Queens, and Staten Island. KEDLI provides natural gas service to approximately 600,000 customers on Long Island and the Rockaway Peninsula.

[2] Upstream Scenario 1 is based on the Department of Energy's (DOE) National Energy Technology Laboratory (NETL) life cycle assessment studies of natural gas and petroleum. Upstream Scenario 2 is based on a 2018 EDF-led assessment of methane emissions from the U.S. oil and gas supply chain and is used to scale the methane emissions associated with Upstream Scenario 1. See Appendix A for detailed assumptions.

## Comparison of Natural Gas, Heating Oil and Electricity Life Cycle Emissions

- The life cycle analysis estimates GHG emissions throughout the natural gas, oil and electricity value chains including: (1) production and processing of natural gas or oil, and generation of electricity; (2) transmission pipeline transport; (3) local distribution (pipeline or truck) to end use; and (4) end-use combustion.

- The analysis includes two energy use scenarios, Low New Construction and High New Construction, to reflect uncertainty in projections of potential oil-to-gas conversions and new construction over the modeling period.[3] See Appendix A for additional detail.

- The analysis also includes two upstream scenarios to estimate life cycle GHG emissions associated with the fuels used in the NESE and No NESE Cases. As detailed in Appendix A, these scenarios reflect uncertainties in methane emissions estimates for the U.S. oil and natural gas supply chains.

- Additionally, MJB&A developed electricity sector GHG emission rates for electric generation facilities in the geographic scope of the life cycle analysis–New York Independent System Operator (NYISO) Zone J and Zone K. The emission rates include end-use combustion during heating months and upstream GHG emissions derived from the two upstream scenarios.[4] See Appendix A for additional detail.

- Under Upstream Scenario 1, heating oil has the highest estimated life cycle GHG emissions when used to meet single family new construction thermal energy needs, followed by electricity used to power air source heat pumps and direct natural gas use. Electricity used to power ground source heat pumps has the lowest estimated life cycle GHG emissions (see Figure 1).[5]

- Across all the energy sources, carbon dioxide released at the point of combustion, either in an end-use appliance or at a power plant generating electricity, represents the majority of life cycle GHG emissions.

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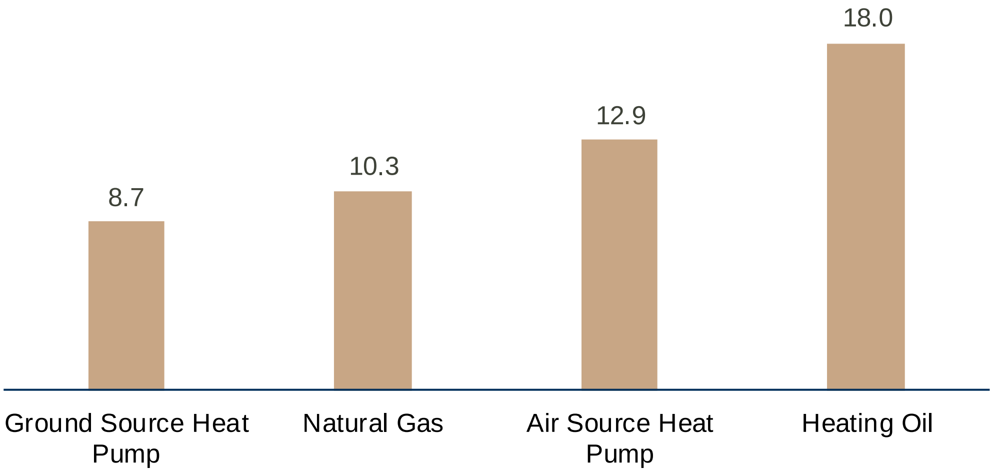
[3] The "Low New Construction Scenario” assumes 31 to 38 percent of natural gas from the NESE project will be used to satisfy demand from new construction each year. The “High New Construction Scenario” assumes 61 to 68 percent of natural gas from the NESE project will be used to satisfy demand from new construction each year.

[4] MJB&A analysis based on data from NYISO and ABB Ability™ Velocity Suite. Demand based on actual hourly load in NYISO Zones J and K during the heating months (October to May) in 2018; supply curve as of May 2019.

[5] The calculation of the estimated life cycle greenhouse gas emissions of the energy options assumes a single-family home, new construction. Natural gas is used for space and water heating, and cooking. Ground source heat pump is used for space and water heating and electric resistance for cooking. Air source heat pump is used for space and water heating and electric resistance for cooking. Heating oil is used for space heating and electric resistance for water heating and cooking.

Figure 1 Estimated Life Cycle Greenhouse Gas Emissions by Energy Option for a New Single-Family Home in the Analysis Geographic Area (metric tons $CO_2$-e per year)

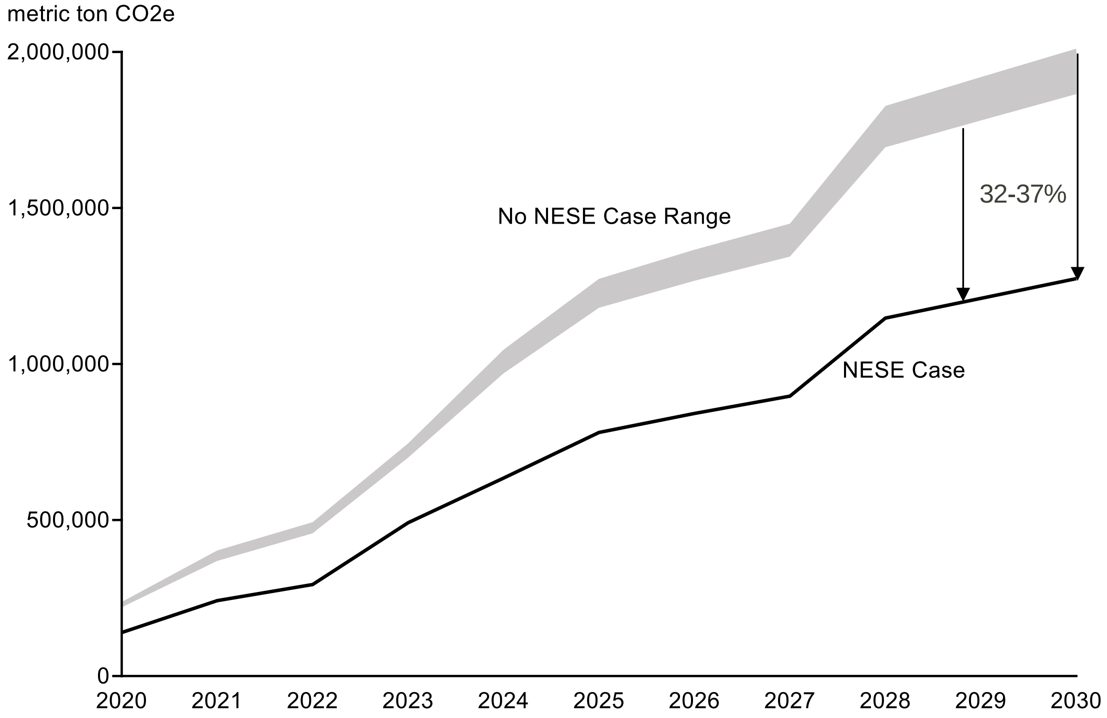


Source: MJB&A Analysis, Upstream Scenario 1, 100-year global warming potential and an electricity grid emission factor (including upstream emissions) of 1,378 lbs. $CO_2$-e/MWh. Under Upstream Scenario 2, and an electricity grid emission factor (including upstream emissions) of 1,429 lbs. $CO_2$-e/MWh, estimated life cycle GHG emissions are: GSHP 9; natural gas 10.6; ASHP 13.4; and oil 18.3.

## Summary of Greenhouse Gas Results

- Under Upstream Scenario 1, annual GHG emissions (calculated as carbon dioxide equivalents or $CO_2$-e) are reduced in the NESE Case relative to the No NESE Case by 400,000 to 492,000 metric tons in 2025 and by 591,000 to 737,000 metric tons in 2030 (see Figure 2 and Table 1).
- Under Upstream Scenario 1, the NESE Case GHG emissions are 32 to 37 percent lower than emissions in the No NESE Case in 2030. Under Upstream Scenario 2, this range narrows to 30 to 35 percent in 2030. Upstream Scenario 2 results are available in Appendix A.
- Through 2030, cumulative life cycle GHG emissions are 33 to 38 percent lower in the NESE Case relative to the No NESE Case. In the NESE Case, cumulative life cycle GHG emissions are approximately 3.9 million to 4.8 million metric tons lower compared to the No NESE Case.

**Figure 2** Projected $CO_2$-e Emissions NESE and No NESE Cases–Upstream Scenario 1



Source: MJB&A Analysis, Upstream Scenario 1, 100-year global warming potential, and range of Low and High New Construction. See Appendix A for the results for Upstream Scenario 2.

**Table 1** Summary of the Life Cycle Analysis Results–Upstream Scenario 1

| Results Year | Incremental Energy Demand (MMBtu) | Life cycle $CO_2$-e NESE Case (metric tons) | Life cycle $CO_2$-e No NESE Case (metric tons) | Net $CO_2$-e reduction in NESE Case (metric tons) | Percent reduction in annual emissions (%) |
|---|---|---|---|---|---|
| 2025 | 11,800,000 | 781,000 | 1,180,000 - 1,273,000 | 399,000 -492,000 | 34 - 39% |
| 2030 | 19,300,000 | 1,270,000 | 1,865,000 - 2,010,000 | 591,000 - 737,000 | 32 - 37% |

Source: MJB&A Analysis, Upstream Scenario 1, 100-year global warming potential, and range of Low and High New Construction. See Appendix A for the results for Upstream Scenario 2.

## Summary of Approach

This analysis calculates the life cycle emissions associated with natural gas use over the years 2020 to 2030 (NESE Case). It also calculates life cycle emissions associated with energy sources that would be used in lieu of natural gas if the NESE project is not built and sufficient gas is unavailable to meet projected demand (No NESE Case).

Under the NESE Case, the natural gas delivered by NESE each year is assumed to meet demand for both gas from new building construction and demand resulting from conversions of other fuels used in older buildings to natural gas. The building types–both new and conversions–are assumed to be a mix of single-family homes, multi-family residential buildings, and commercial buildings. For each building type, the NESE gas is assumed to be used for space heating, water heating, and other purposes (primarily cooking).

The NESE Case includes two scenarios to provide a range of potential oil-to-gas conversions and new construction over the modeling period: 1) Low New Construction and 2) High New Construction. The Low New Construction scenario assumes 31 to 38 percent of natural gas from the NESE project will be used to satisfy demand from new construction each year, with the rest being used to supply gas associated with conversions. The High New Construction scenario assumes 61 to 68 percent of natural gas from the NESE project will be used to satisfy demand from new construction each year.

Under the No NESE Case, most buildings that cannot convert to natural gas due to insufficient supply are assumed to continue to use #2 heating oil for space heating, either #2 oil (boiler) or electricity (electric resistance hot water heater) for water heating, and electricity for cooking. Also, some buildings that cannot convert to natural gas under the No NESE Case are assumed to instead convert to electric heat pumps for both space heating and water heating, which includes air source heat pumps (ASHPs) and ground source heat pumps (GSHPs). The No NESE Case assumes 25 percent of all heat pump technology installed are GSHPs and 75 percent are ASHPs.

The percentage of conversions to heat pumps under the No NESE Case is projected to be small in 2020 but grow each year through 2030. The No NESE Case assumes that two percent of eligible conversions in the residential single-family and multi-family sectors will adopt electric heat pumps starting in 2020, increasing by two percent each year, such that in 2030 adoption comprises 22 percent of eligible residential conversions. For eligible conversions in the commercial sector, electric heat pump adoption is assumed to be two percent in 2020, increasing by three percent annually, such that in 2030 adoption reaches 32 percent. For new construction in the residential single-family, multi-family, and commercial sector, the No NESE Case assumes that 10 percent of buildings constructed in 2020 will adopt electric heat pumps for space heating, increasing by three percent each year such that, in 2030, 40 percent of new construction is expected to adopt heat pumps.

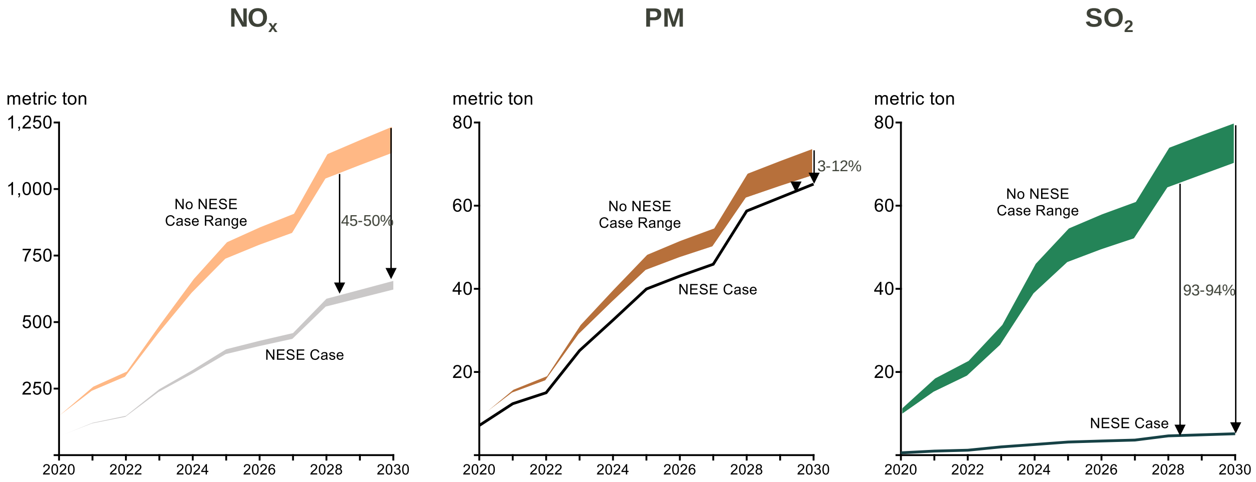
The study does not attempt to quantify financial costs or economic benefits of oil conversions to natural gas or electric, nor related benefits from associated macroeconomic changes (i.e., jobs, consumer energy cost savings, reduced imports of petroleum, or reductions in oil prices due to reduced demand for the fuel). As such, the results of this study are likely conservative with respect to the magnitude of total net societal benefits as these results only include benefits from GHG and air pollution abatement.

Other key assumptions include the quantity of natural gas supplied, the global warming potential values of GHGs (Table 1 is based on IPCC AR5), and the global warming potential timeframe (Table 1 assumes a 100-year timeframe). The analysis focused on the emissions associated with natural gas supplied by the NESE Project (excluding construction-related emissions). The full set of assumptions and methodology are detailed in Appendix A.

### Summary of Air Pollution Co-Benefit Results

- Natural gas supplied by NESE is projected to reduce local $NO_X$, PM and $SO_2$ emissions based on the displacement of heating oil used for heating and electricity generation used to meet the incremental demand from heat pumps in the No NESE Case.
- Local air pollution emissions reductions range from approximately 3,500 to 4,000 metric tons of $NO_X$, 35 to 80 metric tons of PM, and 425 to 500 metric tons of $SO_2$ by 2030 (see Figure 3) in the NESE Case compared to the No NESE Case.

Figure 3 Air Pollution Emissions: NESE Case Compared to No NESE Case in 2030


$NO_x$ PM $SO_2$

Source: MJB&A Analysis, range of Low and High New Construction.

Figure 4 NESE Case and No NESE Case Assumptions

## NESE Case

- Incremental natural gas demand of 2.1 million dekatherms (MMDth) beginning in the 2020/2021 heating season increasing to 11.8 MMDth in 2025 and 19.2 MMDth in 2030
- Natural gas supplied for space heating, water heating, and other uses (cooking and clothes drying) in the single family, multi-family, and commercial sectors
- Oil-to-gas conversions and new construction in the single family, multi-family, and commercial sectors
- Life cycle greenhouse gas emissions–$CO_2$, $CH_4$, $N_2O$
- Local air pollution emissions–$NO_X$, $SO_2$ and PM

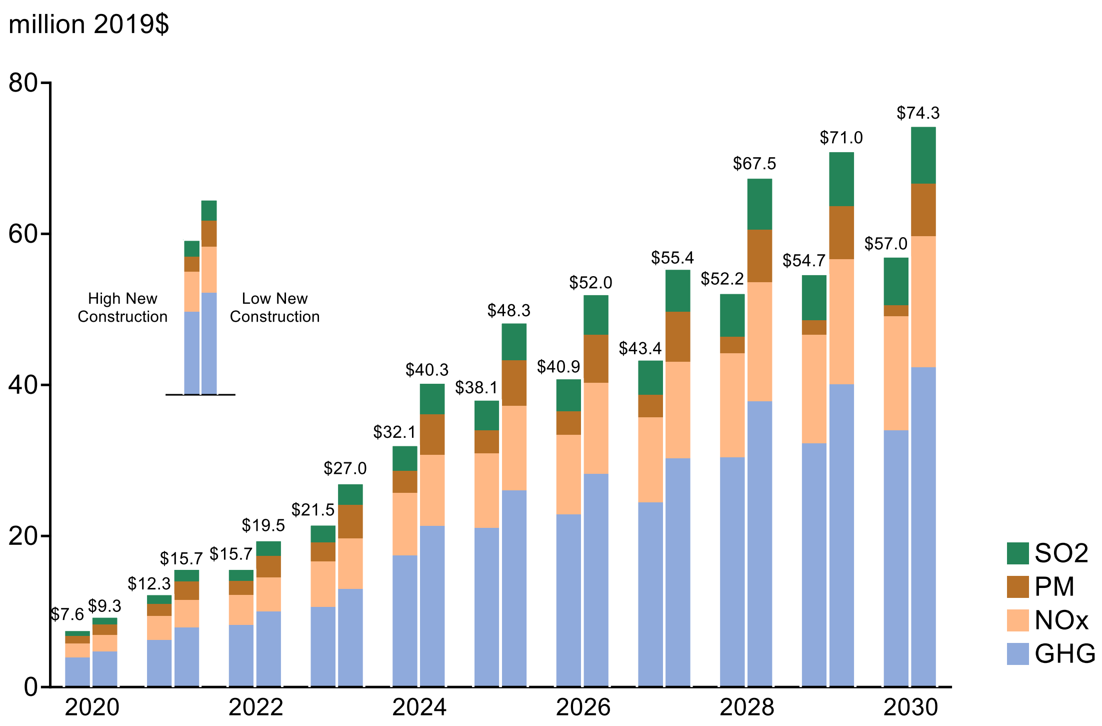
## No NESE Case

- Combination of heating oil and electricity to meet the same energy demands as the NESE Case
- Continued oil use for space heating, water heating in single family, multi-family, and commercial buildings
- Oil-to-electric heat pump conversions in the single family, multi-family, and commercial sectors
- Oil and electric heat pumps in new construction in the single family, multi-family, and commercial sectors
- Life cycle greenhouse gas emissions–$CO_2$, $CH_4$, $N_2O$
- Local air pollution emissions–$NO_X$, $SO_2$ and PM

## Monetized Societal Value of Emission Reductions

- This analysis estimates the monetized societal value of the life cycle GHG, $NO_X$, PM and $SO_2$ emission reductions (see Figure 5). The results of this analysis are likely conservative, because they do not assess indirect benefits from resulting macroeconomic changes and do not account for potential reductions in the cost of traditional fuels due to over-supply that results from reduced demand.
- Under Upstream Scenario 1, the cumulative monetized societal value of life cycle GHG emission reductions is projected to be between $68 and $83 million (2019$) through 2025 and between $212 and $262 million (2019$) through 2030.
- Under Upstream Scenario 1, the cumulative monetized societal value of the non-GHG air pollution emission reductions is between $60 and $77 million (2019$) through 2025 and between $164 and $218 million (2019$) through 2030.

**Figure 5** Societal Value Range of Monetized Greenhouse Gas and Air Pollution Emissions Reductions



Source: MJB&A Analysis, Upstream Scenario 1, 100-year global warming potential, and range of Low and High New Construction.

# New York's Decarbonization and Clean Heat Goals

Both New York State and New York City have established goals for economy-wide decarbonization with key milestones set for 2030 and 2050. The incremental natural gas supply from NESE can help meet these goals, as well as New York City's Clean Heat goals, by allowing for continued oil-to-gas conversions and preventing new construction from relying on heating oil.

## New York State

The 2015 New York State Energy Plan set out three goals: 40 percent reduction in GHG emissions from 1990 levels, 50 percent electricity from renewable resources, and 600 trillion Btu increase in statewide energy efficiency by 2030. The Regional Greenhouse Gas Initiative (RGGI), a regional market to cap and reduce $CO_2$ emissions from the power sector, plays a vital role in this process.

In early 2019, Governor Cuomo announced an even more ambitious Green New Deal, mandating 100 percent clean power by 2040, with the ultimate goal of carbon neutrality. This also included ramping up the state's renewable energy mandates: 9,000 MW of offshore wind by 2035, 6,000 MW of distributed solar deployment by 2025, increasing the Clean Energy Standard to 70 percent renewable energy by 2030, and 3,000 MW of energy storage by 2030. In May 2019, Governor Cuomo announced that all power plants in the state would be required to meet new $CO_2$ emissions limits, a step toward ending the use of coal in New York power plants by the end of 2020.

## New York City

In 2014, New York City committed to reduce GHG emissions 80 percent by 2050 with an interim goal of 40 percent reductions by 2030, both below 2005 levels. The path will include deep decarbonization efforts in the transportation, buildings, waste, and energy sectors.

In April 2019, the New York City Council passed legislation aimed at reducing emissions from the buildings sector. Local Law 97 of 2019 targets 40 percent reductions in GHG emissions by 2030 from a 2005 baseline for new and existing buildings over 25,000 square feet by requiring buildings to reduce their emissions intensity per square foot. More efficient space heating and cooling appliances will be key to many buildings achieving required emissions reductions.

## Decarbonizing Heat

Despite significant clean energy generation upstate, the downstate grid has a higher carbon intensity as the area is limited by constraints on generation and transmission of clean power. Natural gas serves as the marginal fuel, and many buildings use fuel oil for heating. By 2022, the Indian Point nuclear facility, which provides 2,000 MW of carbon-free power to the city, will go offline. These realities complicate heat decarbonization downstate.

The city has targeted reducing the use of heating oil, a disproportionate source of both GHGs and volatile organic compounds (VOCs), through its Clean Heat program. Between 2012 and 2015, the program resulted in nearly 6,000 heating oil conversions from #6 or #4 oil to a cleaner fuel. Number 6 fuel oil was phased out in 2015, and #4 fuel oil must be phased out by 2030. Oil-to-gas and oil-to-electric conversions, as well as improvements in grid efficiency, have been fundamental to the emissions reductions resulting from the Clean Heat program.

## National Grid 80x50 Pathways

In June 2018, National Grid released the “Northeast 80x50 Pathway,” a blueprint for reducing GHG emissions 80 percent below 1990 levels by 2050 (“80x50”) in New York and New England. The Northeast 80×50 Pathway addresses the three most carbon-intensive sectors in the Northeast: heating, power generation, and transportation.

The Pathway proposes three overarching principles: target the highest-emitting fuels and sectors first; optimize the utilization of existing networks; and avoid price shocks through strategic use of electricity and natural gas. It calls for the following shifts in our energy systems, with a mid-term goal of 40 percent reduction in emissions by 2030, to achieve the long-term goal of 80 percent by 2050:

1. Heat – A transformation of the heat sector by doubling the rate of energy efficient retrofits and converting nearly all of the region’s 5 million oil-heated buildings to electric heat pumps or natural gas.
2. Power Generation – Accelerating the zero-carbon electricity transition by ramping up renewable electricity deployment to achieve 67% zero-carbon electricity supply in the Northeast.
3. Transportation – A transformation of the transport sector by deploying more than 10 million electric vehicles on Northeast roads (roughly 50% of all vehicles).

The 80x50 Pathway details the transformation of the heating sector through energy efficiency, electrification and oil-to-gas conversions. This entails a rapid transition from fossil fuels (fuel oil, propane, and kerosene) to heat electrification, reaching 28 percent electrification of residential space heat by 2030 through a mix of air- and ground-source heat pumps. By 2030, roughly 3.85 million Northeast homes are envisioned to be utilizing heat pumps, requiring an average annual rate of conversion of almost 300,000 homes and businesses–more than 10 times the current rate. Oil-to-gas conversions will also need to accelerate over the period, requiring a 3-time increase in oil-to-natural gas conversions from roughly 60,000 homes and business today to approximately 180,000 annually through 2030.

Beyond 2030, the heat sector will require sustained efficiency investment and conversion to heat pumps, the steady decarbonization of natural gas supply (through renewable natural gas, hydrogen, and synthetic fuels), and conversion of many natural gas homes to hybrid natural gas-heat pump configurations.

In April 2019, National Grid submitted a natural gas rate filing which includes the following:

- A green gas tariff that will give customers the choice to supplement their natural gas usage with renewable natural gas (RNG)–pipeline quality gas produced from biomass, wastewater or renewable electricity with lower emissions than from fossil fuel-derived gas.
- A power-to-gas pilot project to create RNG by converting excess renewable electricity to hydrogen through electrolysis of water.
- A hydrogen blending study to assess how much hydrogen can safely be blended into the existing system.
- A program to facilitate RNG interconnections by lowering the cost to connect RNG facilities to the existing network.
- An enhanced gas demand-response program that will give customers the choice to modify their gas consumption in response to price signals.
- An expanded geothermal pilot to test out a utility-ownership business model and its ability to complement gas network operations.

# Appendix A – Life Cycle Analysis Methodology & Assumptions

This analysis estimates the life cycle emissions of the natural gas projected to flow through the NESE project over the years 2020 to 2030 (NESE Case). It also calculates life cycle emissions associated with the energy sources that would be used in lieu of natural gas if the NESE project is not built, and therefore insufficient gas is available to meet projected demand (No NESE Case). The methods used to estimate the benefits from the modeled scenarios, and the sources of major assumptions, are discussed below. All monetary values are in 2019 dollars.

**Energy Demand**

Under the NESE Case, the natural gas delivered by NESE each year is assumed to meet incremental demand for new gas from new building construction, as well as from conversions to natural gas of older buildings that currently use other fuels. The building types–both new and conversions–are assumed to be a mix of single-family homes, multi-family residential buildings, and commercial buildings (see Figure A-1). For each building type the NESE gas is assumed to be used for space heating, water heating, and other purposes (primarily cooking).

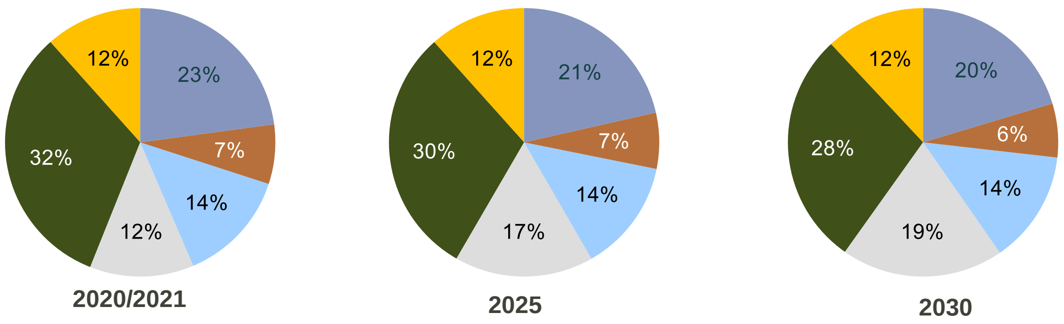
The NESE Case includes two scenarios: 1) Low New Construction and 2) High New Construction. The Low New Construction scenario assumes 31 to 38 percent of natural gas from the NESE project will be used to satisfy demand from new construction each year, with the rest being used to supply gas associated with heating oil conversions. The High New Construction scenario assumes 61 to 68 percent of natural gas from the NESE project will be used to satisfy demand from new construction each year, with the rest being used to supply gas associated with heating oil conversions. This approach provides a range of potential oil-to-gas conversions and new construction over the modeling period (see Figure A-1).

Under the No NESE Case, most buildings that cannot get new natural gas or cannot convert to natural gas due to insufficient supply are assumed to use or continue to use #2 heating oil for space heating, either #2 oil (boiler) or electricity (electric resistance hot water heater) for water heating, and electricity for cooking. A small number of commercial and multi-family buildings that are unable to convert are assumed to continue to use #4 oil, which phases out gradually through 2030. As described in more detail below, some buildings that cannot get new natural gas or cannot convert to natural gas are assumed to instead install a mix of electric air and ground source heat pumps for both space heating and water heating.

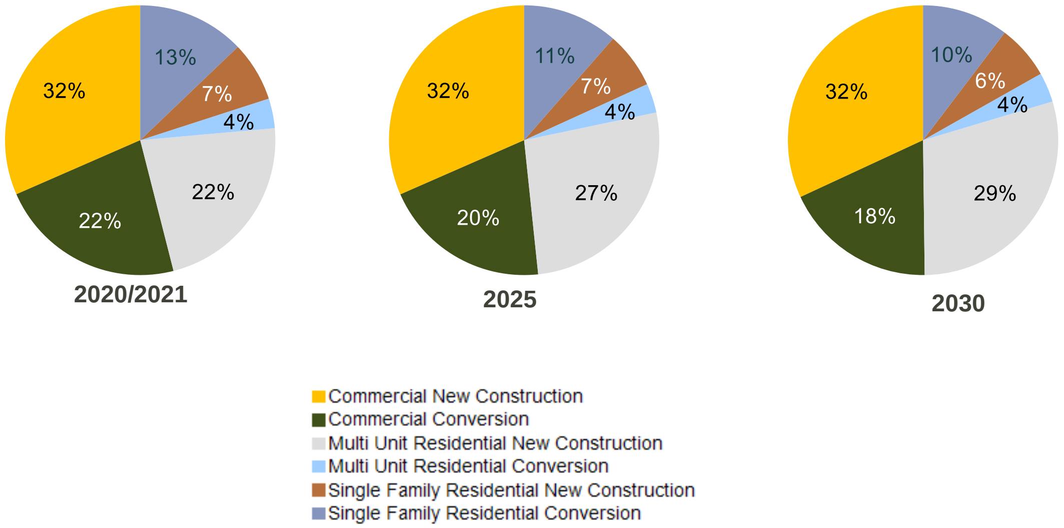
To calculate the amount of #2 oil, #4 oil, and electricity that replaces natural gas in the No NESE Case, the NESE Case gas is apportioned to the different uses (space heating, water heating, other) in each building type, and the “useful” energy derived is calculated by multiplying each apportioned volume by the assumed efficiency of relevant natural gas appliances (i.e. furnace, water heater). The amount of input energy required under the No NESE Case to generate the same amount of useful energy is then calculated by dividing by the efficiency of relevant oil and electric appliances. This calculation accounts for the fact that older appliances (in buildings that convert to gas under the NESE Case) are less efficient than new appliances that would be installed in new buildings.

**Figure A-1** NESE Case Percentage Share of Incremental Gas by Building Type

Low New Construction Scenario



High New Construction Scenario



In the No NESE Case, the energy demand that would have been served by the natural gas delivered by NESE is served by a combination of heating oil and air- and ground-source heat pumps. Given the current market for heat pumps, their installation is projected to start small in 2020 but grow each year through 2030. The No NESE Case assumes that two percent of eligible conversions in the residential single-family and multi-family sectors will adopt electric heat pumps. This percentage of conversions increases by two percent each year, such that in 2030, adoption comprises 22 percent of eligible residential conversions. For eligible conversions in the commercial sector, electric heat pump adoption is assumed to be two percent in 2020, increasing by three percent annually, such that in 2030 adoption reaches 32 percent. For new construction in the residential single-family and multi-family sector, the No NESE Case assumes that 10 percent of buildings constructed in 2020 will adopt electric heat pumps for space heating, increasing by three percent each year such that, in 2030, 40 percent of new construction is expected to adopt heat pumps (see Table A-1).

## Table A-1 No NESE Case Percentage Share of Incremental Energy Demand

| | NO - NESE CASE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SPACE HEAT** | RESIDENTIAL SINGLE FAMILY | | | | RESIDENTIAL MULTIFAMILY | | | | COMMERCIAL | | | | |
| | ELIGIBLE CONVERSIONS | | NEW CONSTRUCTION | | ELIGIBLE CONVERSIONS | | NEW CONSTRUCTION | | ELIGIBLE CONVERSIONS | | | NEW CONSTRUCTION | |
| | % #2 | % Elec | % #2 | % Elec | % #2 | % Elec | % #2 | % Elec | % #4 | % #2 | % Elec | % #2 | % Elec |
| 2020 | 98.0% | 2.0% | 90.0% | 10.0% | 98.0% | 2.0% | 90.0% | 10.0% | 10.0% | 88.0% | 2.0% | 90.0% | 10.0% |
| 2021 | 96.0% | 4.0% | 87.0% | 13.0% | 96.0% | 4.0% | 87.0% | 13.0% | 9.0% | 86.0% | 5.0% | 87.0% | 13.0% |
| 2022 | 94.0% | 6.0% | 84.0% | 16.0% | 94.0% | 6.0% | 84.0% | 16.0% | 8.0% | 84.0% | 8.0% | 84.0% | 16.0% |
| 2023 | 92.0% | 8.0% | 81.0% | 19.0% | 92.0% | 8.0% | 81.0% | 19.0% | 7.0% | 82.0% | 11.0% | 81.0% | 19.0% |
| 2024 | 90.0% | 10.0% | 78.0% | 22.0% | 90.0% | 10.0% | 78.0% | 22.0% | 6.0% | 80.0% | 14.0% | 78.0% | 22.0% |
| 2025 | 88.0% | 12.0% | 75.0% | 25.0% | 88.0% | 12.0% | 75.0% | 25.0% | 5.0% | 78.0% | 17.0% | 75.0% | 25.0% |
| 2026 | 86.0% | 14.0% | 72.0% | 28.0% | 86.0% | 14.0% | 72.0% | 28.0% | 4.0% | 76.0% | 20.0% | 72.0% | 28.0% |
| 2027 | 84.0% | 16.0% | 69.0% | 31.0% | 84.0% | 16.0% | 69.0% | 31.0% | 3.0% | 74.0% | 23.0% | 69.0% | 31.0% |
| 2028 | 82.0% | 18.0% | 66.0% | 34.0% | 82.0% | 18.0% | 66.0% | 34.0% | 2.0% | 72.0% | 26.0% | 66.0% | 34.0% |
| 2029 | 80.0% | 20.0% | 63.0% | 37.0% | 80.0% | 20.0% | 63.0% | 37.0% | 1.0% | 70.0% | 29.0% | 63.0% | 37.0% |
| 2030 | 78.0% | 22.0% | 60.0% | 40.0% | 78.0% | 22.0% | 60.0% | 40.0% | 0.0% | 68.0% | 32.0% | 60.0% | 40.0% |
| **WATER HEAT** | RESIDENTIAL SINGLE FAMILY | | | | RESIDENTIAL MULTIPLE UNIT | | | | COMMERCIAL | | | | |
| | CONVERSIONS | | NEW CONSTRUCTION | | CONVERSIONS | | NEW CONSTRUCTION | | CONVERSIONS | | | NEW CONSTRUCTION | |
| | % #2 | % Elec[1] | % #2 | % Elec[1] | % #2 | % Elec[1] | % #2 | % Elec[1] | % #4 | % #2 | % Elec[1] | % #2 | % Elec[1] |
| 2020 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 75.0% | 25.0% | 10.0% | 60.0% | 30.0% | 75.0% | 25.0% |
| 2021 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 75.0% | 25.0% | 9.0% | 60.0% | 31.0% | 72.5% | 27.5% |
| 2022 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 75.0% | 25.0% | 8.0% | 60.0% | 32.0% | 70.0% | 30.0% |
| 2023 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 75.0% | 25.0% | 7.0% | 60.0% | 33.0% | 67.5% | 32.5% |
| 2024 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 75.0% | 25.0% | 6.0% | 60.0% | 34.0% | 65.0% | 35.0% |
| 2025 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 75.0% | 25.0% | 5.0% | 60.0% | 35.0% | 62.5% | 37.5% |
| 2026 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 72.0% | 28.0% | 4.0% | 60.0% | 36.0% | 60.0% | 40.0% |
| 2027 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 69.0% | 31.0% | 3.0% | 60.0% | 37.0% | 57.5% | 42.5% |
| 2028 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 66.0% | 34.0% | 2.0% | 59.0% | 39.0% | 55.0% | 45.0% |
| 2029 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 63.0% | 37.0% | 1.0% | 56.0% | 43.0% | 52.5% | 47.5% |
| 2030 | 50.0% | 50.0% | 50.0% | 50.0% | 75.0% | 25.0% | 60.0% | 40.0% | 0.0% | 53.0% | 47.0% | 50.0% | 50.0% |
| **OTHER** | RESIDENTIAL SINGLE FAMILY | | | | RESIDENTIAL MULTIPLE UNIT | | | | COMMERCIAL | | | | |
| | CONVERSIONS | | NEW CONSTRUCTION | | CONVERSIONS | | NEW CONSTRUCTION | | CONVERSIONS | | | NEW CONSTRUCTION | |
| | % #2 | % Elec | % #2 | % Elec | % #2 | % Elec | % #2 | % Elec | % #4 | % #2 | % Elec | % #2 | % Elec |
| 2020 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2021 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2022 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2023 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2024 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2025 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2026 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2027 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2028 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2029 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| 2030 | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 100.0% | 0.0% | 50.0% | 50.0% | 50.0% | 50.0% |

[1] Same percentage as electric heat assumed to be ASHP, remainder electric resistance heating.

## Greenhouse Gas and Air Emissions

Annual life cycle emissions are estimated by multiplying the total annual natural gas flow (NESE Case) and total annual oil and electricity (No NESE Case) by relevant emissions factors for each type of fuel. The emissions factors account for emissions associated with production, delivery, and use of each fuel including upstream emissions (production, processing, transport to NYC area), local distribution to end customers, and end-use combustion. For electricity, the emissions factors represent emissions associated with generation of electricity specifically in the New York City region (NYISO Zone J and Zone K). The analysis also includes end-use air pollution emissions.

*Upstream Emissions*

The model includes two upstream scenarios to estimate life cycle GHG emissions associated with the fuels used in the NESE and No NESE Cases:

- Upstream Scenario 1 uses baseline life cycle assessment studies of natural gas and petroleum published by the Department of Energy's (DOE's) National Energy Technology Laboratory (NETL).[6]
- Upstream Scenario 2 uses an assessment of methane emissions from the U.S. oil and gas supply chain published in 2018 and led by researchers at EDF to scale the methane emissions associated with Upstream Scenario 1.[7]

Under Upstream Scenario 1, GHG emissions for the production, processing, and transportation of natural gas are based on NETL's estimate of natural gas produced in the Appalachian region. For the transportation of natural gas, NETL's estimate was scaled to reflect approximately 400 miles of transportation from production areas in Western Pennsylvania to New York City. Distribution system emissions were estimated using data provided by National Grid that had been reported to EPA's Greenhouse Gas Reporting Program and to the ONE Future Coalition, of which National Grid is a member.

Life cycle GHG emissions for #2 and #4 oil under Upstream Scenario 1 were estimated using data published by researchers at NETL in collaboration with researchers at the University of Calgary and Stanford University.[8] Emissions associated with the production, transport, and refining of diesel fuel were based on published estimates of emissions associated with fuel delivered to the East Coast of the U.S. The upstream emissions associated with the production and delivery of fuels were also used as part of the GHG life cycle analysis of electricity based on actual generation and fuel use by electric generators during the heating season in 2018.[9]

Under Upstream Scenario 2, MJB&A, in consultation with researchers at EDF, divided production-related emissions between natural gas systems and petroleum systems using the energy content of the fuels. MJB&A estimated life cycle emissions per unit of energy delivered at the national level for both natural gas and petroleum products.[10] Based on this analysis, MJB&A estimates that the additional methane emissions identified in the 2018 study were about 24 percent higher than the NETL life cycle natural gas GHG estimate and about 12 percent higher than the NETL life cycle GHG petroleum estimate. GHG emissions for Upstream Scenario 2 were estimated by multiplying methane emissions from upstream natural gas by 1.24

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[6] Skone, Timothy J., James Littlefield, Joe Marriott, Greg Cooney, Laura Demetrion, Matt Jamieson, Chris Jones, Michele Mutchek, Chung Yan Shih, Greg Schivley, and Michelle Krynock. "Life Cycle Analysis of Natural Gas Extraction and Power Generation," National Energy Technology Laboratory (NETL). DOE/NETL-2015/1714. August 30, 2016

[7] Alvarez, Ramon A., Daniel Zavala-Araiza, David R. Lyon, David T. Allen, Zachary R. Barkley, Adam R. Brandt, Kenneth J. Davis, Scott C. Herndon, Daniel J. Jacob, Anna Karion, Eric A. Kort, Brian K. Lamb, Thomas Lauvaux, Joannes D. Maasakkers, Anthony J. Marchese, Mark Omara, Stephen W. Pacala, Jeff Peischl, Allen L. Robinson, Paul B. Shepson, Colm Sweeney, Amy Townsend-Small, Steven C. Wofsy, Steven P. Hamburg. "Assessment of methane emissions from the U.S. oil and gas supply chain," Science 361, 186-188 (2018). July 13, 2018.

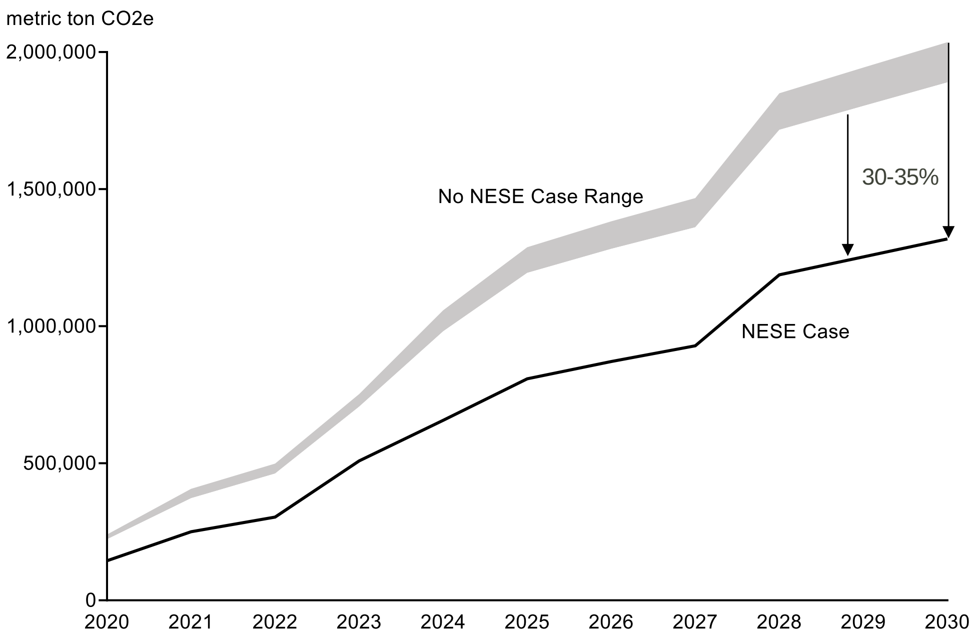
[8] Cooney, Gregory, Matthew Jamieson, Joe Marriott, Joule Bergerson, Adam Brandt, and Timothy J. Skone. "Updating the U.S. Life Cycle GHG Petroleum Baseline to 2014 with Projections to 2040 Using Open-Source Engineering-Based Models" *Environmental Science & Technology* 2017 *51* (2), 977-987

[9] Estimated upstream emission rates of $CO_2$, $CH_4$, and $N_2O$ for each fuel type are converted into a single $CO_2$e value using their respective global warming potential (GWP) numbers. The upstream $CO_2$e values are then added to the $CO_2$ content of each fuel (i.e., their end use combustion related emissions) to arrive at an overall life cycle $CO_2$e emission rate value for each fuel.

[10] MJB&A undertook this analysis to reflect uncertainties around estimates of methane emissions within the U.S. oil and natural gas supply chain. Continuing research on this topic may find emissions that are higher or lower than those identified in the Alvarez et al. 2018 paper.

and multiplying methane emissions from upstream petroleum by 1.12. See Figure A-2 and Table A-2 for the results for Upstream Scenario 2, 100-year GWP, and Low and High New Construction.

**Figure A-2** Projected $CO_2$-e Emissions NESE and No NESE Cases–Upstream Scenario 2



Source: MJB&A Analysis, Upstream Scenario 2, 100-year global warming potential, and range of Low and High New Construction.

**Table A-2** Summary of the Life Cycle Analysis Results–Upstream Scenario 2

| Results Year | Incremental Energy Demand (MMBtu) | Life cycle $CO_2$-e NESE Case (metric tons) | Life cycle $CO_2$-e No NESE Case (metric tons) | Net $CO_2$-e reduction in NESE Case (metric tons) | Percent reduction in annual emissions (%) |
|---|---|---|---|---|---|
| 2025 | 11,800,000 | 808,000 | 1,190,000 - 1,290,000 | 386,000 - 480,000 | 32 - 37% |
| 2030 | 19,300,000 | 1,318,000 | 1,890,000 - 2,036,000 | 571,000 - 717,000 | 30 - 35% |

Source: MJB&A Analysis, Upstream Scenario 2, 100-year global warming potential, and range of Low and High New Construction.

*Local Emissions*

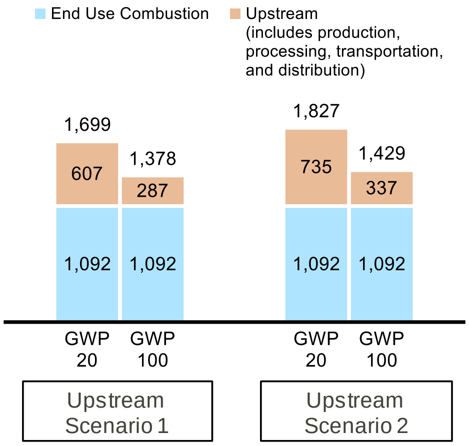
When combusted, fossil fuels emit GHG emissions as well as other air pollutants. To estimate the GHG emissions associated with natural gas combustion, MJB&A used data from National Grid on the methane content of delivered natural gas combined with the calculated energy demand for each scenario. Non-GHG air emissions were estimated using EPA's air emissions factors published in AP-42.[11]

To estimate the GHG and air emissions associated with #2 and #4 diesel combustion resulting from transport, MJB&A used emission factors from AP-42 combined with the calculated energy demand for each scenario. Additional emissions associated with distribution of the refined product to end-use customers in the study region by truck were estimated using EPA vehicle emission factors assuming 50 miles driving.

*Electric Grid Emission Rates*

This analysis uses NYISO Zone J (New York City) and Zone K (Long Island) estimated average 2018 heating season emission rates for $CO_2$-e, $NO_X$, and $SO_2$ using demand based on actual hourly loads during heating months (October - May) in 2018 and the supply curve as of May 2019. See Figure A-2 for $CO_2$-e emission estimates for Upstream Scenarios 1 and 2 using the 100-year and 20-year global warming potentials.[12] The estimated $NO_X$, and $SO_2$ emission rates used in this analysis are 0.52 lbs./MWh and 0.10 lbs./MWh respectively.

Figure A-2 Electricity Grid Emission Rate (lb. $CO_2$-e/MWh)



Source: MJB&A analysis based on data from NYISO and ABB Ability™ Velocity Suite.

In order to derive the estimates, this analysis implicitly assumes that all demand local to the zones is met with supply generated locally. While this is mostly true, not least because local supply requirements mean that most of the zonal demand must be met with local supply, it is possible that the marginal and average emission rates in reality are different from those used in this analysis due to interzonal electricity flows. However, because most of the demand in this analysis takes place in the heating season months, this issue may be somewhat mitigated because the heating season tends to have relatively lower overall electricity demand levels. Even so, imports may still be used depending on market and other conditions. Because of

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[11] U.S. Environmental Protection Agency, AP-42, Fifth Edition Compilation of Air Pollutant Emissions Factors, Volume 1: Stationary Point and Area Sources. Tables 1.3. and 1.4.

[12] Transmission and distribution losses are not accounted for in the calculation of these rates. Depending on the level of such losses, the actual emission rates associated with electricity may be slightly higher. Average transmission and distribution losses for the U.S. is about 5 percent but may vary regionally.

such interzonal dependencies, in terms of both demand and supply, estimation of emission rates with a greater degree of accuracy would require a full redispatch analysis of NYISO and surrounding regions including PJM and ISO-NE, which is beyond the scope of this analysis.

The estimated emission rates derived using the simplified assumptions of this analysis are generally consistent with the very small share of time—two percent—that oil, the primary emitting fuel, is reported to be on the margin in NYISO.[13]

MJB&A also reviewed potential future changes—new projects and retirements—in the zonal and wider NYISO supply portfolios during the 2020 to 2030 period that could alter the estimated emission rates used in this analysis. It found that about 11 GW of new capacity, most of which is zero-emitting, could come online during this period.[14] However, the status of most of the projects were not advanced enough to assess with any level of certainty the likelihood of realization of their in-service dates. If a large portion of the proposed projects is realized before 2030, factoring in requirements of New York's clean energy standard (50 percent renewable energy by 2030), and accounting for the likely retirement of some of the less efficient existing fossil-fired units, average emission rates would likely decline. However, given uncertainties, this analysis holds the electricity emission rate constant for the duration of the modeling period.

*Impact on Existing Electric Generation Units*

MJB&A also explored the possibility of several existing oil- and natural gas-fired electricity generating facilities located in downstate New York operating more frequently as a result of additional natural gas becoming available due to NESE. This high level, indicative analysis assessed electricity generating facilities connected to the local natural gas distribution systems in the KEDNY and KEDLI service areas.[15]

MJB&A reviewed the facilities' estimated electricity production costs relative to other supply resources within NYISO. MJB&A also looked at the facilities' capacity factors and fuel mix during the heating months over a five-year period (2013/14 through 2017/18) and compared them against the number of heating degree days—an indicator of relative energy demand for heating purposes—in each of the five heating seasons. No significant changes to local operating constraints or facilities' production economics were considered during the analyzed period.

The review of facility specific operating data indicates that the facilities have relatively high electricity production costs, suggesting they would generally be run only when non-market constraints are binding. Indeed, the average capacity factor of these units was only about 19 percent during the analyzed period. Further, their generation output levels do not appear to be correlated with the severity of the winters when larger shares of natural gas from the local distribution system are diverted to meet residential and commercial sectors' heating needs. This indicates that the availability of gas is likely not a limiting factor on these facilities.

In short, whether and how much electricity these oil- and natural gas-fired facilities generate is likely to be determined by system-related factors including local capacity requirements, transmission constraints, and local distribution system limits.

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[13] David B. Patton, et al., *2017 State of the Market Report for the New York ISO Markets*, Market Monitoring Unit for the New York ISO, May 2018

[14] MJB&A Analysis based on data from NYISO, ABB Ability™ Velocity Suite, and Upstream Scenarios 1 and 2.

[15] Electric generating units connected to local natural gas distribution systems (sometimes also known as "behind citygate") are subject to the operational constraints of a utility's natural gas delivery obligations to residential and commercial customers, which usually take precedence over the units' need for gas. As a result, such generating units may be less responsive to the economics of dispatch, which would play a more prominent role in the case of units connected directly to transmission pipelines in determining what the additional natural gas would displace in terms of overall electricity resource mix.

## Appliance Efficiencies

MJB&A investigated appliance efficiencies to determine the emissions and energy use impacts of converting between appliances or installing appliances powered by particular fuels. This section outlines and provides references for the appliance efficiency assumptions used in this analysis.

### *Natural Gas-Fired Appliances*

MJB&A evaluated the efficiency of natural gas appliances, including furnaces for space heating, commercial boilers and condensing and non-condensing water heaters, residential storage water heaters, and other appliances like cooking equipment. For the purposes of the calculations, all efficiencies reported for natural gas conversion appliances are efficiencies of the newly installed devices, not of the devices being replaced.

For natural gas furnaces installed in both conversions and new construction, the model includes efficiencies reported in supporting materials for the 2019 U.S. Energy Information Administration (EIA) Annual Energy Outlook (AEO).[16] The AEO conducts a comprehensive assessment of the devices available on the market to develop baseline and projected performance and cost characteristics for residential and commercial end-use equipment. It reviews literature, state and federal standards, and contractor and manufacturer information to determine the required and typical performance expected from appliances on the market. Based on the information presented in the AEO, the model assumes an appliance efficiency of 95 percent for natural gas-fired furnaces in commercial and residential buildings, in both new construction and conversions.

For natural gas boilers and storage water heaters installed in both conversions and new construction, the model also includes efficiencies reported in the EIA AEO 2019. For storage water heaters, higher efficiency models operate at 81 percent efficiency, and the less common but more efficient tankless water heater has a typical efficiency of 81 percent. Therefore, the model uses an efficiency of 81 percent for both new construction and conversions. For larger residential buildings and commercial buildings using boilers, condensing and non-condensing water heaters, typical efficiencies range from 80 to 85 percent. The model includes an estimate of the efficiency of larger-scale water heating devices of approximately 82 percent. For “other” natural gas-fired appliances, like those used for cooking, an efficiency of 95 percent was assumed.

### *Oil-Fired Appliances*

For new oil-fired furnaces, water heaters, and “other” appliances installed in new construction, the model includes efficiencies reported in the EIA AEO 2019. For oil furnaces installed in residential homes, the 2017 ENERGY STAR-qualifying efficiency was 85 percent, and the higher end of device efficiency on the market is 95 percent. The model uses 90 percent as the average efficiency of new oil-fired devices. Commercial furnaces are not ENERGY STAR-rated but have a minimum required efficiency of 80 percent and typically have an efficiency range between 81 and 85 percent. Given the cost-effectiveness of switching to a natural gas appliance, this analysis assumed a higher baseline efficiency for new oil appliances of 90 percent.

All efficiencies reported for oil-fired “conversion” appliances in the model are efficiencies of the devices being replaced. As there is not a collective database of older appliance efficiencies, investigation of these efficiencies ranged across multiple sources. The assumption around residential oil-fired furnaces derived from the NYSERDA residential heat pump analysis conducted as part of the New Efficiency: New York initiative. NYSERDA determined an existing residential fuel oil appliance coefficient of performance (COP) of 66 percent based on a literature review of Department of Energy (DOE) Technical Reference documents, and this analysis adopted NYSERDA’s efficiency assumption. The COP unit represents energy output divided by energy input.

Estimates of 80 percent efficiency for existing residential oil-fired storage water heaters were derived from the AEO 2019 finding that the average annual fuel utilization efficiency (AFUE) of these heaters in 2009 was 80 percent. Existing commercial and larger-scale residential estimates derive from efficiency levels in the

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[16] U.S. Energy Information Administration, Annual Energy Outlook 2019, January 24, 2019.

2007 version of ASHRAE 90.1, the commercial building energy code. Depending on the make and model of commercial water heaters, base required efficiency ranges from 77 to 84 percent. Estimates for efficiencies of #4 oil-fired space and water heating equipment are further corroborated by a recent NYC Department of Environmental Protection (DEP) mandate that increased minimum combustion efficiency of existing commercial oil-fired boilers from 80 to 83 percent. Assuming further heat losses from the 80 percent combustion efficiency baseline, this analysis assumed a minimum thermal efficiency of 75 percent from older commercial oil-fired boilers that continue to burn #4 oil. The same efficiency assumption was applied to older, larger residential oil-fired boilers burning #4 oil, based on this information from the DEP as well as a comment from EIA stating that the minimum thermal efficiency requirement for oil-fired furnaces in 2023 will only be 82 percent. #2-burning existing commercial space and water heating equipment was assumed to have a slightly higher efficiency than #4-burning equipment at 78 percent.

As reported in the AEO 2019, new oil-fired residential water heater AFUE ranged from 83 percent, the 2017 standard efficiency, to 97 percent in highly efficient models. Given the cost-effectiveness of switching to a natural gas appliance and increasing stringency of oil phase-outs, the model assumes relatively high baseline efficiency for new oil appliances of 90 percent.

### *Electric Appliances*

Electric appliance efficiencies are either reported in terms of percentages or in kWh/MMBtu. Lower ratios of kWh/MMBtu represent higher efficiencies. For electric air-source heat pump (ASHP) and ground-source heat pump (GSHP) equipment, existing and new construction efficiencies are assumed to be identical. This analysis leverages NYSERDA's assumption of COP-3 for ASHP residential space heating (~97.7 kWh/MMBtu) as reported in its residential heat pump analysis. It assumes a slightly lower COP of 2.9 (~101.1 kWh/MMBtu) for commercial ASHPs based on the 2017 U.S. Energy Conservation Code.

GSHP residential space heating efficiency is assumed as COP-4.5 (~65.1 kWh/MMBtu) and commercial efficiency is assumed as COP-4 (~73.3 kWh/MMBtu), based on AEO 2019 findings. Residential and commercial ASHP water heaters assume a COP 2 (~146.5 kWh/MMBtu) based on current ENERGY STAR standards.

In the analysis, all efficiencies reported for electric resistance "conversion" appliances are efficiencies of the devices being replaced. For residential models, 90 percent efficiency derives from AEO 2019. While there are no federal minimum efficiencies for commercial electric storage water heaters, federal Energy Conservation Standards require minimum electric instantaneous water heater efficiencies of 77-80 percent for commercial use. The AEO 2019 reports new commercial storage and tankless electric water heater efficiencies to be quite high, at around 98 percent.

## **Electrification Assumptions**

### *Adoption of Heat Pumps*

The current uptake of heat pumps in downstate New York is low. Estimates of adoption hover between one to two percent in the heating market.[17] MJB&A compared the No NESE Case heat pump penetration assumptions to NYSERDA's January 2019 analysis of residential heat pump potential and economics.[18] While the areas covered by the No NESE Case and the NYSERDA analysis are not the same, the assumed heat pump deployment rate in the No NESE Case is greater than the projected heat pump deployment rate in

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[17] NYSERDA, 2017. "Clean Energy Fund Investment Plan: Renewable Heating & Cooling Chapter." https://www.nyserda.ny.gov/- /media/Files/About/Clean-Energy-Fund/cef-renewable-heating-and-cooling-chapter.pdf.

[18] New Efficiency: New York. Analysis of Residential Heat Pump. Potential and Economics. Report Number 18-44, January 2019.

the NYSERDA analysis. Despite covering a smaller geography, the No NESE Case has 25 percent more assumed heat pumps in 2025 than NYSERDA's projection.

*Air- and Ground-Source Heat Pump Adoption Split*

GSHPs, or geothermal systems, are generally more expensive and difficult to install than ASHPs but can still be a compelling option in the right conditions. These systems operate more reliably in very cold temperatures without the need for back-up heat. While a 2014 NYSERDA heat pump study finds that ASHPs are more cost-effective than GSHPs because the additional cost of installing a GSHP does not fully counteract increased savings when compared to a high-efficiency ASHP alternative[19], the 2019 NYSERDA residential heat pump study notes that the cost of GSHPs has decreased significantly in New York State over time as the market has scaled and the state has provided a more supportive policy environment. Despite decreasing costs, GSHPs are not suitable for all sites in New York. In some locations, like Manhattan and Brooklyn, GSHP technical potential is limited by population density, small lot sizes, and extensive underground infrastructure. NYSERDA estimates "applicability factors," or the true technical potential of GSHPs that considers all physical barriers (see Table A-4).

Table A-4 NYSERDA Heat Pump "Applicability Factors"

| Zone | Residential | Commercial |
|---|---|---|
| New York City (NYC) | 30% | 30% |
| Long Island (LI) | 70% | 70% |
| Hudson Valley (HV) | 70% | 70% |
| Upstate (UP) | 80% | 80% |

Source: NYSERDA, Heat Pumps Potential for Energy Savings in New York State, July 2014.

GSHP technical potential for NYC is low compared to areas like Long Island with less underground infrastructure and lower population density. Even so, technical potential does not account for cost, permitting, installation and other barriers that will further reduce the practical applicability of GSHPs. To account for these challenges, the No NESE Case assumes 25 percent of all heat pump technology installed in the National Grid service territory will be GSHPs and 75 percent will be ASHPs.

*Back-up Heating Load Assumptions*

Back-up heat for heat pumps refers to a secondary source of heat powered by electricity, oil, gas, or other fuels that can supplement heat pumps when winter temperatures are very low. The efficiency of an ASHP decreases with temperature, so the device requires more energy to maintain the same indoor temperature as outdoor temperatures drop. This is one reason why heat pumps have been more quickly adopted in states with warmer and milder climates than New York.

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[19] New York State Energy Research and Development Authority. "Heat Pumps Potential for Energy Savings in New York State." Report Number 14-39. July 2014.

An ACEEE study reviewed the need for back-up heat in Minnesota, where winter temperatures can drop as low as -25°F.[20] The author found that heat pumps provide more than 85 percent of heat in homes with electric resistance back-up systems over the course of the winter, indicating that the cold-climate air-source heat pumps can provide comfortable heat in severe winter temperatures. Extrapolating results to other regions, the study found "using some electric resistance heat when the temperatures drop below about 5°F may be acceptable in places where this happens only occasionally."

In 2018, New York City temperatures dropped close to 5°F on three occasions during the official heating season of October 1 to May 31, or on about 1.2 percent of 2018 heating days. Given that the assumed back-up heat source in the downstate New York area is electric resistance heat and considering the inefficiency of electric resistance as compared to ASHPs as well as potential user error that can further decrease efficiency, the No NESE Case assumes that electric resistance back-up heat for ASHPs will comprise 5 percent of total winter heating load.

Review of the literature suggests that GSHPs are more efficient than ASHPs and are assumed to operate without back-up heat at all downstate New York winter temperatures. As such, the No NESE Case assumes that electric resistance back-up heat supporting GSHPs will comprise zero percent of the total annual heating load.

### Global Warming Potentials

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a GHG gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide. The larger the GWP, the more that a given GHG gas warms the Earth compared to carbon dioxide over that time period. The time period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows policymakers to compare emissions and emissions reduction opportunities across sectors and gases.

MJB&A evaluated the life cycle GHG emissions using both the 100-year GWP and 20-year GWP using the values from the Intergovernmental Panel on Climate Change's Fifth Assessment Report[21] (see Table A-5). The range for the 100-year GWP is 28–34 and the range for the 20-year GWP is 84–86.

Table A-5 Global Warming Potentials

| GWP | Methane | Nitrous Oxide |
|---|---|---|
| GWP 100 | 86 | 268 |
| GWP 20 | 34 | 298 |

Source: IPCC, AR5.

### Monetized Benefits

To calculate the monetized value of $CO_2$ reductions, this study used values for the social cost of carbon (SCC) which were developed by the U.S. government's Interagency Working Group on Social Cost of

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[20] Nadel, Steven. "Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps," American Council for an Energy-Efficient Economy. July 2018.

[21] Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report (AR5), April 2014.

Greenhouse Gases.[22] The Interagency Working Group published social cost estimates based on average modeling results using 2.5 percent, three percent and five percent discount rates, as well as 95th percentile results using a three percent discount rate. MJB&A used the average values resulting from a 3 percent discount rate, which is in the middle of the range of estimated values. Total monetized $CO_2$ reduction benefits would be approximately 68 percent lower if using average values resulting from a five percent discount rate, 46 percent higher if using average values resulting from a 2.5 percent discount rate, and three times greater if using 95th percentile values resulting from a three percent discount rate.

The monetized value of the estimated $NO_X$, $SO_2$, and $PM_{2.5}$ reductions was calculated using avoided emission damage estimates ($/MT) developed by EPA which account for the effects of directly emitted $PM_{2.5}$ as well as the effects of $SO_2$ and $NO_X$ as precursors to development of secondary $PM_{2.5}$ in the atmosphere. These avoided emission damage estimates represent the value of avoided human health impacts when emissions are reduced, including the value of reduced morbidity and reduced premature mortality.[23] EPA developed avoided $NO_X$, $SO_2$ ($PM_{2.5}$ precursor) and direct $PM_{2.5}$ damage estimates for 17 different economic sectors, including "Electricity Generating Units" and "End-Use Combustion Sources".

The estimated monetized value of $NO_X$ reductions, based on the role of $NO_X$ as an ozone precursor, was also included in the calculations, based on separate damage estimates ($/MT) also developed by EPA.[24] For these calculations of $NO_X$ benefits related to ozone formation, damage values specific to the eastern part of the country were used, and only $NO_X$ reductions during the six-month peak ozone season were included.

EPA developed a range of estimates for $NO_X$ and $SO_2$ ($PM_{2.5}$ precursor) direct $PM_{2.5}$ and $NO_X$ (ozone precursor) damages ($/MT), based on two different calculation methodologies from the scientific literature, as well as the use of two different discount rates (3 percent and 7 percent). For this study, MJB&A used the average of the values developed by EPA. If using the highest values developed by EPA, the net monetized $NO_X$ and $PM_{2.5}$ benefits would be approximately 44 percent greater than shown here; if using the lowest values developed by EPA, the net monetized $NO_X$ and $PM_{2.5}$ benefits would be approximately 44 percent lower than shown here. See Table A-6 for the social cost of pollutants used in this analysis.

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[22] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (May 2013, Revised July 2015).

[23] U.S. Environmental Protection Agency, Office of Air and Radiation Office of Air Quality Planning and Standards, Technical Support Document: Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors, 2/1/2018.

[24] U.S. Environmental Protection Agency Office of Air and Radiation Office of Air Quality Planning and Standards, Regulatory Impact Analysis for the Clean Power Plan Final Rule, EPA-452/R-15-003, Tables 4-7, 4-8, 4-9, August 2015,

**Table A-6** Social Cost of Pollutants (2019$/Metric Ton)

| GWP | 2020 | 2025 | 2030 |
|---|---|---|---|
| **Carbon dioxide equivalent** | $48 | $53 | $58 |
| **$PM_{2.5}$ Precursors** | | | |
| *NOx* | | | |
| Electricity Generation | $10,875 | $11,652 | $12,484 |
| Fuel Combustion | $15,591 | $17,089 | $18,587 |
| *PM* | | | |
| Electricity Generation | $271,873 | $288,518 | $316,260 |
| Fuel Combustion | $654,714 | $715,747 | $776,780 |
| *$SO_2$* | | | |
| Electricity Generation | $74,349 | $78,233 | $86,001 |
| Fuel Combustion | $100,427 | $108,194 | $116,517 |
| **Ozone Precursors** | | | |
| *NOx* | | | |
| Electricity Generation | $10,925 | $11,748 | $12,856 |
| Fuel Combustion | $10,925 | $11,748 | $12,856 |

Source: MJB&A analysis based on: Interagency Working Group on Social Cost of Greenhouse Gases; Technical Support Document: Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors; and EPA Regulatory Impact Analysis for the Clean Power Plan Final Rule.

# Appendix B – Detailed Modeling Results

**Table B-1** NESE Life Cycle Analysis Modeling Results: Upstream Natural Gas Scenario 1 with Low New Construction

| SCENARIO | METRIC | Unit | ANNUAL RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| NESE | Natural Gas | MMBtu | 2,110,288 | 3,658,729 | 4,440,844 | 7,440,321 | 9,607,569 | 11,822,395 | 12,744,663 | 13,584,002 | 17,373,061 | 18,330,353 | 19,287,646 |
| NESE | CO2 | MT | 118,519 | 205,483 | 249,409 | 417,867 | 539,585 | 663,976 | 715,773 | 762,912 | 975,715 | 1,029,479 | 1,083,243 |
| NESE | CH4 | MT | 600 | 1,041 | 1,263 | 2,116 | 2,733 | 3,363 | 3,625 | 3,864 | 4,942 | 5,214 | 5,487 |
| NESE | N2O | MT | 1 | 3 | 3 | 5 | 7 | 8 | 9 | 10 | 12 | 13 | 14 |
| NESE | GHG (100-yr GWP) | MT CO2-e | 139,365 | 241,623 | 293,280 | 491,371 | 634,501 | 780,815 | 841,734 | 897,177 | 1,147,442 | 1,210,680 | 1,273,919 |
| NESE | GHG (20-yr GWP) | MT CO2-e | 170,536 | 295,667 | 358,876 | 601,273 | 776,416 | 955,441 | 1,029,982 | 1,097,822 | 1,404,052 | 1,481,429 | 1,558,806 |
| NESE | NOx | MT | 70 | 121 | 148 | 248 | 320 | 398 | 430 | 459 | 588 | 621 | 655 |
| NESE | PM | MT | 7 | 12 | 15 | 25 | 32 | 40 | 43 | 46 | 59 | 62 | 65 |
| NESE | SO2 | MT | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 5 | 5 | 5 |
| NO-NESE | #4 Oil | gal | 534,156 | 876,929 | 1,015,953 | 1,525,683 | 1,838,385 | 2,058,343 | 2,130,567 | 2,177,474 | 2,341,417 | 2,357,916 | 2,357,916 |
| NO-NESE | #2 Oil | gal | 15,225,106 | 26,131,913 | 31,473,309 | 51,656,154 | 65,892,496 | 79,816,434 | 85,459,433 | 90,429,080 | 112,582,240 | 117,864,460 | 122,952,399 |
| NO-NESE | Electricity | MWh | 66,001 | 104,262 | 142,281 | 139,139 | 324,331 | 405,668 | 441,041 | 474,543 | 632,106 | 673,924 | 717,690 |
| NO-NESE | CO2 | MT | 227,647 | 384,283 | 473,270 | 712,961 | 1,004,421 | 1,222,865 | 1,312,754 | 1,393,240 | 1,756,837 | 1,846,025 | 1,934,011 |
| NO-NESE | CH4 | MT | 255 | 436 | 525 | 859 | 1,094 | 1,322 | 1,414 | 1,495 | 1,855 | 1,940 | 2,022 |
| NO-NESE | N2O | MT | 3 | 11 | 7 | 11 | 14 | 17 | 18 | 19 | 24 | 25 | 26 |
| NO-NESE | GHG (100-yr GWP) | MT CO2-e | 237,277 | 402,323 | 493,120 | 745,444 | 1,045,784 | 1,272,855 | 1,366,229 | 1,449,774 | 1,826,972 | 1,919,388 | 2,010,473 |
| NO-NESE | GHG (20-yr GWP) | MT CO2-e | 250,419 | 424,689 | 520,207 | 789,775 | 1,102,237 | 1,341,086 | 1,439,218 | 1,526,939 | 1,922,710 | 2,019,534 | 2,114,852 |
| NO-NESE | NOx | MT | 154 | 262 | 318 | 495 | 665 | 804 | 861 | 911 | 1,135 | 1,189 | 1,241 |
| NO-NESE | PM | MT | 9 | 16 | 19 | 32 | 40 | 48 | 52 | 55 | 68 | 71 | 74 |
| NO-NESE | SO2 | MT | 11 | 19 | 23 | 32 | 46 | 55 | 58 | 61 | 74 | 77 | 80 |
| Difference | CO2 | MT | (109,127) | (178,800) | (223,861) | (295,094) | (464,836) | (558,889) | (596,981) | (630,328) | (781,122) | (816,545) | (850,768) |
| Difference | CH4 | MT | 346 | 604 | 738 | 1,258 | 1,639 | 2,041 | 2,211 | 2,369 | 3,087 | 3,274 | 3,464 |
| Difference | N2O | MT | (2) | (8) | (4) | (6) | (7) | (9) | (9) | (9) | (11) | (12) | (12) |
| Difference | GHG (100-yr GWP) | MT CO2-e | (97,913) | (160,700) | (199,840) | (254,074) | (411,283) | (492,041) | (524,495) | (552,597) | (679,530) | (708,708) | (736,555) |
| Difference | GHG (20-yr GWP) | MT CO2-e | (79,883) | (129,022) | (161,331) | (188,503) | (325,821) | (385,646) | (409,237) | (429,117) | (518,658) | (538,105) | (556,045) |
| Difference | NOx | MT | (84) | (140) | (170) | (247) | (345) | (407) | (432) | (452) | (548) | (568) | (587) |
| Difference | PM | MT | (2) | (4) | (4) | (6) | (8) | (9) | (9) | (9) | (9) | (9) | (9) |
| Difference | SO2 | MT | (11) | (18) | (22) | (30) | (44) | (52) | (55) | (58) | (70) | (72) | (75) |
| Difference | GHG (100-yr GWP) | 2019$ mill | $ 4.73 | $ 7.91 | $ 10.02 | $ 12.98 | $ 21.39 | $ 26.04 | $ 28.24 | $ 30.26 | $ 37.84 | $ 40.11 | $ 42.37 |
| Difference | GHG (20-yr GWP) | 2019$ mill | $ 3.86 | $ 6.35 | $ 8.09 | $ 9.63 | $ 16.94 | $ 20.41 | $ 22.03 | $ 23.50 | $ 28.88 | $ 30.46 | $ 31.98 |
| Difference | NOx | 2019$ mill | $ 2.16 | $ 3.66 | $ 4.50 | $ 6.73 | $ 9.37 | $ 11.18 | $ 12.06 | $ 12.85 | $ 15.74 | $ 16.57 | $ 17.37 |
| Difference | PM | 2019$ mill | $ 1.45 | $ 2.43 | $ 2.88 | $ 4.39 | $ 5.37 | $ 6.09 | $ 6.38 | $ 6.57 | $ 6.95 | $ 6.98 | $ 6.91 |
| Difference | SO2 | 2019$ mill | $ 1.01 | $ 1.67 | $ 2.06 | $ 2.91 | $ 4.19 | $ 4.99 | $ 5.37 | $ 5.72 | $ 6.94 | $ 7.31 | $ 7.68 |

Source: MJB&A Analysis.

## Table B-2 NESE Life Cycle Analysis Modeling Results: Upstream Natural Gas Scenario 1 with High New Construction

| SCENARIO | METRIC | Unit | ANNUAL RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| NESE | Natural Gas | MMBtu | 2,110,288 | 3,658,729 | 4,440,844 | 7,440,321 | 9,607,569 | 11,822,395 | 12,744,663 | 13,584,002 | 17,373,061 | 18,330,353 | 19,287,646 |
| NESE | CO2 | MT | 118,519 | 205,483 | 249,409 | 417,867 | 539,585 | 663,976 | 715,773 | 762,912 | 975,715 | 1,029,479 | 1,083,243 |
| NESE | CH4 | MT | 600 | 1,041 | 1,263 | 2,116 | 2,733 | 3,363 | 3,625 | 3,864 | 4,942 | 5,214 | 5,487 |
| NESE | N2O | MT | 1 | 2 | 3 | 5 | 6 | 8 | 8 | 9 | 11 | 12 | 13 |
| NESE | GHG (100-yr GWP) | MT CO2-e | 139,321 | 241,548 | 293,188 | 491,217 | 634,303 | 780,570 | 841,471 | 896,896 | 1,147,083 | 1,210,301 | 1,273,520 |
| NESE | GHG (20-yr GWP) | MT CO2-e | 170,497 | 295,599 | 358,793 | 601,134 | 776,237 | 955,221 | 1,029,745 | 1,097,569 | 1,403,729 | 1,481,088 | 1,558,447 |
| NESE | NOx | MT | 66 | 114 | 139 | 233 | 301 | 375 | 405 | 432 | 554 | 585 | 617 |
| NESE | PM | MT | 7 | 12 | 15 | 25 | 32 | 40 | 43 | 46 | 59 | 62 | 65 |
| NESE | SO2 | MT | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 5 | 5 | 5 |
| NO-NESE | #4 Oil | gal | 369,300 | 603,203 | 693,348 | 1,039,054 | 1,250,172 | 1,383,618 | 1,427,023 | 1,454,260 | 1,559,001 | 1,568,023 | 1,568,023 |
| NO-NESE | #2 Oil | gal | 14,172,259 | 24,283,687 | 29,211,798 | 47,765,412 | 60,792,593 | 73,448,148 | 78,545,157 | 83,001,686 | 102,772,126 | 107,439,096 | 111,898,520 |
| NO-NESE | Electricity | MWh | 62,804 | 93,150 | 136,475 | 152,042 | 315,926 | 397,186 | 432,952 | 467,200 | 629,661 | 672,995 | 718,553 |
| NO-NESE | CO2 | MT | 211,130 | 351,885 | 438,901 | 669,751 | 931,815 | 1,134,303 | 1,217,714 | 1,292,456 | 1,630,741 | 1,713,659 | 1,795,502 |
| NO-NESE | CH4 | MT | 235 | 402 | 483 | 788 | 1,001 | 1,208 | 1,290 | 1,363 | 1,683 | 1,758 | 1,830 |
| NO-NESE | N2O | MT | 3 | 10 | 6 | 10 | 13 | 15 | 17 | 17 | 22 | 22 | 23 |
| NO-NESE | GHG (100-yr GWP) | MT CO2-e | 220,009 | 368,507 | 457,157 | 699,538 | 969,677 | 1,179,962 | 1,266,507 | 1,343,981 | 1,694,377 | 1,780,143 | 1,864,702 |
| NO-NESE | GHG (20-yr GWP) | MT CO2-e | 232,128 | 389,101 | 482,075 | 740,198 | 1,021,362 | 1,242,292 | 1,333,115 | 1,414,321 | 1,781,255 | 1,870,911 | 1,959,179 |
| NO-NESE | NOx | MT | 141 | 237 | 290 | 454 | 607 | 733 | 785 | 831 | 1,035 | 1,084 | 1,132 |
| NO-NESE | PM | MT | 9 | 15 | 18 | 29 | 37 | 44 | 47 | 50 | 62 | 64 | 67 |
| NO-NESE | SO2 | MT | 9 | 15 | 19 | 26 | 39 | 46 | 49 | 52 | 64 | 67 | 70 |
| Difference | CO2 | MT | (92,611) | (146,401) | (189,492) | (251,884) | (392,230) | (470,327) | (501,941) | (529,544) | (655,026) | (684,180) | (712,258) |
| Difference | CH4 | MT | 366 | 639 | 780 | 1,329 | 1,732 | 2,155 | 2,335 | 2,501 | 3,259 | 3,456 | 3,656 |
| Difference | N2O | MT | (2) | (8) | (3) | (5) | (7) | (8) | (8) | (9) | (10) | (11) | (11) |
| Difference | GHG (100-yr GWP) | MT CO2-e | (80,688) | (126,959) | (163,969) | (208,322) | (335,375) | (399,392) | (425,036) | (447,085) | (547,294) | (569,842) | (591,182) |
| Difference | GHG (20-yr GWP) | MT CO2-e | (61,631) | (93,502) | (123,281) | (139,064) | (245,124) | (287,072) | (303,370) | (316,752) | (377,525) | (389,823) | (400,731) |
| Difference | NOx | MT | (75) | (123) | (151) | (221) | (305) | (359) | (380) | (398) | (481) | (499) | (515) |
| Difference | PM | MT | (1) | (2) | (3) | (4) | (4) | (4) | (4) | (4) | (3) | (2) | (2) |
| Difference | SO2 | MT | (9) | (14) | (18) | (24) | (36) | (43) | (46) | (48) | (59) | (62) | (65) |
| Difference | GHG (100-yr GWP) | 2019$ mill | $ 3.90 | $ 6.25 | $ 8.22 | $ 10.64 | $ 17.44 | $ 21.14 | $ 22.88 | $ 24.48 | $ 30.47 | $ 32.25 | $ 34.00 |
| Difference | GHG (20-yr GWP) | 2019$ mill | $ 2.98 | $ 4.60 | $ 6.18 | $ 7.10 | $ 12.75 | $ 15.19 | $ 16.33 | $ 17.34 | $ 21.02 | $ 22.06 | $ 23.05 |
| Difference | NOx | 2019$ mill | $ 1.91 | $ 3.20 | $ 3.98 | $ 5.98 | $ 8.25 | $ 9.81 | $ 10.57 | $ 11.25 | $ 13.72 | $ 14.43 | $ 15.10 |
| Difference | PM | 2019$ mill | $ 0.97 | $ 1.58 | $ 1.83 | $ 2.58 | $ 2.97 | $ 3.07 | $ 3.06 | $ 2.97 | $ 2.20 | $ 1.87 | $ 1.43 |
| Difference | SO2 | 2019$ mill | $ 0.80 | $ 1.30 | $ 1.64 | $ 2.34 | $ 3.40 | $ 4.07 | $ 4.39 | $ 4.69 | $ 5.80 | $ 6.14 | $ 6.49 |

Source: MJB&A Analysis.

**Table B-3** NESE Life Cycle Analysis Modeling Results: Upstream Natural Gas Scenario 2 with Low New Construction

| SCENARIO | METRIC | Unit | ANNUAL RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| NESE | Natural Gas | MMBtu | 2,110,288 | 3,658,729 | 4,440,844 | 7,440,321 | 9,607,569 | 11,822,395 | 12,744,663 | 13,584,002 | 17,373,061 | 18,330,353 | 19,287,646 |
| NESE | CO2 | MT | 118,519 | 205,483 | 249,409 | 417,867 | 539,585 | 663,976 | 715,773 | 762,912 | 975,715 | 1,029,479 | 1,083,243 |
| NESE | CH4 | MT | 744 | 1,290 | 1,565 | 2,623 | 3,387 | 4,167 | 4,492 | 4,788 | 6,124 | 6,461 | 6,799 |
| NESE | N2O | MT | 1 | 3 | 3 | 5 | 7 | 8 | 9 | 10 | 12 | 13 | 14 |
| NESE | GHG (100-yr GWP) | MT CO2-e | 144,246 | 250,085 | 303,551 | 508,579 | 656,722 | 808,158 | 871,211 | 928,595 | 1,187,624 | 1,253,076 | 1,318,528 |
| NESE | GHG (20-yr GWP) | MT CO2-e | 182,882 | 317,072 | 384,856 | 644,800 | 832,622 | 1,024,604 | 1,104,540 | 1,177,291 | 1,505,688 | 1,588,665 | 1,671,642 |
| NESE | NOx | MT | 70 | 121 | 148 | 248 | 320 | 398 | 430 | 459 | 588 | 621 | 655 |
| NESE | PM | MT | 7 | 12 | 15 | 25 | 32 | 40 | 43 | 46 | 59 | 62 | 65 |
| NESE | SO2 | MT | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 5 | 5 | 5 |
| NO-NESE | #4 Oil | gal | 534,156 | 876,929 | 1,015,953 | 1,525,683 | 1,838,385 | 2,058,343 | 2,130,567 | 2,177,474 | 2,341,417 | 2,357,916 | 2,357,916 |
| NO-NESE | #2 Oil | gal | 15,225,106 | 26,131,913 | 31,473,309 | 51,656,154 | 65,892,496 | 79,816,434 | 85,459,433 | 90,429,080 | 112,582,240 | 117,864,460 | 122,952,399 |
| NO-NESE | Electricity | MWh | 66,001 | 104,262 | 142,281 | 139,139 | 324,331 | 405,668 | 441,041 | 474,543 | 632,106 | 673,924 | 717,690 |
| NO-NESE | CO2 | MT | 229,235 | 386,792 | 476,694 | 716,310 | 1,012,226 | 1,232,627 | 1,323,367 | 1,404,660 | 1,772,048 | 1,862,242 | 1,951,282 |
| NO-NESE | CH4 | MT | 284 | 487 | 586 | 959 | 1,222 | 1,477 | 1,579 | 1,670 | 2,072 | 2,167 | 2,259 |
| NO-NESE | N2O | MT | 3 | 11 | 7 | 11 | 14 | 17 | 18 | 19 | 24 | 25 | 26 |
| NO-NESE | GHG (100-yr GWP) | MT CO2-e | 239,878 | 406,568 | 498,631 | 752,209 | 1,057,939 | 1,287,875 | 1,382,467 | 1,467,139 | 1,849,560 | 1,943,322 | 2,035,786 |
| NO-NESE | GHG (20-yr GWP) | MT CO2-e | 254,569 | 431,588 | 528,911 | 801,765 | 1,121,045 | 1,364,147 | 1,464,058 | 1,553,397 | 1,956,580 | 2,055,269 | 2,152,464 |
| NO-NESE | NOx | MT | 154 | 262 | 318 | 495 | 665 | 804 | 861 | 911 | 1,135 | 1,189 | 1,241 |
| NO-NESE | PM | MT | 9 | 16 | 19 | 32 | 40 | 48 | 52 | 55 | 68 | 71 | 74 |
| NO-NESE | SO2 | MT | 11 | 19 | 23 | 32 | 46 | 55 | 58 | 61 | 74 | 77 | 80 |
| Difference | CO2 | MT | (110,716) | (181,309) | (227,285) | (298,442) | (472,641) | (568,651) | (607,595) | (641,748) | (796,333) | (832,763) | (868,039) |
| Difference | CH4 | MT | 459 | 802 | 979 | 1,663 | 2,165 | 2,691 | 2,913 | 3,118 | 4,052 | 4,294 | 4,540 |
| Difference | N2O | MT | (2) | (8) | (4) | (6) | (7) | (9) | (9) | (9) | (11) | (12) | (12) |
| Difference | GHG (100-yr GWP) | MT CO2-e | (95,633) | (156,482) | (195,080) | (243,630) | (401,217) | (479,717) | (511,256) | (538,544) | (661,936) | (690,246) | (717,258) |
| Difference | GHG (20-yr GWP) | MT CO2-e | (71,687) | (114,516) | (144,055) | (156,965) | (288,423) | (339,543) | (359,517) | (376,107) | (450,892) | (466,604) | (480,822) |
| Difference | NOx | MT | (84) | (140) | (170) | (247) | (345) | (407) | (432) | (452) | (548) | (568) | (587) |
| Difference | PM | MT | (2) | (4) | (4) | (6) | (8) | (9) | (9) | (9) | (9) | (9) | (9) |
| Difference | SO2 | MT | (11) | (18) | (22) | (30) | (44) | (52) | (55) | (58) | (70) | (72) | (75) |
| Difference | GHG (100-yr GWP) | 2019$ mill | $ 4.62 | $ 7.70 | $ 9.78 | $ 12.44 | $ 20.86 | $ 25.39 | $ 27.53 | $ 29.49 | $ 36.86 | $ 39.07 | $ 41.26 |
| Difference | GHG (20-yr GWP) | 2019$ mill | $ 3.46 | $ 5.64 | $ 7.23 | $ 8.02 | $ 15.00 | $ 17.97 | $ 19.36 | $ 20.60 | $ 25.11 | $ 26.41 | $ 27.66 |
| Difference | NOx | 2019$ mill | $ 2.16 | $ 3.66 | $ 4.50 | $ 6.73 | $ 9.37 | $ 11.18 | $ 12.06 | $ 12.85 | $ 15.74 | $ 16.57 | $ 17.37 |
| Difference | PM | 2019$ mill | $ 1.45 | $ 2.43 | $ 2.88 | $ 4.39 | $ 5.37 | $ 6.09 | $ 6.38 | $ 6.57 | $ 6.95 | $ 6.98 | $ 6.91 |
| Difference | SO2 | 2019$ mill | $ 1.01 | $ 1.67 | $ 2.06 | $ 2.91 | $ 4.19 | $ 4.99 | $ 5.37 | $ 5.72 | $ 6.94 | $ 7.31 | $ 7.68 |

Source: MJB&A Analysis.

**Table B-4** NESE Life Cycle Analysis Modeling Results: Upstream Natural Gas Scenario 2 with High New Construction

| SCENARIO | METRIC | Unit | ANNUAL RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| NESE | Natural Gas | MMBtu | 2,110,288 | 3,658,729 | 4,440,844 | 7,440,321 | 9,607,569 | 11,822,395 | 12,744,663 | 13,584,002 | 17,373,061 | 18,330,353 | 19,287,646 |
| NESE | CO2 | MT | 118,519 | 205,483 | 249,409 | 417,867 | 539,585 | 663,976 | 715,773 | 762,912 | 975,715 | 1,029,479 | 1,083,243 |
| NESE | CH4 | MT | 744 | 1,290 | 1,565 | 2,623 | 3,387 | 4,167 | 4,492 | 4,788 | 6,124 | 6,461 | 6,799 |
| NESE | N2O | MT | 1 | 2 | 3 | 5 | 6 | 8 | 8 | 9 | 11 | 12 | 13 |
| NESE | GHG (100-yr GWP) | MT CO2-e | 144,202 | 250,010 | 303,459 | 508,425 | 656,524 | 807,914 | 870,947 | 928,314 | 1,187,265 | 1,252,697 | 1,318,130 |
| NESE | GHG (20-yr GWP) | MT CO2-e | 182,843 | 317,004 | 384,773 | 644,662 | 832,443 | 1,024,384 | 1,104,303 | 1,177,038 | 1,505,365 | 1,588,324 | 1,671,284 |
| NESE | NOx | MT | 66 | 114 | 139 | 233 | 301 | 375 | 405 | 432 | 554 | 585 | 617 |
| NESE | PM | MT | 7 | 12 | 15 | 25 | 32 | 40 | 43 | 46 | 59 | 62 | 65 |
| NESE | SO2 | MT | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 4 | 5 | 5 | 5 |
| NO-NESE | #4 Oil | gal | 369,300 | 603,203 | 693,348 | 1,039,054 | 1,250,172 | 1,383,618 | 1,427,023 | 1,454,260 | 1,559,001 | 1,568,023 | 1,568,023 |
| NO-NESE | #2 Oil | gal | 14,172,259 | 24,283,687 | 29,211,798 | 47,765,412 | 60,792,593 | 73,448,148 | 78,545,157 | 83,001,686 | 102,772,126 | 107,439,096 | 111,898,520 |
| NO-NESE | Electricity | MWh | 62,804 | 93,150 | 136,475 | 152,042 | 315,926 | 397,186 | 432,952 | 467,200 | 629,661 | 672,995 | 718,553 |
| NO-NESE | CO2 | MT | 212,642 | 354,126 | 442,186 | 673,410 | 939,418 | 1,143,861 | 1,228,133 | 1,303,699 | 1,645,893 | 1,729,854 | 1,812,793 |
| NO-NESE | CH4 | MT | 262 | 449 | 539 | 880 | 1,118 | 1,349 | 1,441 | 1,522 | 1,880 | 1,964 | 2,044 |
| NO-NESE | N2O | MT | 3 | 10 | 6 | 10 | 13 | 15 | 17 | 17 | 22 | 22 | 23 |
| NO-NESE | GHG (100-yr GWP) | MT CO2-e | 222,454 | 372,346 | 462,361 | 706,330 | 981,262 | 1,194,323 | 1,282,057 | 1,360,643 | 1,716,222 | 1,803,331 | 1,889,272 |
| NO-NESE | GHG (20-yr GWP) | MT CO2-e | 236,001 | 395,385 | 490,216 | 751,781 | 1,039,037 | 1,263,998 | 1,356,515 | 1,439,271 | 1,813,337 | 1,904,794 | 1,994,881 |
| NO-NESE | NOx | MT | 141 | 237 | 290 | 454 | 607 | 733 | 785 | 831 | 1,035 | 1,084 | 1,132 |
| NO-NESE | PM | MT | 9 | 15 | 18 | 29 | 37 | 44 | 47 | 50 | 62 | 64 | 67 |
| NO-NESE | SO2 | MT | 9 | 15 | 19 | 26 | 39 | 46 | 49 | 52 | 64 | 67 | 70 |
| Difference | CO2 | MT | (94,123) | (148,643) | (192,777) | (255,543) | (399,832) | (479,885) | (512,360) | (540,787) | (670,178) | (700,375) | (729,550) |
| Difference | CH4 | MT | 482 | 841 | 1,026 | 1,743 | 2,268 | 2,818 | 3,051 | 3,266 | 4,244 | 4,497 | 4,754 |
| Difference | N2O | MT | (2) | (8) | (3) | (5) | (7) | (8) | (8) | (9) | (10) | (11) | (11) |
| Difference | GHG (100-yr GWP) | MT CO2-e | (78,252) | (122,337) | (158,902) | (197,905) | (324,738) | (386,409) | (411,110) | (432,329) | (528,958) | (550,635) | (571,142) |
| Difference | GHG (20-yr GWP) | MT CO2-e | (53,158) | (78,381) | (105,442) | (107,119) | (206,593) | (239,614) | (252,211) | (262,233) | (307,972) | (316,470) | (323,597) |
| Difference | NOx | MT | (75) | (123) | (151) | (221) | (305) | (359) | (380) | (398) | (481) | (499) | (515) |
| Difference | PM | MT | (1) | (2) | (3) | (4) | (4) | (4) | (4) | (4) | (3) | (2) | (2) |
| Difference | SO2 | MT | (9) | (14) | (18) | (24) | (36) | (43) | (46) | (48) | (59) | (62) | (65) |
| Difference | GHG (100-yr GWP) | 2019$ mill | $ 3.78 | $ 6.02 | $ 7.97 | $ 10.11 | $ 16.89 | $ 20.45 | $ 22.13 | $ 23.67 | $ 29.45 | $ 31.17 | $ 32.85 |
| Difference | GHG (20-yr GWP) | 2019$ mill | $ 2.57 | $ 3.86 | $ 5.29 | $ 5.47 | $ 10.74 | $ 12.68 | $ 13.58 | $ 14.36 | $ 17.15 | $ 17.91 | $ 18.61 |
| Difference | NOx | 2019$ mill | $ 1.91 | $ 3.20 | $ 3.98 | $ 5.98 | $ 8.25 | $ 9.81 | $ 10.57 | $ 11.25 | $ 13.72 | $ 14.43 | $ 15.10 |
| Difference | PM | 2019$ mill | $ 0.97 | $ 1.58 | $ 1.83 | $ 2.58 | $ 2.97 | $ 3.07 | $ 3.06 | $ 2.97 | $ 2.20 | $ 1.87 | $ 1.43 |
| Difference | SO2 | 2019$ mill | $ 0.80 | $ 1.30 | $ 1.64 | $ 2.34 | $ 3.40 | $ 4.07 | $ 4.39 | $ 4.69 | $ 5.80 | $ 6.14 | $ 6.49 |

Source: MJB&A Analysis.