New York State Energy Research and Development Authority

Applying the Multi-Pollutant Policy Analysis Framework to New York: An Integrated Approach to Future Air Quality Planning

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APPLYING THE MULTI-POLLUTANT POLICY ANALYSIS FRAMEWORK TO NEW YORK: AN INTEGRATED APPROACH TO FUTURE AIR QUALITY PLANNING

Final Report

Prepared for the
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ABSTRACT

As climate change has joined the multiple competing air quality challenges that states face, there is a pressing need for new analytical approaches to support integrated and simultaneous energy and air quality planning. This report presents findings of a first-of-its-kind effort to integrate numerous environmental objectives with regional energy and economic models to help state policy makers satisfy multiple environmental requirements in a regulatory environment with limited resources. This proof-of-concept exercise developed, refined, and employed a set of energy, economic, air quality and health assessment analytical tools to foster multi-pollutant planning.

The project demonstrated that an analytic framework can be used to examine multiple air quality goals concurrently, identifying potential control approaches and their environmental, public health, energy, and economic impacts. This analytic framework employed tools that are capable of producing outputs useful to state agencies in future planning endeavors. Furthermore, the project identified how the tools could be improved, and how agencies could build capacity to use them.. Critical aspects of the framework were its ability to identify tradeoffs of implementing one strategy over another, help set priorities and appropriate planning horizons, assess unintended consequences of various control approaches, and identify the best mix and levels of policies and controls, given the mandate to protect public health and the environment.

Key Words: multi-pollutant, integrated assessment, energy and air quality, regional modeling, climate planning

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NESCAUM is an association of the eight northeast state air pollution control programs. Its staff provides technical guidance and policy advice to its member states.

TABLE OF CONTENTS

Section **Page**

SUMMARY S-1

INTRODUCTION 1-1

The Need for Integrated Multi-Pollutant Planning 1-2

An Overview of Multi-Pollutant Analysis Framework 1-3

Overall Project Goals and Tasks 1-4

Caveats 1-6

ANALYTICAL FRAMEWORK: METHODOLOGY AND DATA COLLECTION 2-1

The NE-MARKAL Model 2-1

Data Collection 2-2

Model Calibration 2-2

Reference Case and Scenario Analyses 2-3

Bringing in the Other MPAF Modules: Mapping Between NE-MARKAL, SMOKE, and CMAQ 2-4

The Community Multi-Scale Air Quality Model (CMAQ): Air Quality Predictions 2-5

Chemical Transport Models 2-5

Linkage Between NE-MARKAL and CMAQ 2-6

The CMAQ Modeling Platform 2-8

Previous Work 2-8

Model Inputs and Specifications 2-11

Health Benefits Assessment: The Environmental Benefits Mapping and Analysis Program (BenMAP) 2-20

Potential Data Sources 2-23

BenMAP Interface and Processing Steps 2-24

Macroeconomic Assessment: REMI Projections 2-30

THE REMI Model 2-30

New York State REMI Analysis in the 12-Regional Northeast REMI Model 2-33

References 2-36

APPLYING THE MULTI-POLLUTANT POLICY ANALYSIS FRAMEWORK TO NEW YORK STATE: A CASE STUDY 3-1

Introduction 3-1

Air Quality and Climate Planning in New York State 3-1

Integrated Planning 3-2

NE-MARKAL Results: Air Emissions and Energy Projections 3-7

Reference Case Results 3-8

Sector-Specific Policy-Lever Analyses and Results 3-17

Scenario Analyses and Results 3-72

CMAQ Results: Air Quality Beefits Projections 3-83
  2018 Reference Case 3-83
  2018 Combination Scenario 3-84
  Results 3-85
  Summary 3-100
Health Benefits (BENMAP) Assessment Results 3-101
  Recap of 2018 Reference Case and Combination Scenario 3-101
  Results 3-103
  Summary 3-107
Macroeconomic Assessment (REMI) Results 3-108
  Sensitivity Analysis of Complementary Fiscal Policies 3-111
  Implications 3-111
THE MULTI-POLLUTANT NARRATIVE: PULLING THE PIECES TOGETHER 4-1
The Multi-Pollutant Narrative 4-1
  Description of the Combination Scenario 4-1
  MPAF Phase 1: Projected Emissions and Technology Changes 4-3
  MPAF Phase 2: Projected Air Quality Effects 4-4
  MPAF Phase 3: Evaluating Health Benefits 4-8
  MPAF Phase 4: Macroeconomic Analysis 4-9
LESSONS LEARNED AND IMPLICATIONS FOR FUTURE PLANNING 5-1
Planning and Process Aspects: Successes, Challenges, and Lessons Learned 5-1
  Broadening Planning Horizons 5-1
  Data Collection and Management Decisions and Process 5-3
  Information Gaps and Research Needs 5-4
  Building Capacity in New York State 5-4
  Education and Outreach 5-5
Placing the Results into the Policy Context 5-6
Implications for Future Air Planning 5-8
APPENDIX A: NE-MARKAL INPUT ASSUMPTIONS FOR NEW YORK STATE A-1
Introduction A-1
Building Sector Input Assumptions & Reference Case Results A-1
  Commercial/Residential Demand Projections A-1
  Demand Projection Methodology A-4
  Building Sector Demand Technologies A-4
  Technology/Fuel Share Constraints A-6
  Residential & Commercial Sector Fuel Price Projections A-9

    - Commercial Sector Reference Case Energy Consumption Trends A-10
    - Residential Sector Reference Case Energy Consumption Trends A-12
  - Transportation Sector Input Assumptions A-14
    - Transportation Demand Projections A-15
    - Transportation Sector Technology Characteristics A-16
    - Transportation Sector Reference Case Results A-19
  - Industrial Sector Input Assumptions A-20
    - Industry Sector Demand Projections A-20
    - Demand Projection Methodology A-21
    - Industrial Sector Fuel Share Constraints A-21
    - Industrial Sector Reference Case Results A-25
  - Power Sector Input Assumptions & Reference Case Results A-27
    - Existing Power Plants A-27
    - New Power Plants A-34
    - Power Sector Reference Case Results A-36
    - Renewable Resource Assumptions Wind Resources. A-37
  - State/Regional Policies and Regulations A-42
    - State RPS A-42
    - New York State RGGI Characterization A-42
- APPENDIX B: SAMPLE OUTREACH PRESENTATIONS B-1
  - Ozone Transport Commission Meeting B-1
    - Power Point Presentation B-1

FIGURES

Figure **Page**

Figure 1-1. NESCAUM's Multi-Pollutant Policy Analysis Framework. 1-4

Figure 2-1. Schematic of MARKAL to CMAQ Linkage. 2-7

Figure 2-2. Scatterplots of CMAQ Version 4.6 versus CMAQ Version 4.5.1 Annual Average PM2.5 and Annual Maximum 8-hour Ozone for 2002 for New York State Grid Cells. 2-10

Figure 2-3. Domain and Modeling Specifications. 2-11

Figure 2-4. Schematic of MARKAL to CMAQ to BenMAP Linkage. 2-22

Figure 2-5. BenMAP Flow Diagram (from Abt Associates, 2010b). 2-23

Figure 2-6. BenMAP Calculation Equations. 2-24

Figure 2-7. BenMAP User Interface. 2-25

Figure 2-8. REMI Model Structural Framework for a Regional Economy. 2-31

Figure 2-9. Economic Impact Estimation in the REMI Model. 2-32

Figure 3-1. Power Sector Technology Deployment for New York State Reference Case. 3-9

Figure 3-2. Annual Power Sector Emissions Projections for New York Reference Case. 3-10

Figure 3-3. Light-duty Vehicle Technology Deployment Projections for New York State Reference Case. 3-11

Figure 3-4. Heavy-duty Vehicle Technology Deployment Projections for New York State Reference Case. 3-12

Figure 3-5 Projected Transportation Fuel Shares for NYS Reference Case. 3-13

Figure 3-6. Transportation sector emissions projections for New York State Reference Case. 3-13

Figure 3-7. Manufacturing Industry Shares Projections for New York State Reference Case. 3-15

Figure 3-8. Projected Industrial Sector Energy Consumption for New York State Reference Case. 3-15

Figure 3-9. Projected Commercial Sector (a) and Residential Sector (b) Building End-use Demand Shares for New York State Reference Case. 3-16

Figure 3-10. a and b Commercial Sector (a) and Residential Sector (b) Building Energy Consumption Fuel Shares by Fuel Type for New York State Reference Case. 3-16

Figure 3-11. Projected Residential, Commercial, and Industrial Sector Emissions for New York State Reference Case. 3-17

Figure 3-12. Reference and Case A Power Sector Capacity Mix by Fuel Type. 3-19

Figure 3-13. Reference and Case A Power Sector Generation Mix by Fuel Type. 3-19

Figure 3-14. Reference and Case B Power Sector Capacity Mix by Fuel Type. 3-21

Figure 3-15. Reference and Case B Power Sector Generation Mix by Fuel Type. 3-21

Figure 3-16. Reference and Case C Power Sector Capacity Mix by Fuel Type. 3-23

Figure 3-17. Reference and Case C Power Sector Generation Mix by Fuel Type. 3-23

Figure 3-18. Reference and Case D Power Sector Capacity Mix by Fuel Type. 3-25

Figure 3-19. Reference and Case D Power Sector Generation Mix by Fuel Type. 3-25

Figure 3-20. CO2 Emissions Trajectory for New York State that Meets GHG Goals. 3-27
Figure 3-21. Reference and Case E Projected Power Sector Generation Mix by Fuel Type.................... 3-28
Figure 3-22. Reference and Case E Projected Power Sector Generation Mix by Fuel Type.................... 3-29
Figure 3-23. Projected Commercial and Residential Sectors Energy Changes for Case E Relative to Reference Case (tBTU). 3-30
Figure 3-24. Reference and Case F Power Sector Capacity Mix by Fuel Type. 3-32
Figure 3-25. Reference and Case F Power Sector Generation Mix by Fuel Type.................................... 3-32
Figure 3-26. Projected Commercial and Residential Sector Energy Changes for Case F 3-33
Figure 3-27. Projected Power Sector Generation Mix Relative to the Reference Scenario for Several Cases 3-34
Figure 3-28. Projected Power Sector Emissions Relative to the Reference Scenario for Several Cases... 3-35
Figure 3-29. Power Sector Costs Relative to the Reference Scenario for Several Cases. 3-36
Figure 3-30. Reference and Case A Projected Transportation Energy Consumption by Fuel Type. 3-37
Figure 3-31. Projected Change in Transportation Energy Consumption between Reference and Case A between 2007 and 2030.. 3-37
Figure 3-32. Reference and Case A Transportation Technology Deployment by Type........................... 3-38
Figure 3-33. Reference and Case B Projected Transportation Energy Consumption by Fuel Type.......... 3-39
Figure 3-34. Projected Change in Transportation Energy Consumption between Reference and Case B over 30-year Model Horizon. 3-40
Figure 3-35. Reference and Case B Projected Transportation Technology Deployment by Type. 3-40
Figure 3-36. Reference and Case C Transportation Energy Consumption by Fuel Type......................... 3-42
Figure 3-37. Change in Transportation Energy Consumption Between Reference and Case C over 30-year Model Horizon. 3-42
Figure 3-38. Reference and Case C Projected Transportation Technology Deployment by Type. 3-43
Figure 3-39. Reference and Case D Projected Transportation Energy Consumption by Fuel Type. 3-45
Figure 3-40. Change in Transportation Energy Consumption Between Reference and Case D Over 30-year Model Horizon 3-45
Figure 3-41. Reference and Case D Projected Power Generation Mix. 3-45
Figure 3-42. Reference and Case D Projected Transportation Technology Deployment by Type. 3-46
Figure 3-43. Reference and Case E Projected Transportation Energy Consumption by Fuel Type.......... 3-48
Figure 3-44. Projected Changes in Transportation Energy Consumption Between Reference and Case E Between 2007 and 2030. 3-49
Figure 3-45. Reference and Case E Projected Transportation Technology Deployment by Type. 3-49
Figure 3-46. Reference and Case F Projected Transportation Energy Consumption by Fuel Type. 3-51
Figure 3-47. Projected Change in Transportation Energy Consumption between Reference Case and Case F between 2007 and 2030.. 3-51
Figure 3-48. Reference and Case F Projected Transportation Technology Deployment by Type............ 3-52

Figure 3-49. Reference and Case G Transportation Energy Consumption by Fuel Type.......................... 3-54
Figure 3-50. Projected Change in Transportation Energy Consumption between Reference and Case G between 2007 and 2030... 3-54
Figure 3-51. Reference Case and Case H Projected Transportation Energy Consumption by Fuel Type... 3-56
Figure 3-52. Projected Change in Transportation Energy Consumption between Reference Case and Case H between 2007 and 2030. 3-56
Figure 3-53. Reference Case and Case H Projected Transportation Technology Deployment by Type. 3-56
Figure 3-54. Reference Case and Case I Projected Transportation Energy Consumption by Fuel Type... 3-58
Figure 3-55. Projected change in Ttransportation Energy Consumption between Reference Case and Case I between 2007 and 2030.. 3-58
Figure 3-56. Reference and Case I Projected Transportation Technology Deployment by Type. 3-58
Figure 3-57. Projected Change in Energy Consumption relative to Reference Case by Case for Each Fuel Type.. 3-60
Figure 3-58. Change in Light Duty Vehicle Technology Deployment for Each Case by Technology Type.. 3-61
Figure 3-59. Net change in Light Duty Vehicle Emissions by Pollutant/Gas for Each Case. 3-61
Figure 3-60. Net Change in Light Duty Vehicle CO2 Emissions for Each Case. 3-62
Figure 3-61. Projected Net Present Value Cost Change by Case. 3-63
Figure 3-62. Projected Commercial Sector Energy Consumption for the Reference Case and Residential. Commercial, Industrial Case A Simulations.. 3-63
Figure 3-63. Projected Residential Sector Energy Consumption for the Reference Case and Residentail, Commercial, Industrial Case A Simulations.. 3-64
Figure 3-64. Projected Commercial Sector Energy Consumption for the Reference Case and Residential, Commercial, Industrial Case B Simulations.. 3-65
Figure 3-65. Projected Residential Sector Energy Consumption for the Reference Case and Residential. Commercial, Industrial Case B Simulations.. 3-65
Figure 3-66. Projected Residential Hot Water Energy Use under Reference Case and Case C Assumptions... 3-67
Figure 3-67. Projected Residential, Commercial, and Industrial Sector Emissions Under Reference and Case D Assumptions.. 3-68
Figure 3-68. Projected NO_x Emissions for Residential, Commercial, and Industrial Sector under Reference Case and Case E Assumptions. 3-70
Figure 3-69. Projected Transportation Sector Technology Deployment under Reference Case and 52% Reduction by 2030 Scenario.. 3-73

Figure 3-70. R/C/I Fuel Consumption under Reference Case and 52% CO2 Reduction by 2030 Scenario. 3-73

Figure 3-71. Projected Power Sector Technology Deployment under Reference Case and Combination Scenario Consisting of the Most Effective Measures 3-74

Figure 3-72. Projected Tansportation Sector Technology Deployment under Reference Case and Combination Scenario Consisting of the Most Effective Measures. 3-75

Figure 3-73. Projected R/C/I Fuel Consumption under Reference Case and Combination Scenario Consisting of the Most Effective Measures. 3-75

Figure 3-74. Projected Power Sector Technology Deployment under Reference Case and Kitchen Sink Scenario. 3-77

Figure 3-75. Projected Transportation Sector Technology Deployment under Reference Case and Kitchen Sink Scenario 3-77

Figure 3-76. Projected R/C/I Fuel Consumption under Reference Case and Kitchen Sink Scenario. 3-77

Figure 3-77. Projected Cumulative Emissions Changes between 2007 and 2030 by Sector under Five Scenarios. 3-80

Figure 3-78. Projected Cumulative Cost Changes between 2007 and 2030 by Sector Under Five Scenarios. 3-81

Figure 3-79. Projected GHG Reduction Pathways for Several Scenarios Explored through a Regional Integrated Assessment Framework. 3-82

Figure 3-80. Annual Average $PM_{2.5}$ for (a) 2002 and (b) 2018 Reference Case. 3-86

Figure 3-81. Annual Maximum 8-hour Ozone for (a) 2002 and (b) 2018 Reference Case. 3-87

Figure 3-82. Difference between 2018 Reference Case and 2018 Combination Scenario for Annual Average (a) PM2.5 and (b) Daily Maximum 8-hour Ozone. 3-89

Figure 3-83. Difference between 2018 Reference Case and 2018 Comination Scenario 3-93

Figure 3-84. Annual Average $PM_{2.5}$ Difference: 2018 Reference Case – Combination Scenario 3-94

Figure 3-85. Annual Average Concentration Differences between 2018 Reference Case and 2018 Combination Scenario for (a) Total $PM_{2.5}$, (b) Primary Organic Serosol, (c) Unspeciated “Other” $PM_{2.5}$, and (d) Sulfate. 3-94

Figure 3-86. Annual NO_x Emissions Differences between 2018 Reference Case and 2018 Combination Scenario. 3-95

Figure 3-87. Annual PM Emissions Differences between 2018 Reference Case and 2018 Combination Scenario. 3-95

Figure 3-88. Annual SO_x Emissions Differences between 2018 Reference Case and 2018 Combination Scenario. 3-96

Figure 3-89. Annual Emissions Differences between 2018 Reference Case and 2018 Combination Scenario for PM from (a) Area sources, (b) Point sources other than Major EGUs, (c) Mobile Sources, and (d) SO_x from Major EGUs. 3-96

Figure 3-90. Annual NO_x Emissions Differences between 2018 Reference Case and 2018 Combination Scenario from (a) Area Sources, (b) Point Sources other than Major EGUs, (c) Mobile Sources, and (d) Major EGUs 3-98
Figure 3-91. Annual Average 8-Hour Max O_3 Difference: 2018 Reference Case – Combination Scenario (grey cells are < 0). 3-100
Figure 3-92. Total Population Levels from 2000 Census Data. 3-103
Figure 3-93. Average Delta $PM_{2.5}$ (monitor and model relative) between 2018 Reference Case and 2018 "Combination" Scenario ($\mu g/m^3$) (baseline – control)... 3-104
Figure 3-94. Average Delta O_3 (monitor and model relative) between 2018 Reference Case and 2018 Combination Scenario (ppb) (baseline – control). 3-105
Figure 4-1. Power Generation Technology Projections under a Combination Scenario Consisting of Seven Highly Effective Policy Measures. The energy efficiency measures suppress demand early in the period and relatively weak RPS and EV mandates do not result in a large renewable energy mandate or increased electric demand like other scenarios examined in Chapter 4. 4-2
Figure 4-2. Transportation Technology Projections under a Combination Scenario. The mandate for 25 percent electric vehicles is just met in 2030, whereas the similar mandate for 25 percent hybrid-electric vehicles is found to be more economically attractive and leads to over-compliance with the requirement. 4-2
Figure 4-3. Residential, Commercial, and Industrial Technology Projections under a Combination Scenario. These projections show that demand reductions resulting from efficiency options lead to shifts in fuel use (less wood and oil) across these sectors in 2018. 4-3
Figure 4-4. Annual Modeled Emissions Differences between 2018 Reference Case and 2018 Combination Scenario for PM from (a) Area Sources, (b) Point Sources other than Major EGUs, (c) Mobile Sources, and (d) SO_x from Major EGUs using CMAQ. 4-5
Figure 4-5. Annual Modeled NO_x Emissions Differences between 2018 Reference Case and 2018 Combination Scenario from (a) Area Sources, (b) Point Sources other than Major EGUs, (c) Mobile Sources, and (d) Major EGUs using CMAQ. 4-6
Figure 4-6. Ratio of Combination Scenario SO_2 Emissions to Reference Case Emissions. Reductions of more than half across the state are due, in large part, to area source reductions due to the low-sulfur heating oil program. 4-7

Figure A-1. New York State 2002 Final Energy Consumption Snapshot. A-1
Figure A-2. Commercial Sector Demand Projections. A-2
Figure A-3. Residential Demand Projections. A-3
Figure A-4. Commercial Sector Fuel Price Projections.. A-9
Figure A-5. Residential Sector Fuel Price Projections. A-10
Figure A-6. Projected Commercial Sector Fuel Consumption. A-11

Figure A-7. Projected Residential Sector Fuel Consumption. A-13
Figure A-8. VMT Demand Projections. A-15
Figure A-9. Other Transportation Fuel Demands. A-16
Figure A-10. Transportation Sector Fuel Price Projections. A-18
Figure A-11. Projected Transportation Energy Consumption by Fuel. A-19
Figure A-12. Industry Demand. A-21
Figure A-13. Industrial Sector Price Projections. A-25
Figure A-14. Projected Industrial Energy Consumption. A-26
Figure A-15. Power Sector Price Projections. A-35
Figure A-16. Electricity Generation by Fuel Type. A-36
Figure A-17. New York State Renewable Portfolio Standards. A-42

TABLES

Table **Page**

Table 2-1. SCC NE-MARKAL Code Map for the Transportation Sector. 2-16

Table 2-2. NE-MARKAL Codes for the Transportation Sector. 2-17

Table 2-3. SCC NE-MARKAL Code Map for the Residential Sector Area Sources. 2-18

Table 2-4. SCC NE-MARKAL Code Map for the Commercial Sector Area Sources............................. 2-19

Table 2-5. SCC NE-MARKAL Code Map for the Industrial Sector Area Sources. 2-20

Table 2-6. Health Endpoints and Epidemiological Studies Used to Quantify Health Impacts 2-27

Table 2-7. Endpoint-Specific Valuation Methods.. 2-29

Table 2-8. Aspects of the Multi-pollutant Scenario Influencing the New York State Economy. 2-33

Table 2-9. a & b: Scenario-specific net Direct Effects to Influence.. 2-34

Table 2-10. Biomass Feedstock Allocation by Sector.. 2-34

Table 2-11. Transportation Sector Light-duty Fleet Allocation. 2-34

Table 3-1. NYSDEC Environmental Priority and Actions, Project Goals, and
Programs Analyzed through NE-MARKAL. 3-5

Table 3-2. Annual Power Sector Cost Assumptions for New York Reference Case. 3-10

Table 3-3. Annual Transportation Sector Costs for New York Reference Case. 3-14

Table 3-4. Annual R/C/I Sector Costs for New York Reference Case.. 3-17

Table 3-5. Power Sector Cost Breakout for Case A.. 3-20

Table 3-6. Projected Power Sector Emissions Changes for Case A.. 3-20

Table 3-7. Projected Power Sector Emissions Changes for Case B.. 3-22

Table 3-8. Power Sector Cost Breakout for Case B. 3-22

Table 3-9. Projected Power Sector Emissions Changes for Case C.. 3-24

Table 3-10. Projected Power Sector Cost Breakout for Case C. 3-24

Table 3-11. Power Sector Emissions Changes for Case D... 3-26

Table 3-12. Projected Power Sector Cost Breakout for Case D... 3-26

Table 3-13. Projected Power Sector Emissions Changes for Case E. 3-30

Table 3-14. Projected Power Sector Cost Breakout for Case E. 3-31

Table 3-15. Projected Power Sector Emissions Changes for Case F. 3-33

Table 3-16. Projected Power Sector Cost Breakout for Case F... 3-34

Table 3-17. Projected Transportation Sector Emissions Changes for Case A. 3-38

Table 3-18. Projected Transportation Sector Cost Breakout for Case A... 3-39

Table 3-19. Projected Transportation Sector Emissions Changes for Case B... 3-41

Table 3-20. Transportation Sector Projected Cost Breakout for Case B... 3-41

Table 3-21. Projected Transportation Sector Emissions Changes for Case C... 3-43

Table 3-22. Transportation Sector Projected Cost Breakout for Case C... 3-44

Table 3-23. Transportation Sector Projected Emissions Changes for Case D... 3-46

Table 3-24. Power Sector Projected Emissions Changes for Case D. 3-47
Table 3-25. Transportation Sector Projected Cost Breakout for Case D. 3-47
Table 3-26. Power Sector Projected Cost Breakout for Case D. 3-48
Table 3-27. Projected Transportation Sector Emissions Changes for Case E. 3-50
Table 3-28. Transportation Sector Projected Cost Breakout for Case E. 3-50
Table 3-29. Projected Transportation Sector Emissions Changes for Case F. 3-53
Table 3-30. Transportation Sector Projected Cost Breakout for Case F. 3-53
Table 3-31. Projected Heavy-duty [only] Emissions Changes for Case G. 3-55
Table 3-32. Projected Heavy-duty [only] Cost Breakout for Case G. 3-55
Table 3-33. Projected Transportation Sector Emissions Changes for Case H. 3-57
Table 3-34. Projected Transportation Sector Cost Breakout for Case H. 3-57
Table 3-35. Projected Transportation Sector Emissions Changes for Case I. 3-59
Table 3-36. Transportation Sector Projected Cost Breakout for Case I. 3-59
Table 3-37. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case A. 3-64
Table 3-38. Projected Residential and Commercial Cost Changes for Case A. 3-64
Table 3-39. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case B. 3-66
Table 3-40. Projected Residential and Commercial Cost Changes for Case B. 3-66
Table 3-41. Projected Residential, Commercial, and Industrial Sector Emissions changes for Case C. 3-67
Table 3-42. Projected Residential and Commercial cost changes for Case C. 3-68
Table 3-43. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case D. 3-69
Table 3-44. Projected Residential, Commercial, and Industrial Sector Cost Changes for Case D 3-69
Table 3-45. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case E. 3-71
Table 3-46. Projected Residential, Commercial, and Industrial Sector Cost Changes for Case E. 3-71
Table 3-47. Projected Cost Changes relative to the Reference Case for Several Scenarios (Bill 2008 $s). 3-83
Table 3-48. Projected Emission Changes relative to the Reference Case for Several Scenarios. 3-83
Table 3-49. Difference in Annual Average $PM_{2.5}$ (%, µg/m^3) Annual average Daily maximum 8-hour O_3 (%, ppb) between the 2018 Reference Case and the Combination Scenario over New York State.** 3-90
Table 3-50. Difference in 8th Highest Daily Average $PM_{2.5}$ (µg/m^3, %) 4th Highest Daily 8-hour O_3 (ppb, %) between the 2018 Reference Case and the Combination Scenario over New York State.** 3-91

Table 3-51. Top Area $PM_{2.5}$ emissions Difference (2018 Reference Case – 2018 Combination Scenario) Ccontributions by SCC code for 9** Counties near Albany. 3-97

Table 3-52. Sorted Statewide “Other” Point Annual NO_x Emissions Differences between the 2018 Reference Case and the Combination Scenario for SCC C with the Largest Absolute Differences. (Data for natural gas turbines is highlighted.) 3-99

Table 3-53. Health Costs/Benefits for the 2018 Combination Scenario (2000$). 3-106

Table 3-54. Health Incidence Changes between the 2018 Reference Case and the 2018 Combination Scenario. 3-107

Table 3-55. Employment (EMP) and Gross State Product (GSP) Impacts of the 52 x 30 Multi-Pollutant Strategy (MPS) Scenario relative to Base Case, (*No* Health Outcome Considerations). 3-108

Table 3-56. Employment (EMP) and Gross State Product (GSP) Impacts from the Combination Multi-Pollutant Strategy (MPS) Scenario relative to Base Case (*before* Health Outcome Considerations). 3-109

Table 3-57. Combination Scenario 2018 Economic Impacts from BENMAP Health Outcomes relative *to* Base Case. 3-110

Table 3-58. 52 x 30 Scenario: “*NAICS 335 Doubling In-state Fulfillment for new Demand*,” Economic Impacts relative to Base Case (no Health Outcome Considerations). 3-111

Table 4-1. 2030 Annual and Cumulative Changes in Capital Investment, Operations and Maintenance, and Fuel Costs for the Combination Scenario relative to a Reference Case (2008 $billion) 4-4

Table 4-2. Monetized Public Health Benefits (costs) (in $US million) from the BenMAP Tool for the Combination Scenario. 4-8

Table A-1. Commercial Demand Growth. A-2

Table A-2. Residential Demand Growth. A-3

Table A-3. Commercial Technologies. A-5

Table A-4. Residential Technologies. A-6

Table A-5. Commercial Calibration/Technology Constraints. A-7

Table A-6. Residential Calibration/Technology Constraints. A-8

Table A-7. Commercial Energy Consumption Shares A-11

Table A-8. Commercial Energy Consumption Calibration Results. A-12

Table A-9. Energy Consumption Shares. A-13

Table A-10. Residential Energy Consumption Calibration Results. A-14

Table A-11. VMT Demand Growth. A-15

Table A-12. Other Transportation Demand Growth. A-16

Table A-13. HDV Technical Characteristics. A-17

Table A-14. LDV Technical Characteristics. A-17
Table A-15. Technology Share Constraints. A-18
Table A-16. Transportation Consumption Shares. A-20
Table A-17. Industry Demand Growth. A-21
Table A-18. Chemical Sector Fuel Share Constraints. A-22
Table A-19. Metal Manufacturing Sector Fuel Share Constraints. A-22
Table A-20. Durable Goods Manufacturing Sector Fuel Share Constraints. A-23
Table A-21. Paper Manufacturing Sector Fuel Share Constraints. A-23
Table A-22. Glass & Cement Sector Fuel Share Constraints. A-24
Table A-23. Other Industrial Sectors Fuel Share Constraints. A-24
Table A-24. Industry Consumption Shares. A-26
Table A-25. Existing Power Plants #1. A-29
Table A-26. Existing Power Plants #2. A-30
Table A-27. Existing Power Plants #3. A-31
Table A-28. Existing Power Plants #4. A-32
Table A-29. Existing Power Plants #5. A-33
Table A-30. Summary of Installed Capacity by Fuel Type. A-34
Table A-31. New Power Plant Characteristics. A-35
Table A-32. Electricity Generation Shares. A-37
Table A-33. Criteria for Defining Available Windy Land A-38
Table A-34. Wind Resource Data. A-39
Table A-35. Capacity Factors for Central Solar PV Systems. A-39
Table A-36. PV Investment Cost Projections. A-40
Table A-37. Renewable Energy Cost Assumptions. A-41
Table A-38. Renewable Energy Resource Bounds (Trillion Btu). A-41
Table A-39. RGGI CO2e Limits by State over Time. A-43

SUMMARY

Historically, air quality concerns have been addressed by states on a pollutant-by-pollutant basis. Each criteria pollutant (e.g., ozone, fine particulate) and non-criteria pollutant (e.g., air toxics), has required its own planning effort. Climate change has become another critical air quality challenge. A comprehensive multi-pollutant approach that integrates air quality goals with regional energy and economic models could help policy makers satisfy multiple environmental requirements in a regulatory environment with limited resources. To this end, the Northeast States for Coordinated Air Use Management (NESCAUM), the New York State Department of Environmental Conservation (NYSDEC) and the New York State Energy Research and Development Authority (NYSERDA) worked collaboratively to develop, refine, and use analytical tools that foster multi-pollutant planning. This effort served as a proof-of-concept exercise, producing outputs useful in future planning endeavors. It identified how the analytical tools could be improved, how agencies could build capacity to use the tools, and policy benefits and challenges that accompany shifting to a multi-pollutant planning paradigm.

Integrated multi-pollutant planning has the potential to be a more economical way to address environmental and public health issues. By looking at multiple air quality goals concurrently and identifying potential control approaches and their environmental, public health, energy, and economic impacts together, a more complex set of policy questions emerges that can then be addressed in a more resource-efficient manner. Multi-pollutant planning, if done correctly, should identify the tradeoffs of implementing one strategy over another, help set priorities and appropriate planning horizons, allow for more informed decisions, and ultimately provide more regulatory certainty. It should be able to help assess unintended consequences of various control approaches and identify the best mix of policies and controls, given the mandate to protect public health and the environment.[1]

NESCAUM developed the Multi-pollutant Policy Analysis Framework (MPAF), a four-stage regional-scale integrated assessment framework, and applied it to the New York State (NYS) energy system. The framework integrates and uses energy, economic, air quality, and health impacts assessment models, tools and databases, including: (1) NE-MARKAL (the Northeast version of the Market Allocation model); (2) the Regional Economic Model, Inc (REMI); (3) the U.S. Environmental Protection Agency's (EPA's) Community Multi-scale Air Quality (CMAQ) model; and (4) EPA's Environmental Benefits Mapping and Analysis (BenMAP) program. This tailored framework enabled multi-pollutant assessments of various potential control strategies to simultaneously address air quality and climate goals in NYS.

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[1] Weiss, L., M. Manion, G. Kleiman, C. James, Building Momentum for Integrated Multipollutant Planning; Northeast States' Perspective. *EM*, May 2007, 25-29.

The centerpiece of the framework, illustrated in Figure S-1, is the NE-MARKAL model, an energy model that simulates least-cost approaches to achieving pollution reductions. The model covers 11 states plus the District of Columbia,[2] and characterizes electricity generation, transportation, and the industrial, residential and commercial building sectors over a 30-year time horizon.

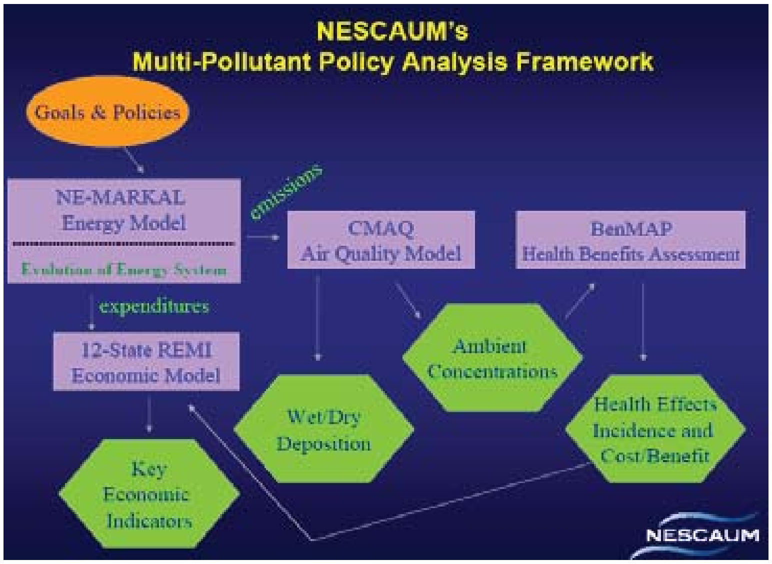

Figure S-1. NESCAUM's Multi-Pollutant Policy Analysis Framework.

For this effort, NE-MARKAL was calibrated to better reflect the current energy system, available technology options and their respective resource and policy constraints. This calibration provided a robust analysis system for exploring the potential evolution of NYS's energy system in response to policy goals and objectives. The model was challenged with a variety of individual policy levers to ensure reasonable model behavior was observed in response to each option. Analyses were then conducted on a series of policy scenarios focused on combinations of multi-sector strategies and sensitivities to fuel and technology cost. NE-MARKAL's outputs provided ideas about technology evolution that informed policy discussions. Such an approach, and the resultant data, is outside of the traditional air quality assessment framework.

The full MPAF framework was applied to one policy scenario. Outputs of the NE-MARKAL model served as inputs for REMI and CMAQ; CMAQ outputs were used as inputs for BenMAP. Using the breadth of information derived from the MPAF tools, a narrative emerged as to how each set of policies could result in technology shifts, economic costs and savings, and changes in emissions, as well as air quality, public health outcomes, and macroeconomic indicators. This narrative was presented in the context of cross-sectoral interactions and environmental tradeoffs that would not otherwise be available in an analysis limited to an individual component of the framework.

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[2] The jurisdictions covered in the NE-MARKAL model include: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

This proof-of-concept exercise enabled NYSDEC to understand how various factors and programs interact. The analyses introduced the reality of co-benefits and tradeoffs through data, and provided illustrative results of the relative importance of various modeled strategies. The MPAF provides linked analyses and data that are not currently available to air planners through their typical State Implementation Plan (SIP) planning efforts. Furthermore MARKAL provided: (1) specific information on program characteristics from its technology evolution analyses that can be used directly in air program planning analyses, regulation development and implementation, and (2) the capability to more easily identify influences and interactions of an individual policy lever with the other levers in the suite of policies that are modeled. As such, the MPAF has significant value as a planning and screening tool towards developing more refined environmental planning products.

The planning and analysis processes of this project, and the iterative nature of reviewing results, helped identify key dynamics that policy makers should be aware of in developing their environmental plans. It emphasized the importance of tools that can observe cross-sectoral impacts and consider technology evolution as well as assess emissions reductions in evaluating programs. It underscored the need for evaluating the effectiveness of programs through the lens of fostering renewable energy and energy efficiency while working to meet air quality, climate, and energy goals simultaneously.

States will continue to play a significant role in evolving the tools to conduct more rigorous multi-pollutant analyses and planning. In order to maximize use of these tools, the staff in the air and energy agencies must continue to work together to ensure that the input data are appropriately quality assured. Shifting to a multi-pollutant paradigm is challenging for any state regulatory agency, as it requires significant up-front commitment to understand and work with staff from other agencies and other disciplines that have different legislative and regulatory requirements and agendas. Notwithstanding, this process has fostered a new understanding of multi-pollutant relationships and provided critical data that will help inform future policy and planning endeavors.

Section 1

INTRODUCTION

APPLYING THE MULTI-POLLUTANT POLICY ANALYSIS FRAMEWORK TO NEW YORK: AN INTEGRATED APPROACH TO FUTURE AIR QUALITY PLANNING

Historically, air quality concerns have been addressed by states on a pollutant-by-pollutant basis. Each criteria pollutant (e.g., ozone, fine particulate) and non-criteria pollutant (e.g., air toxics), has required its own planning effort. Climate change has now become another primary air quality challenge. A comprehensive multi-pollutant approach that integrates air quality goals with regional energy and economic models could help policy makers satisfy multiple environmental requirements in an agency environment with limited resources. To this end, the Northeast States for Coordinated Air Use Management (NESCAUM), the New York State Department of Environmental Conservation (NYSDEC) and the New York State Energy Research and Development Authority (NYSERDA) have been working collaboratively to develop, refine, and use analytical tools as well as identify potential policy challenges to multi-pollutant planning.

This report presents the findings of a first-of-its-kind – and therefore proof-of-concept – effort to integrate numerous environmental objectives into a multi-pollutant assessment for environmental and energy policy analysis. This effort tailored and iteratively improved the data inputs to the Multi-pollutant Policy Analysis Framework (MPAF), a regional-scale integrated framework developed by NESCAUM, and calibrated the Market Allocation model for the Northeast States (NE-MARKAL) to consistently reflect the New York State (NYS) energy system. The framework integrates and makes use of energy, economic, and air quality models, tools and databases, including: NE-MARKAL; the Regional Economic Model, Inc (REMI); the Sparse Matrix Operator Kernel Emissions (SMOKE) model; the Community Multi-scale Air Quality (CMAQ) model; and the Environmental Benefits Mapping and Analysis (BenMAP) program. This tailored framework enabled analysts at NESCAUM, NYSDEC, and NYSERDA to demonstrate multi-pollutant assessments of various potential emissions control strategies in order to simultaneously address air quality and climate goals in NYS.

In this report, we describe the process by which we tailored and employed NESCAUM's MPAF. First, we provide the overall technical approach, including the methodology and data collection activities that were undertaken to prepare and calibrate the models in the framework. This includes mapping and linkages between NE-MARKAL, SMOKE, and CMAQ, as well as preparatory activities to employ BenMAP and REMI. Second, we describe how NYSDEC identified its environmental goals and prioritized potential programs and scenarios for analysis. Third, we present the results of the NE-MARKAL Reference Case, sectoral, and scenario analyses, and the air quality, health benefits, and economic analyses for a few select scenarios. Fourth, we reflect on the multi-pollutant narrative that the MPAF framework provides, discuss planning and process issues that arose during the effort, including successes and challenges, and describe education and outreach that NESCAUM and NYSDEC provided to states and other agencies on multi-pollutant planning. In sum, we present how applying the various tools of the MPAF can provide planners with a new and unique narrative that can advance multi-pollutant planning in the future.

THE NEED FOR INTEGRATED MULTI-POLLUTANT PLANNING

Under the federal Clean Air Act (Act), states have been required to prepare their plans and programs to mitigate each air pollutant problem discretely. While this approach was necessary and appropriate at the time the Act was first enacted, it has tended to encouraged a single-pollutant planning mindset and planning institution that may not serve today's more complex environmental challenges. Motor vehicles, stationary sources, and power generation technologies contribute not only to the formation of ground level ozone, but also fine particle pollution, mercury (an air toxic), acid deposition, and climate change by emitting nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOCs), particulate matter (PM), mercury (Hg), and carbon dioxide (CO_2). States are therefore recognizing the limits of the existing air quality management framework and the importance of moving to a more integrated, multi-pollutant, economy-wide approach.

Integrated multi-pollutant planning has the potential to be a more economical way to address environmental and public health issues. By looking at multiple air quality goals concurrently and by identifying potential control approaches and their environmental, public health, energy, and economic impacts together, a more complex set of policy questions emerges that can then be addressed. Multi-pollutant planning, if done correctly, should identify the tradeoffs of implementing one strategy over another, help set priorities and appropriate planning horizons, allow for more informed decisions, and ultimately provide more regulatory certainty. It should be able to help assess unintended consequences of various control approaches and identify the best mix of policies and controls, given the mandate to protect public health and the environment.[3]

In June 2007, the federal Clean Air Act Advisory Committee recommended that governments adopt a comprehensive statewide air quality planning process and move from a single to a multiple pollutant approach to managing air quality.[4] The EPA initiated pilot projects with three jurisdictions that were already engaging in air quality planning to explore various ways to approach multi-pollutant planning by

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[3] Weiss, L., M. Manion, G. Kleiman, C. James, Building Momentum for Integrated Multipollutant Planning; Northeast States' Perspective. *EM*, May 2007, 25-29.

[4] Recommendations to the Clean Air Act Advisory Committee: Air Quality Management Subcommittee. Phase II Recommendations, June 2007, available at: http://epa.gov/air/caaac/aqm/phase2finalrept2007.pdf.

developing Air Quality Management Plans (AQMPs).[5] This effort indirectly ties into EPA's effort, as it provides technical support for NYS AQMPs.

While many states have taken steps towards multi-pollutant planning and analysis for some criteria pollutants, few are integrating greenhouse gases (GHGs) and mercury along with other air toxics into criteria pollutant planning. Modeling potential technological evolution, corresponding emission reductions, and possible co-benefits associated with multi-pollutant programs is a complex effort, and must be performed using regional-scale tools of appropriate detail. NESCAUM has developed such modeling capabilities and has engaged with some of the Northeast states in exploring multi-pollutant analytical techniques. This effort with NYS is the first time that NESCAUM has employed the full MPAF for a comprehensive analysis.

AN OVERVIEW OF MULTI-POLLUTANT ANALYSIS FRAMEWORK

To assist states in moving to an integrated multi-pollutant planning approach, NESCAUM developed the MPAF, illustrated in Figure 1-1. It brings together and uses a series of models to integrate energy, climate, and air quality planning. The MPAF contains models that assess: (1) energy economics -- the Northeast Market Allocation (NE-MARKAL) Model; (2) regional macroeconomic impacts – the Regional Economic Models, Inc. (REMI); (3) air quality and acid deposition -- the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System and the Community Multi-scale Air Quality Modeling System (CMAQ), and; (4) health effects – the Benefits Mapping and Analysis Program (BenMAP) or Co-Benefits Risk Assessment Model (COBRA).[6]

The centerpiece of the framework is the NE-MARKAL model. NE-MARKAL is an energy model that simulates least-cost approaches to achieving pollution reductions. The model covers 11 states plus the District of Columbia,[7] and characterizes electricity generation, transportation, and the industrial, residential and commercial building sectors over a 30-year time horizon.

NESCAUM's framework provides a range of outputs. In addition to estimating potential emissions reductions, it allows the user to input those reductions into other models, thus providing additional information on potential air quality and health benefits. The framework also links the energy model to a regional economic model that estimates economic metrics such as gross state product, jobs, and household disposable income. These types of economic indicators are important for policy makers to garner support

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[5] See: http://www.epa.gov/air/aqmp/

[6] For this analysis, BenMAP was employed for the public health benefits assessment.

[7] The jurisdictions covered in the NE-MARKAL model include: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

for prospective regulatory programs. NESCAUM has engaged in pilot projects using its multi-pollutant analysis framework with environmental agencies in Maryland and Massachusetts.

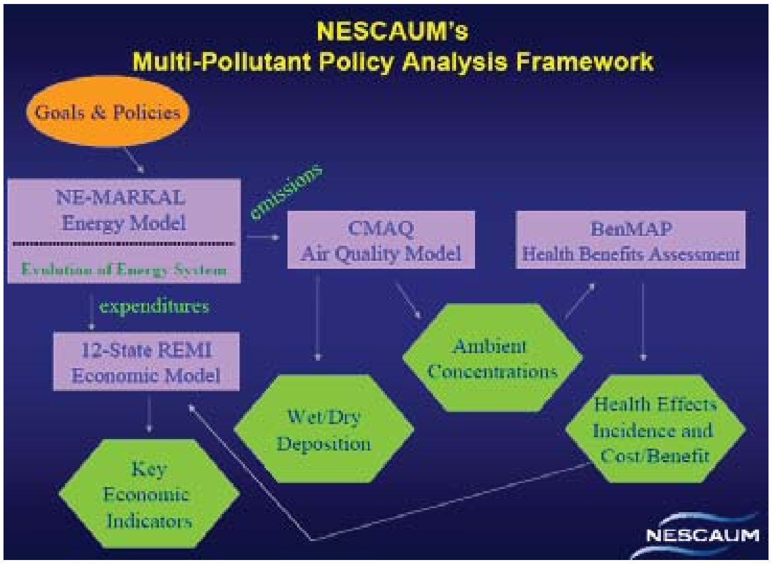

Figure 1-1. NESCAUM's Multi-Pollutant Policy Analysis Framework.

OVERALL PROJECT GOALS AND TASKS

The overarching goals of this project were to foster multi-pollutant planning by: (1) helping to build capacity at NYSDEC and NYSERDA to use NESCAUM's MPAF; (2) providing data usable by NYSDEC and NYSERDA policy analysts to develop sound multi-pollutant assessments of potential control measures that could assist the State in achieving its short and longer term air quality and climate goals; and (3) further refine the MPAF based on this proof-of-concept experience as well as feedback from NYSDEC and NYSERDA. This project not only modeled the interaction of ozone and $PM_{2.5}$ control strategies, but also climate, acid deposition, and mercury control programs simultaneously. It provides a true multi-pollutant planning framework that is capable of assessing environmental, economic, and public health consequences of various technological evolution options of energy infrastructure in NYS and the region. The project findings can be used to enhance model representations, promote the use of integrated modeling frameworks, and promote integrated approaches to air quality planning in NYS, the NESCAUM region, and in other states across the country.

For this effort, and to employ the MPAF, the following tasks were undertaken:

1. Identify emission reduction goals and interim targets based on existing NYS-specific and regional air quality goals for ozone, $PM_{2.5}$, air toxics, acid deposition, and climate change. For this effort, NYSDEC staff used its Commissioner's environmental priorities in effect at the beginning of the project in 2007 as a starting framework.[8]

2. Identify a suite of strategies and policy approaches to be assessed.

3. Review existing NE-MARKAL model inputs and collect appropriate state-based data to update the regional energy model. For this task, NESCAUM provided NYSDEC and NYSERDA with a list of model assumptions regarding economic factors, fuel cost, growth, and demand projections, current technology stocks, and future technology characterizations. NESCAUM also provided a set of technical potential and policy constraints that, in combination with the other inputs, determined the future technology evolution for NYS through the least-cost optimization model.

4. Calibrate the NE-MARKAL model to enhance model performance.

5. Develop the NE-MARKAL Reference Case. To start the analysis, NESCAUM developed a Reference Case using best available, accurate data and modeling constraints against which subsequent policies and their benefits were later measured. The Reference Case was defined by future projections of technological evolution, multi-pollutant emissions trajectories, and total system costs. It was then reviewed by NYSDEC and NYSERDA staff to assess future growth and trends, and subsequently adjusted and approved. NESCAUM then performed a series of sectoral policy lever analyses, which helped to further adjust the model.

6. Employ NE-MARKAL to assess strategies that could be used to achieve NYS's air quality goals. NESCAUM applied its framework to analyze the identified policy initiatives, comparing these policies to the Reference Case. Five overarching policy scenarios were evaluated:

    (i) a comparison of an economy-wide carbon cap to the sum of smaller individual abatement measures (i.e., policy levers) tested in the sectoral analyses;

    (ii) a combination of several of the most promising options based on individual policy lever analyses;

    (iii) a combination of reasonable levels of all policy levers;

    (iv) a sensitivity of results to fuel prices; and

    (v) a sensitivity of results to the cost of advanced technology.

7. Quantify the associated environmental, public health, and regional economic benefits associated with the chosen strategies, and monetize a subset of these strategies. Estimates of criteria pollutant emission changes and associated health benefits were developed for one policy scenario (the Combination Scenario) using CMAQ, BenMAP, and REMI, respectively.

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[8] For the Commissioner's environmental priorities as of March 21, 2012, see: http://www.dec.ny.gov/about/80503.html . This web address is subject to change,

8. Use the project's findings to enhance model representations and promote use of integrated modeling frameworks.
9. Promote integrated approaches to air quality planning in NYS, the eight-state NESCAUM region, and other states outside the region.

CAVEATS

It should be noted that this study was developed as a proof-of-concept, and has limitations that are inherent to the various models used. Perhaps the most significant hurdle in applying these tools for policy analyses is the degree to which the underlying databases have been quality assured by the states. The results of NE-MARKAL derive from the wide array of input data and assumptions, which include such things as technology costs, resource availability and energy demand. As with any programming model, its results should not be viewed as a forecast, and the pathways projected by the model do not reflect individual or societal behavior associated with risk aversion, uncertainty or informational bias. For example, the model will not recognize the societal trend towards large cars and sport utility vehicles, given that such a trend works against individual economic self-interest (i.e., for larger cars there are larger capital and fuel expenses relative to smaller cars that satisfy the same transportation demands); to address this deficiency, we imposed constraints to more realistically represent projected vehicle fleets. Notwithstanding, the model can provide valuable insights into how the input assumptions may affect the economics of the regional energy system.

Section 2

ANALYTICAL FRAMEWORK: METHODOLOGY AND DATA COLLECTION

THE NE-MARKAL MODEL

The centerpiece of NESCAUM's integrated modeling framework is a Northeast-specific version of the Market Allocation (NE-MARKAL) model.[9] NE-MARKAL is an economy-wide model that encompasses the entire energy infrastructure of the Northeast; it is capable of modeling all energy demand and supply in the transportation, commercial, industrial, residential, and power generation sectors.[10]

As an engineering cost model, NE-MARKAL calculates a least-cost combination of energy technologies available to meet energy demand in each sector. The model contains highly-detailed depictions of energy technologies and their associated economic factors, such that each generated technology combination is based on the relative costs of the various energy technology options and constraints on the energy system. For example, for the region's power generation infrastructure, the model includes a detailed, bottom-up characterization, with unit-by-unit specification, of power plants 25 MW or larger.[11] Renewable generation capacity is specified with characterization of new renewable generation potential and resources provided by the Department of Energy's National Renewable Energy Laboratory. For the transportation sector, a detailed study of emerging vehicle technologies was used to characterize the technical and economic characteristics of the transportation technology classes.[12] NE-MARKAL's industrial sector is characterized for major regional and GHG-intensive industries, and the residential and commercial building sector covers the majority of GHG emissions resulting from buildings.

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[9] For information on the MARKAL model, *see* Loulou, R., G. Goldstein, and K. Noble, The MARKAL Family of Models, Energy Technology Systems Analysis Programme (ETSAP), October 2004. See www.etsap.org.

[10] NE-MARKAL currently includes the six New England states, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Washington, D.C.

[11] NE-MARKAL can accommodate power plants smaller than 25 MW if the data are available.

[12] Light-duty transportation technologies in NE-MARKAL have been characterized from a recent study of "off-the-shelf" advanced technology vehicle options; *see* Reducing Greenhouse Gas Emissions from Light-duty Motor Vehicles, September 2004. Northeast States Center for a Clean-Air Future (NESCCAF), Boston, MA, available at http://www.nescaum.org/documents/reducing-greenhouse-gas-emissions-from-light-duty-motor-vehicles-technical-support-study/rpt040923ghglightduty.pdf/.

Data Collection

The NE-MARKAL Reference Case is based on several data sources. [13] Foremost of these is the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS), used to produce the Annual Energy Outlook. Technology characterizations have been extracted from the NEMS, along with data on base year technology stocks, resource supply options, and the sectoral growth rates used in developing demand projections for each model region (state). Other data sources include: the State Energy Data System, which provides final energy use for each demand sector by fuel type; Gross State Product data from the Bureau of Economic Analysis; EIA's three sectoral energy consumption surveys; EPA's eGRID emissions database; and NYS sector-specific energy prices and demand forecasts provided by NYSERDA. In the Reference Case, NESCAUM calibrated each sector's energy consumption to the most current state energy data system provided by the EIA. All of the data specific to the NYS Reference Case energy system are presented in Appendix A.

As a linear programming model that optimizes outcomes based on cost, NE-MARKAL's strength is in exploring the relative cost-effectiveness of meeting various policy goals, such as limits on CO_2 emissions from power generation or minimum performance requirements on vehicles. NE-MARKAL is *not* a computable general equilibrium model that generates estimates of economy-wide price and welfare effects (i.e., gains or losses of producer and consumer surplus) associated with introducing various policies. It is, however, one of the few models of its kind that considers all energy-consuming sectors and characterizes energy use, emissions of GHGs and criteria air pollutants, technology deployment, and costs at a high level of detail. This formulation provides a powerful tool for decision-makers to assess the relative benefits of environmental policies, viewed individually or collectively.

Model Calibration

A critical task for the analysis involved calibrating the model. This involves a sector-specific energy calibration as well as a sector-specific emissions calibration corresponding to the historical record. At the time this project started, 2002 was the operative base year. For the 2002 base year, the EIA State Energy Data Survey provided total energy consumption by fuel type and by sector. The 2009 NYS Energy Plan had additional information on State energy consumption as well as forecasts for future projected consumption. Also for 2002, the MANE-VU [14] emission inventory provided a detailed, sector-specific set of emissions data. NE-MARKAL emission factors, technology stocks, and efficiencies were adjusted to ensure adequate representation of total energy consumption and emissions relative to these data sets. The

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[13] A more detailed description of the NE-MARKAL model and its inputs and assumptions is provided at http://www.nescaum.org/topics/ne-markal-model. We focus here on providing an overview of the model, its capabilities, and the types of data sources that were used to develop NE-MARKAL inputs.

[14] The Mid-Atlantic Northeast Visibility Union (MANE-VU) is a regional planning organization of Mid-Atlantic and Northeast states, tribes, and federal agencies. Its purpose is to coordinate regional haze planning activities for the region. See: http://www.otcair.org/manevu/

process can be labor-intensive, but the end result is a highly detailed representation of the 2002 energy system against which alternative scenarios can be easily compared.

Another component of model calibration is to ensure that subsequent time periods simulated by the model that have already become part of the historical record (i.e., 2005 and 2008) comport with available historical datasets on energy use and technology deployment to ensure that the modeled simulation remains consistent with actual technology usage. The result was that 2008 was established as the "policy" base year from which the model was free to choose least-cost energy solutions within the Reference Case constraints and assumptions. In retrospect, it may have made sense to extend some system constraints through 2011, given the lead time required to implement any model-identified policy options.

Reference Case and Scenario Analyses

The Reference Case provided the basis for examining how the various policy scenarios examined in this effort would affect environment and energy infrastructure in NYS. For purposes of this analysis, several assumptions were made in developing a reference case. NESCAUM assumed that the Regional Greenhouse Gas Initiative (RGGI) was part of the Reference Case and that individual policies would be compared to a future in which this policy was in place. In addition, a renewable portfolio standard (RPS) was not assumed in the Reference Case; rather, this was explored as a separate policy option. In the transportation sector, an assumption was made that light-duty vehicle class shares (the fraction of large trucks, SUVs or minivans relative to small and large cars) were held fixed. While conditions may change in the future that would cause a shift to smaller, more fuel efficient (and cheaper) cars, we imposed fixed class shares to prevent the model from dramatically shifting the class share in favor of small cars. While the popularity of SUVs and other inefficient light-duty transportation may be viewed as a market failure, it also represents a consumer preference that NE-MARKAL is not in a position to project. An additional assumption for the transportation sector was made to reflect our lack of cost information for additional fueling infrastructure in the model. In order to prevent the model from switching on a large scale to compressed natural gas, which may be a cleaner and slightly cheaper commodity relative to gasoline, we limited the maximum penetration of this fuel to no more than 1% of total transportation sector fuel consumption. Finally we constrain residential and commercial sector fuel shares (the relative share of gas, oil and electricity) such that they would not disrupt current regional fuel markets, although these constraints were lifted for some policy cases when large carbon reductions are required.

In this way, each of the sectors was allowed to evolve in the NE-MARKAL model based on principles of least-cost optimization. The key outputs from the Reference Case used to evaluate the policy scenarios included fuel and technology choices, environmental indicators and commodity prices. The assumptions and corresponding data sources that influence the economics and feasibility of technology and energy choices within each sector of the Reference Case are detailed throughout Appendix A. The Reference Case was reviewed by NYSDEC and NYSERDA. After developing the Reference Case, NESCAUM built the policy scenarios for analyses, which were also reviewed by NYSDEC and NYSERDA.

Bringing in the Other MPAF Modules: Mapping Between NE-MARKAL, SMOKE, and CMAQ

Once data needs were addressed, the scenarios defined, and simulations conducted using NE-MARKAL, NESCAUM, NYSDEC, and NYSERDA identified which policy scenario would best be analyzed through the other modules of the MPAF for this proof-of -concept exercise. The chosen policy scenario (the Combination Run) and its results are described in Section 3. NE-MARKAL results were mapped into the SMOKE emissions processing tool to feed EPA's CMAQ regional air quality model. These steps allowed for the potential programs that constitute the air quality management plan to be examined from an environmental perspective. NESCAUM then employed the CMAQ model to demonstrate whether the environmental targets would be met, based on NE-MARKAL projections.

The initial mapping of various sectors of the NE-MARKAL model within each state was important to quality assure the inventory assumptions. NESCAUM did not anticipate being able to simulate 100% of the emissions inventory, but anticipated that the energy infrastructure included in the power generation, transportation, industrial, residential and commercial sectors would account for a significant percentage of many of the key pollutants. For those areas of the emissions inventory driven by energy technologies included in the model, we were able to provide a tool to examine projected inventory changes over a 30-year time horizon.

Simulations based on the Reference Case representations of a future time period (e.g., 2020) were compared to a future policy scenario that represented the implementation of a suite of programs. Thus, a set of policy actions was identified that were projected to cost-effectively achieve a significant portion of needed emissions reductions necessary to meet the State's environmental targets and goals. Additional pollutant-specific strategies would likely be needed to fully meet all of the NYSDEC's targets and goals.

BenMAP. The ambient concentration data produced by the regional CMAQ platform were used to drive BenMAP, a Windows-based program developed jointly by the U.S. EPA and Abt Associates Inc.[15] BenMAP was created to estimate health impacts and associated economic values resulting from changes in ambient air pollution. NESCAUM used outputs from the CMAQ model to create air quality grids to estimate average exposure to particulate matter and ozone of people living in the northeastern U.S. Included in the BenMAP package are databases of concentration-response functions and economic valuations of health impacts. By selecting appropriate health endpoints for the Northeast's population considered here and appropriate epidemiological studies (for incidence rates), we estimated changes in

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[15] Abt Associates. 2007. Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP 2.4.8 US Version. Available at: http://www.epa.gov/air/benmap/download.html

mortality and morbidity for each endpoint by scenario. The health valuation functions available for different health endpoints within the tool were used to derive a key regional economic feedback, which is described in the following section.

The Regional Economic Model. It is important that policy makers are able to consider economic impacts, even when proposed measures have the potential to deliver clear, unequivocal climate and air quality benefits. NESCAUM mapped the estimated public health benefits developed by BenMAP into the regional economic assessment by associating those benefits with appropriate economic sectors using the 12-state Regional Economic Models, Inc. (REMI).[16] This model linked to the NE-MARKAL results to generate estimates of economic impacts to the region associated with implementing the various climate and air quality programs. REMI Policy Insight® is a peer-reviewed model for evaluating the effects of policy initiatives and similar changes on the economies of local regions. NESCAUM used REMI to generate estimates of changes in regional employment, income (i.e., gross state product), and output resulting from policies and/or other changes that were first evaluated using the MARKAL framework.

THE COMMUNITY MULTI-SCALE AIR QUALITY MODEL (CMAQ): AIR QUALITY PREDICTIONS

While the NE-MARKAL model can project estimates of future emissions for select species for multiple policy scenarios, it is unable to capture the impacts of these scenarios on future air quality. For this reason, NE-MARKAL is linked in NESCAUM's MPAF to the Community Multiscale Air Quality Modeling System (CMAQ), which is a one-atmosphere chemical transport model (CTM), in order to simulate future air quality changes given alternate emissions scenarios.

This section describes CTMs, explains the linkage between NE-MARKAL and CMAQ, provides the platform simulation specifications and emissions preparation process, and presents annual $PM_{2.5}$ and O_3 results from simulations of the 2018 Reference Case and an alternate control scenario as a proof-of-concept for how this framework can provide comprehensive integrated assessments in the future.

Chemical Transport Models

Elevated levels of anthropogenic pollutants in the atmosphere have a wide range of adverse effects on the planet and its inhabitants. From negative health outcomes and visibility reduction to ecosystem degradation and climate change, the motivation to control criteria pollutants and GHG emissions is clear. While there is a range of temporal and spatial scales involved as well as a diversity of sources, there is no question that there exists a complex interplay between individual pollutants. Not only are a variety of pollutants often emitted from the same sources, but many of these compounds engage in complex physicochemical

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[16] The REMI Policy Insight® model is a product developed by Regional Economic Models, Incorporated of Amherst, MA. NESCAUM retains a license to a 12-state version of REMI that depicts the regional economy of the six New England states, Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania.

interactions with one another once in the atmosphere. It is only when we consider the interactions between multiple atmospheric pollutants and climate that we can develop optimal solutions to these complex and pressing issues. Unlike traditional planning endeavors where only one pollutant is considered at a time, the move toward a multi-pollutant and multi-issue paradigm enables decision-makers to structure sound action plans that avoid progress on one issue at the detriment of another.

Model simulations are often essential to better understand multi-pollutant interactions and their response to system changes. While observations can provide insight to pollutant concentrations at limited locations and times, CTMs can be useful in conjunction with measurements to characterize the nature of air pollution and climate problems on larger temporal and spatial scales. Particularly useful in policy development, CTMs can be used in "what-if" analyses to estimate the impacts of potential policies on future ambient concentrations. These models are driven by meteorology and emissions inputs, and these inputs are in turn generated by models and based on data taken from various sources. The output of CTMs -- concentration predictions at various locations and times -- can be used as inputs to other models that estimate a given policy's health or economic impacts. Constructing linkages between these models (e.g., physicochemical, energy, economics, emissions, and health) are a necessary step to develop effective and efficient multi-pollutant policies.

Linkage Between NE-MARKAL and CMAQ

Chemical transport models, including CMAQ, require a number of inputs, including meteorology, initial and boundary conditions, emissions, and domain specifications. Emissions inputs must be transformed from coarsely resolved annual inventories to hourly speciated emissions, from both anthropogenic and biogenic sectors, gridded over the modeling domain. To generate the necessary temporally- and spatially-resolved emissions inputs required for CMAQ for this project, we used the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System, version 2.5. SMOKE generates and combines emissions from multiple anthropogenic and biogenic sectors, including mobile source, area, and point source emissions. While EPA and states have developed comprehensive emissions inventories representative of historical conditions, growth and control factors must be developed to generate emissions inventories representative of future conditions, and often for alternative control scenarios. Thus for any project proposing to examine the air quality impacts of future control scenarios, developing a sound methodology for estimating future emissions growth and control is a necessary early step.

NE-MARKAL solves for the least cost set of technologies and fuels to meet the projected demand for energy services in three-year time steps given a set of constraints. For each of these three-year time steps, NE-MARKAL projects fuel consumption and emissions for select species for different processes, sectors, and fuel types. This information can be used in conjunction with a more highly sophisticated emissions inventory, typically used as an input to SMOKE, to project future fuel combustion emissions of select species at the state level for many sources in the residential, commercial, industrial, and mobile source sectors. Because CMAQ requires emissions information from a more diverse and highly resolved group of sources than NE-MARKAL can provide, one must aggregate a subset of the SMOKE emission entries into NE-MARKAL categories in order to link the emissions between the two models. These results may be used to grow or control inventory emissions in the appropriate sectors for input into SMOKE. In addition, other emissions sources for which NE-MARKAL provides no future growth or control information must be projected by alternate methods.

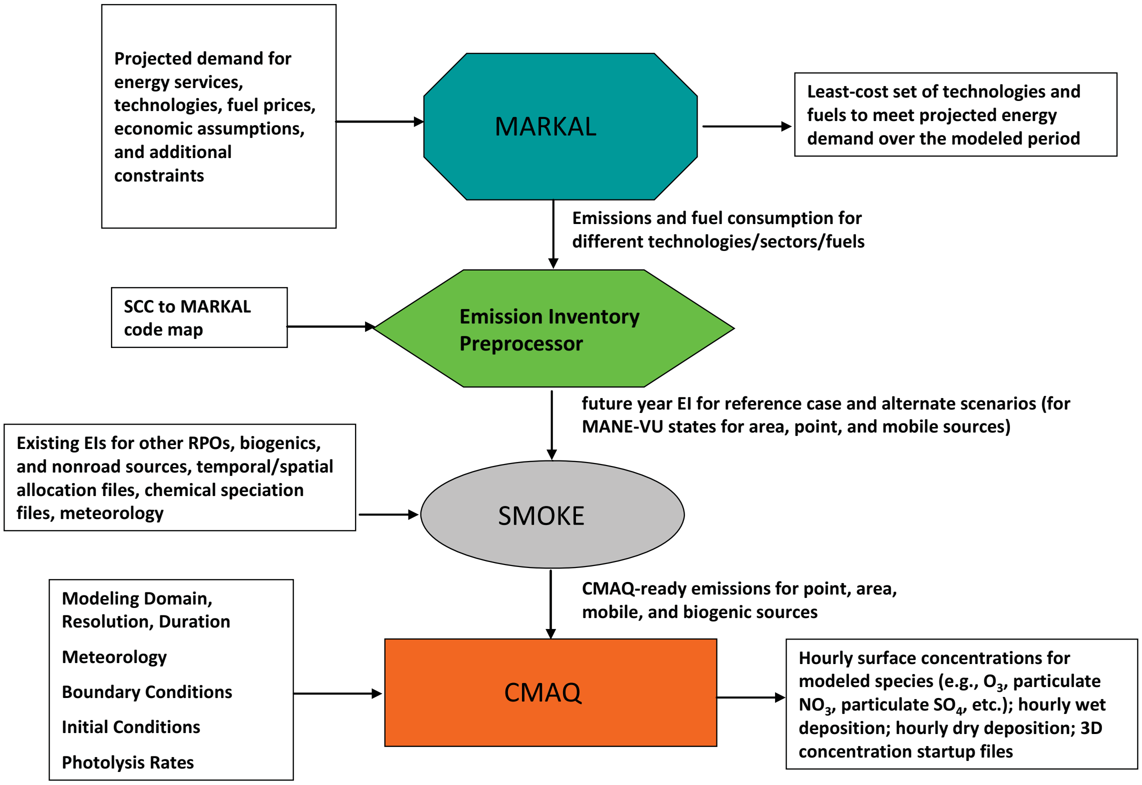

Figure 2-1. Schematic of MARKAL to CMAQ Linkage.

Figure 2-1 illustrates the linkage between NE-MARKAL and CMAQ by emissions. Projected emissions and fuel consumption for certain processes and sectors in NE-MARKAL are used to generate growth factors. These growth factors are used to grow emissions from a baseline SMOKE modeling inventory for 2002, developed for earlier regional haze modeling, based on a map linking Source Classification Codes (SCCs) (used to identify SMOKE emissions sources) and NE-MARKAL technology and process codes. This type of mapping has proven an effective means of creating MARKAL-derived growth and control factors in response to control programs implemented on a national basis (Loughlin et al., 2011). Those emissions categories not well-represented in NE-MARKAL are grown according to the 2018 "Beyond On-the-Way" inventory developed for previous regional haze modeling work (NESCAUM, 2008a). Further detail on how these emissions categories are mapped between the two modeling systems is given in subsequent sections.

The CMAQ Modeling Platform

CMAQ is a state-of-the-science "one-atmosphere" CTM that treats major atmospheric and land processes (e.g., advection, diffusion, gas phase chemistry, gas-particle mass transfer, nucleation, coagulation, wet and dry deposition, secondary organic aerosol formation, aqueous phase chemistry) and a range of species (e.g., anthropogenic and biogenic, primary and secondary, gaseous and particulate) in a comprehensive framework (Byun and Ching, 1999; Byun and Schere, 2006). CMAQ has been extensively peer-reviewed, is well-documented, and regularly updated to reflect the latest changes in scientific understanding. CMAQ has been applied successfully in a range of environments and on many spatial and temporal scales. It has a modular structure that facilitates the swapping of science modules and parameterizations and is primarily coded in Fortran.[17]

Outputs from the model include hourly average surface concentrations of user-specified species, hourly cumulative wet and dry deposition amounts, and if specified by the user, hourly three-dimensional instantaneous species concentrations. Input and output files use a "hybrid" netCDF (Network Common Data Form) – I/O API (Input/Output Applications Programming Interface) format and are platform-independent. These files are self-describing, sharable, appendable, and permit efficient, direct access of data (Rew et al., 2010; Coats et al., 1999).

Previous Work

NESCAUM previously conducted chemical transport modeling over the eastern U.S. for 2002, 2009, and 2018 with CMAQ version 4.5.1 and the CB4 gas phase chemical mechanism. The modeling has been used to support the development of SIPs for regional haze for the northeast states, and has been subjected to an evaluation of outputs and inputs with observational data, as recommended in U.S. EPA guidelines. The previous modeling effort for 2002 incorporated emissions developed by NYSDEC and MM5 meteorological modeling developed by the University of Maryland. For this effort, we built upon prior work by using the same modeling domain and many of the same inputs (e.g., meteorology, initial

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[17] CMAQ version 4.6, the version used here, contains multiple options for gas-phase photochemical mechanisms (CB4, CB05, SAPRC99), cloud routines, aerosol mechanisms, solvers (ROS3, EBI, SMVGEAR), and transport algorithms (Byun and Schere, 2006; Byun and Ching, 1999; CMAS, 2007). It is an Eulerian model with a domain that depends upon the resolution and horizontal and vertical grid structure of the driving meteorological model. Meteorological inputs are typically generated with the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5) or the Weather Research and Forecasting (WRF) model. The Meteorology-Chemistry Interface Processor (MCIP), distributed with CMAQ, can be used to process meteorological model outputs and develop properly formatted input fields for CMAQ (Grell et al., 1995; Skamarock et al., 2005; Byun and Ching, 1999). Additional inputs can be generated by external programs or other preprocessors included with the model. Temporally- and spatially-varying gridded emissions can be generated from annual county-level emissions inventories using SMOKE (Institute for the Environment, 2009). Clear-sky photolysis rates, initial conditions, and boundary conditions can be generated using CMAQ's JPROC, ICON, or BCON processors, respectively. Initial and boundary conditions can be generated from a static, uniform profile or can be extracted from other model results and vary with time and space.

conditions, and boundary conditions). A more recent version of CMAQ (version 4.6), however, was applied here. One change was made to the code: the model representation of N_2O_5 heterogeneous chemistry was replaced with the representation in previous versions of CMAQ (versions 4.5.1 and earlier), as the N_2O_5 heterogeneous chemistry representation in CMAQ version 4.6 contained an error. It was desired that the model formulation be similar enough to that of 4.5.1, so that another model performance evaluation (beyond the one performed for the regional haze work) would not be necessary for this project. Figure 2-2 illustrates that there are minimal differences between CMAQ version 4.6 and CMAQ version 4.5.1 runs for 2002. Additional information on the previous regional haze work, including model validation and meteorological inputs, can be found elsewhere (NESCAUM, 2008).

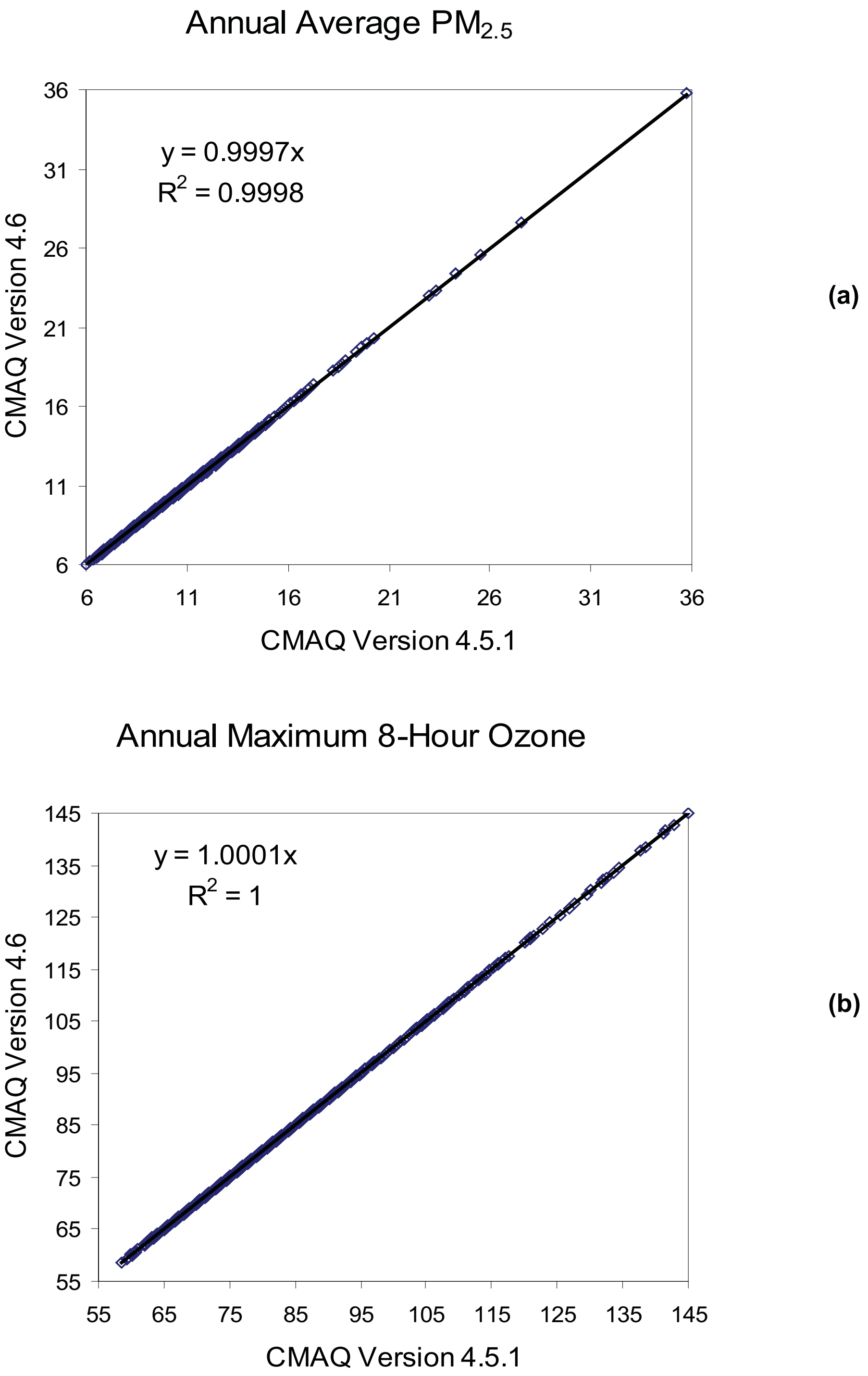
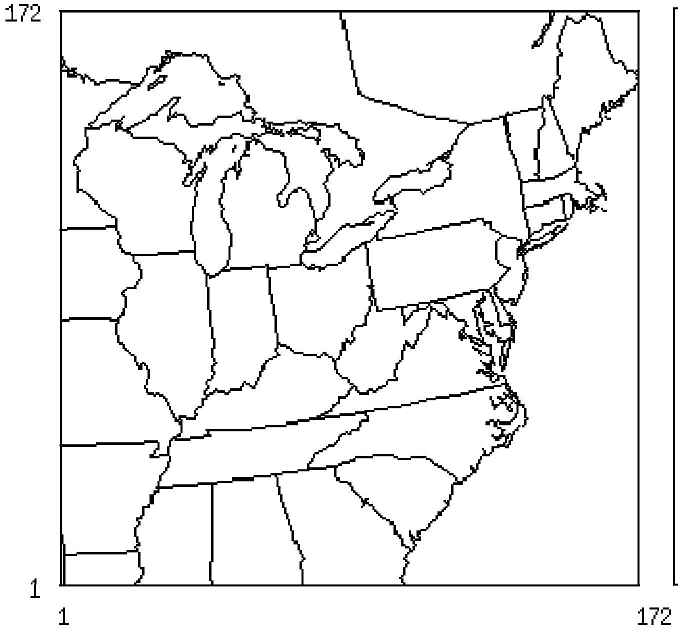


Figure 2-2. Scatter plots of CMAQ Version 4.6 versus CMAQ Version 4.5.1 Annual Average PM2.5 and Annual Maximum 8-hour Ozone for 2002 for NYS Grid Cells.

Model Inputs and Specifications

CMAQ requires a number of gridded inputs, including emissions, boundary conditions, initial conditions, land use information, photolysis rates, and meteorological fields. The modeling domain depends upon the resolution and horizontal and vertical grid structure of the driving meteorological model. The general specifications of the CMAQ modeling domain used here are given in Figure 2-3. We used a 172 x 172 lateral cell 12-km resolution domain over the eastern U.S. using a Lambert Conformal Conic Projection with parallels at 33^{O}N and 45^{O}N. There were 22 model layers, spanning from the ground to 50 mb. CMAQ was run for the 2018 Reference Case and a 2018 control scenario, and the Combination Scenario as described in Section 3 and summarized below. For each annual simulation, the model run was split into two legs (January-June and July-December) and run using four to six processors. Each simulation included a two-week spin-up period to minimize the impact of initial conditions on model results. Shell scripts were developed to run the model and automate additional processing of model inputs and outputs.



Modeling Specifications
CMAQ version 4.6
CB4 Chemical Mechanism
Aerosol Module 3
Aqueous Phase Chemistry
Eastern U.S. Domain
Meteorology from MM5
Annual Simulations for 2018

Modeling Domain
Lambert Conformal Conic Proj.
172 by 172 grid cells, 22 layers
Cell resolution (12 km)
E-W range: 66º W - 94º W
N-S range: 29º N - 50º N

Note: The domain covers much of the eastern U.S. and has been used in previous modeling exercises for the northeastern U.S. The modeling domain includes 22 terrain-following vertical layers, spanning from the ground to 50 hPa, with finer resolution in the lowest layers**.**

Figure 2-3. Domain and Modeling Specifications.

Meteorology. Meteorological outputs from the Penn State/NCAR Mesoscale Model (MM5) or the Weather Research Forecast (WRF) model typically drive CMAQ simulations and dictate the resolution and horizontal/vertical grid structure of the CMAQ modeling domain. The annual meteorological fields for 2002 used in this project were generated with MM5. MM5 is a non-hydrostatic meteorological model with a terrain-following sigma-coordinate developed to simulate mesoscale atmospheric circulation (Grell et al., 1995). The MM5 simulation was performed by the University of Maryland to support earlier regional haze modeling work.

The MM5 simulation was performed over a two-way nested domain with a coarse 36-km 149 x 129 cell domain over the continental U.S. and a fine 12-km 175x175 cell subdomain over the eastern U.S. The domain had 29 vertical terrain-following layers at sigma levels of 1.0000, 0.9974, 0.9940, 0.8980, 0.9820, 0.9720, 0.9590, 0.9430, 0.9230, 0.8990, 0.8710, 0.8390, 0.8030, 0.7630, 0.7180, 0.6680, 0.6180, 0.5680, 0.5180, 0.4680, 0.3680, 0.3180, 0.2680, 0.2180, 0.1680, 0.1230, 0.0800, 0.0400, 0.0000 with the first layer set at ~10 meters and a model top at 50 hPa. The model layers are more highly resolved within the planetary boundary layer, with greater distance between layers near the model top. Important model physics options selected for these simulations included a modified version of the Blackadar planetary boundary layer scheme, explicit cloud physics with simple ice microphysics (without the mixed phase), the Kain-Fritsch convective parameterization, and a multi-layer soil temperature model. The model was initialized with outputs from the NCEP Eta Model (Black, 1994). Eta analyses of upper-air winds, temperature and water-vapor mixing ratio as well as their associated surface fields were used for nudging every six hours, and the Eta surface wind fields blended with surface wind observations were used to nudge every three hours (NYSDEC, 2006).

This simulation had been previously subjected to a model evaluation against observed data by NYSDEC (NYSDEC, 2006; NESCAUM, 2008). The model evaluation included comparisons to National Weather Service (NWS) and Clean Air Status and Trends Network (CASTNET) surface data, vertical wind profiler data, and cloud data from satellite images. The model performance analyses showed that MM5 performance was reasonable and that the MM5 output fields would be acceptable for use in the development of CMAQ model input fields. For further information on past meteorological modeling performance evaluations, refer to NYSDEC (2006).

The Meteorology-Chemistry Interface Processor (MCIP), a pre-processing program distributed with the CMAQ modeling package, was used to generate CMAQ-ready meteorological inputs from the MM5 output files. MCIP utilizes user-provided modeling specifications such as the horizontal and vertical extent of the CMAQ domain and the simulation time period to extract the appropriate variables from the MM5 output files and generates formatted CMAQ input files of the appropriate horizontal, vertical, and temporal structure (Byun and Ching, 1999).

Boundary and Initial Conditions. Lateral boundary conditions and initial conditions for this domain were developed for previous modeling work. A 36-km resolution CMAQ simulation for 2002 was run over the continental U.S. by NYSDEC to support the region's SIP work. Boundary conditions for this more coarsely resolved simulation were developed from annual outputs from GEOS-CHEM, a global chemical transport model. As was the case with the 12-km meteorology, meteorological fields for the 36-km simulation were generated by the University of Maryland. Emissions were developed based on information obtained from the five regional haze Regional Planning Organizations (RPOs). The output three-dimensional concentration fields were then processed through CMAQ's Boundary Condition "BCON" processor to provide one-way spatially- and temporally-varying boundary conditions for our 12-km subdomain. A clean profile was used to establish initial conditions for our simulations. Nevertheless, the impact of initial conditions on model results was minimized by the two-week spin-up period that preceded every run.

Photolysis Rates. CMAQ requires the clear-sky photolysis rates at fixed altitudes, various latitude bands, and solar hour angles calculated by its Photolysis Rate Processor (JPROC). JPROC calculates these chemical-mechanism specific rates using tabulated absorption cross section and quantum yield data (CSQY) which are distributed with CMAQ for the default chemical mechanisms or ozone column data from the NASA TOMS (Total Ozone Mapping Spectrometer) satellite. CMAQ interpolates the data generated with JPROC for each grid cell and then adjusts for clouds if they are present. As with our previous modeling exercises for 2002, daily ozone column TOMS data were used as inputs to the JPROC processor.

Emissions. CMAQ-ready emissions inputs were prepared using the SMOKE modeling system (Institute for the Environment, 2009). SMOKE was developed to perform rapid and flexible processing of annual and average-day emission inventories to create the gridded, speciated, hourly emissions inputs required by a chemical transport model. SMOKE can process criteria pollutant and toxics inventories and supports the processing of anthropogenic area, onroad, nonroad, and point source emissions, as well as biogenic emissions. The code is set up in a modular fashion with separate processing steps for different emissions sectors, growth and control, speciation, temporal distribution, and spatial distribution. In a final step, all source categories are merged to generate input files for CMAQ. Because many of the matrices developed to apply control, growth, speciation, and gridding to the vector of inventory emissions are independent, many processing steps can be performed in parallel and merged together at the final step. This also allows changes to be made to one process, like growth and control, without requiring all the emissions processing steps to be repeated (Institute for the Environment, 2009).

The 2002 and 2018 "Beyond on the Way" (BOTW) emissions inventories, which were developed by MANE-VU, Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Regional Planning Organization (MWRPO), and the Central Regional Air Planning Association (CENRAP), served as the basis for emissions inputs for each future year run. Most spatial surrogates were taken from EPA's Emissions Modeling Clearinghouse, temporal profiles were developed by individual RPOs, and chemical speciation profiles were based on U.S. EPA's Clean Air Interstate Rule (CAIR) files with MANE-VU (RPO)-specific updates. Biogenic emissions were estimated using the Biogenics Emissions Inventory System (BEIS3) with Biogenic Emissions Landcover Database version 3 data. Mobile source emissions were developed using MOBILE6 (NESCAUM, 2008).

For those categories not treated in NE-MARKAL (and for those regions outside of MANE-VU), the 2002 inventory was grown according to the 2018 BOTW inventory used in the regional haze work. The BOTW inventory includes control measures under consideration in addition to those regulations already in place. For those emissions categories represented in NE-MARKAL, the NE-MARKAL-to-SMOKE emissions interface developed for this project was used to generate growth factors based on MARKAL emissions or fuel consumption changes between 2002 and 2017. These growth factors were applied to the 2002 inventory by a MARKAL-code to an SCC code map as described below.

NE-MARKAL to SMOKE Emissions Interface. The NE-MARKAL-to-SMOKE Emissions Interface (NSEI) is a multi-step, semi-automatic process built around a map of NE-MARKAL codes to the SCC identifiers commonly used in SMOKE inventories and auxiliary files. The interface is coded in MATLAB. Future year emissions inventory development processes vary by sector. While the emissions of SO_2 and NO_x from those power plants explicitly modeled in NE-MARKAL were used directly in the future year inventories, future year emissions for area, mobile, and other point sources were estimated with a growth factor applied to the 2002 emissions inventory. For those processes represented in NE-MARKAL, growth factors were developed based on the ratios of NE-MARKAL fuel consumption or NO_2 emissions between 2002 and 2017.

Electric Generating Units (EGUs). With respect to emissions from EGUs, different techniques were applied to develop future year emissions depending on whether the EGU existed in the base year and is large enough to be explicitly represented in NE-MARKAL, is represented by "aggregated" EGUs, or is a new plant. MARKAL simulates explicitly those EGUs above a threshold generating capacity of 25 MW. The ORIS ID codes of these explicitly-modeled EGUs were used to retrieve from the MANE-VU inventory the additional required information for entries in the new future year SMOKE inventory file (e.g., CYIDs, PLANTIDs, stack parameters, SICs, coordinates).

For smaller EGUs aggregated into composite entities in NE-MARKAL, growth factors were developed from NE-MARKAL NO_x emissions ratios between 2002 and 2017, according to state, technology, and fuel, and applied to the base year emissions of EGUs in the MANE-VU IPM inventory that were not matched to any of the EGUs explicitly modeled in NE-MARKAL.

When a new EGU is created in NE-MARKAL, there is no information on where the new plant might be sited. This poses a problem when generating future year emissions files for the air quality runs because specific information (i.e., latitude and longitude) are required to properly position major point sources within the modeling domain. In the case of new EGUs, rather than arbitrarily siting the new source as a new major point source in the modeling domain, emissions were distributed proportionally amongst the previously-existing, explicitly-modeled EGUs.

Table 2-1. SCC NE-MARKAL Code Map for the Transportation Sector.

SCC code (format AABBBBBCCC, where AA = 22 = mobile sources)	SCC Description (BBBBB)	NE-MARKAL Codes
2201001000	LDGV: Light-Duty Gasoline Vehicles	TLSCRGS TLSCRET TLSCRHG TLBCRGS TLBCRET TLBCRHG
2201020000	LDGT1: Light-Duty Gasoline Trucks 1	TLMVNGS TLMVNET TLMVNHG TLSTKGS TLSTKET TLSTKHG
2201040000	LDGT2: Light-Duty Gasoline Trucks 2	TLLTKGS TLLTKET TLLTKHG
2201070000	HDGV: Heavy-Duty Gasoline Vehicles	TBBUSGS TBBUSET TBBUSHG THHTKGS THHTKET THHTKHG THMTKGS THMTKET THMTKHG
2230001000	LDDV: Light-Duty Diesel Vehicles	TLSCRDS TLSCRCN TLSCRHD TLBCRDS TLBCRCN TLBCRHD
2230060000	LDDT: Light-Duty Diesel Trucks	TLMVNDS TLMVNCN TLMVNHD TLSTKDS TLSTKCN TLSTKHD TLLTKDS TLLTKCN TLLTKHD
2230070000	HDDV: Heavy-Duty Diesel Vehicles	TBBUSDS TBBUSCN TBBUSHD THHTKDS THHTKCN THHTKHD THMTKDS THMTKCN THMTKHD
2230071000	HDDV2B: Class 2b Heavy-Duty Diesel Vehicles	THMTKDS THMTKCN THMTKHD
2230072000	HDDV3-5: Class 3-5 Heavy-Duty Diesel Vehicles	THMTKDS THMTKCN THMTKHD
2230073000	HDDV6-7: Class 6-7 Heavy-Duty Diesel Vehicles	THMTKDS THMTKCN THMTKHD
2230074000	HDDV8a-8b: Class 8a -8b Heavy-Duty Diesel Vehicles	THHTKDS THHTKCN THHTKHD
2230075000	HDDBT & HDDBS: Diesel Transit/Urban Buses and Diesel School Buses	TBBUSDS TBBUSCN TBBUSHD

Transportation. NE-MARKAL projects emissions for light-duty and heavy-duty vehicles. Growth factors were developed based on the NO_x emissions ratio between 2002 and 2017 for these vehicle categories. Motorcycle emissions are not included in NE-MARKAL, so motorcycle emissions were carried over from the 2002 MANE-VU inventory. Traditional and non-traditional vehicle types/fuels in NE-MARKAL were aggregated to MOBILE vehicle categories according to the map illustrated in Table 2-1 and Table 2-2. With a 2018 VMT inventory for the MOBILE vehicle types, future year on-road emissions were estimated with MOBILE6, as implemented in SMOKE, using the same parameters employed in the 2018 MANE-VU mobile emissions inventory development.

Table 2-2. NE-MARKAL Codes for the Transportation Sector.

NE-MARKAL Code Segment	Description
TLSCR	Light-Duty Small Car
TLBCR	Light-Duty Large Car
TLMVN	Light-Duty Minivan
TLSTK	Light-Duty Small Truck
TLLTK	Light-Duty Large Truck
THMTK	Heavy-Duty Medium Truck
THHTK	Heavy-Duty Heavy Truck
TBBUS	Bus
GS	Gasoline
ET	Ethanol
HG	Gasoline Hybrid
DS	Diesel
HD	Diesel Hybrid
CN	Compressed Natural Gas

Note: NE-MARKAL transportation codes are of the format AAAAABB where AAAAA corresponds to the 5-letter code segments and BB corresponds to the 2-letter code segments in the table above.

Area and Other Point Sources. For area sources and point sources other than the explicitly-modeled EGUs in NE-MARKAL, growth factors were calculated from NE-MARKAL results for 2002 and 2017 fuel consumption and mapped to SCC and FIPs codes. For those emissions categories that are characterized in NE-MARKAL, a NE-MARKAL growth factor was applied to grow 2002 area source and other point source emissions to 2018 levels. For other emissions categories not included in NE-MARKAL, the entry in the 2018 MANEVU emission inventory was used.

Table 2-3, Table 2-4, and Table 2-5 illustrate the mapping between the SCC codes used in SMOKE and NE-MARKAL codes for consumed commodities for area sources.

Table 2-3. SCC NE-MARKAL Code Map for the Residential Sector Area Sources.

SCC code	SCC Description	NE-MARKAL Codes	NE-MARKAL Code Description
2104001000	Residential Area Source Fuel Combustion – Anthracite Coal	RESCOA	Residential Coal Consumption
2104002000	Residential Area Source Fuel Combustion – Bituminous/ Sub-bituminous Coal	RESCOA	Residential Coal Consumption
2104004000	Residential Area Source Fuel Combustion – Distillate Oil	RESDSL	Residential Distillate Oil Consumption
2104006000	Residential Area Source Fuel Combustion – Natural Gas	RESNGA	Residential Natural Gas Consumption
2104007000	Residential Area Source Fuel Combustion – Liquefied Petroleum Gas	RESLPG	Residential Liquefied Petroleum Gas Consumption
2104008000	Residential Area Source Fuel Combustion – Wood	RESBWD	Residential Biomass-Wood Consumption
2104011000	Residential Area Source Fuel Combustion – Kerosene	RESKER	Residential Kerosene Consumption

Table 2-4. SCC NE-MARKAL Code Map for the Commercial Sector Area Sources.

SCC code	SCC Description	NE-MARKAL Codes	NE-MARKAL Code Description
2103001000	Commercial Area Source Fuel Combustion – Anthracite Coal	COMCOA	Commercial Coal Consumption
2103002000	Commercial Area Source Fuel Combustion – Bituminous/ Sub-bituminous Coal	COMCOA	Commercial Coal Consumption
2103004000	Commercial Area Source Fuel Combustion – Distillate Oil	COMDSL	Commercial Distillate Oil Consumption
2103005000	Commercial Area Source Fuel Combustion – Residual Oil	COMRFO	Commercial Residual Fuel Oil Consumption
2103006000	Commercial Area Source Fuel Combustion – Natural Gas	COMNGA	Commercial Natural Gas Consumption
2103007000	Commercial Area Source Fuel Combustion – Liquefied Petroleum Gas	COMLPG	Commercial Liquefied Petroleum Gas Consumption
2103008000	Commercial Area Source Fuel Combustion – Wood	COMBWD	Commercial Biomass-Wood Consumption
2103011000	Commercial Area Source Fuel Combustion – Kerosene	COMKER	Commercial Kerosene Consumption

Table 2-5. SCC NE-MARKAL Code Map for the Industrial Sector Area Sources.

SCC code	SCC Description	NE-MARKAL Codes	NE-MARKAL Code Description
2102001000	Industrial Area Source Fuel Combustion – Anthracite Coal	INDCOA	Industrial Coal Consumption
2102002000	Industrial Area Source Fuel Combustion – Bituminous/ Sub-bituminous Coal	INDCOA	Industrial Coal Consumption
2102004000	Industrial Area Source Fuel Combustion – Distillate Oil	INDDSL	Industrial Distillate Oil Consumption
2102005000	Industrial Area Source Fuel Combustion – Residual Oil	INDRFO	Industrial Residual Fuel Oil Consumption
2102006000	Industrial Area Source Fuel Combustion – Natural Gas	INDNGA	Industrial Natural Gas Consumption
2102007000	Industrial Area Source Fuel Combustion – Liquefied Petroleum Gas	INDLPG	Industrial Liquefied Petroleum Gas Consumption
2102008000	Industrial Area Source Fuel Combustion – Wood	INDBWD	Industrial Biomass-Wood Consumption

For those categories not represented in the NE-MARKAL projections, the future year inventory entries were based on the 2018 emissions inventories developed for earlier regional haze SIP modeling. The 2018 BOTW inventory described in detail elsewhere (NESCAUM, 2008), was used to grow emissions in categories not represented in NE-MARKAL, as well as emissions from states outside of the MANE-VU region. Once annual emissions inventories were developed for the three future year scenarios described below, SMOKE was run using the temporal, spatial, and chemical speciation auxiliary files described in NESCAUM (2008) to generate hourly gridded emissions inputs for CMAQ.

HEALTH BENEFITS ASSESSMENT: THE ENVIRONMENTAL BENEFITS MAPPING AND ANALYSIS PROGRAM (BENMAP)

A large body of epidemiological evidence points to an association of elevated ambient $PM_{2.5}$ and O_3 levels with a range of adverse health effects, including increased incidence of pulmonary and cardiovascular impairment and, in extreme cases, death. Both short-term air pollution episodes and long-term elevated averages may have significant deleterious effects on human health, with sensitive populations like the elderly and young children particularly susceptible. The estimate of health impacts due to concentration differences between scenarios is therefore a necessary component of NESCAUM's MPAF. An assessment of the economic impacts of controlling emissions and reducing air pollution would not be complete without a representation of the monetized health benefits associated with decreasing levels of widespread pollutants such as $PM_{2.5}$ and O_3.

BenMAP is a tool developed to estimate health incidence changes and associated economic impacts for a change in ambient pollutant concentrations (e.g., O_3 or $PM_{2.5}$). Figure 2-4 illustrates how BenMAP inputs are derived by other elements of NESCAUM's MPAF. Projected fuel consumption and emissions data for alternate policy scenarios are fed from NE-MARKAL into an emissions inventory preprocessor. This emissions inventory preprocessor processes this data in conjunction with a map of NE-MARKAL codes to SCCs to generate future year emissions inventories for SMOKE, an emissions aggregation and geographical distribution model. SMOKE generates gridded, hourly, model-ready emissions files, combined for all source sectors, for input into CMAQ. Driven by annual hourly meteorology, CMAQ produces hourly surface pollutant concentrations for an entire year, for each policy scenario. It is these concentration fields that are post-processed to provide the $PM_{2.5}$ and O_3 concentration inputs to BenMAP. In addition to generating concentration fields, a GIS shapefile must be created for the modeling domain, as well as population information for each grid cell. Once health impact costs/benefits due to $PM_{2.5}$ and O_3 concentration changes are estimated, these costs and other projected economic information from NE-MARKAL can be fed into the REMI to develop macroeconomic simulations of the NYS economy. The REMI analyses performed for this project are described in more detail in the following section.

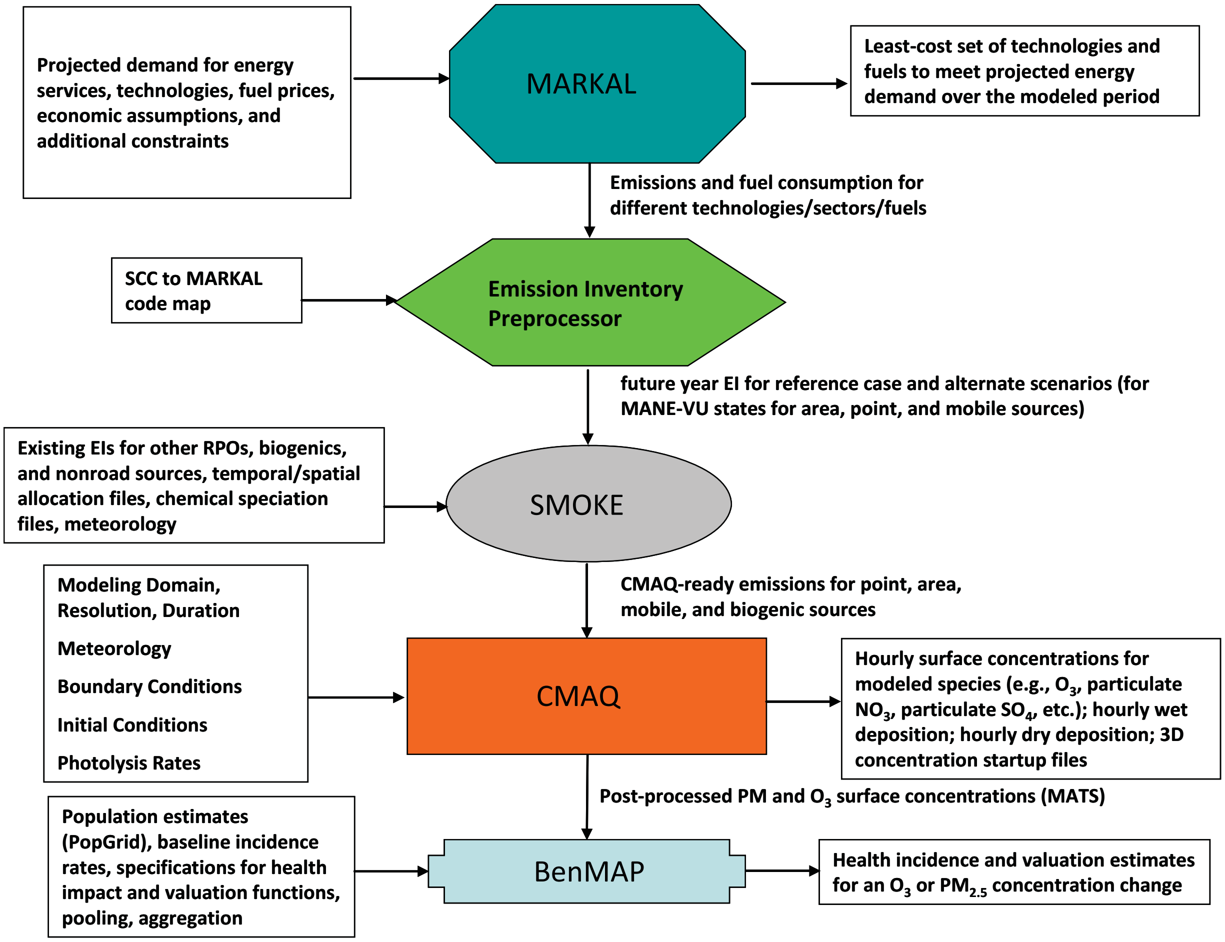


Figure 2-4. Schematic of MARKAL to CMAQ to BenMAP Linkage.

A BenMAP flow diagram is illustrated in Figure 2-5. BenMAP requires data from a number of sources to develop health impact assessments. Calculations are performed in a series of discrete steps, starting with calculation of population projections by grid cell. Depending on whether the target domain is one of the default domains in the BenMAP database or not, population estimates may be generated internally in BenMAP (for default domains) or must be developed externally using PopGrid software. In PopGrid, 2000 Census block data are aggregated within each grid cell to form the basis of the gridded population estimates and may be projected to future years based on county-level forecast ratios (Abt Associates, 2010a).

Change in population exposure is estimated by multiplying the spatially-resolved projected population data with a pollutant concentration change (here, $PM_{2.5}$ and O_3) for a given grid cell. These concentration fields can be generated by air quality modeling, spatially interpolated monitoring data, or a combination of both. It is assumed that the entire population in a grid cell is exposed to the same pollutant levels. Adverse health effects are then calculated using concentration response functions (see Figure 2-6, Eq. 6-1), which relate a change in concentration of a given pollutant with a change in a particular health endpoint. These functions require as inputs baseline incidence and (sometimes) prevalence rates and "population exposure" information. In a final step, the health impacts estimated for a given concentration change are then multiplied against a valuation function specific to the type of health effect (Figure 2-6, Eq. 6-2). In order to perform these calculations, BenMAP requires large amounts of data. Some information must be supplied to BenMAP at run time (e.g., modeled concentrations), while other data are included within BenMAP's default database (e.g., U.S. monitoring data for select species such as O_3 and $PM_{2.5}$).

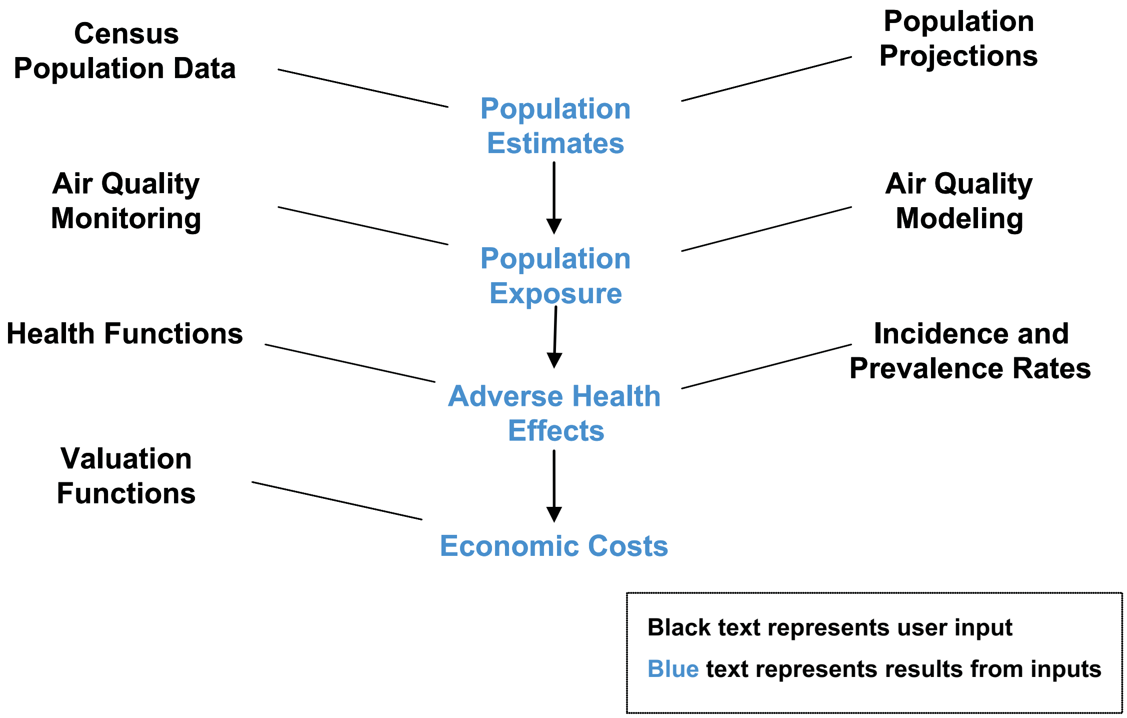


Figure 2-5. BenMAP Flow Diagram (from Abt Associates, 2010b).

Potential Data Sources

There are number of sources one can use to develop the necessary inputs to estimate health impacts as they are calculated in BenMAP (See Figure 2-6, Eq 6-1). Air quality change comes from monitoring and/or modeling data for a baseline and alternate scenario. These data can come from CMAQ model outputs or monitoring data preloaded in the BenMAP or Modeled Attainment Test Software (MATS) databases, for example. Epidemiological studies are a source for health effect estimates, and the U.S. Census Bureau is a good source of information on population. Health incidence rates are often collected by the government or can often be obtained from the World Health Organization. Additionally, there are a number of ways in which the health effects can be monetized (See Figure 2-6, Eq. 6-2). BenMAP contains data on a number of metrics to estimate the value of a given health effect. Some of these include calculating the medical costs of the illness (COI) or value of statistical life (VSL), and the amount that people are willing to pay to reduce the risk of premature death. There are a range of valuation functions in the BenMAP database, sometimes multiple for a given endpoint, and these functions vary between illnesses and subject age range.

Health Effect = ΔAQ * HEE * Pop_{ex} * BInc **(Eq. 6-1)**

Where ΔAQ = Air quality change = the difference between the baseline and control concentration grids
HEE = Health Effect Estimate = percentage change in a health effect due to a one unit change in ambient air pollution
Pop_{ex} = Exposed population
BInc = Baseline health incidence = estimate of health impacts from all causes in a population over a given period of time

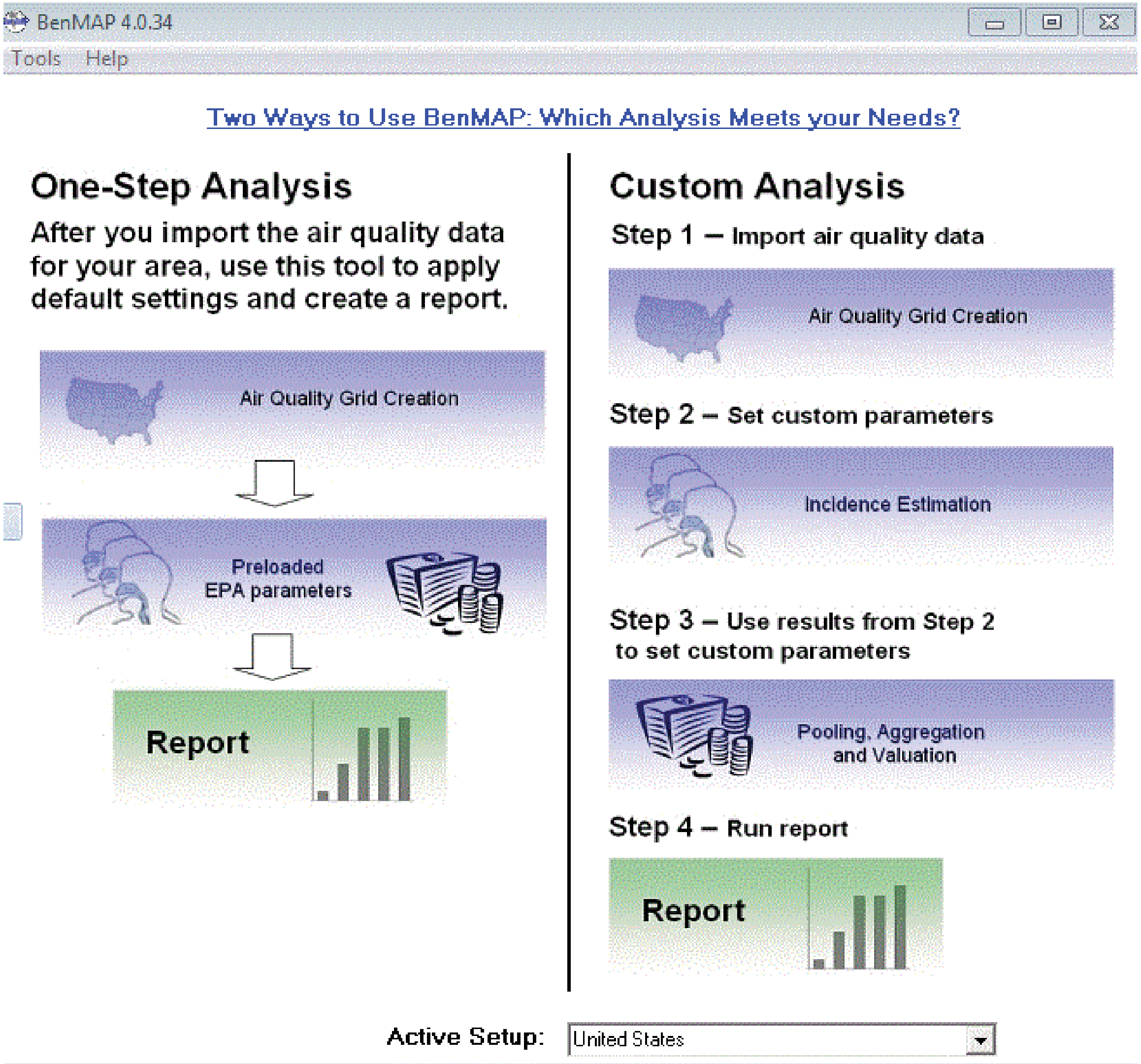
Economic Value = Health Effect * Value of Health Effect **(Eq. 6-2)**

Figure 2-6. BenMAP Calculation Equations.

BenMAP Interface and Processing Steps

Figure 2-7 shows the user-interface for BenMAP 4.0. BenMAP allows the user to choose between a simple, default “one-step” analysis and a custom analysis. The one-step analysis option is sufficient for beginning users interested in simple analyses using default data with limited user options. For projects where one would like to use a unique air quality grid or apply valuation and health functions that differ from those in the default setup, one must perform a “custom analysis,” taking the path on the right hand side of the user-interface. For this project, NESCAUM employed a custom analysis.

Setup. Prior to running BenMAP, if one wants to use modeled air quality concentration fields, one must perform at least a baseline and control air quality simulation. The baseline simulation usually represents current or future emissions scenarios as usual (or as planned), and the control scenario includes the alternative emissions control scenario you would like to investigate. BenMAP also requires population estimates for each grid cell before being able to develop population exposure estimates for pollutants of interest. If the air quality grid does not match one of the standard EPA modeling domains, then population estimates and projections need to be generated for the modeling domain prior to running BenMAP. For this, Abt Associates developed PopGrid, an application that aggregates census block data for user-defined grid cells defined by a GIS shape file. For both the generation of population estimates and processing within BenMAP, a shapefile is required to transfer the necessary spatial characteristics of the modeling domain.



Two Ways to Use BenMAP: Which Analysis Meets your Needs?

One-Step Analysis

After you import the air quality data for your area, use this tool to apply default settings and create a report.

Custom Analysis

Step 1 – Import air quality data

Step 2 – Set custom parameters

Step 3 – Use results from Step 2 to set custom parameters

Step 4 – Run report

Active Setup: United States

Figure 2-7. BenMAP User Interface.

<u>Air Quality Grid Creation.</u> In the first BenMAP processing step, BenMAP calculates the change in ambient air pollution for a given area. To do this, one must generate air quality grids for the baseline and control case in the first step of the analysis. One can generate an air quality grid in BenMAP via one of four methods: (1) model direct; (2) monitor direct; (3) monitor rollback; or (4) monitor and model relative. The model direct method involves using the model data directly and assuming that the population in a grid cell is subjected to the concentrations estimated by the model. The monitor direct approach employs only air quality monitoring data and creates an air quality grid for a chosen domain by either assigning the nearest monitor’s data to a grid cell, averaging the concentrations of all the monitors within a fixed radius, or by interpolating the monitored concentrations using Voronoi Neighbor Averaging. There are monitoring data for $PM_{2.5}$ and O_3 pre-loaded into BenMAP for U.S. monitors for a number of years. Monitor rollback allows one to generate an air quality grid by reducing the monitoring data by an across-the-board increment, percentage, or reduction to a given air quality standard. The fourth "monitor and model relative" option involves using the modeling data to adjust monitored concentrations temporally, spatially, or both. There are benefits in combining both forms of data. Monitored data represent actual concentration levels at limited temporal resolution and a few point sites, and modeled data can provide information on how concentrations vary spatially and temporally at a much more refined level.

For this effort, the monitor and model relative approach was employed to develop air quality grids for the 2018 Reference Case and the 2018 Combination Scenario. In the BenMAP "Air Quality Grid Creation" step, Voronoi Neighbor Averaging (VNA) was used to interpolate the 2002 O_3 monitoring data over the domain using an inverse distance squared weighting approach. Then 2002 and 2018 modeled daily metric concentrations (e.g., 1-hour max, 8-hour max, daily average, etc.) were applied to the monitored O_3 fields to adjust the air quality grid spatially and temporally. Similarly for $PM_{2.5}$, VNA was used to interpolate monitored $PM_{2.5}$ species data. Nevertheless, because BenMAP does not contain $PM_{2.5}$ species concentrations, only $PM_{2.5}$ total concentrations, the $PM_{2.5}$ modeled and monitored species concentration fields were combined external to BenMAP using EPA's MATS (Abt Associates, 2010c). As with O_3, modeled $PM_{2.5}$ species concentrations from 2002 and 2018 were used to adjust monitored $PM_{2.5}$ species concentrations within MATS. Following the MATS combination of monitored and modeled data, the gradient adjusted quarterly total $PM_{2.5}$ monitored/modeled data were then post-processed to generate an input file recognizable by BenMAP. Note that while hourly concentrations were available from CMAQ output, NESCAUM could not load hourly data for the year or season directly into BenMAP (or MATS) due to memory limitations. As a result, it was necessary to generate average concentrations and other metrics externally, and input those metric values to BenMAP and MATS rather than input the "raw" modeled data.

Incidence Estimation. After generating air quality grids for the baseline (i.e., 2018 Reference Case) and control (i.e., 2018 Combination Scenario) cases, the next step in BenMAP processing is to choose which concentration-response functions to include in the health impacts analysis. Table 2-6 lists the $PM_{2.5}$ and O_3 health effects examined here and the epidemiological study that provided the source of the applied concentration-response functions.

Table 2-6. Health Endpoints and Epidemiological Studies Used to Quantify Health Impacts

Endpoint	**Pollutant**	**Study**	**Age**	**Pooling**
Premature Mortality				
Mortality, Non-Accidental	O3	Bell et al. (2004) - 95 U.S. cities	0-99 years	Random/Fixed Effects
Mortality, Cardiopulmonary		Huang et al. (2005) - 19 U.S. cities		
Mortality, Non-Accidental		Schwartz (2005) - 19 U.S. cities		
Mortality, All Cause		Bell et al. (2005) - U.S. and Non-U.S.		
Mortality, Non-Accidental		Ito et al. (2005)		
Mortality, All Cause		Levy et al. (2005) - U.S. and Non-U.S.		
Mortality, All Cause	PM2.5	Pope et al. (2002) - 51 cities	30-99 years	
Mortality, All Cause	PM2.5	Woodruff et al. (2006) - 204 counties	Infant (< 1 year)	
Chronic Illness				
Chronic bronchitis	PM2.5	Abbey et al. (1995) - SF, SD, South Coast Air Basin	27 - 99 years	
Nonfatal heart attacks	PM2.5	Peters et al. (2001)	18-99	
Hospital Admissions				
Respiratory	O3	Schwartz (1995) - All Respiratory	> 64 years	Random/ Fixed Effects (over all HA, Respiratory 65+ years after random/fixed effects over Minneapolis studies)
		Detroit - Schwartz (1994a) - (sum - dependent) Chronic Lung Disease (less Asthma) + Pneumonia		
		Minneapolis - Moolgavkar et al. (1997) - (sum - dependent) Pneumonia + Chronic Lung Disease		
		Minneapolis - Schwartz (1994b) - Pneumonia		
	O3	Burnett et al. (2001) - All respiratory	0-1 years	
	PM2.5	Moolgavkar (2003) - Chronic Lung Disease		Random/Fixed Effects
		Ito (2003) - Chronic Lung Disease		
	PM2.5	Moolgavkar (2000a) - Chronic Lung Disease (less Asthma)	18-64 years	
	PM2.5	Ito (2003) - Pneumonia	65-99 years	
	PM2.5	Sheppard (2003) - Asthma	0-64 years	
Cardiovascular	PM2.5	Moolgavkar (2003)—All Cardiovascular (less Myocardial Infarctions)	65-99 years	Random/Fixed Effects
		Ito (2003)— (sum - dependent) Congestive Heart Failure, Dysrhythmia, Ischemic heart disease		
		Moolgavkar (2000b)— All Cardiovascular (less Myocardial Infarctions)	18-64 years	
Emergency Room Visits, Asthma	O3	Peel et al. (2005)	0-99 years	Random/Fixed Effects
		Wilson et al.(2005) - Portland (ME) and Manchester (NH)		
	PM2.5	Norris et al. (1999)	0-17 years	
Other Health Endpoints				
Acute bronchitis	PM2.5	Dockery et al. (1996)	8–12 years	
Lower respiratory symptoms	PM2.5	Schwartz and Neas (2000)	7–14 years	
Asthma exacerbations	PM2.5	Ostro et al. (2001) (pooled - random/fixed effects - cough, wheeze and shortness of breath)	6-18 years	Random/Fixed Effects
		Vedal et al. (1998) (cough)		
Work loss days	PM2.5	Ostro (1987)	18–64 years	
School absence days	O3	Gilliland et al. (2001)	5–17 years	Random/Fixed Effects
		Chen et al. (2000)		
Acute Respiratory Symptoms	PM2.5	Ostro and Rothschild (1989)	18–64 years	

The choice of studies employed here was based on availability in BenMAP 4.0 (i.e., we did not add any additional concentration-response functions to the BenMAP database) and the choices made in two previous analyses: EPA's "Regulatory Impact Analysis for the Proposed Federal Transport Rule" (U.S. EPA, 2010) and NESCAUM (2008). For more information on these studies, refer to the original references listed here as well as the BenMAP User's Manual and Appendices (Abt Associates, 2010a; 2010b). Additional run parameters to specify in the "Incidence Estimation" step include the population year (here, 2018) and the number of Latin Hypercube points to use when generating the results (here, 10). Note that due to a probable bug in BenMAP version 4.0, chronic bronchitis impacts were estimated using BenMAP version 3.0, with a threshold of 10, as there was no "no-threshold" option.

Aggregation, Pooling and Valuation. In the next processing step, "Aggregation, Pooling, and Valuation," the results of the incidence estimation are further processed based on how the user would like to aggregate, pool, and valuate the health impacts. Aggregation refers to the summing of grid-cell results to the county, state, or national level. Pooling refers to the manner in which one combines different sets of data – here, health impact functions or parameters from multiple studies looking at the same endpoint/pollutant. Some possibilities for pooling within BenMAP include summing, random/fixed effects, or subjective weighting. For more information on the pooling options in BenMAP, refer to Appendix L in Abt Associates (2010a). For each endpoint group and study chosen, one must choose a valuation method to estimate a cost for a given health impact. Table 2-7 shows the valuation methods chosen for each health impact examined here. Note that all results are aggregated to the state level. For more information about each valuation method, including unit values ($) and assumed distributions, refer Appendix J of Abt Associates (2010a).

Table 2-7. Endpoint-Specific Valuation Methods.

Endpoint Group	Endpoint	Study Age	Valuation Method
Mortality	Mortality, All Cause	0-99	Value of Statistical Life; based on 26 value-of-life studies | 0-99
Acute Myocardial Infarction	Acute Myocardial Infarction, Nonfatal	18-24	average Cost of Illness from 2 studies:5 yrs med; 5 yrs wages; 3% DR; Russell (1998) | 0-24 and 5 yrs med; 5 yrs wages; 3% DR; Wittels (1990) | 0-24
		25-44	average Cost of Illness from 2 studies:5 yrs med; 5 yrs wages; 3% DR; Russell (1998) | 25-44 and 5 yrs med; 5 yrs wages; 3% DR; Wittels (1990) | 25-44
		45-54	average Cost of Illness from 2 studies:5 yrs med; 5 yrs wages; 3% DR; Russell (1998) | 45-54 and 5 yrs med; 5 yrs wages; 3% DR; Wittels (1990) | 45-54
		55-64	average Cost of Illness from 2 studies:5 yrs med; 5 yrs wages; 3% DR; Russell (1998) | 55-64 and 5 yrs med; 5 yrs wages; 3% DR; Wittels (1990) | 55-64
		65+	average Cost of Illness from 2 studies:5 yrs med; 5 yrs wages; 3% DR; Russell (1998) | 65-99 and 5 yrs med; 5 yrs wages; 3% DR; Wittels (1990) | 65-99
HA, Respiratory	HA, Chronic Lung Disease	65-99	Cost of Illness: med costs + wage loss | 65-99
	HA, Chronic Lung Disease (less Asthma)	18-64	Cost of Illness: med costs + wage loss | 20-64
	HA, Pneumonia	65-99	Cost of Illness: med costs + wage loss | 65-99
	HA, Asthma	0-64	Cost of Illness: med costs + wage loss | 0-64
		65-99	Cost of Illness: med costs + wage loss | 65-99
	HA, All Respiratory	0-1	Cost of Illness: med costs + wage loss | 0-2
ER Visits, Respiratory		0-17	average Cost of Illness from 2 studies:Smith et al. (1997) | 0-99 and Standford et al. (1999) | 0-99
Acute Bronchitis		8-12	Willingness-to-Pay: 28 symptom-days; Dickie and Ulery (2002). | 0-17
Lower Respiratory Symptoms		7-14	Willingness-to-Pay: 2 symptoms 1 day; Dickie and Ulery (2002). | 0-17
Work Loss Days		18-64	Median daily wage; county-specific | 18-65
Acute Respiratory Symptoms		18-64	Willingness-to-Pay: 3 symptoms 1 day, Dickie and Ulery (2002)
HA, Cardiovascular	HA, All Cardiovascular (less Myocardial Infarctions)	65-99	Cost of Illness: med costs + wage loss | 65-99
		18-64	Cost of Illness: med costs + wage loss | 20-64
Asthma Exacerbation		6-18	Willingness-to-Pay: 1 symptom-day; Dickie and Ulery (2002) | 0-17
School Loss Days		5-17	Default BenMAP value | 0-17
Chronic Bronchitis**	Chronic Bronchitis	27-44	Cost of Illness: med costs + wage loss, 3% DR | 27-44
		45-64	Cost of Illness: med costs + wage loss, 3% DR | 45-64
		65-99	Cost of Illness: med costs + wage loss, 3% DR | 65-99

Reports. The final step in the BenMAP analysis is the generation of output reports. BenMAP can display the results of an analysis with comma-separated-value format reports. There are many options for output reports, with varying levels of aggregation and content (e.g., health effects or valuation). Most of the results shown in the following sections come from “pooled valuation” reports. In addition to spreadsheet-style reports, BenMAP can also output an “audit trail” report on any BenMAP file. Audit trail reports are useful to determine what options were chosen and what input files were used to drive an analysis. BenMAP also has a mapping utility, so, in addition to outputting spreadsheet or text files of results, spatial plots of inputs and outputs (averaged over the modeling period) can also be generated.

MACROECONOMIC ASSESSMENT: REMI PROJECTIONS

This section describes the final link in the integrated assessment framework, as macroeconomic effects from strategies are analyzed based on projected costs and savings from NE-MARKAL as well as health benefits from the BenMAP tool. Specifically, the economic impact modeling framework consists of providing the various changes predicted by the NE-MARKAL model runs of sector-specific proposed alternatives to the REMI model. The changes relate to the composition of investment demand, facility operation and maintenance and fuel spending, and cost differentials (by those who would pay them). Also included in the macroeconomic assessment are select (endpoint groups) health outcomes in the form of monetized health benefits derived from the BenMAP tool for the Combination Scenario where such data are available.

THE REMI Model

Since 2003, NESCAUM has subscribed to a 12-state Policy Insight model developed in 1986 by REMI. The 12-state economic forecasting and simulation modeling system, which includes NYS, has enabled NESCAUM to investigate macroeconomic impacts as part of comprehensive analyses of air quality/environmental policy considerations that affect the 12 jurisdictions covered by the model.

The REMI Policy Insight model is a regionally-calibrated computable general equilibrium (CGE) model. Its current version forecasts, on an annual basis, a large set of socio-economic (and approximate 3-digit NAICS industry-level) variables for each region in the model to the year 2050. Forecasting is possible through an extensive set of dynamic (time adjusting) macroeconomic equations, which are routinely re-examined with respect to the embedded econometrically-derived estimates as well as new research based on more recent advances in regional economic literature. The model is refreshed each year to embed the latest available year of historical data. The subscription license used for this study contained historical data through 2007. Though the equation set is too elaborate to present in this document (see REMI *Model Equations* publication, 2008, available at www.remi.com), Figure 2-8 provides the framework for the REMI model logic and the feedback, denoted by arrows, of equations involved to determine specific variables within each major "block" of the regional economy.

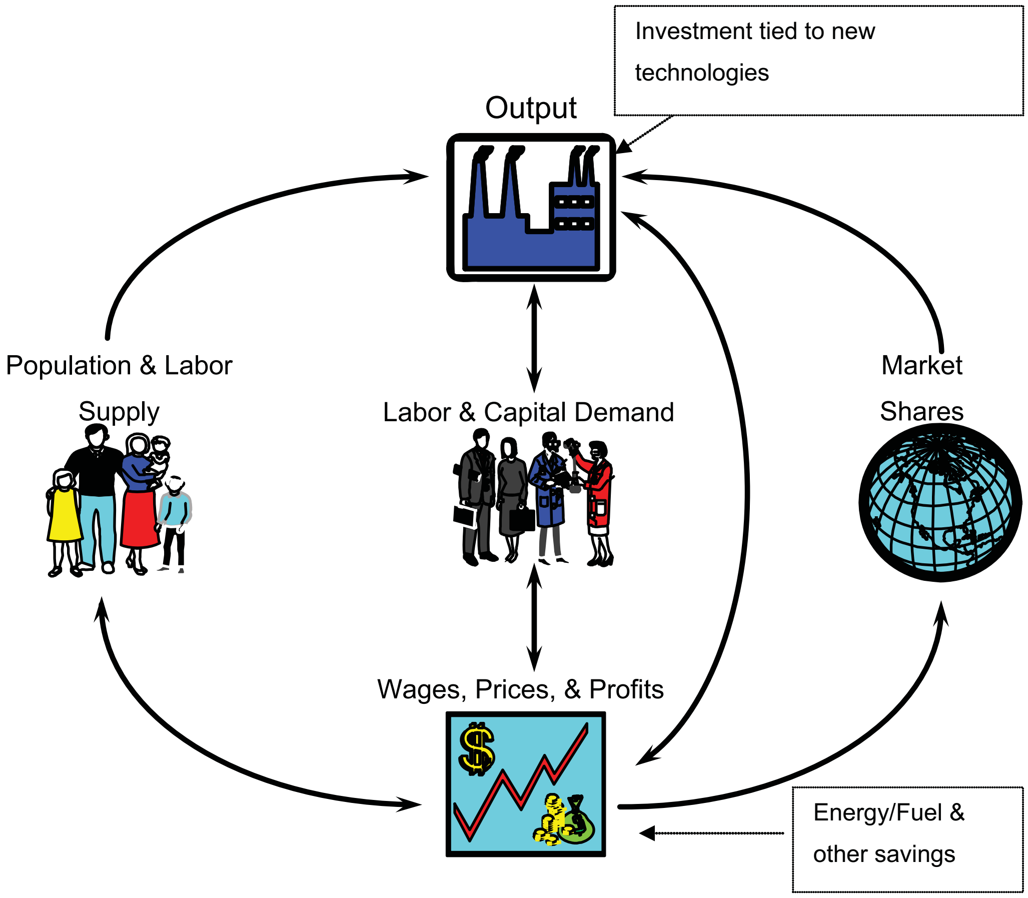


Figure 2-8. REMI Model Structural Framework for a Regional Economy.

The "Output block" consists of output, demand, consumption, investment, government spending, exports, and imports, as well as feedback from output change due to the change in the productivity of intermediate inputs. The "Labor and Capital Demand block" includes labor intensity and productivity as well as demand for labor and capital. Labor force participation rate and migration equations are in the "Population and Labor Supply block." The "Wages, Prices, and Costs block" includes composite prices, determinants of production costs, the consumption price deflator, housing prices, and the wage equations. The proportion of local, interregional, and export markets captured by each region is included in the "Market Shares block."

The forecasting capability can be applied to a base case stance of the regional economy, as well as under the imposition of a policy change. The comparison of the change in a key economic variable in "year T," under the base case and the policy alternative defines the impact. Figure 2-9 portrays this relationship.

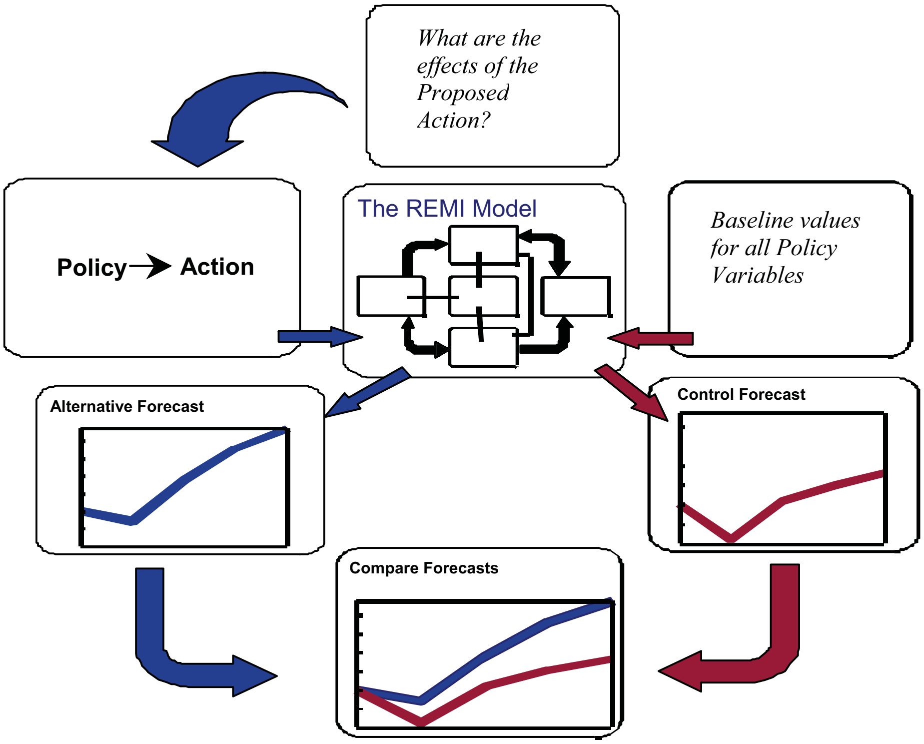


Figure 2-9. Economic Impact Estimation in the REMI Model.

While REMI's equation set renders the model capable of forecasting impacts on many aspects of a region's economic and demographic make-up, there are limits to what the system is designed to handle. Since the model logic is based on economic transactions between businesses (B2B), business and working age households (labor supply), and business and capital goods, it is not suited to work with willingness-to-pay effects. Thus, the model cannot accurately assess the societal willingness-to-pay for avoided cardiac deaths due to reduced fine particle pollution. These monetized benefits are some of the key drivers of the monetized health outcomes discussed in the preceding section; however, these costs and benefits are not analyzed by REMI for this effort.

The model forecasts (in the "base case" setting) are based upon a combination of historical trends, with weighting towards more recent history and current values of key independent variables (economic factors) as solved in the simultaneous equation algorithm. Therefore, the model cannot know, for instance, the complexion of future policy directives that would aim to dramatically alter the industry-mix to achieve some stated goal of within region production for clean technology goods that historically have chosen other locations. A sensitivity analysis was conducted to attempt to provide some insight into the potential effects of complementary policies, but this is admittedly an incomplete picture of potential future economic dynamics that could arise from such policies.

NYS REMI Analysis in the 12-Regional Northeast REMI Model

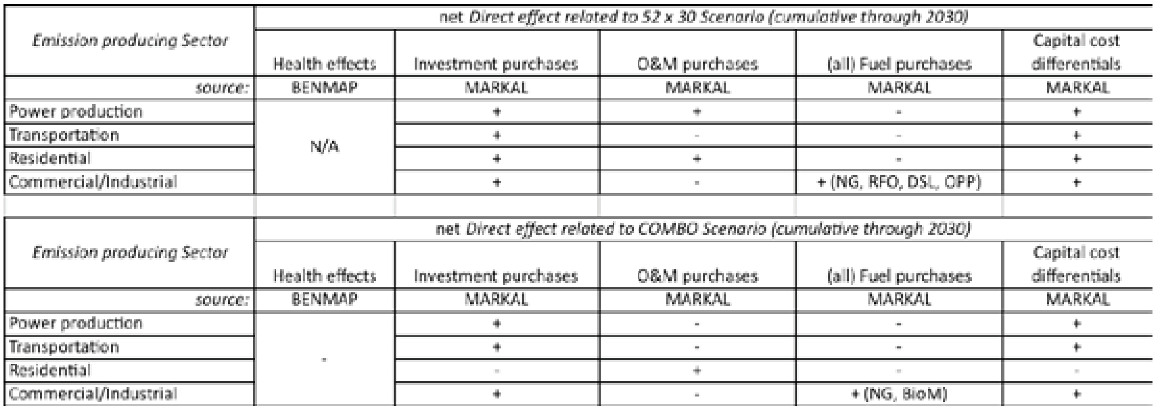
The mechanics of developing the multi-pollutant scenario analysis in the REMI model consists of making a policy lever set for the NYS region in the 12-region model. The policy lever set is what is used to “shoe horn” the information derived from NE-MARKAL (after some additional processing) into the REMI database. Based upon this added information (referred to as the direct effects) and the base case economic forecast, a new forecast is solved, which reflects the NYS economy pursuing a multi-pollutant strategy. The new forecast, when compared against the base case, will undoubtedly define “impacts” or differences when looking at a specific point in time. Those impacts are foremost attributable to the direct effects and then some portion of the impacts are due to subsequent multiplier effects within the NYS economy, and some portion is due to interactions between NYS under this policy setting, and the 11 other states in the larger regional context. Last, there is some portion of the overall NYS impacts attributable to implicit interactions with the rest of world’s economies (which includes the rest of the U.S.) due to trade flows affected by the changes within NYS.

The scenario-specific monetized output from MARKAL was mapped into relevant variable types in REMI (based upon assumptions of how the policy is believed to work, or relying upon default approaches available in the REMI model) and mapped into: (1) relevant industries as affected by shifts in investment demand, changes in operating budgets of facilities, changes in type and location of fuel supplies, and changes in the cost of doing business for the sector-based measures; and (2) the household sector related to costs of household operations (differentials in equipment outlays, fuel expense) and the offset to other household discretionary spending. Table 2-8 through Table 2-11 provide scenario-specific, sector-specific assumptions for guiding the MARKAL outputs into the REMI model.

Table 2-8. Aspects of the Multi-pollutant Scenario Influencing the NYS Economy.

Emission producing Sector	*Modeled as a result of Scenario* "changes in.."				
	Health effects	Investment purchases	O&M purchases	Fuel purchases	Capital cost differentials
Power production	Y	Y	Y	Y	Y
Transportation		Y	Y	Y	Y
Residential		Y	Y	Y	Y
Commercial/Industrial		Y	Y	Y	Y

Table 2-9. a & b: Scenario-specific net Direct Effects to Influence the NYS Economy.



Emission producing Sector	net *Direct effect related to 52 x 30 Scenario (cumulative through 2030)*				
	Health effects	Investment purchases	O&M purchases	(all) Fuel purchases	Capital cost differentials
source:	BENMAP	MARKAL	MARKAL	MARKAL	MARKAL
Power production	N/A	+	+	-	+
Transportation		+	-	-	+
Residential		+	+	-	+
Commercial/Industrial		+	-	+ (NG, RFO, DSL, OPP)	+

Emission producing Sector	net *Direct effect related to COMBO Scenario (cumulative through 2030)*				
	Health effects	Investment purchases	O&M purchases	(all) Fuel purchases	Capital cost differentials
source:	BENMAP	MARKAL	MARKAL	MARKAL	MARKAL
Power production	-	+	-	-	+
Transportation		+	-	-	+
Residential		-	+	-	-
Commercial/Industrial		+	-	+ (NG, BioM)	+

Table 2-10. Biomass Feedstock Allocation by Sector.

Emission producing Sector	*Alternate* Fuel Providing sectors		
	Biomass-AGRIC	*Biomass-FOREST*	Ethanol
Power production	37%	63%	*na*
Transportation	*na*	*na*	Y
Residential	37%	63%	*na*
Commercial/Industrial	37%	63%	*na*

Table 2-11. Transportation Sector Light-duty Fleet Allocation.

	Fleet Composition		
Transportation Sector	Residential	Commercial	Government
	96.5%	2.2%	1.3%

While this mapping for the REMI structure and set of assumptions is necessary to translate NE-MARKAL outputs into meaningful REMI input parameters, additional rules are needed to ascribe changes in spending into changes in sales from NYS firms. These rules include the following:

- Biomass feedstock comes from NYS-based farming and forestry operations
- Vehicle O&M purchases are fulfilled in-state
- Vehicle fuel purchases affect retail (in-state), wholesale (in-state), and petroleum product manufacturing activities
- Residential and Commercial/Industrial existing fuel purchases are fulfilled through the utility sector
- For the Commercial/Industrial sectors, the wholesale and repair services components of O&M spending changes are fulfilled in-state

- All remaining aspects of changes in spending are treated as a change in demand arising from NYS households or power producers or Commercial/Industrial businesses, and therefore are exerted to the NYS REMI model's industry-specific (measured) regional purchase coefficients
- Capital goods investment into the future allocates over various NAICS industries depending on the multi-pollutant sector, and the technology within the sector. This was handled as changes in (future) demand and relies upon the NYS REMI model's industry-specific (measured) regional purchase coefficients.

Finally, rules are also needed for directing the key scenario elements into the macro modeling and include the following:

- For every change in a scenario-specific household spending item there is an equal but opposite effect on the remaining consumer basket
- For every change in a scenario-specific commercial/industrial establishment spending item there is a commensurate change in its cost-of-doing business in NYS
- Power producers' change in costs (e.g. capital, operating, and fuel) will be borne fully by ratepayers in NYS, and allocated as follows: residential 44%, commercial 41%, and industrial 15% (shares based on historical system benefit charge revenue data from NYSERDA, adjusted to reflect multi-family dwellings under the residential segment instead of the commercial segment).

An additional component of the macroeconomic assessment looks at the macro impacts of monetized public health costs and savings. Just as with the NE-MARKAL results, a set of rules for ascribing changes in health outcomes into economic events in the NYS economy:

- Individuals' changes in morbidity-related health expenses (evaluated at a total scenario level) affect household out-of-pocket at 17% of the cost of illness (source: http://www.healthreform.gov/reports/out_of_pocket/index.html); there is an equal but opposite effect on the remaining consumer basket
- The full amount of changes in the cost of illness affects 1:1 activity of NYS-based health care services providers
- Changes in the wage value of worker loss days, once re-stated as the commensurate output (sales) affected, signals a change in labor productivity at NYS-based businesses (e.g. fewer work days lost leads to increased labor productivity)

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Section 3

APPLYING THE MULTI-POLLUTANT POLICY ANALYSIS FRAMEWORK TO NYS: A CASE STUDY

INTRODUCTION

Air Quality and Climate Planning in NYS

NYS has a history of being a leader in environmental stewardship and fostering policies that improve environmental and public health. In 1984, NYS enacted the State Acid Deposition Control Act to lower in-state SO_2 and NO_x emissions beyond federal requirements. Such actions accelerated ecosystem recovery in the sensitive ecosystems of the Adirondacks.[18] In 1996, the Environmental Bond Act ushered in numerous environmental programs, including preserving lands for future generations, brownfields cleanup, and the Clean Fuel Bus Program.

Recognizing the challenges of increasingly expensive energy production and its contribution to ambient air emissions, NYS has become a national leader in promoting energy efficiency and clean energy development. It has also required strict limits on emissions through various mechanisms, including tax credits, regulations, and policies.

NYS initiated the discussions that led to the RGGI, an effort by the Northeast and Mid-Atlantic States to reduce GHG emissions through a cap-and-trade program.[19] Leadership in energy initiatives such as the Energy $mart Program, renewable portfolio standards, and energy efficiency portfolio standards will lead to greater energy efficiency, electric system reliability, and emissions reductions. Innovative use of allowance set-asides in EPA's Clean Air Interstate Rule (CAIR) program were designed to accelerate these changes. In 2007, a high-level policy group, the Renewable Energy Task Force, set new goals for increased energy efficiency and renewable energy for the State.

On Earth Day 2007, New York City released PlaNYC, a comprehensive sustainability plan. PlaNYC puts forth a strategy to reduce the City's GHG footprint while accommodating a population growth of nearly one million, and improving its infrastructure and environment.

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[18] NAPAP, 2005. National Acid Precipitation Assessment Program, Report to Congress: An Integrated Assessment, NAPAP project office, Washington, D.C., Available at: http://www.esrl.noaa.gov/csd/aqrs/reports/napapreport05.pdf

[19] See: http://rggi.org/home

All of the above initiatives will result in some degree of lowering SO_2, NO_x, CO_2, PM, Hg, and other air toxics emissions. They will also positively affect public health, ecosystem recovery, and climate. Understanding how various energy and control technologies can yield emissions impacts for a broad range of pollutants, and understanding their effects on public health, environment, and the economy, is critically important in order to avoid unintended consequences.

Integrated Planning

Identifying Environmental Goals and Targets. The first major task for this effort was to identify environmental goals and targets. For the purposes of this analysis, goals were considered to be the environmental endpoints. Targets were used to establish plausible reduction levels that may be necessary to achieve the environmental endpoints. The goals were established to represent indicators of air quality and climate change mitigation, and assisted in developing a set of environmental targets and constraints for the modeling exercise. NESCAUM, NYSDEC, and NYSERDA reviewed pending Clean Air Act requirements, state and regional environmental policies, and major NYS energy efficiency (EE) and renewable energy (RE) policy initiatives, NYS SIP requirements for attaining the ozone and PM2.5 NAAQS, climate action plans, regional haze reasonable progress goals, and critical loads for sensitive ecosystems for mercury and acid deposition.

NYSDEC chose to frame the project's environmental goals through the lens of its Commissioner's environmental issue priorities and actions for the Agency at the time.[20] Within this context, NYSDEC developed a list of air and climate goals that arose from the federal Clean Air Act and NYS executive orders, statutes, regulations, and policies. The model constraints that were subsequently developed by NESCAUM, and approved by NYSDEC and NYSERDA, were designed to conform to existing state and federal requirements and deadlines.

After the environmental goals were identified, NYSDEC identified and assigned emission reduction targets based on work done by NYSDEC and through regional efforts such as the Ozone Transport Commission (OTC) and MANE-VU. The targets were best estimates of the magnitude of emission reductions needed to meet the established environmental goals based on past modeling that indicates the environmental response for a given reduction, or the environmental sensitivity to emissions. These targets were then used as indicators for the analysis of the chosen programs and policy options.

The goals and targets were represented in the NE-MARKAL model or other modules of the MPAF framework as a set of emission constraints that evolved over time to achieve the approximate reductions in

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[20] For the Commissioner's environmental priorities as of March 21, 2012, see: http://www.dec.ny.gov/about/80503.html . This web address is subject to change,

NO_x, SO_2, Hg, CO_2, and primary $PM_{2.5}$ emissions needed to achieve the state's climate and air quality goals.

Identifying Programs and Scenarios to be Analyzed. Another major task for this effort was developing a set of programs that could be represented in the modeling framework. As part of its broader air quality planning effort, NYSDEC had already identified a number of emission reduction opportunities through forums such as its SIP development efforts, OTC, and MANE-VU. Added to this list were primarily climate and energy programs that lent themselves to analysis through the NE-MARKAL model.

A key consideration was whether and how the NESCAUM framework could represent the various programs. Given that NE-MARKAL is a data-intensive technology optimization model, some programs would not be well represented in this model. Those programs, however, may be important in SIPs or achieving other air quality goals. To address this limitation, NESCAUM and NYSDEC conducted exogenous analyses so that those programs could be represented in other MPAF modules (e.g., CMAQ or REMI). For example, the RGGI targets included in the Reference Case were drawn from a previous IPM analysis and low-sulfur fuel program costs were estimated based on industry analysis.

Given that the framework assesses all programs simultaneously, the analytical goal was to identify and probe the key factors to which the optimization is most sensitive. Individual cases identify tradeoffs between timing of programs versus stringency, as well as the response to individual technologies. Once the overall responses are understood, creating scenarios around these key factors provide insight into the implications of alternative projections, thus serving decision-makers as they consider policy recommendations in the face of uncertainty. For example, cost of fuel and rate of technology development have a huge impact on the feasibility of many programs. Another factor driving the choice of programs in this analysis was the level of desired GHG reduction. For example, the 30% carbon equivalent reduction identified for 2020 (52% reduction by 2030) was a binding constraint on the system that, in turn, would drive technological change the most.

NESCAUM recommended that five primary sets of multi-sector policy scenarios be constructed for analysis using NE-MARKAL that assessed the implications of alternative technology deployment relative to an agreed-upon Reference Case representing the "business as usual" approach to technology evolution. The five sets of scenarios were as follows:

1. A comparison of an economy-wide carbon cap to the sum of smaller individual abatement measures (i.e., policy levers);
2. A combination of several of the most promising options based on previous individual policy lever analyses -- by identifying the most effective individual policy levers and comparing the technical

potential of several options, NESCAUM was able to select a set of policy levers options that could maximize reductions and minimize price;

3. A combination of reasonable levels of all policy levers -- for this set of scenarios, NESCAUM examined the extent to which GHG targets alone were driving the degree of technology change and costs. By examining the system without the GHG constraint (Scenario 1), NESCAUM was able to examine the extent to which this factor was an important constraint on the system;
4. A sensitivity of results to fuel prices -- for this set of scenarios, NESCAUM examined the price sensitivity of the solutions with respect to the unknown future cost of oil, gas, and coal. Given that this scenario would be the driving influence on the previous set of scenarios, NESCAUM opted to explore a combined set of “high fuel price/high technology deployment” and “low fuel price/low technology deployment” scenarios;
5. A sensitivity of results to the cost of advanced technology -- for this set of scenarios, NESCAUM examined the effects that advanced technology deployment would play in enabling a rapid reduction in carbon, criteria pollutant, and toxic emissions at a reasonable cost. A moderate technology case included advanced technology deployment consistent with past historical practice. A high technology case included more rapid introduction of key enabling technologies such as printable solar cells or fuel-cell vehicles powered by hydrogen production facilities using carbon sequestration.

NYSDEC first identified a comprehensive suite of programs for consideration to meet its environmental goals. From this list, NESCAUM then identified which of those programs were best suited for analysis through the NE-MARKAL model (see Table 3-1) and which would be analyzed through other modules of the MPAF. Once the programs for the NE-MARKAL modeling were identified, they were incorporated as modeling constraints and made available for the model to select as cost-effective technological approaches to satisfy environmental goals and targets.

Table 3-1. NYSDEC Environmental Priority and Actions, Project Goals, and Programs Analyzed through NE-MARKAL.

NYSDEC Priority	NYSDEC Actions	Project Goals (and Timelines)	Types of Programs to be Analyzed in NE-MARKAL
Combat Climate Change	▪ Reduce greenhouse gas emissions ▪ Encourage low-carbon design technologies ▪ Elevate climate change awareness, research and adaptation ability ▪ Foster carbon sequestration and sustainable forestry ▪ Lead state agencies' efforts to tackle climate change	▪ Achieve the Renewable Portfolio Standard goal of 25% of energy to be produced from renewable sources. (2013) ▪ Implement "15 by 15," a comprehensive plan to reduce energy demand and curb pollution in New York by reducing electricity demand by 15% from forecast levels by 2015. (2015) ▪ Achieve a 10% reduction in vehicle miles traveled. (2020) ▪ Achieve a 30% reduction in CO_2e emissions. (2020) ▪ Achieve an 80% reduction in CO_2e emissions. (2050)	▪ Renewable Portfolio Standard ▪ Residential and Commercial Building Efficiency ▪ Transportation Efficiency Standards ▪ Vehicle Miles Traveled (VMT) Reduction Programs ▪ Fuel Switching ▪ Power Sector (repowering) ▪ Municipal Solid Waste ▪ Transmission Efficiency ▪ Combined Heat and Power (CHP)
Foster Green and Healthy Communities	▪ Use NYSDEC's program areas to encourage smart growth ▪ Clean up contaminated land, especially in urban centers ▪ Attain and maintain all National Ambient Air Quality Standards	▪ Attain the 0.08 ppm 8-hour ozone standard in the Poughkeepsie, NY; Buffalo – Niagara Falls, NY; and Jamestown, NY non-attainment areas (based on 2007-2009 ambient data). (2010) ▪ Attain the 15 ug/m^3 annual $PM_{2.5}$ standard in the New York-N. New Jersey-Long Island, NY-NJ-CT-PA non-attainment area (based on 2007-2009 ambient data). (2010) ▪ Attain the 0.08 ppm 8-hour ozone standard in the New York – N. New Jersey – Long Island, NY-NJ-CT non-attainment area (based on 2010-2012 ambient data). (2013) ▪ Attain the 0.075 ppm 8-hour ozone standard in the Albany-Schenectady-Troy, NY; Essex Co. (Whiteface Mountain), NY; Jefferson County, NY; Syracuse Area, NY; and Rochester, NY projected to be marginal non-attainment areas. (2013)	▪ Industrial Efficiency ▪ Distributed Generation ▪ NO_x RACT ▪ Solar Thermal ▪ Increase clean transportation technologies (e.g. clean diesels, hybrids, electric vehicles)

		▪ Attain the new (2006) 24-hour $PM_{2.5}$ NAAQS of 35 $\mu g/m^3$ in the New York-N. New Jersey-Long Island, NY-NJ-CT-PA nonattainment area. (Approximate attainment date is March 18, and would incorporate 2011-2013 ambient data). (2014) ▪ Attain the 0.075 ppm 8-hour ozone standard in the New York – N. New Jersey – Long Island, NY-NJ-CT; Poughkeepsie, NY; Buffalo – Niagara Falls, NY; and Jamestown, NY projected to be moderate non-attainment areas. (2016)	
Connect New Yorkers to Nature	▪ Preserve and provide access to green space close to where people live, work and play	▪ Promulgate and fully implement, by January 1, a Best Available Retrofit Technology (BART) regulation that addresses haze and other pollution for older stationary sources. (2013) ▪ Meet regional haze reasonable progress goals as established through MANE-VU under the Clean Air Act. (2018)	▪ Clean Air Interstate Rule (CAIR)
Promote a Toxic-Free Future	▪ Reduce waste and use of toxics ▪ Promote green alternatives and technologies ▪ Enhance public access to information on toxics	▪ Achieve a statewide average of 50% reduction in emissions of diesel particulate matter, especially polycyclic organic matter (POM) formaldehyde, acetaldehyde, diesel particulate matter, and 1,3-butadiene. This should coincide with the 2014 24-hour $PM_{2.5}$ NAAQS of 35 ug/m^3. (2014) ▪ Reduce ambient nickel concentrations associated with the burning of distillate and residual oil in downstate urban areas to coincide with the 2014 24-hour $PM_{2.5}$ NAAQS of 35 ug/m^3. (2014) ▪ Full implementation of 6NYCRR Part 246, Mercury Reduction Program for Coal-fired Electric Utility Steam Generating Units to help achieve regional Total Maximum Daily Load (TMDL) projections. (2015)	▪ Increased Renewables

		▪ Achieve a 75% reduction in benzene emissions statewide, equating to an overall statewide average monitored level of 0.2 ug/m^3. This should coincide with the 2016 8-hour ozone standard of 0.075 ppm for moderate non-attainment areas. (2016)	
Safeguard New York's Unique Natural Assets	▪ Conserve, protect and restore watersheds and coastal resources ▪ Protect biodiversity and unique ecosystems across New York	▪ Make progress toward achieving critical loads at all areas that currently exceed critical loads for deposition of sulfur, nitrogen, and mercury. (2018)	▪ Low-Sulfur Fuel Standards

After consideration of the NE-MARKAL results, a Combination Scenario consisting of seven of the most effective policy levers was examined (relative to the Reference Case) in CMAQ and BenMAP, and the health costs and benefits of this scenario were then carried into the macroeconomic assessment using the REMI model. The analysis of this scenario with all of the components of the MPAF provides the proof-of-concept for using this set of integrated assessment tools for future air quality and energy planning.

NE-MARKAL RESULTS: AIR EMISSIONS AND ENERGY PROJECTIONS

As the centerpiece of the MPAF, the results from the NE-MARKAL model are what drive the subsequent modeling platform and the air quality, economic, and public health results. The NE-MARKAL results comprise the component that relates most directly to policy goals and implementation requirements, as they are where energy producing, transforming, and consuming technologies – and the largest pollution sources – are most directly represented. This Section provides an overview of the Reference Case results, followed by a description of sector-specific results and overarching scenario results, all in terms of technology deployment, emissions, and cost. The sector-specific simulations describe how various policies were represented in the model and the model responses to imposing specific constraints intended to represent one or more policies. The overarching scenarios look at multi-sector simulations where multiple constraints are imposed under a variety of circumstances reflecting different plausible future circumstances (e.g. price or technology deployment sensitivities). These simulations can serve as a demonstration of the analytical capacity required to examine the selected breadth of policy options available to NYS.

For this effort, NESCAUM first developed the Reference Case for NE-MARKAL analysis, which represents a “business-as-usual” evolution of the State’s energy infrastructure over a 30-year timeframe. Appendix A documents the baseline assumptions of the NE-MARKAL model, and includes base year demand by sector and projections extending to 2029. The technologies available in the model are also detailed in Appendix A, and include estimates of investment costs and efficiencies. Initial model constraints on fuel share and technology penetration rates are also provided. NESCAUM consulted with

NYSDEC and NYSERDA in reviewing and finalizing the NYS input assumptions for this analysis and calibrating the model.

After developing the Reference Case consistent with 2009 NYS Energy Plan reference scenarios, NESCAUM then built the policy scenarios for analysis, and compared the results for each case individually to the Reference Case results. This study focused on the list of policies in Table 3-1. In addition, the five policy scenarios were modeled that examined price sensitivity, technology sensitivity, a comparison of a carbon cap to individual policy levers, and a combination of the most promising opportunities from each sector. The key results of each policy scenario are presented below, including a summary of each scenario's climate implications.

Reference Case Results

The reference case serves as a basis for comparison for all policy scenarios analyzed. **It is important to note that NE-MARKAL is not appropriately used as a forecast tool, thus the reference case should not be considered as a "prediction" of future events absent major policy changes.** Rather, the reference case was developed as one of many plausible future outcomes that will be influenced by factors simulated within the framework. While any simulation result is characterized by technology deployment, cost, and emissions, each simulation – and the Reference Case in particular - is shaped by the database used and the assumptions or constraints placed on the system. The NE-MARKAL database was developed over many years from national, state, and local sources, and is documented elsewhere.[21] The Reference Case assumptions used for this analysis are what the project team identified as the most likely plausible future outcome at that point in time.

Given the structure of NE-MARKAL, results are best expressed in terms of the various sectors that compose the model. For NYS, the supply side consists of the quantities of various energy commodities purchased from outside the state at a price (i.e. coal, oil, gas, and electricity imports) and electricity generated within the power sector. The commodities are essentially model inputs and are described in Appendix A.

The Power Generation Sector. Figure 3-1 shows technology deployment in the power sector, as determined by NE-MARKAL, in response to Reference Case assumptions, including the RGGI program. There is an increase in natural gas and hydroelectric generation projected at a rate of 2 and 0.3% per year, respectively. This new generation accounts for the projected increase in demand. Coal, oil, nuclear, and renewable energy remain relatively stable throughout the model horizon. The changes reflect the least-cost means of satisfying the CO_2 emissions reductions required under the RGGI program while allowing for the

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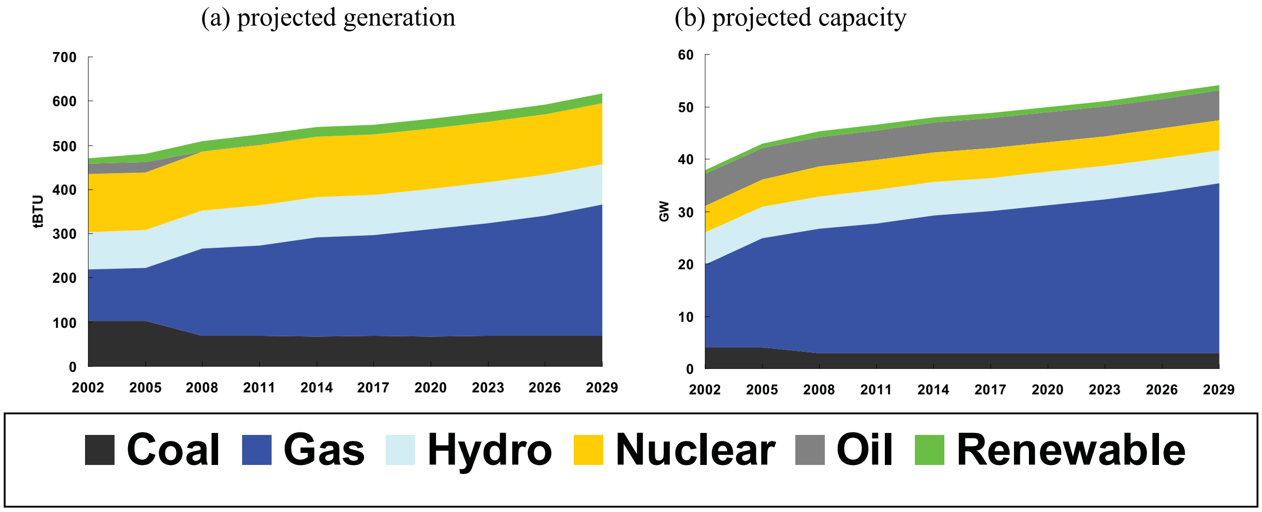
[21] Goldstein, G.A., L.A. Goudarzi, P. Delaquil, E. Wright. NE-12 MARKAL Final Report: Structure, Data and Calibration, NESCCAF, June 2008. (See: http://www.nescaum.org/topics/ne-markal-model/ne-markal-model-documents)

capacity expansion required to meet overall electric demand. NYS's Renewable Portfolio Standard (RPS) requires 30% of the State's electricity generation to come from renewable sources by 2015, but is not included in the Reference Case. It is analyzed as a distinct policy option in the power sector analysis.


(a) projected generation

(b) projected capacity

Figure 3-1. Power Sector Technology Deployment for NYS Reference Case.

NE-MARKAL uses estimates of future demand for energy services as an input and, as shown below, creates a cost-optimized evolution of demand technologies and infrastructure as a critical output. This set of technologies can be directly compared to goals needed for specific policy measures and may assist in designing programs to meet broad environmental goals (e.g., GHG reductions). The two other outputs of the model, technology-specific emissions and costs, are also important in estimating environmental and economic implications of achieving these policy goals.

Figure 3-2 shows projections of aggregate emissions from all technologies included within the NE-MARKAL representation of NYS's power generation sector. This figure shows reductions in emissions in the 2008 timeframe likely due to some known plant closures and stabilization of CO_2 emissions due to RGGI constraints. Eventually, demand for new generation pushes up CO_2 emissions slightly in the out years.

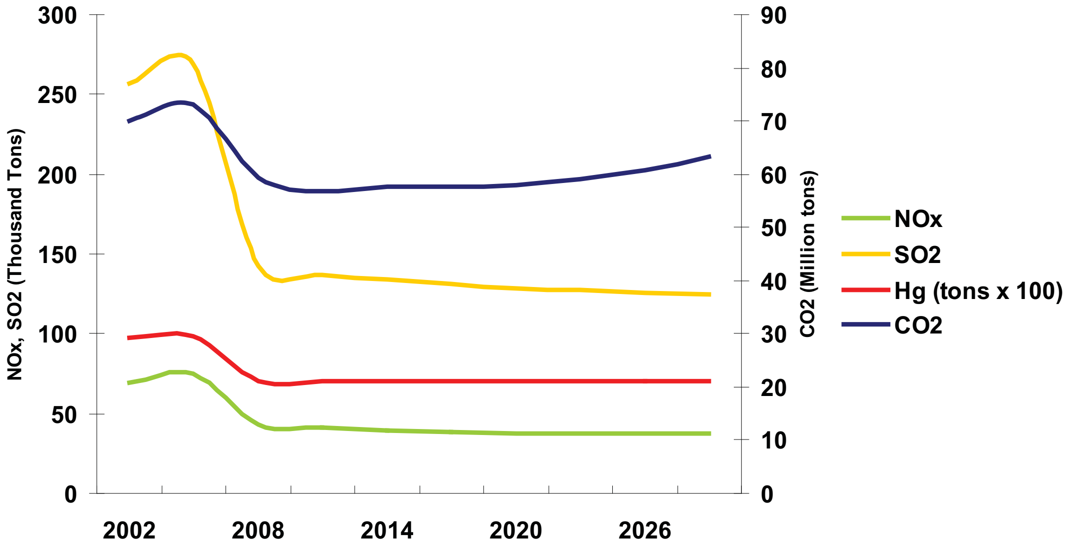


Figure 3-2. Annual Power Sector Emissions Projections for NYS Reference Case.

With respect to cost, the total system cost (i.e., the cost of running NYS's energy infrastructure, including capital investment, operations and maintenance, and fuel) between 2008 and 2029 is estimated at over $178 billion (in 2008 US dollars). While this may appear to be a significant cost, it has relatively little meaning from an analysis perspective. Rather, the *change* in total system cost in response to a policy will be useful in determining costs or benefits from an economic perspective. The cost of power generation in the State includes capital costs required to build and improve power plants on an annualized basis as well as the fixed and variable costs associated with operations and maintenance of power generation facilities. Table 3-2 shows these annualized costs and the fuel expenditures for this sector. It is important to balance any increased capital costs for more efficient or lower emitting technologies against the fuel savings that can accrue over the lifetime of the project.

Table 3-2. Annual Power Sector Cost Assumptions for NYS Reference Case.

Costs of NYREF (2008 $ Billion US)	Capital cost (Billions)	Fixed & variable costs (Billions)	Fuel costs (Billions)
Annual for 2008	0.13	2.3	5.3
Annual for 2029	0.52	2.4	5.6
Cumulative (2008-2029)	7.5	56	115

The Transportation Sector. The demand side of NE-MARKAL consists of the transportation and industrial sectors and residential and commercial buildings. The transportation sector Reference Case results are driven to a large degree by the minimum technology constraints imposed on the system to reflect consumer behavior. Table A-15 of Appendix A lists the specific constraints for this sector, but it is the minimum share of small trucks, which increases from 22.8% in 2002 to over 33% in 2029, that drives much of the resulting efficiency projections. Figure 3-3 shows light-duty transportation sector technology deployment over the model horizon. Traditional internal combustion engines dominate the light-duty fleet with a small amount of gasoline hybrids projected to enter the market over the next two decades. Fuel cell technologies are projected to begin to be economical in 2029, entering the market at the end of the modeling horizon.

Heavy-duty vehicles represent only 13% of total transportation sector energy consumption, but produce a disproportionate share of black carbon and fine particulate pollution. Several of NYS's environmental policies are directed at this sector, thus it is important to examine how these technologies are projected to change under the various proposed policies. Figure 3-4 shows heavy-duty vehicles by technology type for the Reference Case.

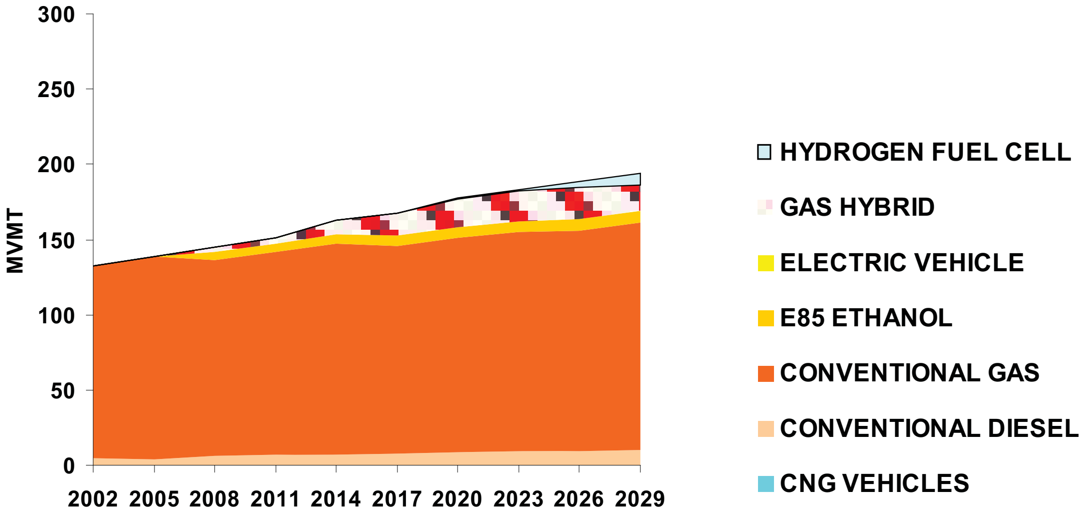


Figure 3-3. Light-duty Vehicle Technology Deployment Projections for NYS Reference Case.

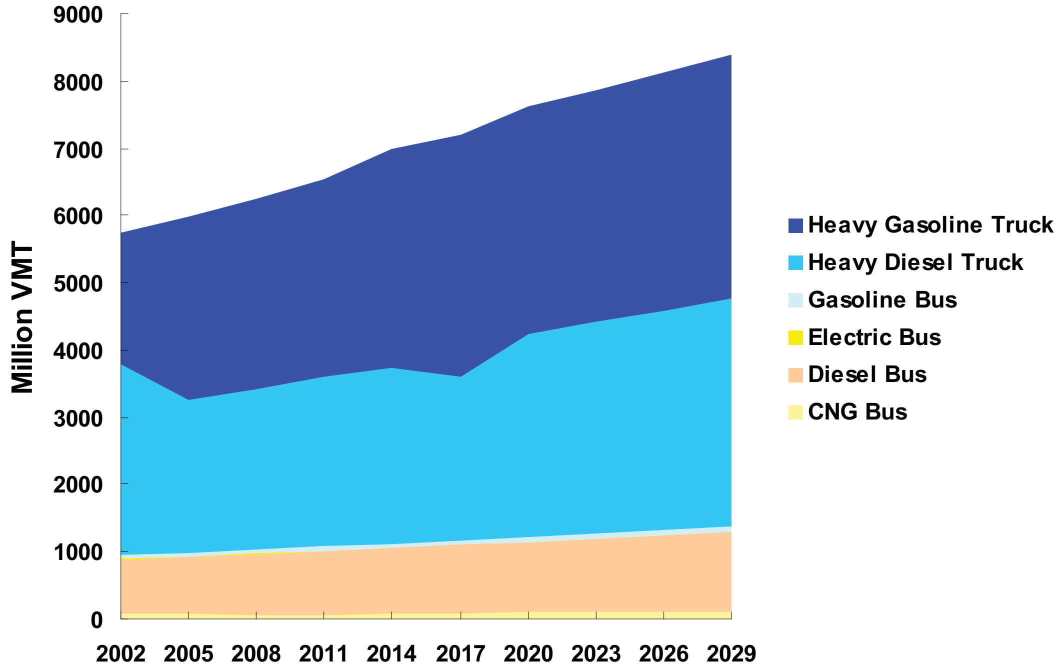


Figure 3-4. Heavy-duty Vehicle Technology Deployment Projections for NYS Reference Case.

Fuel shares are of equal importance to technology shares in the transportation sector, as many of the potential policy choices relate to fuel switching as well as technology shifting (e.g., ethanol, compressed natural gas (CNG), hydrogen). Figure 3-5 shows fuel shares for the transportation sector under the Reference Case. Gasoline and diesel are projected to remain as the predominant transportation fuels absent any policy change. Note that we constrained CNG to no more than 1% of total transportation fuel consumption; we chose to do so because the fuel price projections do not include important economic factors such as the cost of building CNG infrastructure or technology development. Because these factors are excluded, CNG would be viewed by the model as one of the least expensive fuel options and would therefore be artificially attractive. If CNG was viewed as a key potential strategy, then infrastructure costs that would enable widespread deployment of CNG technologies would need to have been added to the model.

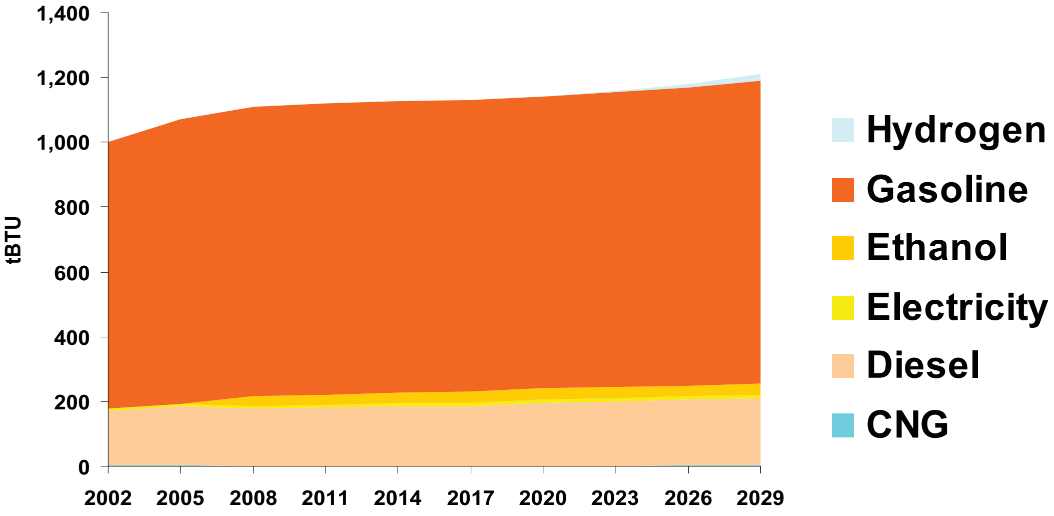


Figure 3-5. Projected Transportation Fuel Shares for NYS Reference Case.

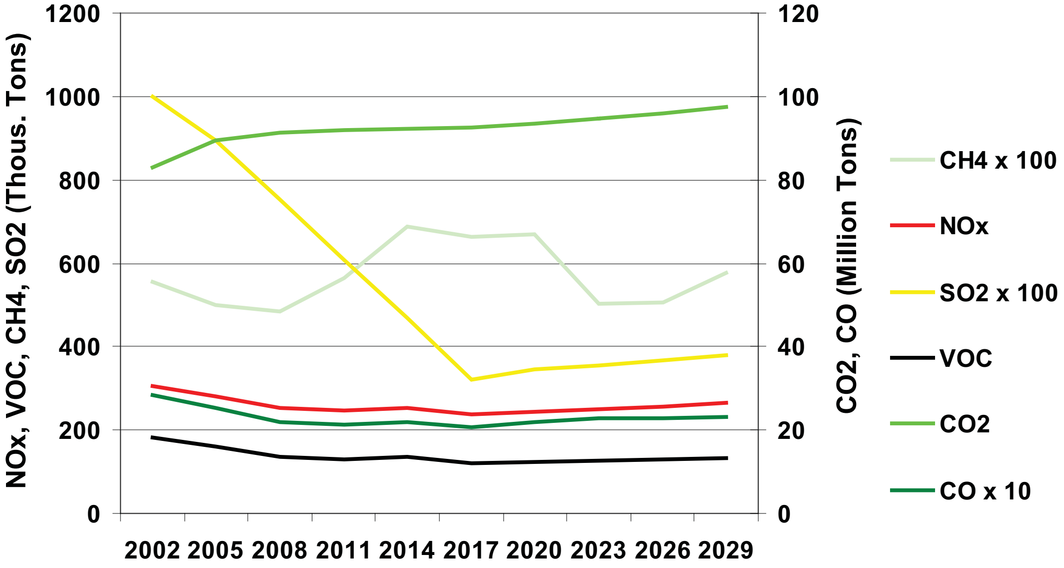


Figure 3-6. Transportation sector emissions projections for NYS Reference Case.

Emissions from the transportation sector are comprised of many pollutants, including CO_2, NO_x, SO_2, CO, VOC and methane. The latter two compounds are associated with ethanol production. Methane is a powerful GHG and additional emissions must be considered in discussing tradeoffs between conventional gas and ethanol technologies. Emissions of key transportation sector pollutants are shown in Figure 3-6.

The cost of transportation in NYS includes capital costs required to purchase new vehicles (both light-duty and heavy-duty) on an annualized basis, as well as the fixed and variable costs associated with operations and maintenance of these vehicles and bus and freight systems. Table 3-3 shows annualized costs as well as the fuel expenditures within this sector for the Reference Case.

The Industrial Sector. Industrial sector energy demand covers a generic set of process technologies in the manufacturing industries depicted in Figure 3-7[22]. The U.S. Department of Energy's (DOE's) Manufacturing Energy Consumption Survey (MECS) was used to map industrial energy consumption reported in the Annual Energy Outlook 2006 forecast into a set of processes common to all industries modeled. These processes include process heating, steam usage, electro-chemical devices, machine drives, petro-chemical feed stocks and other industrial process demands. As these technologies are allowed to age and be replaced by more efficient vintages, the energy consumption profile of the sector changes in response to the least-cost optimization. The Reference Case industrial sector fuel consumption is shown in Figure 3-8.

Table 3-3. Annual Transportation Sector Costs for NYS Reference Case.

Costs of NYREF (2008 $ Million US)	Capital cost (Millions)	Fixed & variable costs (Millions)	Fuel costs (Millions)
Annual for 2008	16	5.8	23
Annual for 2029	52	8.1	19
Cumulative (2008-2029)	320	56	146

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[22] The National Energy Modeling System (NEMS) reports energy consumption by North American Industrial Classification System (NAICS) code for the manufacturing sector. Paper 322, Metal 3311-3313, Chemicals 325, Durables 332-336, Glass & Cement 3272-3273, Other Manufacturing 339.

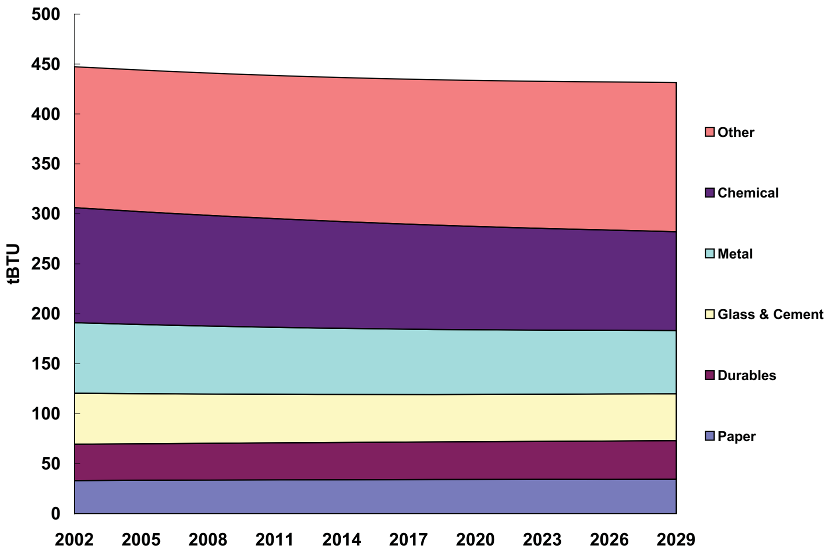

Figure 3-7. Manufacturing Industry Shares Projections for NYS Reference Case.

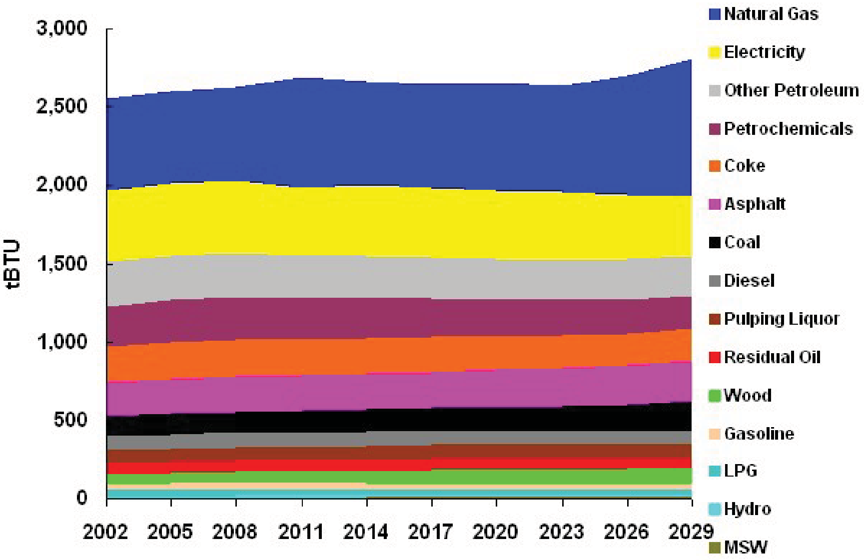

Figure 3-8. Projected Industrial Sector Energy Consumption for NYS Reference Case.

The Residential and Commercial Building Sector. Residential and commercial buildings consume half the energy in NYS. A wide variety of end-use demands are responsible for this consumption, but heating, cooling, and lighting are the largest energy categories. Figure 3-9 a and b show end-use demand shares for residential and commercial buildings for the Reference Case. As with the industrial sector, the replacement rate and the efficiency profile of replacement technologies determine future consumption in the model. Figure 3-10 a and Figure 3-10 b show the energy consumption by fuel type for these sectors.

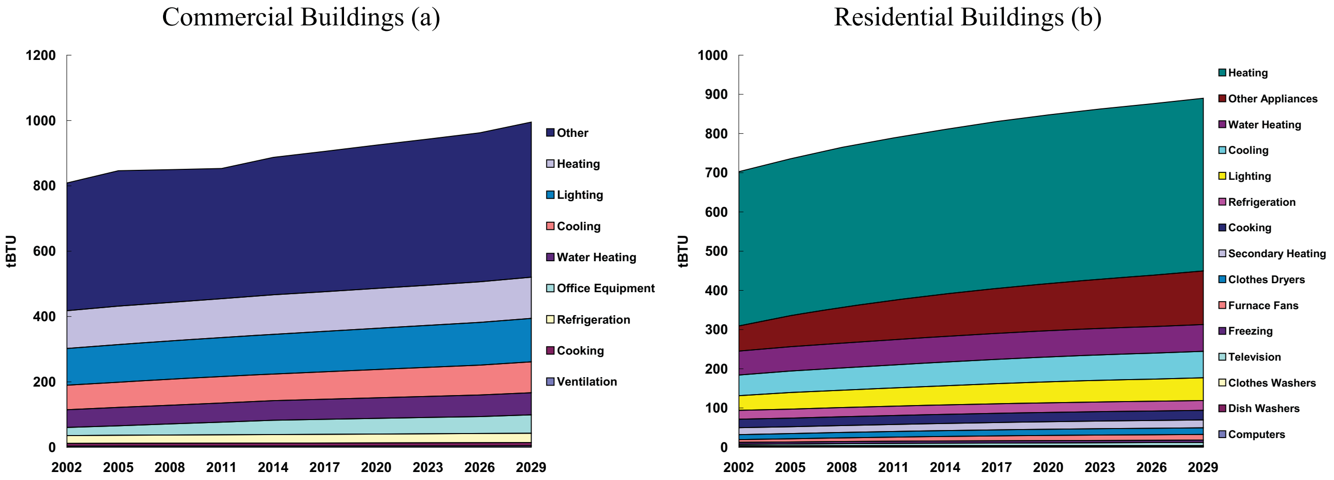

Figure 3-9. Projected Commercial Sector (a) and Residential Sector (b) Building End-use Demand Shares for NYS Reference Case.

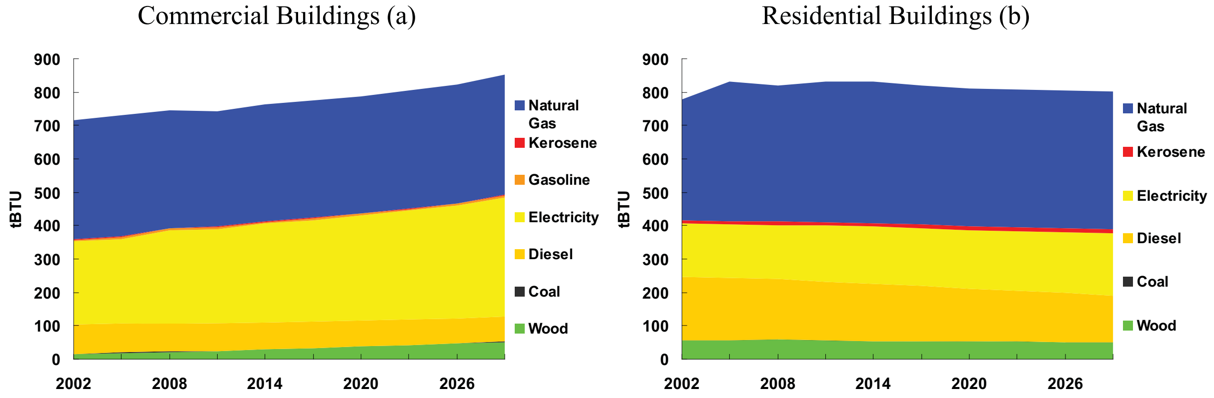

Figure 3-10. a and b Commercial Sector (a) and Residential Sector (b) Building Energy Consumption Fuel Shares by Fuel Type for NYS Reference Case.

Non-technology approaches to energy efficiency (e.g., household insulation, low emissivity glass, building codes) and retrofit efficiency opportunities for existing technologies (e.g., hot water heater blankets, programmable thermostats) are represented by conservation technologies that are made available to the model, which can satisfy a fraction of the demand at a given cost (corresponding to program costs for an efficiency measure). These technologies are not allowed to enter the Reference Case as they represent market failures. These are negative cost options that the model would always choose to buy in the greatest quantity available. By constraining them out of the Reference Case, we were able to gauge the effects of adopting these options in an energy efficiency scenario.

Figure 3-11 shows aggregate combined emissions and Table 3-4 lists aggregate costs from all technologies included within the NE-MARKAL representation of NYS's residential, commercial, and industrial (R/C/I) sector.

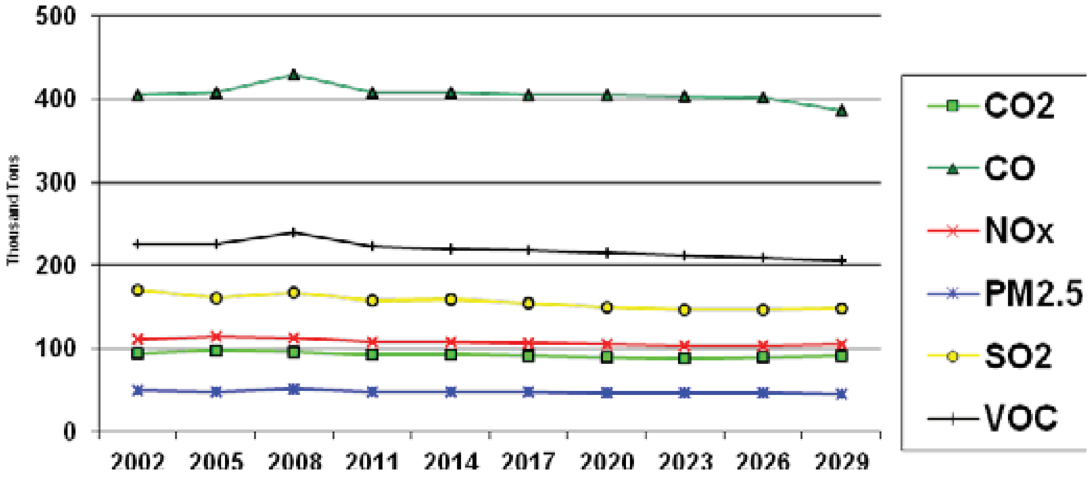

Figure 3-11. Projected Residential, Commercial, and Industrial Sector Emissions for NYS Reference Case.

Table 3-4. Annual R/C/I Sector Costs for New York Reference Case.

Costs of NYREF (2008 $ Billion US)	Capital cost (Billions)	Fixed & variable costs (Billions)	Fuel costs (Billions)
Annual for 2008	6.1	4.6	46
Annual for 2029	15	5.2	42
Cumulative (2008-2029)	98	39	305

Sector-Specific Policy-Lever Analyses and Results.ector-specific analyses typically provide information on system responses to individual policies within a single sector. NYS's goal of an 80% reduction in GHG emissions by 2050 implies much more dramatic and significant shifts in the energy infrastructure than what is typically tested within sector specific analyses. In this context, the individual single-sector analyses are therefore more appropriately viewed as an extension of the calibration process to develop the Reference Case. Hence these analyses tested the model responses to individual programs and policies (i.e., policy levers) to ensure that appropriate responses were produced as a result of a given system constraint. After simulating a wide variety of policy levers for each sector that produced rational responses, a combination of policy levers could then be examined simultaneously under different scenarios (e.g., high cost, high technology).

Power Generation. A significant portion of GHG and criteria pollutant emissions are due to electricity generation. Historically, this sector has played a central role in air quality planning due to the large volume and nature of its emissions; tall power plant stacks allow for transport and dispersion of emissions over vast regions of the globe. For this analysis, several policy options for additional control were considered in order to meet the Commissioner's goals for combating climate change, fostering clean and healthy communities, connecting New Yorker's to nature, and promoting a toxics-free future. All of the options were analyzed from the perspective of multiple pollutants key to this sector, i.e., NO_x, SO2, CO2, and mercury Hg. While fine particle emissions were considered from the perspective of reducing NO_x and SO2, which are key precursor pollutants leading to secondary formation of fine particles, primary PM emissions associated with power plants in MARKAL were not carefully calibrated against the MANE-VU emissions inventory, as was done with other pollutants.

Case A: Ten GW of wind power by 2030. Renewable power generation is a key alternative for the electricity generation sector. A preliminary case study examined the build out of 10,000 MW of wind-powered electricity generation in NYS. While this represents a significant increase in wind generation, it is within the technical potential for the state, notwithstanding potential licensing, siting, and other regulatory and political hurdles that may need to be addressed in order to achieve this level of deployment.

Figure 3-12 shows Reference and Case A power generation capacity for the state, demonstrating that a large increase in wind capacity could moderate natural gas expansion plans in favor of carbon-free wind generation. The carbon emissions reductions would only be realized if the capacity was used for actual generation. While NE-MARKAL is not a dispatch model and cannot give a reliable estimate of which generation resources would run for every hour of the year, annual estimates of simulated generation for the same two cases are shown in Figure 3-13.

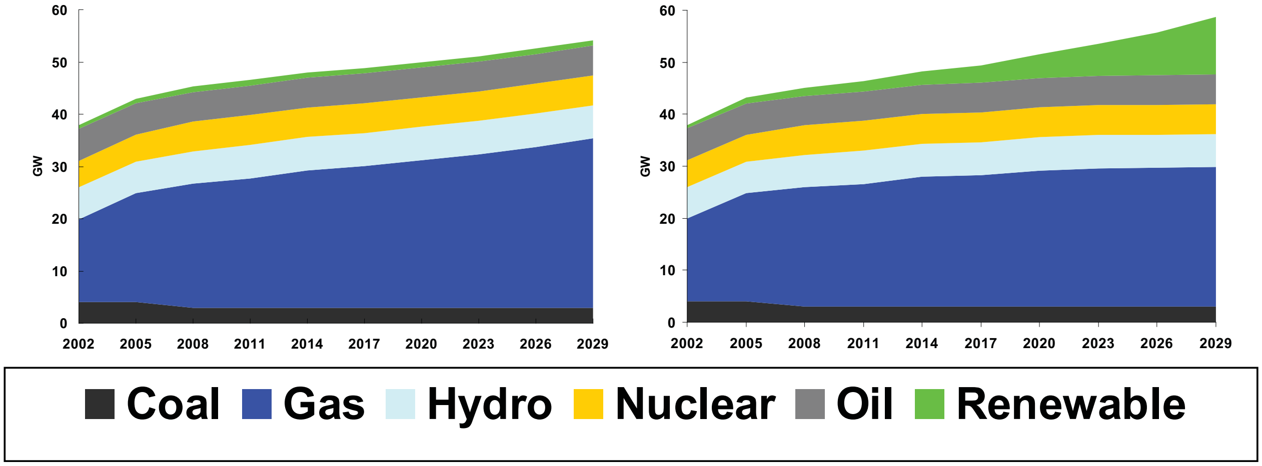

Figure 3-12. Reference and Case A Power Sector Capacity Mix by Fuel Type.

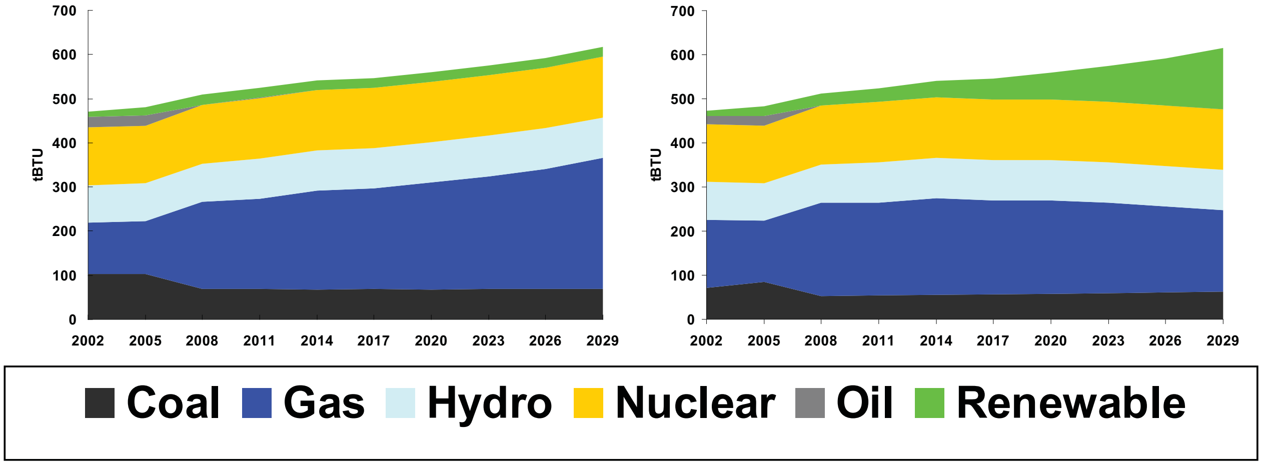

Figure 3-13. Reference and Case A Power Sector Generation Mix by Fuel Type.

The results suggest that wind assets would be used, once built, thereby lowering the overall carbon footprint of the statewide generation mix. Still, a comparison between the dominant natural gas capacity in 2030 under Case A (Figure 3-12) and the more evenly split generation mix for 2030 under this case (Figure 3-13; generation is split more evenly between gas, nuclear, hydro, and wind power) suggests that this case would result in significant stranded natural gas assets that would not be used under these assumptions. Case A therefore shows an example of a resource that lowers carbon intensity, but at a cost. In this case, costs are associated with increased up-front capital as well as the opportunity cost of the potentially stranded assets down the road.

Table 3-5. Projected Power Sector Emissions Changes for Case A.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand Tons)	SO2 (Thousand Tons)	Hg (lbs)
Annual (2029)	-14 (-21%)	-2.1 (-5.4%)	-0.04 (<0.1%)	-2.8 (-0.2%)
Cumulative (2007-2030)	-134 (-8.8%)	-19 (-1.8%)	-0.4 (<0.1%)	-150 (-0.4%)

Table 3-6. Power Sector Cost Breakout for Case A.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed & variable costs	Change in fuel costs
Annual (2029)	+$3.5 B (6.8 times REF)	+$130 M (+5%)	-$1.7 B (-31%)
Cumulative (2007-2030)	$33 B (4.4 times REF)	+$1.2 B (+2%)	-$15 B (-13%)

Emission reductions associated with Case A are large. Table 3-5 shows cumulative reductions of CO_2 on the order of 9% for the power sector over the next two decades. Note that these large cumulative reductions continue to grow into the future, with annual, single-year CO_2 reductions in 2029 at 21% below Reference Case emissions due to prior investment in renewable capacity. NO_x emissions reductions are projected to be more modest (approximately 5% in 2029), but still significant, at more than 2,100 tons per year.

Costs are also large, with an anticipated investment of $33 billion above that required under the Reference Case assumptions during the next two decades. While this level of finance represents a significant hurdle to bringing clean power online, the projected $15 billion of savings would significantly reduce the net cost of this scenario over time, especially considering that the savings would continue to accrue for the lifetime of these projects. Table 3-6 shows 2029 annual costs and cumulative costs between 2007 and 2030.

<u>Case B: Increase transmission efficiency by 10%.</u> Reducing line losses by improving transmission efficiency is another opportunity within the power generation sector. Estimates of potential improvement suggest that a 10% efficiency improvement is not an unrealistic target. Case B examines the cost and emissions implications of achieving a 10% improvement in transmission efficiency by 2011.

Figure 3-14 and Figure 3-15 show virtually no change at all relative to Reference Case capacity and generation mix. The same resources are projected to be brought online in roughly the same amounts at the same time. A detailed look shows that there is slightly less natural gas generation, but not enough to show up in these figures.

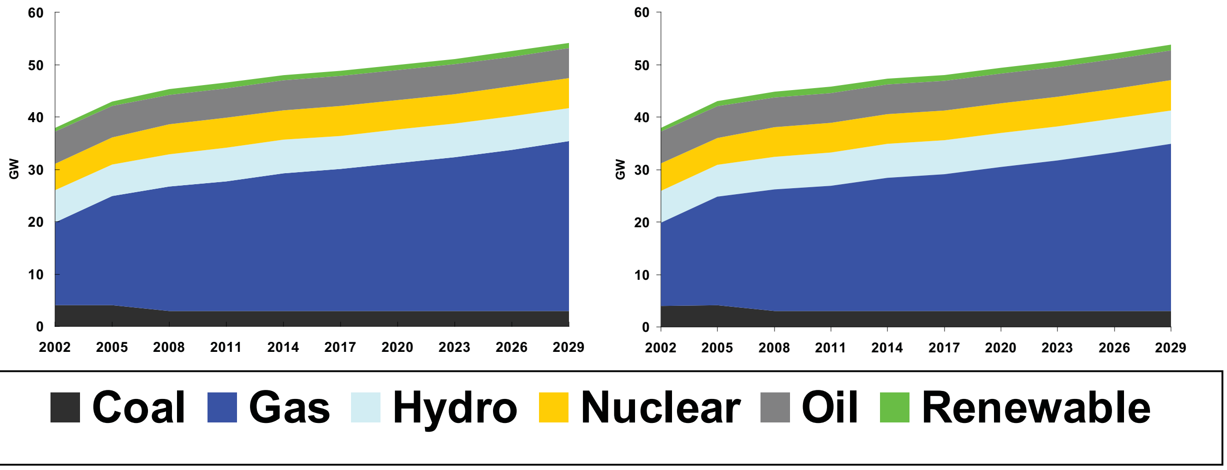

Figure 3-14. Reference and Case B Power Sector Capacity Mix by Fuel Type.

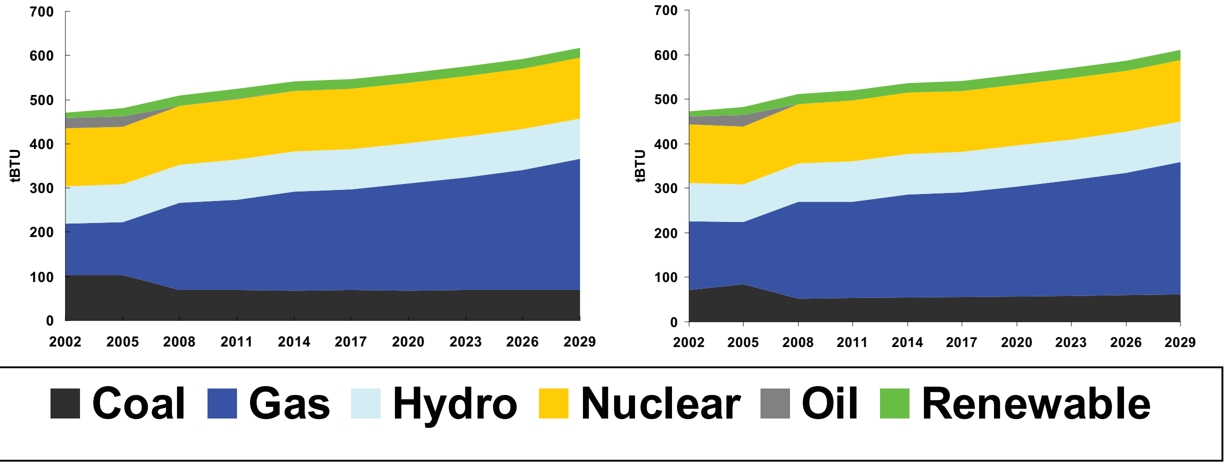

Figure 3-15. Reference and Case B Power Sector Generation Mix by Fuel Type.

Emission reductions associated with Case B are more modest relative to Case A. This was expected, given the limited investment in new advanced capacity. Table 3-7 shows cumulative reductions of CO_2 on the order of 1% for the power sector over the next two decades and about 1% per year in 2029. NO_x, SO_2, and Hg emissions reductions are also modest, at less than 1%.

Table 3-7. Projected Power Sector Emissions Changes for Case B.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand Tons)	SO2 (Thousand Tons)	Hg (lbs)
Annual (2029)	-0.9 (-1.3%)	-0.2 (-0.5%)	0 (<0.1%)	-2.4 (-0.2%)
Cumulative (2007-2030)	-18 (-1.2%)	-5.8 (-0.5%)	-6 (-0.2%)	-39 (-0.1%)

Investment costs in the power sector are projected to be negative, reflecting the reduced demand that is achieved through a system efficiency improvement. The costs of the transmission system improvements, however, are not reflected in this cost, so the net savings shown in these tables need to be balanced against the cost to the grid required to achieve the transmission efficiency improvements. Table 3-8 shows projected 2029 annual costs and cumulative costs between 2007 and 2030 for the power generation sector.

Table 3-8. Power Sector Cost Breakout for Case B.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed & variable costs	Change in fuel costs
Annual (2029)	-$9.8 M (-1.9%)	-$11 M (-0.4%)	-$80 M (-1.4%)
Cumulative (2007-2030)	-$143 M (-1.9%)	-$200 M (-0.4%)	-$1.5 B (-1.3%)

<u>**Case C: Renewable Portfolio Standard: 25% by 2013**</u>. The State's RPS program was represented in the analyses as a distinct policy case, rather than a part of the Reference Case. By so doing, we could examine specific benefits of increasing the renewable capacity beyond current levels to meet the RPS targets. Figure 3-16 shows that additional non-hydro renewable is projected to be brought online by 2014 to meet the 25% RPS requirement. This would slightly reduce the amount of natural gas capacity expansion. In terms of generation, Figure 3-17 shows that these new resources would significantly offset natural gas generation in the 2014 timeframe. The annual average growth rate in gas generation was projected to decrease from 2% in the Reference Case to roughly 0.1% in Case C.

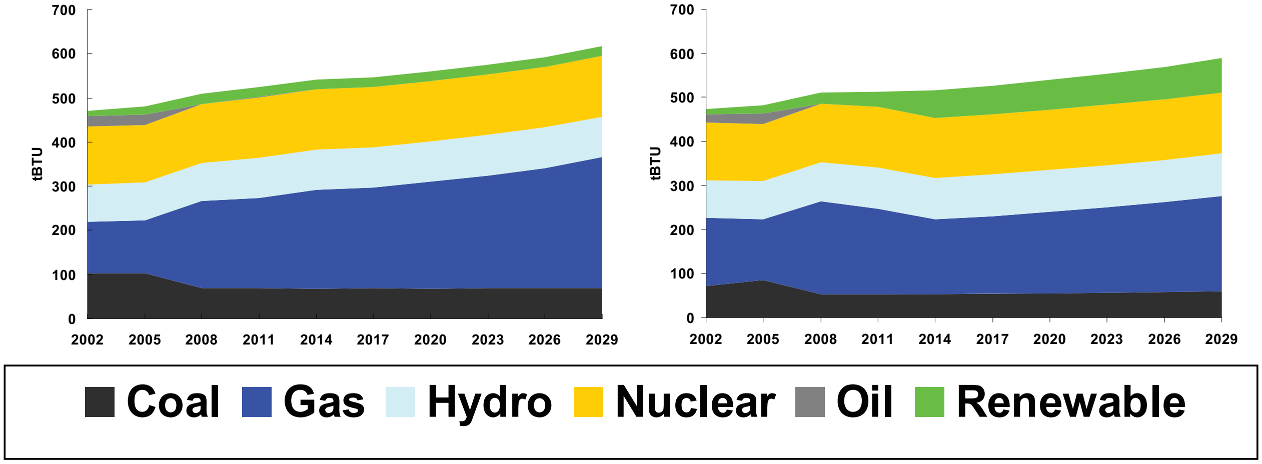

Figure 3-16. Reference and Case C Power Sector Capacity Mix by Fuel Type.

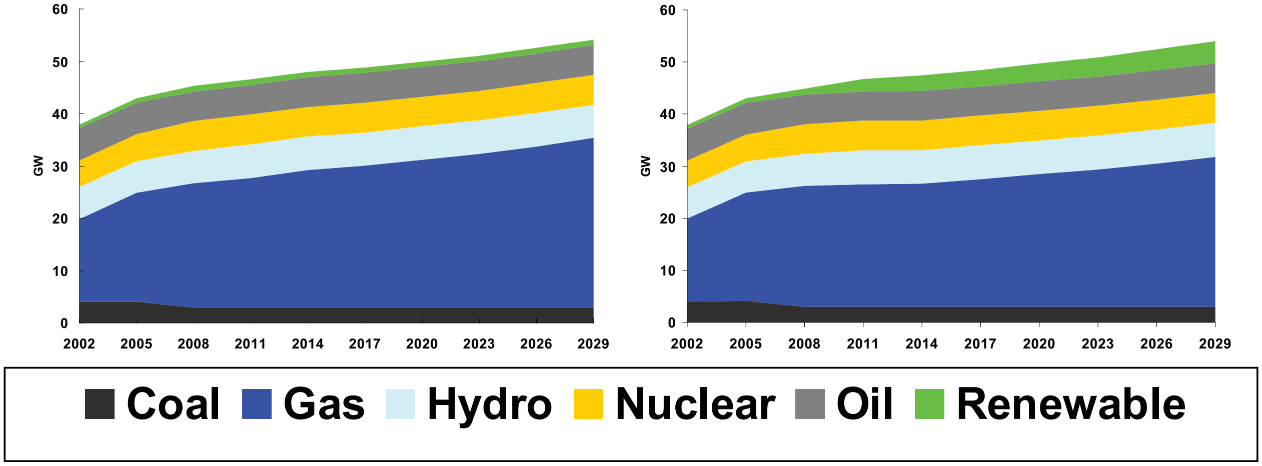

Figure 3-17. Reference and Case C Power Sector Generation Mix by Fuel Type.

Projected emissions for Case C, shown in Table 3-9 below, are somewhat lower than the Reference Case, but not as low as for Case A. The reason for this is that a significant portion of the RPS had already been achieved through large hydro generation capacity in-state; by 2008, NYS had approximately 16% of its generation coming from renewable resources, mostly hydropower. The additional renewable capacity needed to meet the RPS requirement in 2013 was therefore less than 3,400 megawatts, compared to the 10,000 MW of new wind capacity in Case A.

Table 3-9. Projected Power Sector Emissions Changes for Case C.

Emission Changes relative to NYREF	**CO2 (Million Tons)**	**NOx (Thousand Tons)**	**SO2 (Thousand Tons**	**Hg (lbs)**
Annual (2029)	-12 (-18%)	-2.5 (-6.3%)	-1.5 (-1.1%)	-11 (-0.8%)
Cumulative (2007-2030)	-180 (-12%)	-47 (-4.5%)	-25 (-0.7%)	-120 (-0.3%)

The net cost for achieving the RPS was projected to be approximately $6.5 billion, with $21.5 billion invested and $15 billion in savings accrued between now and 2030. Cost figures are shown in. Table 3-10.

Table 3-10. Projected Power Sector Cost Breakout for Case C.

Cost Changes relative to NYREF (2008 $US)	**Change in capital costs**	**Change in fixed & variable costs**	**Change in fuel costs**
Annual (2029)	+$1.1 B (2.2 times REF)	+$75 M (+3.1%)	-$1.1 B (-20%)
Cumulative (2008-2029)	+$20 B (2.6 times REF)	+$1.5 B (+2.6%)	-$15 B (-13%)

Case D: Reduce demand by 15% by 2015. The State's "15 by 15" program is designed to reduce electric demand by 15% by 2015. Case D stimulates the 15 by 15 program by constraining the total electric demand for all periods after 2011. While MARKAL is not well suited to simulating how the demand reductions can be achieved, Figure 3-18 and Figure 3-19 show the implications of achieving that level of demand reduction. The projected result is that less natural gas capacity would be added and significantly less natural gas generation is used.

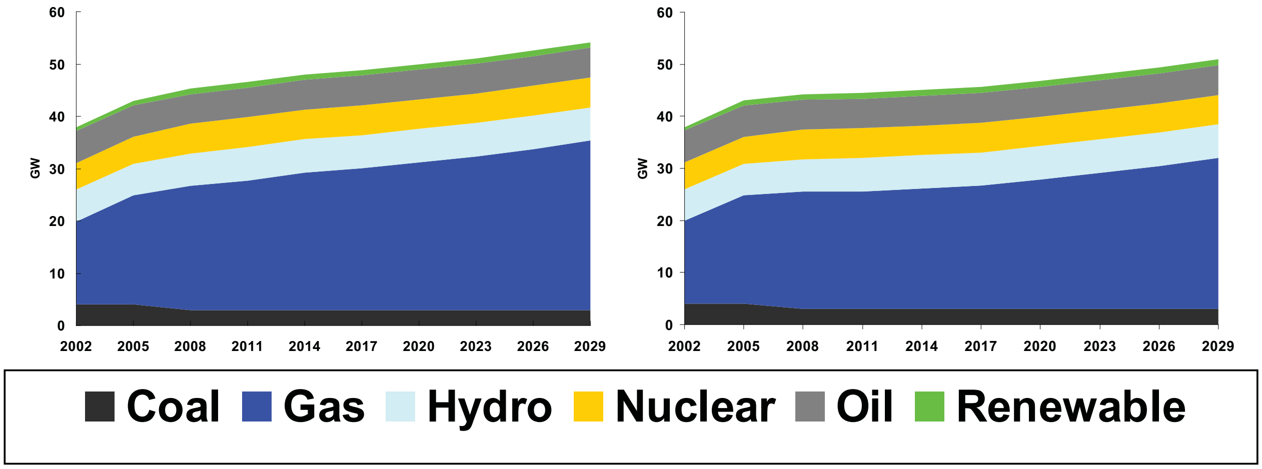

Figure 3-18. Reference and Case D Power Sector Capacity Mix by Fuel Type.

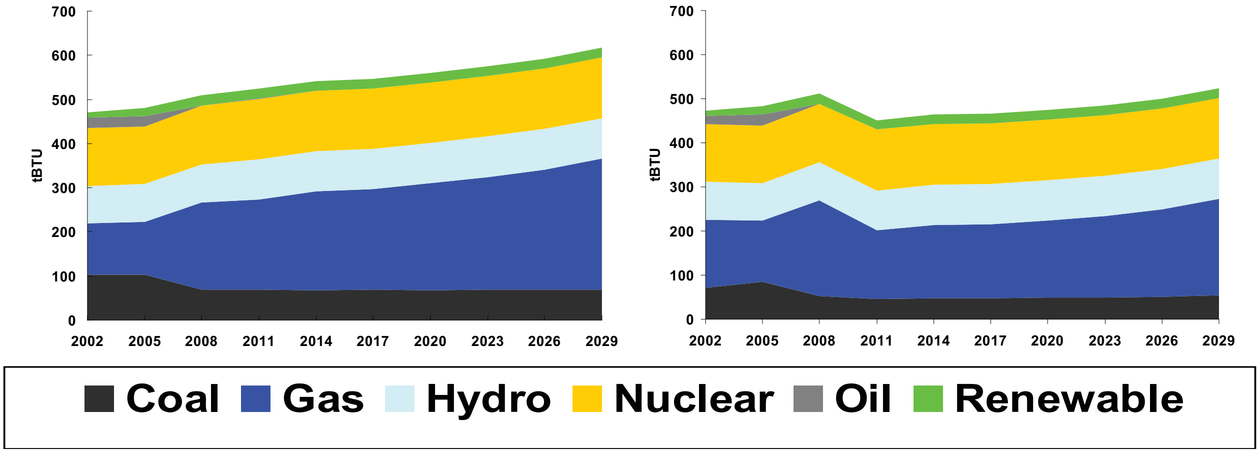

Figure 3-19. Reference and Case D Power Sector Generation Mix by Fuel Type.

The projected emission reductions for Case D, shown in Table 3-11, are large, given the dramatic scale-back of natural gas generation. Natural gas has very little SO_2 and Hg emissions associated with it, thus relatively fewer emission reductions are projected for these pollutants.

Table 3-11. Power Sector Emissions Changes for Case D.

Emission Changes relative to NYREF	**CO2 (Million Tons)**	**NOx (Thousand Tons)**	**SO2 (Thousand Tons)**	**Hg (lbs)**
Annual (2029)	-14 (-21%)	-5.4 (-14%)	-8.8 (-6%)	-120 (-8%)
Cumulative (2007-2030)	-188 (-12%)	-130 (-12%)	-280 (-8%)	-2600 (-8%)

Table 3-12. Projected Power Sector Cost Breakout for Case D.

Cost Changes relative to NYREF (2008 $US)	**Change in capital costs**	**Change in fixed & variable costs**	**Change in fuel costs**
Annual (2029)	-$130 M (-25%)	-$170 M (-7%)	-$1.3 B (-24%)
Cumulative (2007-2030)	-$2.3 B (-30%)	-$3.3 B (-6%)	-$ 24 B (-21%)

From a cost perspective, demand reduction represents a huge savings. A reduced electric demand implies that less fuel is consumed, less capacity is developed, and there is less maintenance on existing capacity. There are, however, costs that are not reflected by this simulation. These include program costs that may be needed to educate the public as to the benefits of demand reduction or to subsidize energy saving technologies in the home or office (e.g., programmable thermostats, motion sensitive lighting). Such costs have been reflected to some extent in conservation technologies that are used in Case E, but for simplicity have not been included here. Projected cost figures are shown in Table 3-12.

Case E: 52% reduction by 2030 with conservation.[23] NYS established a climate change goal that calls for reducing GHG emissions 80% below 1990 levels by 2050. One projected emissions trajectory that

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[23] The 52 x 30 scenario represents one of many pathways that could lead to substantial greenhouse gas reductions. This scenario differs from other potential climate scenarios, such as those developed in the context of the *NYS Interim Climate Action Plan (*www.dec.ny.gov/energy/80930.html). Scenarios and models differ in their approach to selecting types and quantities of measures, setting practical limits on implementation of strategies, and the assumptions used to quantify the economic impacts of strategies. For

achieves these goals is shown in Figure 3-20 and implies a mid-term target of approximately a 52% reduction in GHG emissions by the year 2030 (52x30). For this analysis, Cases E and F challenged the model to find the most cost-effective way to achieve this greenhouse gas reduction across all sectors. This is not necessarily the only emissions trajectory for achieving the State's 2050 target and is not, per se, an analysis of a recommended approach for achieving the State's climate goals. It does, however, provide insight into the energy system implications of two approaches (Case E and F) to achieving GHG reduction targets of this magnitude. Below are the findings from that analysis, and an initial discussion of implications primarily from the perspective of changes in electricity generation and consumption. This case is also further explored in the multi-sector scenarios at the end of this Section.

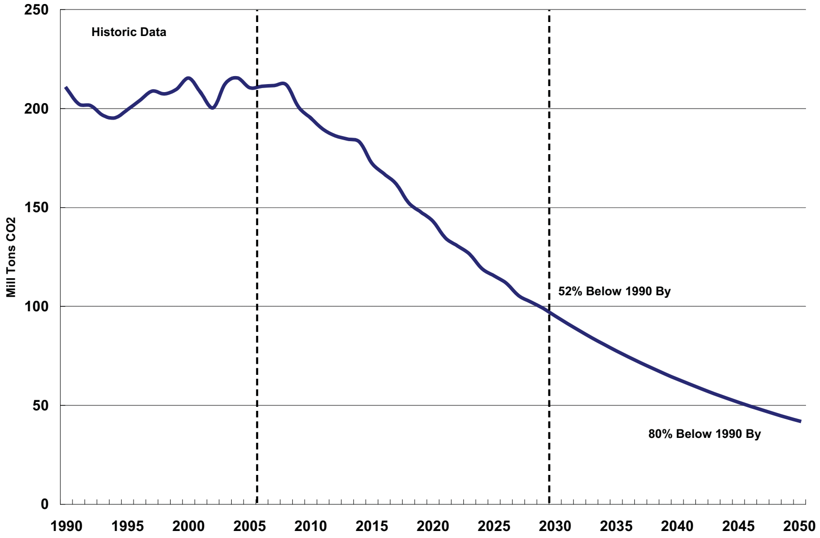

Figure 3-20. 52x30 CO_2 Emissions Trajectory.

Based on a NYSERDA analysis of energy efficiency potential in the state conducted by Optimal Energy (NYSERDA, 2008), several efficiency measures were identified (e.g., improved ballasts for fluorescent lights, hot water heater blankets, residential insulation, programmable thermostats, window glazings). A key factor that these measures have in common is that they do not depend directly on energy technologies for their benefit, but rather, they complement various energy technologies that are already represented in the model. Thus, the analysis simulated the benefits of two types of energy efficiency: explicit efficiency

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example, there can be substantial variance in assumptions for future costs of emerging technologies and net carbon impacts associated with changes in land use due to biomass development. Further, it is generally expected that scenarios based on less aggressive emission reduction goals for 2030 would be achievable at lower overall costs due to the ability to rely on measures that are more cost-effective.

improvement from alternate high-efficiency energy technologies (MARKAL’s native strength) as well as a class of “conservation” measures that are represented by artificial or “pseudo”-technologies in the model framework. These pseudo-technologies are used as part of the built-in accounting framework of the model, and can satisfy a fraction of the end-use demand for various energy services at costs estimated by the NYSERDA/Optimal study.

Case E explores the implications of achieving the GHG targets with the assistance of the above mentioned conservation technologies as well as increased use of combined heat and power (CHP) in the residential and commercial sectors (limits of no more than 10% of heating demand were relaxed to be no more than 20%). Case F, which is presented next, demonstrates the increased difficulty and cost of achieving the GHG goals without increased use of conservation technologies and/or CHP.

Figure 3-21 and Figure 3-22, respectively, show the projected changes in capacity and generation mix in the power sector for Case E relative to the Reference Case.

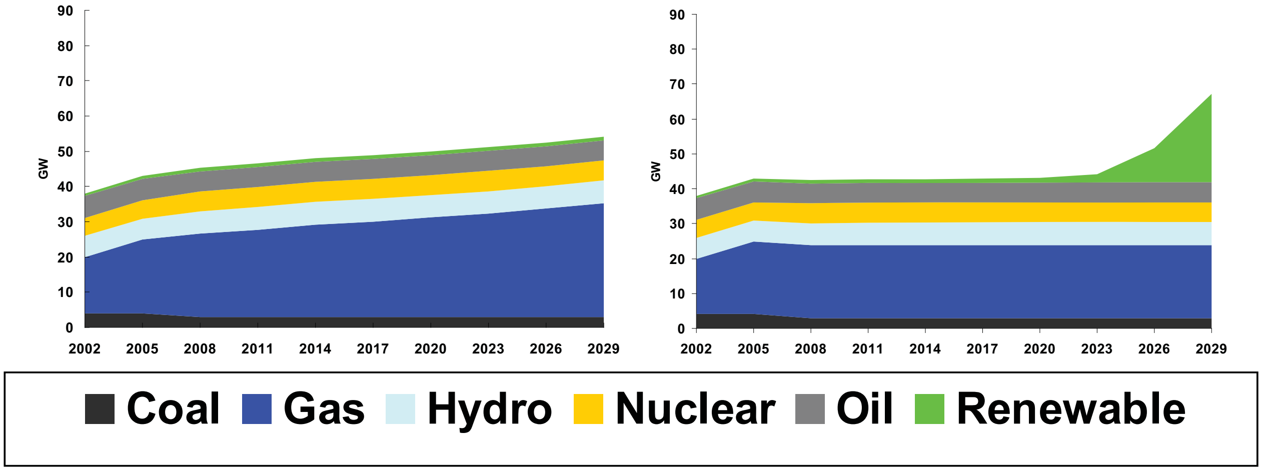

Figure 3-21. Reference and Case E Projected Power Sector Generation Mix by Fuel Type.

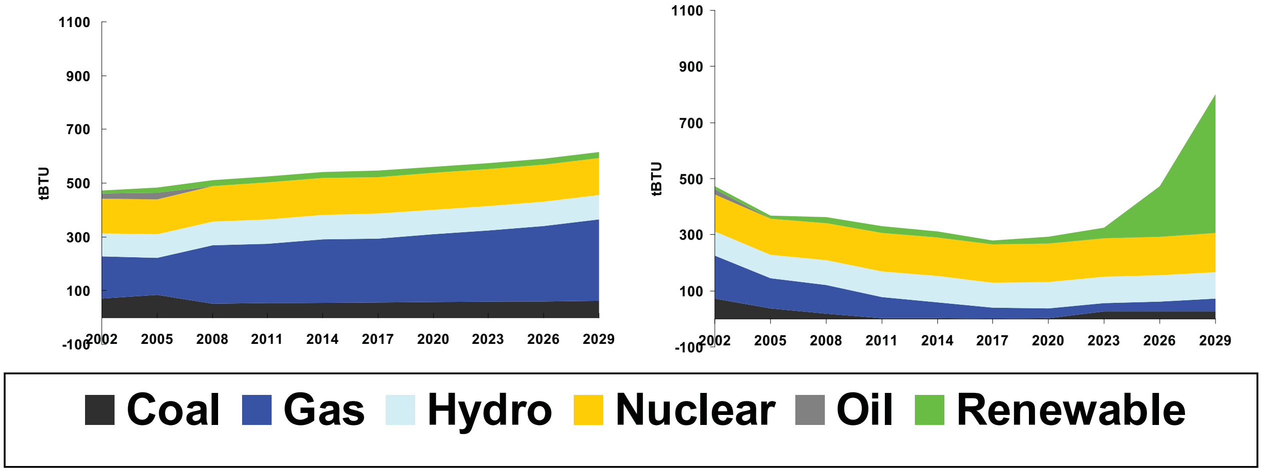

Figure 3-22. Reference and Case E Projected Power Sector Generation Mix by Fuel Type.

The most obvious finding from these simulations is the dramatic electric demand reduction that is projected, driven by efficiency, conservation, and technology changes. The virtual elimination of fossil fuel power generation would lead to significant levels of stranded natural gas generation capacity. Renewable generation is projected to increase, but mostly in time periods beyond 2023 when transportation fossil fuel reductions create an increase in overall electricity demand. Nuclear power generation and the significant hydro power generation are assumed to maintain at consistent levels throughout the model horizon..

One can better understand the demand reductions projected in Case E by looking at changes in energy use in the commercial and residential sectors.

Figure 3-23 indicates that the conservation technologies and a shift to more efficient demand technologies in these sectors would generate significant electricity savings in the commercial sector, as well natural gas and oil savings in the residential sector.

The projected emission reductions in Case E (Table 3-13) are very large, given the dramatic scale back of natural gas and coal generation relative to the Reference Case. Overall emissions reductions are likely to be larger, but this table only examines power sector emissions reductions. Implications across all economic sectors are discussed in the scenario analyses at the end of this Section.

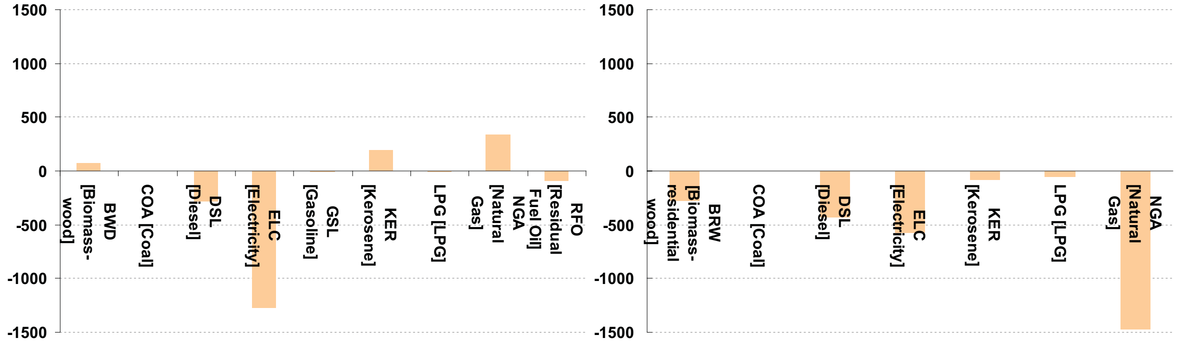

Figure 3-23. Projected Commercial and Residential Sectors Energy Changes for Case E Relative to Reference Case (tBTU).

Table 3-13. Projected Power Sector Emissions Changes for Case E.

Emission Changes relative to NYREF	**CO2 (Mt)**	**NOx (Kt)**	**SO2 (Kt)**	**Hg (lbs)**
Annual (2029)	-56 (-84%)	-17 (-43%)	-127 (-9%)	-1200 (-86%)
Cumulative (2007-2030)	-1200 (-77%)	-652 (-62%)	-2900 (-84%)	-27,000 (-82%)

From a cost perspective, the demand reduction introduced through efficiency measures reduces both capital costs and fuel costs. The reduced capital expenditure for natural gas capacity expansion in the Reference Case offsets a large fraction of the additional renewable capacity investments needed, but not entirely. Cost figures are shown in Table 3-14.

Table 3-14. Projected Power Sector Cost Breakout for Case E.

Cost Changes relative to NYREF (2008 $US)	**Change in capital costs**	**Change in fixed & variable costs**	**Change in fuel costs**
Annual (2029)	+17 B (+32%)	+$2.1 B (+86%)	-$4.5B (-80%)
Cumulative (2007-2030)	+62 B (+8.1%)	-$4.6 B (-8%)	-$79 B (-69%)

Case F: 52% reduction by 2030 without conservation.[24] Case F explores the implications of achieving 52x30 *without* taking advantage of conservation technologies or additional combined heat and power in the residential and commercial sectors. Pre-set limits on CHP were maintained at no more than 10% of total heating demand, and conservation technologies that were characterized based on the NYSERDA/Optimal study were not allowed to enter the solution. Figure 3-24 presents the simulated generation capacity and Figure 3-25 shows simulated generation for the power sector under Case F relative to the Reference Case.

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[24] The 52 x 30 scenario represents one of many pathways that could lead to substantial greenhouse gas reductions. This scenario differs from other potential climate scenarios, such as those developed in the context of the *NYS Interim Climate Action Plan* (www.dec.ny.gov/energy/80930.html). Scenarios and models differ in their approach to selecting types and quantities of measures, setting practical limits on implementation of strategies, and the assumptions used to quantify the economic impacts of strategies. For example, there can be substantial variance in assumptions for future costs of emerging technologies and net carbon impacts associated with changes in land use due to biomass development. Further, it is generally expected that scenarios based on less aggressive emission reduction goals for 2030 would be achievable at lower overall costs due to the ability to rely on measures that are more cost-effective.

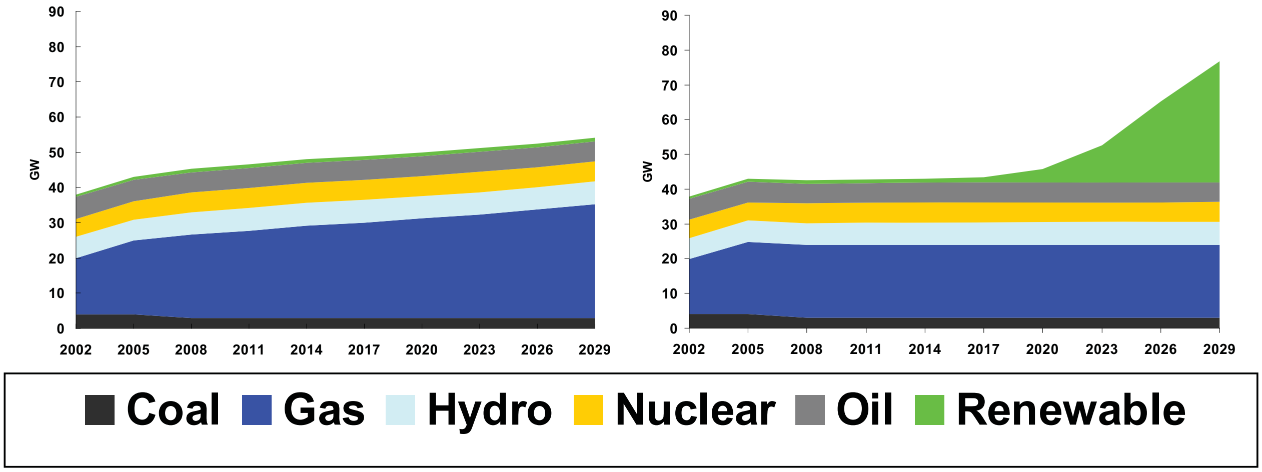

Figure 3-24. Reference and Case F Power Sector Capacity Mix by Fuel Type.

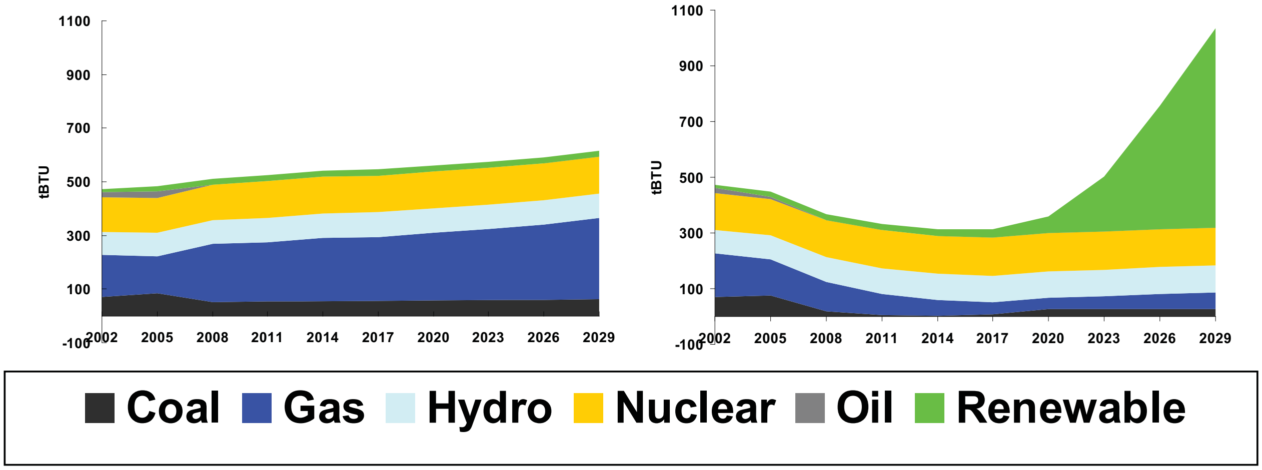

Figure 3-25. Reference and Case F Power Sector Generation Mix by Fuel Type.

In this case, the electric demand was projected to drop as in the prior case, however, because fewer efficiency opportunities were available to the model, it was achieved through more efficient alternative energy technologies. Presumably, the model spent more to buy this form of efficiency, but the much larger investment in renewable power generation technologies (relative to Case E) indicates that efficiency alone is less effective than the combination of efficiency and conservation. In this case, there is projected stranded natural gas capacity, but renewable generation is also projected to increase at a rate of roughly 18% per year.

Electric and heating oil demand reductions are projected in the residential and commercial sectors in Case F. Figure 3-26 shows that alternative, efficient demand technologies in these sectors can still generate significant electricity savings in the commercial sector as well natural gas and oil savings in the residential sector. Highly efficient natural gas is projected to be used in the commercial sector and biomass energy is projected to become the marginal fuel of choice in the residential sector, perhaps due to overall higher costs under these assumptions.

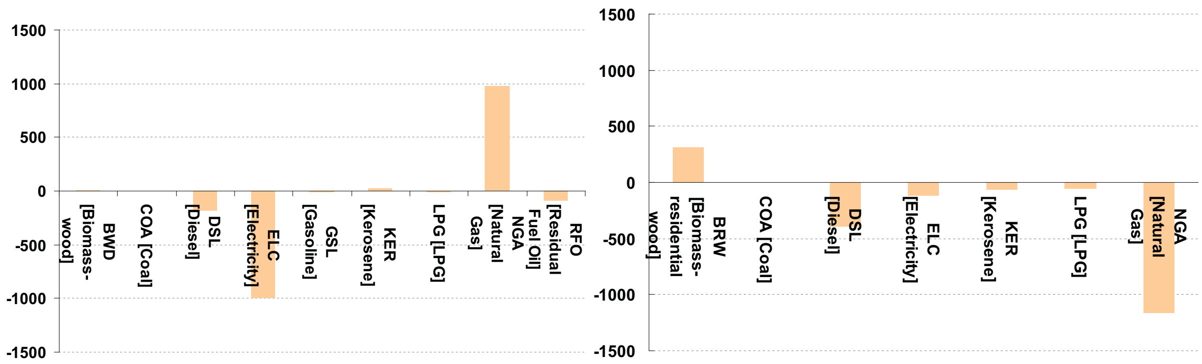

Figure 3-26. Projected Commercial and Residential Sector Energy Changes for Case F Relative to Reference Case (tBTU).

Table 3-15. Projected Power Sector Emissions Changes for Case F.

Emission Changes relative to NYREF	**CO2 (Mt)**	**NOx (Kt)**	**SO2 (Kt)**	**Hg (lbs)**
Annual (2029)	-53 (-80%)	-13 (-34%)	-124 (-92%)	-1200 (-86%)
Cumulative (2007-2030)	-1100 (-75%)	-559 (-53%)	-2900 (-84%)	-26,000 (-80%)

Projected emission reductions in Case F (Table 3-15) are nearly as large as those for Case E. Nevertheless, the associated costs (Table 3-16 below) are markedly different, with a significant investment in renewable energy eroding the large fuel savings that accumulate under either case.

Table 3-16. Projected Power Sector Cost Breakout for Case F.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed & variable costs	Change in fuel costs
Annual (2029)	+$2.5 B (48 times REF)	+$3.6 B (1.5 times)	-$4.3 B (-77%)
Cumulative (2007-2030)	+$137 B (18 times REF)	+8.8 B (+16%)	-$77 B (-67%)

Power Generation Summary: Technology, emissions, and costs. A variety of options is available for addressing CO_2 emissions in the power sector. Different approaches with respect to technology choice and implementation mechanism will have different results in terms of emissions benefit and overall cost. Figure 3-27 summarizes the patterns of technology deployment (relative to the Reference Case) for the six cases examined.

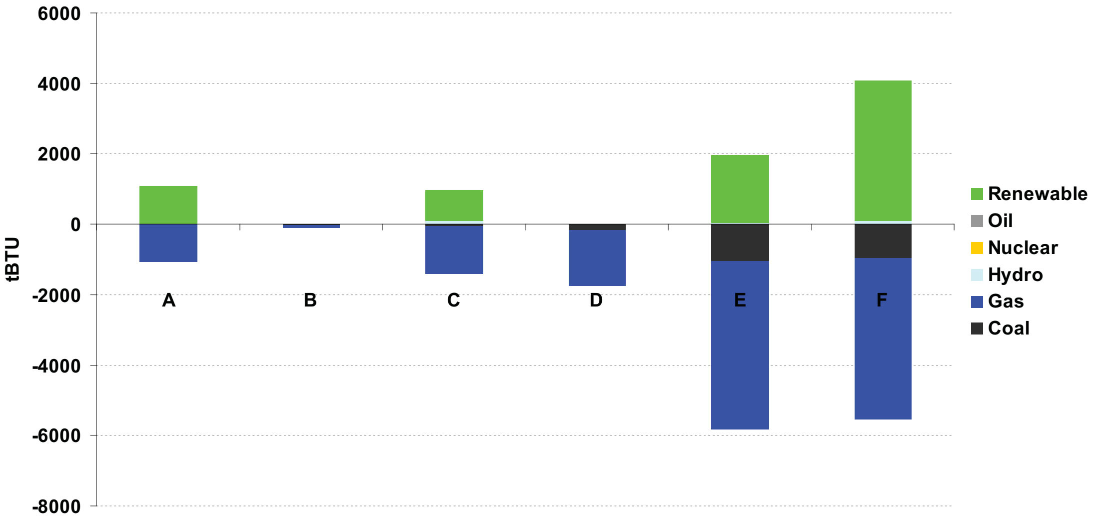

Figure 3-27. Projected Power Sector Generation Mix Relative to the Reference Scenario for Several Cases.

The large differences between projected generation changes in the early scenarios relative to Case E or F demonstrate the enormity of the challenge in meeting the goal of a 52% reduction in CO_2 by 2030. The reductions in natural gas and coal generation required to meet this challenge is over three times greater than the next available case examined (15% demand reduction), suggesting that no single approach may be able to achieve such large generation changes on its own.

The projected emissions reductions shown in Figure 3-28 reinforce this finding. While the CO_2 emissions reductions in the power sector basically mirror the changes to fossil fuel generation, the criteria pollutant emissions are relatively unaffected by small changes given that most of those changes are dealt with exclusively by moderating the amount of relatively cleaner natural gas generation. The 52% GHG reduction target requires much larger gas reductions and coal reductions that have significant consequences for multiple pollutants. It is clear that the State's carbon reduction targets can be a significant driver of criteria pollutant emissions reductions moving forward.

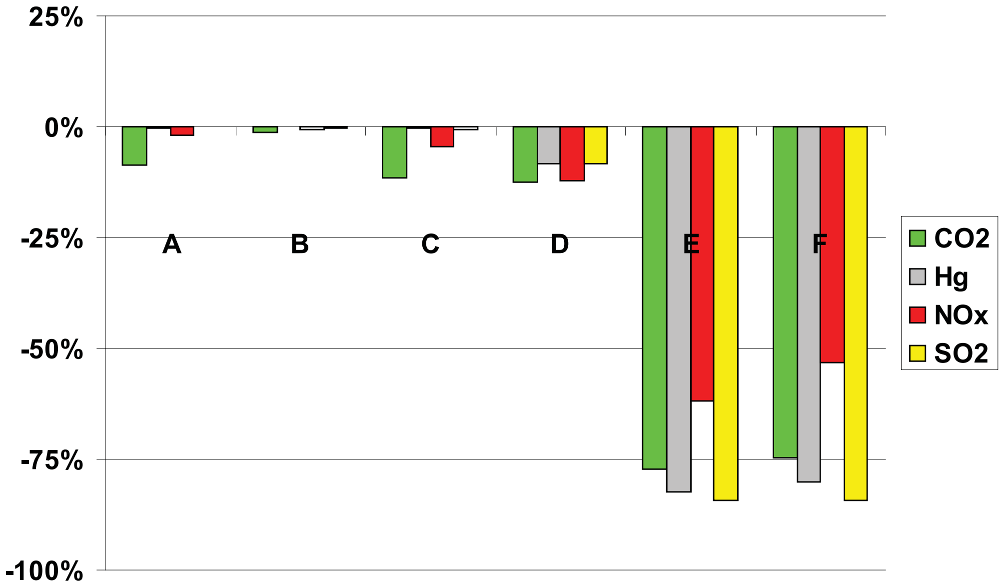

Figure 3-28. Projected Power Sector Emissions Relative to the Reference Scenario for Several Cases.

An analysis of costs demonstrates that not all opportunities for emission reduction will come at the same price. While the MARKAL model is not able to estimate the costs associated with government program expenses, public outreach, or education campaigns that may be needed to change consumer behavior, it provides a robust estimate of cost changes associated with alternative technology deployment schemes, as tested, and the fuel savings that may be achieved through those alternate cases.

Figure 3-29 shows that the greatest economic benefits accrue under programs involving demand reduction through consumer behavior changes or energy efficiency deployment (when excluding program costs, several economic opportunities are seen without their attendant costs). For Case B, D, and E, net benefits are projected to be achieved through the reduced need for electricity generation and tremendous fuel savings associated with greater efficiency.

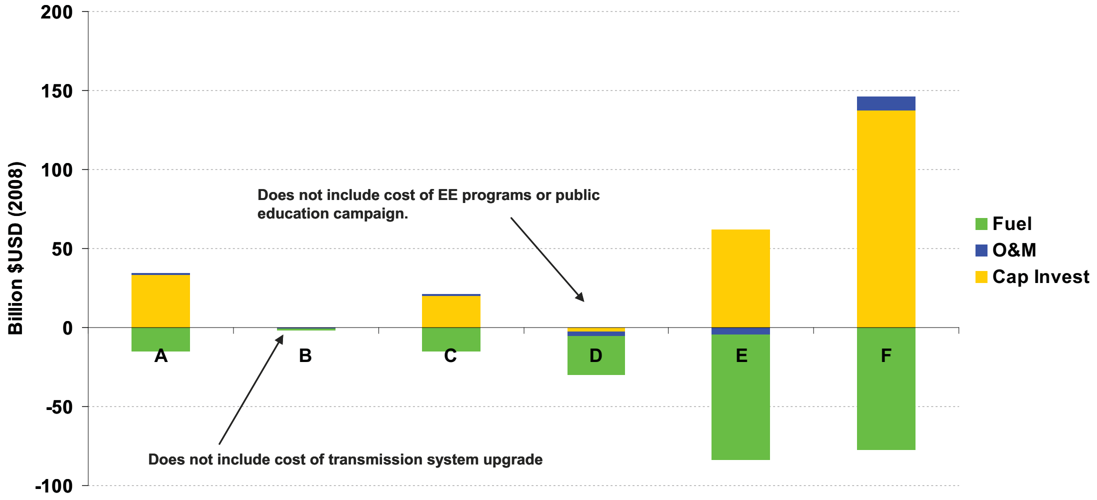

Figure 3-29. Power Sector Costs Relative to the Reference Scenario for Several Cases.

Transportation Sector. For the transportation sector, a number of specific policies was analyzed that were derived from the potential actions listed in Table 3-1. The transportation options tested included: significant penetration of the light-duty transportation fleet by high-efficiency diesel vehicles; hybrid electric vehicles; ethanol vehicles; and pure electric vehicles (no plug-in hybrids). Additional scenarios explored VMT demand reduction, a minimum performance standard for light-duty vehicles (as opposed to a fleet average), and an across-the-board efficiency increase for heavy-duty vehicles. Two scenarios explored the implications of a combined electric vehicle/minimum performance standard case and a combined diesel/hybrid/heavy-duty efficiency case. Each scenario is described and the results are presented below. The summary at the end of this section describes how the cases compare against one another in terms of fuel use, emissions, and cost.

Case A: 10% of light-duty fleet consists of 37 miles per gallon diesel vehicles by 2014. In order to meet the Commissioner's goal of combating climate change and fostering green and health communities, a variety of transportation efficiency options were explored. Among these, a shift in light-duty vehicle miles traveled (VMT) from traditional gasoline-fueled internal combustion engines to high efficiency diesel engines achieving at least 37 miles per gallon (mpg) was seen as a potentially viable strategy. In order to explore this case in NE-MARKAL's transportation sector, potential policies aimed at encouraging diesel cars were represented as a hard minimum constraint on the total VMT for the light-duty sector. At least 10% of the 2014 light-duty vehicle fleet (including existing and new sales) must be composed of 37 mpg diesel vehicles. The constraint started in 2011 at 2% and increased linearly between 2011 and 2014. After 2014 the constraint remained in place at the same level for the duration of the model horizon.

The result of this constraint is shown in terms of fuel usage in Figure 3-30, which shows the Reference Case and the Case A energy consumption by fuel share. As expected, there was a significant decrease in gasoline usage as diesel technologies were broadly introduced. An unexpected result was that, once diesels started to be introduced, the model showed a preference for the diesel economics and far exceeded the 10% target. By 2030, diesel represents half of light-duty fuel consumption. Figure 3-31 shows the time-integrated implications of this shift on fuel consumption between 2007 and 2030, demonstrating that the increase in diesel usage is more than offset by the gasoline reductions due to the increased efficiency of the new diesel technologies relative to what they replaced in the Reference Case.

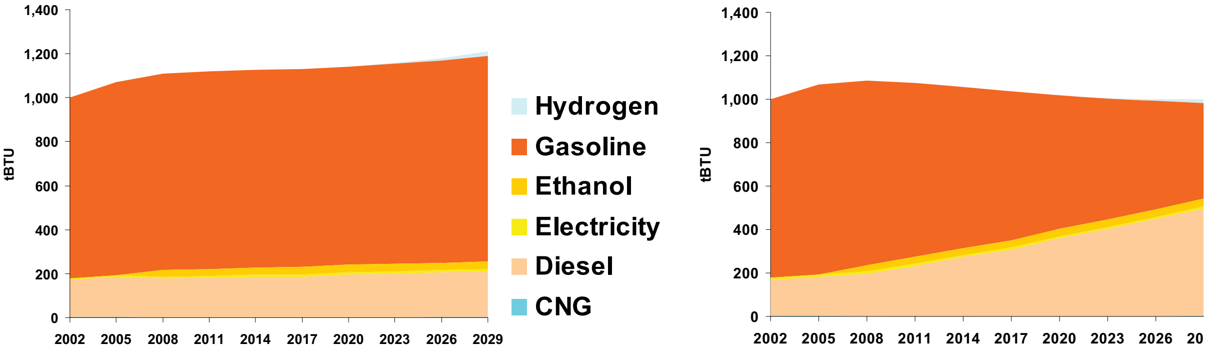

Figure 3-30. Reference and Case A Projected Transportation Energy Consumption by Fuel Type.

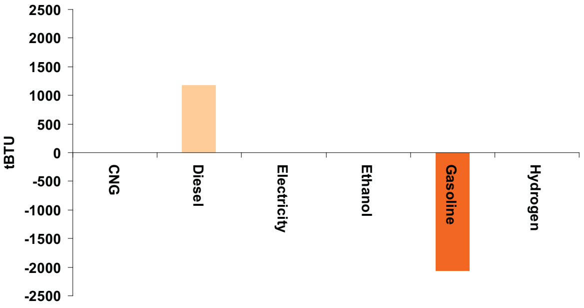

Figure 3-31. Projected Change in Transportation Energy Consumption between Reference and Case A between 2007 and 2030.

This finding is also evident in the deployment of technologies, which is shown in Figure 3-32. The Reference and Case A results are shown for comparison purposes.

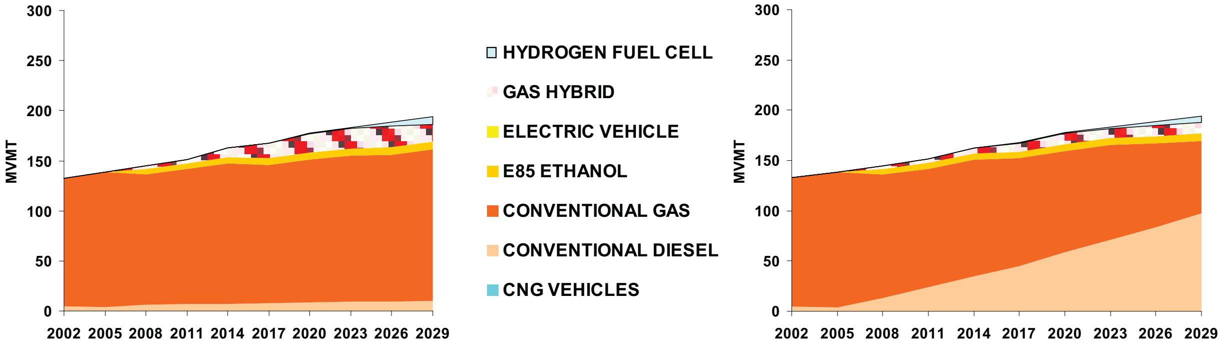

Figure 3-32. Reference and Case A Transportation Technology Deployment by Type.

Projected emissions changes relative to the Reference Case are shown in Table 3-17. Due to the large shift away from spark ignition engines toward higher efficiency diesel engines, emissions of CO and CO_2 are both reduced significantly. NO_x, VOC, and CH_4 emissions are projected to be reduced with modern diesel engines as well.

Table 3-17. Projected Transportation Sector Emissions Changes for Case A.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand tons)	SO2 (Tons)	CO (Thousand tons)	VOC (Thousand Tons)	CH4 (Thousand Tons)
Annual (2029)	-14 (-14%)	-85 (-32%)	-70 (-1.9%)	-1,230 (-53%)	-46 (-35%)	-3.4 (-59%)
Cumulative (2007-2030)	-183 (-8%)	-1,000 (-17%)	-670 (-0.6%)	-14,700 (-28%)	-540 (-18%)	-57 (-41%)

The economics that drive the projected large penetration of diesel cars is demonstrated in Table 3-18, which shows cost changes relative to the Reference Case. As the first row demonstrates, by 2030, when half the light-duty fleet is composed of diesel cars, fuel savings are projected on the order of $3.7 billion per year. Cumulatively, as these savings pile up, approximately $48 billion in fuel savings are seen relative to the less than $5 billion in increased expenditure associated with diesel cars.

Table 3-18. Projected Transportation Sector Cost Breakout for Case A.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$0.4 B (+0.7%)	-$10 M (-0.1%)	-$3.7 B (-19%)
Cumulative (2007-2030)	+$4.5 B (+0.5%)	-$240 M (-0.1%)	-$48 B (-11%)

<u>Case B: 25% of light-duty fleet consists of 50 mpg hybrid-electric vehicles by 2017.</u> A second case looked at the implications of significant hybrid penetration into the light-duty vehicle fleet. Here, potential policies aimed at encouraging hybrid-electric vehicle deployment were represented as a minimum constraint on the total light-duty VMT. At least 25% of the 2017 light-duty vehicle fleet (including existing and new sales) must be composed of 50 mpg hybrids. The constraint started in 2008 at 2%, and increased linearly between 2008 and 2017. After 2017, the constraint remained in place at the same level for the duration of the model horizon.

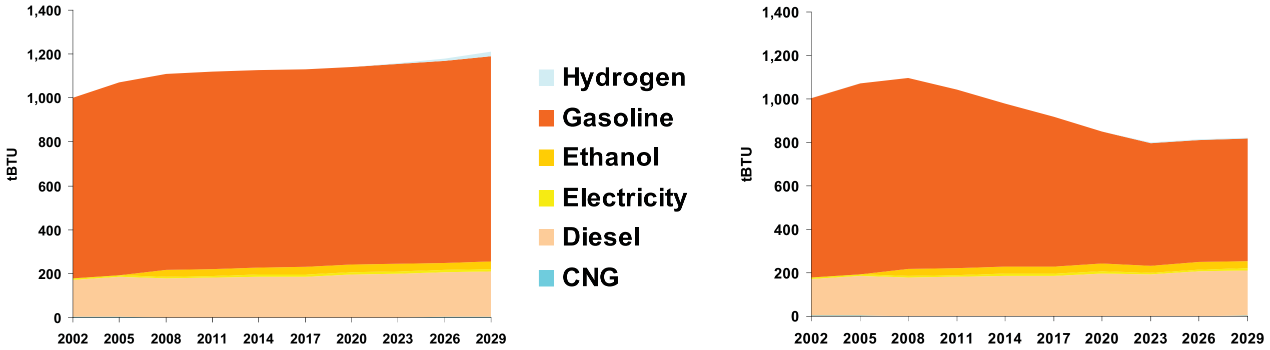

Figure 3-33. Reference and Case B Projected Transportation Energy Consumption by Fuel Type.

The result of the Case B constraint is shown in terms of fuel usage in Figure 3-33, which shows both the Reference Case and the Case B energy consumption by fuel share. As with the prior case, gasoline consumption was significantly reduced, resulting in fuel savings that drove the model to exceed the constraint by a wide margin. Nevertheless, in this case, a significant compensating rise in diesel usage was not observed.

As Figure 3-34 demonstrates, the introduction of more efficient hybrid vehicles projected large cumulative (time-integrated) reductions in gasoline use over the model horizon, with no increase in diesel usage. Case B is projected to incur greater expense relative to Case A due to the cost differential between a new diesel and a new hybrid car, as shown below.

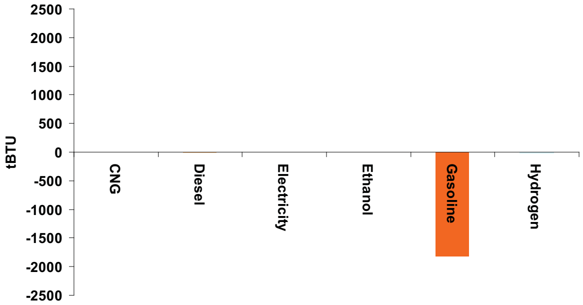

Figure 3-34. Projected Change in Transportation Energy Consumption between Reference and Case B over 30-year Model Horizon.

Figure 3-35 depicts the projected technology deployment by type for Case B as compared to the Reference Case. The model deployed hybrid-electric vehicles at levels that met and exceeded the constraints imposed in Case B, with the result that nearly 64% of the 2030 fleet is projected to be composed of hybrid electric vehicles.

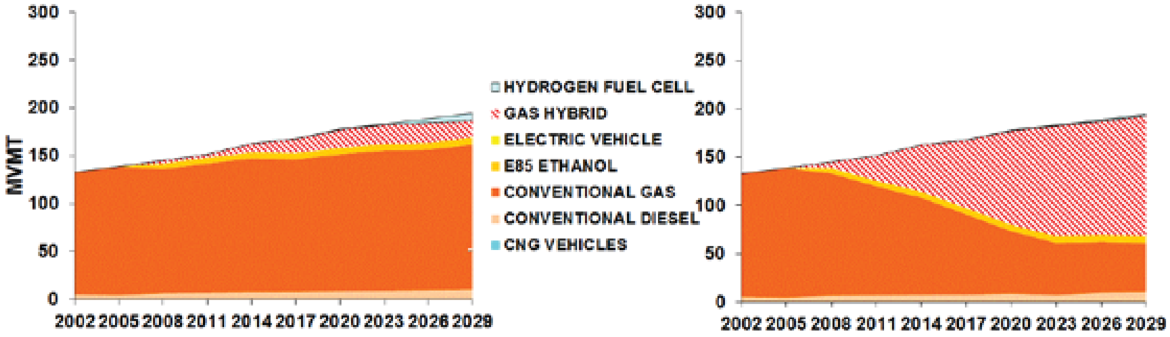

Figure 3-35. Reference and Case B Projected Transportation Technology Deployment by Type.

Projected emissions changes relative to the Reference Case are shown in Table 3-19. The higher efficiency alternative to conventional gasoline is projected to reduce CO and CO_2 emissions by 11 and 17%, respectively, between 2007 and 2030. NO_x,VOC, and CH_4 emissions are also projected to be reduced by significant amounts.

Table 3-19. Projected Transportation Sector Emissions Changes for Case B.

Emission Changes relative to NYREF	**CO2 (Million Tons)**	**NOx (Thousand tons)**	**SO2 (Tons)**	**CO (Thousand tons)**	**VOC (Thousand tons)**	**CH4 (Thousand tons)**
Annual (2029)	-26 (-27%)	-15 (-5.6%)	+37 (+1%)	-260 (-11%)	-27 (-20%)	-1.3 (-22%)
Cumulative (2007-2030)	-390 (-17%)	-360 (-5.8%)	+12 (<0.1%)	-5,700 (-11%)	-450 (-14%)	-22 (-16%)

The cost of a hybrid-electric vehicle is significantly more than that of a diesel or a conventional gasoline vehicle, but the large savings in fuel consumption are great enough to more than offset these costs. Thus, as Table 3-20 shows, a net savings of over $33 billion is projected to be achieved between 2007 and 2030.

Table 3-20. Transportation Sector Projected Cost Breakout for Case B.

Cost Changes relative to NYREF (2008 $US)	**Change in capital costs**	**Change in fixed costs**	**Change in fuel costs**
Annual (2029)	+$3.2 B (+ 6%)	+$0.2 B (+2.6%)	-$6.1 B (-32%)
Cumulative (2007-2030)	$+51 B (+5%)	+$2.7 B (+1.6%)	-$87 B (-20%)

Case C: 50% of light-duty fleet consists of E85 ethanol vehicles by 2029. A third case (Case C) looked at the implications of E85 ethanol vehicles servicing half the light-duty transportation demand.[25] Potential policies aimed at encouraging ethanol vehicle deployment were represented as a minimum constraint on the total light-duty VMT: at least 50% of the 2029 light-duty vehicle fleet (including existing and new sales) must be composed of E85 ethanol vehicles. The constraint started in 2008 at 2% and increased linearly between 2008 and 2029, the end of the model horizon.

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[25] Based on analysis by the California Air Resources Board, it was assumed for the purposes of these analyses that upstream indirect land-use impacts of ethanol production render this fuel to be carbon-equivalent to gasoline.

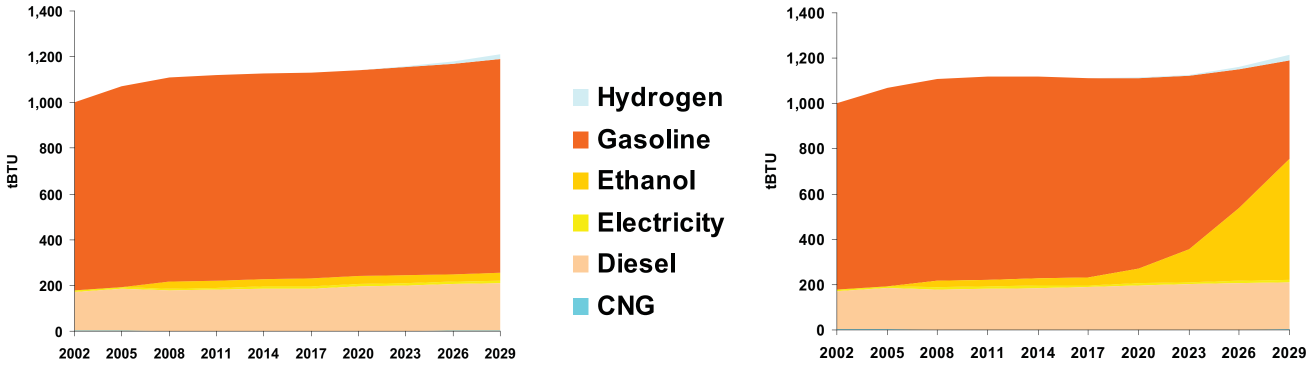

Figure 3-36. Reference and Case C Transportation Energy Consumption by Fuel Type.

Figure 3-36 shows the projected displacement of gasoline consumption with ethanol consumption in Case C. Figure 3-37 shows how that displacement adds up over time, resulting in total energy consumption in Case C balanced between decreased gasoline consumption and increased ethanol. This policy was analyzed under the assumption that ethanol represents a renewable fuel that may significantly reduce CO_2 emissions.

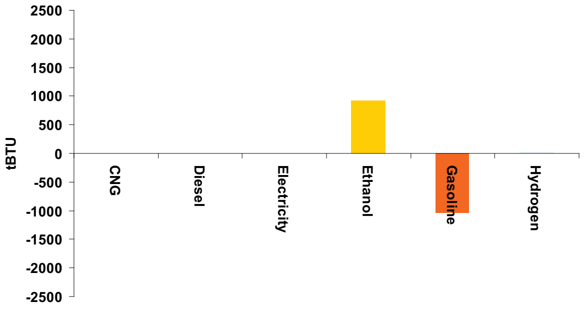

Figure 3-37. Change in Transportation Energy Consumption Between Reference and Case C over 30-year Model Horizon.

As there is significant controversy over this assumption, this analysis used estimates from the California Air Resources Board for carbon emission factors that include estimated contributions of ethanol production to upstream indirect land-use changes. These land-use changes may have a significant impact on GHG emissions, and should be accounted for when considering alternative strategies for reducing GHG emissions. The assumptions regarding GHG emissions associated with ethanol production may need to be revisited in the future as research is able to better quantify the direct and indirect impacts of biofuel production on land-use related GHG emissions.

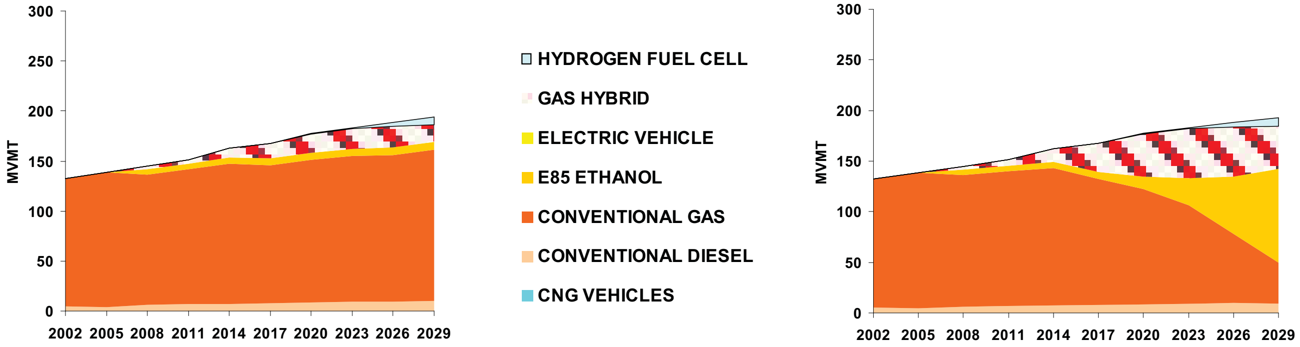

Figure 3-38. Reference and Case C Projected Transportation Technology Deployment by Type.

Figure 3-38 shows the corresponding technology deployment for Case C. The new ethanol/flex-fuel vehicles offset the conventional gas vehicle shares as well as some of the hybrid shares. Diesel vehicles increase slightly relative to the Reference Case.

For Case C, the projected emissions changes relative to the Reference Case, shown in Table 3-21, are inconsequential for CO_2 as a direct result of the assumption that indirect land-use associated emissions make ethanol equivalent to gasoline from a CO_2 perspective. There are small benefits, however, for NO_x, SO_2, CO, and VOC associated with the differing technologies employed. The large increase in methane emissions associated with ethanol production stand out as a consideration from an emissions perspective.

Table 3-21. Projected Transportation Sector Emissions Changes for Case C.

Emission Changes relative to NYREF	**CO2 (Million Tons)**	**NOx (Thousand tons)**	**SO2 (Tons)**	**CO (Thousand tons)**	**VOC (Thousand tons)**	**CH4 (Thousand tons)**
Annual (2029)	-0.2 (-0.2%)	-29 (-11%)	-500 (-13%)	-500 (-22%)	-11 (-8.3%)	+12 (+209%)
Cumulative (2007-2030)	-23 (-1%)	-170 (-2.8%)	-2,600 (-2.4%)	-3,100 (-5.8%)	-93 (-3%)	+75 (+53%)

Table 3-22. Transportation Sector Projected Cost Breakout for Case C.

Cost Changes relative to NYREF (2008 $US)	**Change in capital costs**	**Change in fixed costs**	**Change in fuel costs**
Annual (2029)	+0.8 B (+1.6%)	+50 M (+0.6%)	+2.4 B (+13%)
Cumulative (2007-2030)	+$11 B (+1.2%)	$750 M (+0.4%)	+11 B (+2.5%)

The cost of ethanol vehicles is not considerably different than the cost of conventional gasoline engines, but there are some slight increased costs projected, just over 1% over the model horizon. As Table 3-22 demonstrates, the added cost of producing the fuel relative to gasoline will increase fuel costs. The increase relative to the Reference Case is only about 2.5% between 2007 and 2030, however this masks the true cost due to the slow phase-in of these vehicles until very late in the model horizon. Unless production costs decline in the future, the fuel cost could be as much as 13% higher on an annual basis once the full fleet is in place.

Case D: 60% of light-duty fleet consist of pure electric vehicles by 2029. Case D looked at the implications of electric vehicles (EVs) servicing 60% of the light-duty transportation demand. Potential policies aimed at encouraging EV deployment were represented as a minimum constraint on the total light-duty VMT. At least 60% of the 2029 light duty vehicle fleet (including existing and new sales) were required to be composed of EVs. The constraint started in 2008 at 2%, and increased linearly between 2008 and 2029. Figure 3-39 shows the fuel shares relative to the Reference Case. An important consideration in this case is the large introduction of electricity as a significant transportation fuel. While overall gasoline reductions are projected to be significant in this case, as shown in Figure 3-40, it is important to understand the relative emissions profiles of the displaced gasoline versus the electric power generation that replaces it. Figure 3-41 shows the Reference and Case D projected generation mix for the power generation sector. Note that the new electric demand from the transportation sector is satisfied by expanding natural gas-fired generation. In addition, overall energy consumption is reduced given the larger reductions in gasoline energy consumption relative to the increase in electricity consumptions, as shown in Figure 3-40.

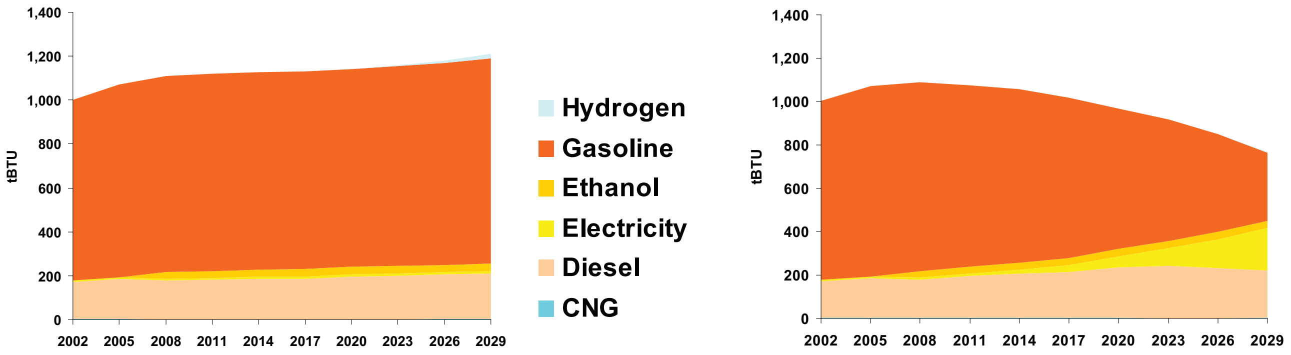

Figure 3-39. Reference and Case D Projected Transportation Energy Consumption by Fuel Type.

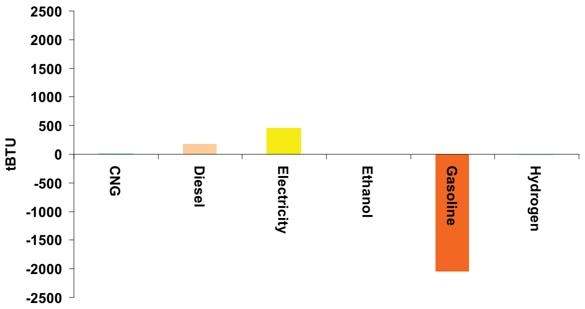

Figure 3-40. Change in Transportation Energy Consumption Between Reference and Case D over 30-year Model Horizon.

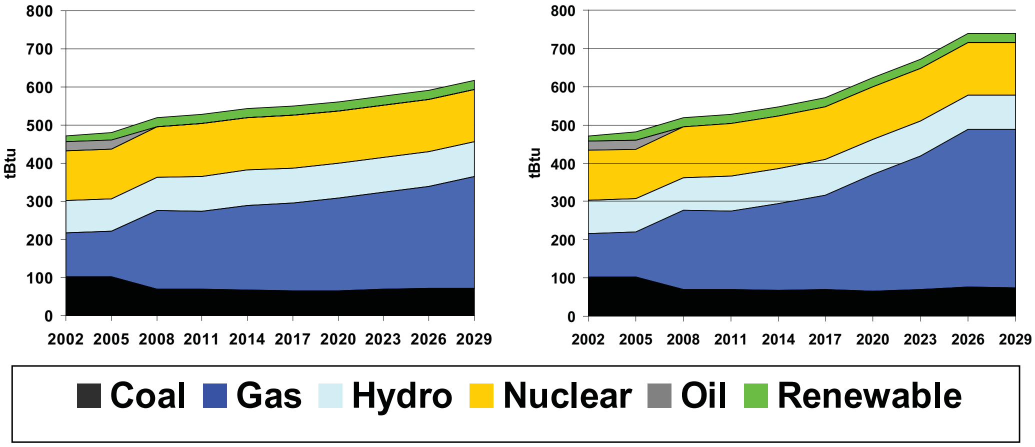

Figure 3-41. Reference and Case D Projected Power Generation Mix.

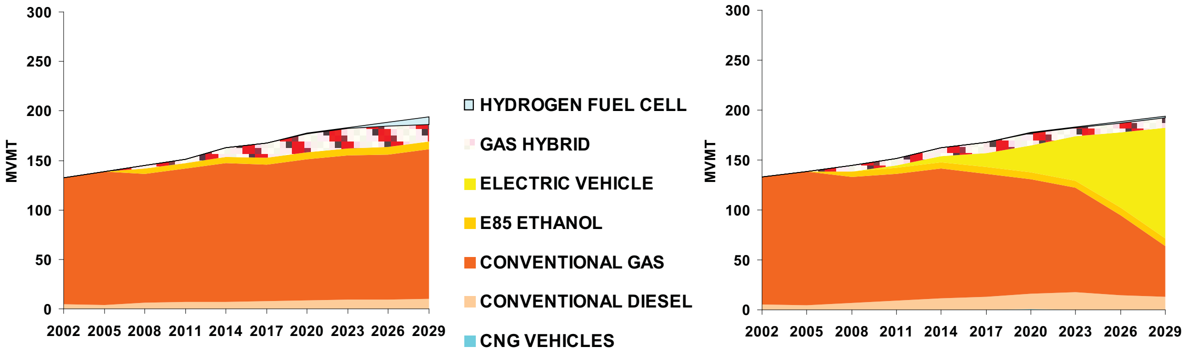

Figure 3-42. Reference and Case D Projected Transportation Technology Deployment by Type.

In terms of technology deployment, as expected, a large number of EVs are projected to enter the market, but only as the constraint is imposed, with the result that conventional and hybrid-electric gasoline LDVs hold a steadily declining share of the market. Figure 3-42 shows the technology shares by type.

Projected emissions associated with Case D change dramatically over time. As Table 3-23 shows, transportation sector emissions of CO_2 decline more than 14% over the next 20 years, but by the end of the period when the full electric vehicle mandate is phased in, CO_2 emissions are more than 40% below reference emissions on an annual basis. This suggests very significant reductions would continue relative to the Reference Case. Electric vehicles have no transportation sector emissions, thus this strategy has the potential for significant reductions in criteria pollutants as well. Projected emissions reductions of over 60% for CO and VOC add to the appeal of this case from a purely environmental perspective.

Table 3-23. Transportation Sector Projected Emissions Changes for Case D.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand tons)	SO2 (Tons)	CO (Thousand tons)	VOC (Thousand tons)	CH4 (Thousand tons)
Annual (2029)	-42 (-43%)	-110 (-40%)	-850 (-22%)	-1,500 (-65%)	-80 (-61%)	-4.2 (-73%)
Cumulative (2007-2030)	-320 (-14%)	-840 (-14%)	-6,900 (-6.5%)	-11,700 (-22%)	-600 (-19%)	-28 (-20%)

Table 3-24. Power Sector Projected Emissions Changes for Case D.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand Tons)	SO2 (Thousand Tons)	Hg (lbs)
Annual (2029)	+16 (+25%)	+4 (+12%)	+2 (+2%)	+86 (+2%)
Cumulative (2007-2030)	+170 (+12%)	+51 (+5%)	+60 (+2%)	+800 (+2%)

As Table 3-24 indicates, there are also emissions penalties in the power generation sector from this strategy that must be accounted for. One must consider the roughly 42 million tons per year in CO_2 emissions reduction shown in Table 3-23 in relation to the 16 million ton per year increase in power sector emissions shown in Table 3-24. This lessens the net reduction of CO_2 to 26 million tons per year.

Costs are also a key consideration for this scenario, given the high price of pure electric vehicles. Table 3-25 shows that a projected additional $18 billion per year would need to be invested by 2030, while fuel savings are only projected at $10 billion. Reduced maintenance costs for electric vehicles further reduce the economic hurdle, but there is still a net $6 billion annual cost in the transportation sector projected in 2029. Adding the $2 billion in additional costs in the power generation sector (See Table 3-26), the net cost of this program grows to $8 billion in 2029 or approximately $37 billion over the period between 2007 and 2030.

Table 3-25. Transportation Sector Projected Cost Breakout for Case D.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$18B (+35%)	-$1.8 B (-22%)	-$10 B (-52%)
Cumulative (2007-2030)	+$120 B (+13%)	-$15 B (-8.7%)	-$90 B (-20%)

Table 3-26. Power Sector Projected Cost Breakout for Case D.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$174 M (+29%)	+$108 M (+6%)	+1.9 B (+23%)
Cumulative (2007-2030)	+$2 B (+20%)	+$1.2 B (+3%)	+$19 B (+12%)

Case E: Demand reduction leads to 12,000 VMT per year per vehicle by 2014. While the MARKAL model takes projected demand for transportation service as an input and is therefore not ideal for simulating demand reduction scenarios, it can explore the implications of successful demand-reduction programs. Case E looks at the implications of achieving significant demand reduction without specifying how that demand reduction would occur. The constraint was calculated based on a maximum 12,000 VMT per vehicle per year assumption. This limit corresponds to approximately a 13% annual reduction in VMT for 2008, based on available data. This fractional demand reduction (13%) was then applied for the entire period between 2011 and 2029.

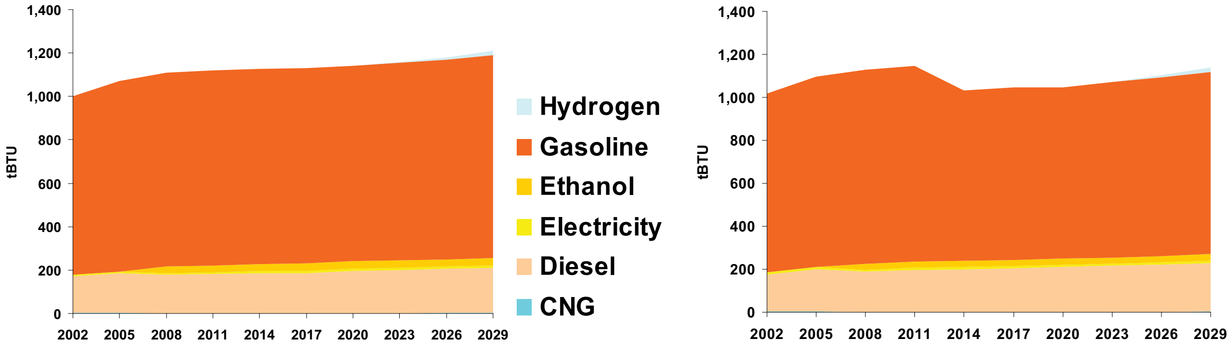

Figure 3-43. Reference and Case E Projected Transportation Energy Consumption by Fuel Type.

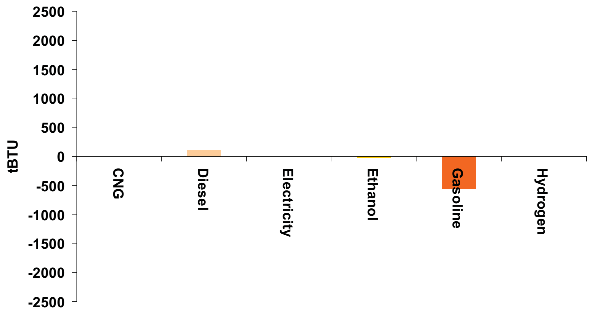

Figure 3-44. Projected Changes in Transportation Energy Consumption Between Reference and Case E Between 2007 and 2030.

The reduced demand relative to the Reference Case resulted in reduced energy consumption and reduced deployment of all vehicle technologies across the board, suggesting that it would be a very effective environmental policy if it could be achieved in practice. Figure 3-43 shows projected changes to the fuel consumption patterns between the Reference and Case E. Figure 3-44 shows the cumulative fuel reduction from this case, and Figure 3-45 shows projected changes in technology deployment patterns.

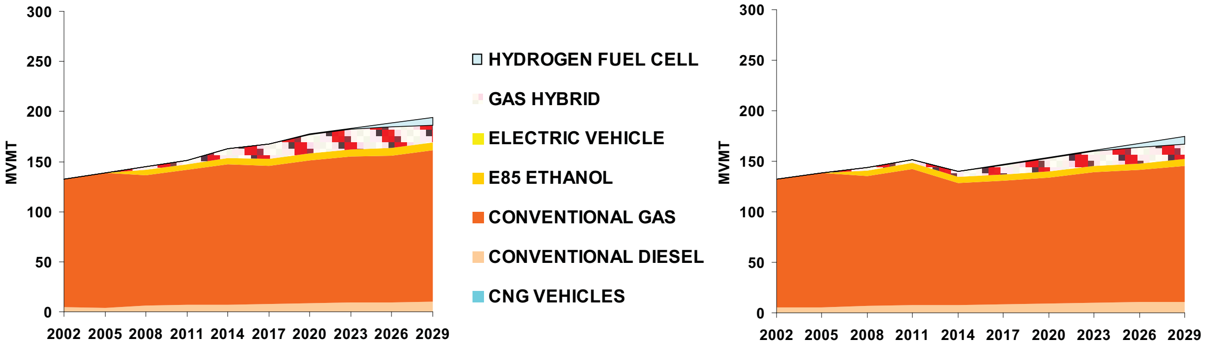

Figure 3-45. Reference and Case E Projected Transportation Technology Deployment by Type.

The large reduction in gasoline usage is evident in both Figure 3-43 and Figure 3-45. The slight increase in diesel fuel is due to the increased availability of transportation fuels more generally and a slight cost advantage for diesel relative to regular gasoline. Figure 3-45 shows that the technology mix in the LDV sector is projected to change, with a significant dip in the number of conventional gas cars after 2011.

Table 3-27. Projected Transportation Sector Emissions Changes for Case E.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand tons)	SO2 (Tons)	CO (Thousand tons)	VOC (Thousand tons)	CH4 (Thousand tons)
Annual (2029)	-15 (-15%)	-39 (-15%)	-380 (-10%)	-480 (-21%)	-26 (-20%)	-1.5 (-26%)
Cumulative (2007-2030)	-230 (-10%)	-600 (-10%)	-5,900 (-5.5%)	-7,500 (-14%)	-390 (-13%)	-18 (-13%)

Projected emissions changes under Case E assumptions are all beneficial, as shown in Table 3-27. Under a demand reduction, emissions are scaled back nearly one-for-one. There is a projected 10-20% reduction in almost all pollutants, consistent with 13% reduction in VMT across the board.

The cost savings, listed in Table 3-28, are considerable, as this policy leads to a reduction in capital costs and fuel savings on the order of $140 billion over the time period between 2007 and 2030. It should be noted that program costs or incentives that are required to achieve consumer behavior and/or market changes in order to reduce demand by this magnitude are not included in these estimates.

Table 3-28. Transportation Sector Projected Cost Breakout for Case E.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	-$5.8 (-11%)	-$0.5 B (-6.7%)	-$1.2 B (-6.3%)
Cumulative (2007-2030)	-$120 B (-12%)	-$11 B (-6.5%)	-$23 B (-5.1%)

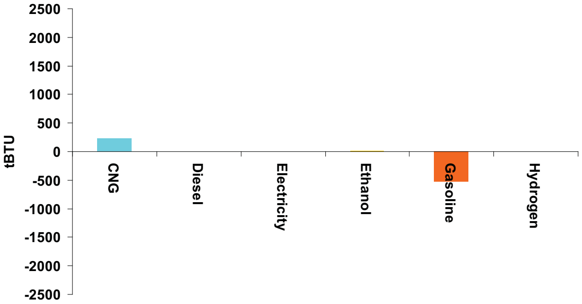

Figure 3-46. Reference and Case F Projected Transportation Energy Consumption by Fuel Type.

Case F: Minimum fuel efficiency of 25 mpg. Case F imposes a minimum efficiency standard on all LDVs, regardless of size class. This constraint prevented the model from purchasing any LDV in 2014 or after with a fuel efficiency below 25 mpg. This case is fundamentally different from the prior scenarios in that there was not a prescribed market share for a given technology type or constraining demand. For this case, the technology options were limited to meet a specified efficiency standard. Figure 3-46 shows the projected effect on energy consumption by fuel type. Figure 3-47 shows the projected cumulative impact of these changes relative to the Reference Case.

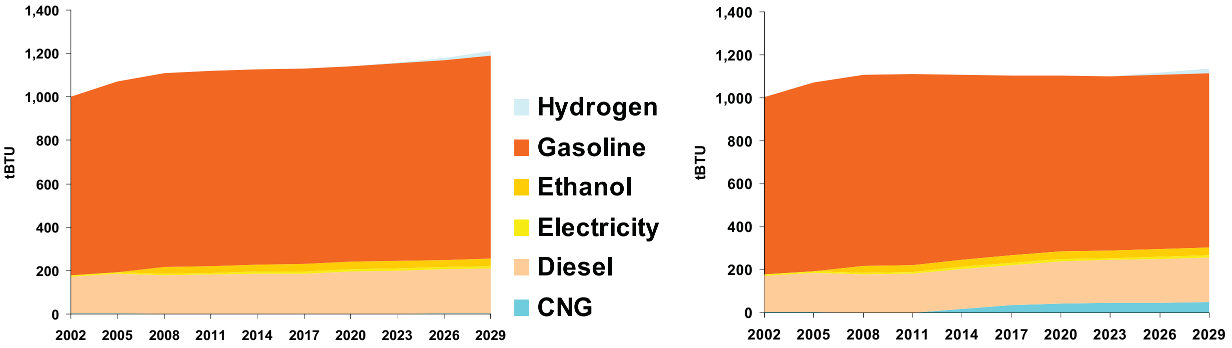

Figure 3-47. Projected Change in Transportation Energy Consumption between Reference Case and Case F between 2007 and 2030.

It is immediately obvious that the resulting scenario changes the economics to favor the purchase of compressed natural gas (CNG) consuming LDVs at the expense of conventional gasoline cars. The reason for this relates to the marginal cost of CNG versus gasoline consuming technologies with minimum performance of 25 mpg. When the low efficiency vehicles are eliminated as options, the CNG technologies are listed as being the most cost-effective from the perspective of delivering VMT for a given expenditure. Nonetheless, this is not suggesting that CNG per se could provide the future solution in the event of a national LDV performance standard, but rather, that the most cost-effective LDV technology could. The uncertainty in the cost characterizations between CNG and gasoline technology characterizations is large enough that it is not certain which technology is likely to be most cost-effective in the future. CNG might have been projected to penetrate to a greater extent, if not for being constrained at a relatively low level due to a lack of information on infrastructure costs. Until the appropriate infrastructure costs of CNG fueling stations are included in the model, decisions about large-scale deployment of such technologies should be approached with caution.

Figure 3-48 shows the projected technology deployment of LDVs, with a slight increased penetration of CNG vehicles beginning in 2014 through 2029.

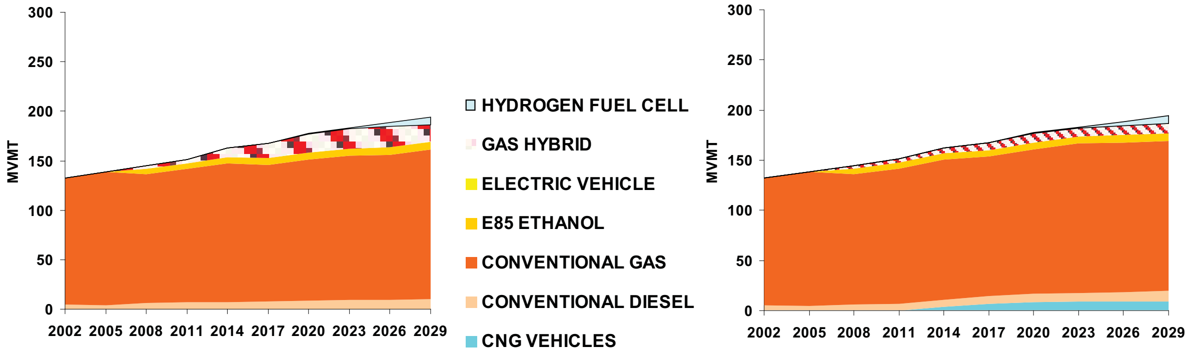

Figure 3-48. Reference and Case F Projected Transportation Technology Deployment by Type.

Projected emissions changes under Case F assumptions are small, as shown in Table 3-29. Due to the limits on CNG penetration, there was limited opportunity for CNG technologies to compete against otherwise slightly more efficient conventional gasoline technologies with small emissions benefit. While significant percentage reductions were seen for CO, CO_2, and SO_2, those benefits are small when compared to the large-scale changes examined in previous cases.

Table 3-29. Projected Transportation Sector Emissions Changes for Case F.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand tons)	SO2 (Tons)	CO (Thousand tons)	VOC (Thousand tons)	CH4 (Thousand tons)
Annual (2029)	-5.4 (-5.6%)	-2.4 (-0.9%)	-180 (-4.8%)	-140 (-6.1%)	+3 (+2.3%)	
Cumulative (2007-2030)	-60 (-2.7%)	-69 (-1.2%)	-2,400 (-2.3%)	-2,000 (-3.8%)	+9.6 (+0.3%)	

The projected cost savings, presented in Table 3-30, were small, with a modest increase in capital costs eroding nearly half of the fuel savings of a little more than $1.4 billion per year after the program is fully implemented.

Case G: Heavy-duty efficiency increase of 10%. The NYS Smartways program is aimed at energy efficiency measures in the heavy-duty fleet. Case G attempts to represent the combination of actions within this program as an overall improvement in fuel-efficiency for new heavy-duty vehicles. The constraint was imposed only on new vehicles sold in 2017 and later, but imposed an across-the-board 10% efficiency improvement on each new truck relative to Reference Case efficiencies. Figure 3-49 shows that the projected changes in fuel consumption in Case G is virtually indistinguishable from the Reference Case. A small cumulative decrease in diesel shown in Figure 3-50 (note the scale) reflects the small projected increase in efficiency for the heavy-duty fleet.

Table 3-30. Transportation Sector Projected Cost Breakout for Case F.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$0.8 B (+1.4%)	-$50 M (-0.6%)	-$1.4 B (-7.1%)
Cumulative (2007-2030)	$7.8 B (+0.8%)	-$800 M (-0.5%)	-$16 B (-3.6%)

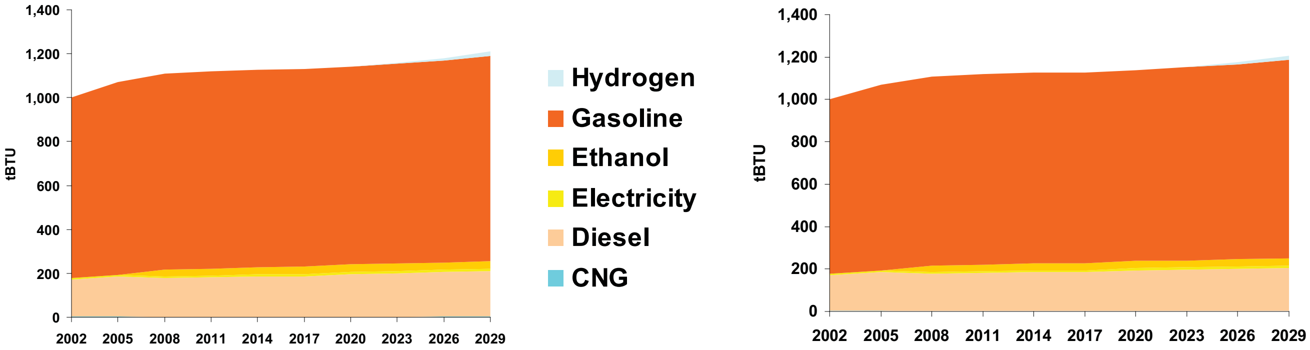

Figure 3-49. Reference and Case G Transportation Energy Consumption by Fuel Type.

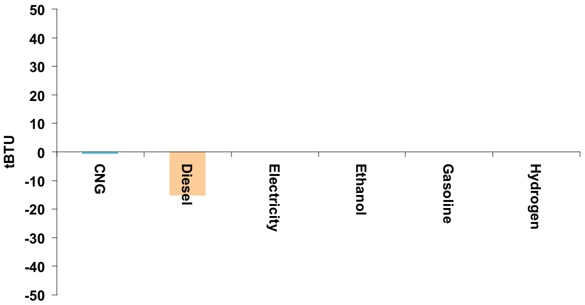

Figure 3-50. Projected Change in Transportation Energy Consumption between Reference and Case G between 2007 and 2030.

With heavy-duty energy consumption at only 13% of the transportation sector total, the 10% shift in energy efficiency is only expected to reduce overall sector energy use by roughly 1%. The small shift in fuel consumption seems appropriate for the Case G constraint. Technology deployment in this case is identical to the Reference Case, and is not shown here.

The projected emissions changes under Case G assumptions are modest, as shown in Table 3-31. By the time the program (fashioned after the Smartways program) is fully phased in, significant percentage reductions are projected across the board. Nevertheless, these percentages are expressed as a fraction of heavy-duty emissions only, and thus the absolute magnitude of these reductions is very small relative to the light-duty measures considered previously.

The projected cost savings, presented in Table 3-32, are also small, with fuel savings of around $150 million per year after the program is fully implemented.

Table 3-31. Projected Heavy-duty [only] Emissions Changes for Case G.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand tons)	SO2 (Tons)	CO (Thousand tons)	VOC (Thousand tons)	CH4 (Thousand tons)
Annual (2029)	-681 M (-5.4%)	-122 (-4.7%)	-3 (-4.6%)	-577 (-9%)	-38 (-8%)	
Cumulative (2007-2030)	-4.6 B (-5.5%)	-960 (-9.1%)	-22 (-5%)	-4,322 (-9%)	-286 (-8%)	

Table 3-32. Projected Heavy-duty [only] Cost Breakout for Case G.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	$28 M (2.6%)	$0 (<0.1%)	-$164 M (-5.5%)
Cumulative (2007-2030)	$111 M (2.6%)	$0 (<0.1%)	-$1.25 B (-5.7%)

Case H: Combined run: Case D + Case F. After the initial cases had been simulated, it was apparent that Case D, the electric vehicle mandate, had a tremendous impact late in the model horizon after 2020. Case F, the minimum performance standard, introduced more efficient vehicles earlier in the time horizon, improving the overall efficiency of the fleet, but tapered out as in-use vehicles were turning over in favor of more efficient vintages available after 2020. Case H represents a combined run of both constraints in the hope that early benefits accrued through a performance standard, coupled with the later benefits of a technology forcing standard, would combine to yield greater overall benefits. Figure 3-51 shows the combined influence of both constraints. There is a slightly greater use of CNG technologies just as was observed in Case D, but ethanol was projected to increase early in the period, and diesel, a bit later. By the end of the modeling horizon, the large influx of electric vehicles dominates, with cumulative reductions of gasoline usage and increased CNG, ethanol, diesel, and electricity for transportation fuels (Figure 3-52). Such findings should not be construed to imply that any one of these vehicles is the solution, but rather, that the combination of a near-term performance standard coupled with a technology forcing standard achieves greater combined benefits than either strategy on its own.

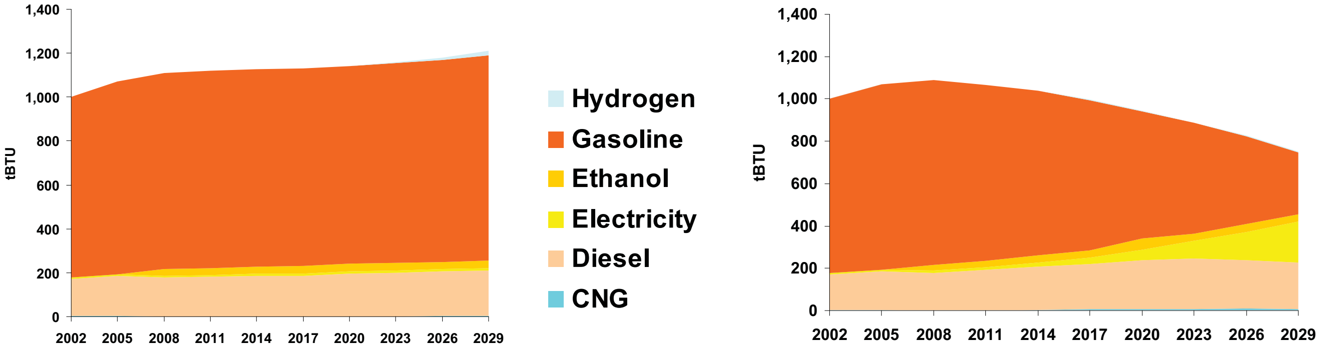

Figure 3-51. Reference Case and Case H Projected Transportation Energy Consumption by Fuel Type.

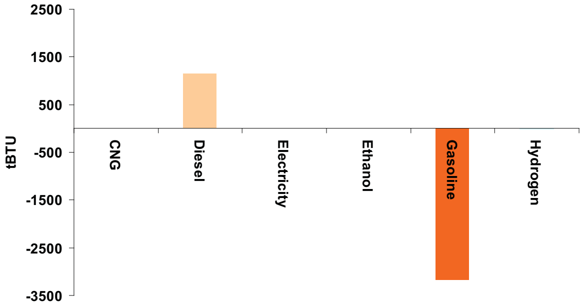

Figure 3-52. Projected Change in Transportation Energy Consumption between Reference Case and Case H between 2007 and 2030.

Projected technology deployment for Case H is shown relative to the Reference Case in Figure 3-53. The small buildup of diesel and ethanol cars leading up to 2020 is followed by a subsequent takeover of electric vehicles to meet the 2029 constraint. The model chose to delay the investment in electric vehicles as late in the model horizon as possible while still meeting the constraint in 2029.

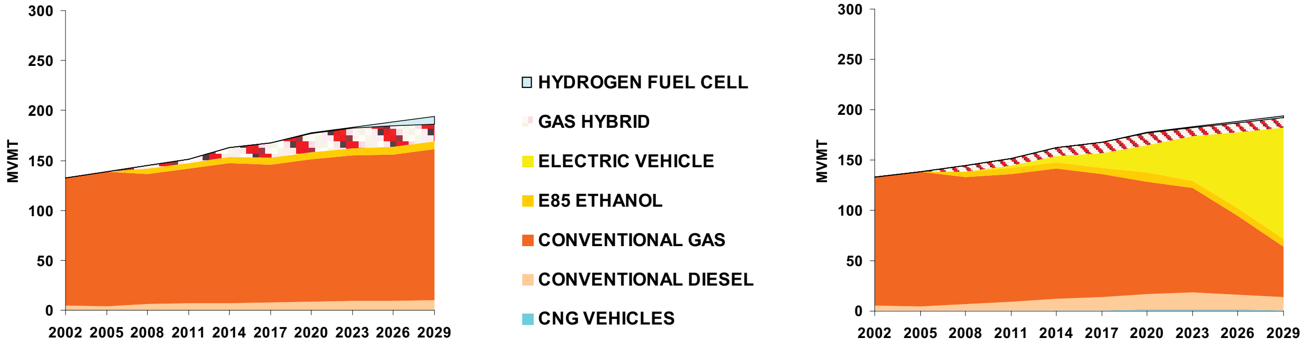

Figure 3-53. Reference Case and Case H Projected Transportation Technology Deployment by Type.

Emissions changes under Case H can be thought of as the sum of the emission changes for Case D plus the emission changes for Case F, and the projected results come reasonably close to this rough guide. Table 3-33 presents the projected changes. There are large decreases in CO_2, NO_x, CO and VOC associated with the electric vehicles.

Table 3-33. Projected Transportation Sector Emissions Changes for Case H.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand tons)	SO2 (Tons)	CO (Thousand tons)	VOC (Thousand tons)	CH4 (Thousand tons)
Annual (2029)	-44 (-45%)	-110 (-40%)	-900 (-24%)	-1,500 (-66%)	-80 (-61%)	
Cumulative (2007-2030)	-360 (-16%)	-900 (-15%)	-8,300 (-7.7%)	-13,200 (-25%)	-660 (-21%)	

Table 3-34. Projected Transportation Sector Cost Breakout for Case H.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$16 B (+ 31%)	-$1.8 B (-22%)	-$10 B (-53%)
Cumulative (2007-2030)	+$120 B (+12%)	-$15 B (-8.8%)	-$96 B (-22%)

The costs for Case H are dominated by the electric vehicle costs and mirror Case D costs, as shown in Table 3-34.

Case I: Combined run: Case A + Case B + Case G. Another case was simulated that examined a combination of technology-forcing constraints to better understand how the model responds to multiple demands for new technologies. Diesel vehicles with 10% higher efficiency and 25% hybrid electric vehicles in the light-duty vehicle fleet were coupled with a 10% fuel efficiency increase in the heavy-duty vehicle fleet. Results are shown in Figure 3-54. A tremendous reduction in gasoline consumption was evident, relative to the Reference Case. More efficient hybrids and diesel automobiles led to a projected cumulative drop in gasoline consumption of nearly 2,800 tBtu, relative to just over 1,200 tBtu increase in diesel usage (Figure 3-55).

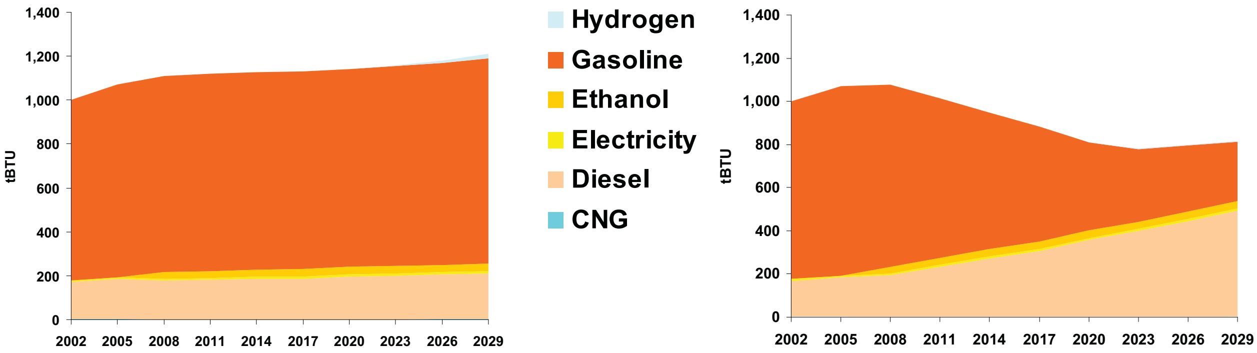

Figure 3-54. Reference Case and Case I Projected Transportation Energy Consumption by Fuel Type.

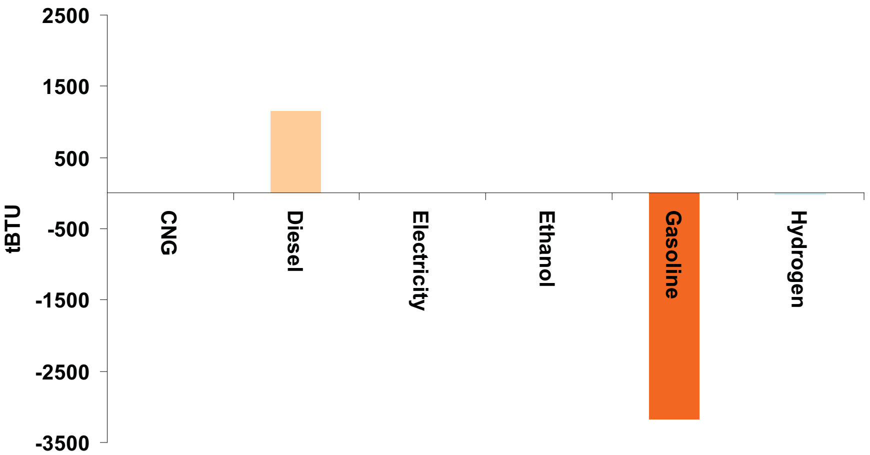

Figure 3-55. Projected change in Transportation Energy Consumption between Reference Case and Case I between 2007 and 2030.

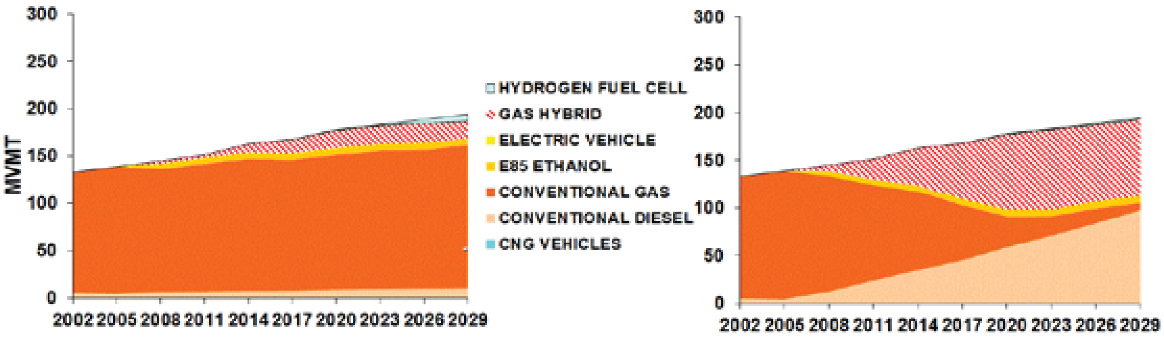

Figure 3-56. Reference and Case I Projected Transportation Technology Deployment by Type.

Figure 3-56 shows the projected changes at the technology level, with diesels and hybrids virtually squeezing conventional gasoline engines entirely out of the fleet.

Just as emission changes under Case H approximate the sum of the emission changes for case D plus the emission changes for Case F, Case I is similar to the sum of changes for Cases A plus B plus G. Table 3-35 lists the projected emissions changes. SO_2 emissions are projected to increase slightly, reflecting the increase in diesel consumption. All other pollutants decline fairly dramatically. The projected costs for Case I are shown in Table 3-36, and reflect large cost savings that exceed the capital costs for more efficient technologies.

Table 3-35. Projected Transportation Sector Emissions Changes for Case I.

Emission Changes relative to NYREF	CO2 (Million Tons)	NOx (Thousand tons)	SO2 (Tons)	CO (Thousand tons)	VOC (Thousand tons)	CH4 (Thousand tons)
Annual (2029)	-26 (-27%)	-76 (-29%)	+150 (+4%)	-1,270 (-55%)	-54 (-41%)	-3.3 (-58%)
Cumulative (2007-2030)	-420 (-19%)	-1,100 (-18%)	+1,600 (+1.5%)	-18,000 (-34%)	-750 (-24%)	-63 (-45%)

Table 3-36. Transportation Sector Projected Cost Breakout for Case I.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$1.7 B (+3.3%)	+$150 M (+1.9%)	-$6.5 B (-34%)
Cumulative (2007-2030)	$33 B (+3.4%)	+$2.2 B (+1.3%)	-$99 B (-23%)

Transportation Summary: technologies, emissions, and cost. The next step in the analysis, after having explored fuel and technology implications of each scenario, was examining how each case compares against the others. Figure 3-57 presents the projected fuel consumption changes, relative to the Reference Case, of each Case, A through I. While most of the cases projected significant reductions in gasoline consumption, several led to increases in diesel, ethanol, CNG, or electricity. Obviously, the relative emissions factors for the production of these alternate fuels determined the environmental performance of each case. This is particularly important to consider for ethanol, where the GHG emissions associated with land-use change could be significant. Considerable caution is thus warranted when interpreting the environmental benefits of Case C.

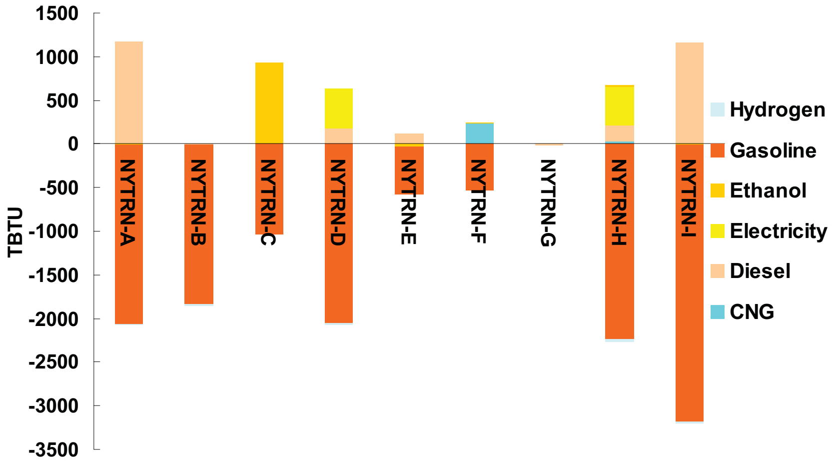

Figure 3-57. Projected Change in Energy Consumption relative to Reference Case by Case for Each Fuel Type.

Figure 3-58 shows the projected change in technology deployment for each case by technology type. While almost every scenario led to a reduction in conventional gasoline engines, the choice between replacement diesels, hybrids, ethanol, or electric vehicles are clearly shown in Cases A through D. The demand reduction case (Case E) and the heavy-duty efficiency improvement case (Case G) showed little effect on the choice of light-duty technologies, as expected. The performance standard case (Case F) chose CNG technologies as the most cost effective way of achieving a minimum performance standard; this is explored more in the summary of costs that follow. The combined scenarios show the greatest benefits in terms of reducing energy consumption, but also require the greatest change in technologies.

NE-MARKAL tracks a wide range of pollutants within the transportation sector, thus allowing examination of the relative performance of each case with respect to several pollutants, simultaneously. Figure 3-58 shows the projected net change in emissions, relative to the Reference Case, for CO_2, CH_4, CO, NO_x, SO_2, and VOC for each of the cases examined.

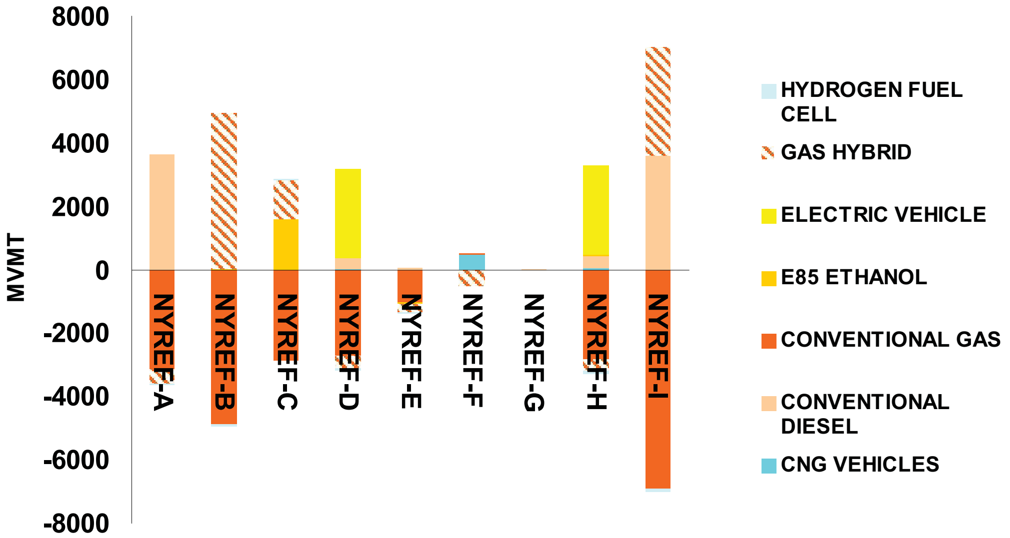

Figure 3-58. Change in Light Duty Vehicle Technology Deployment for Each Case by Technology Type.

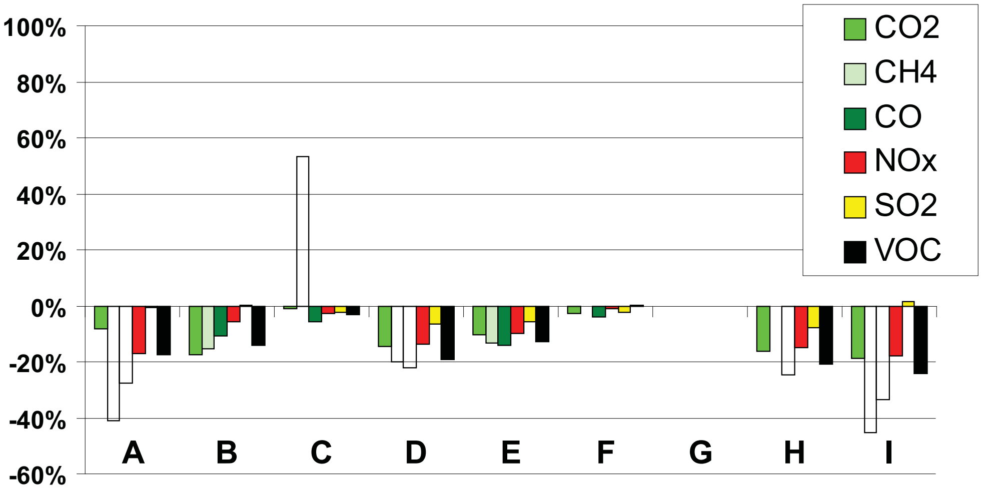

Figure 3-59. Net change in Light Duty Vehicle Emissions by Pollutant/Gas for Each Case.

While Case C showed promise in terms of reduced gasoline consumption, this comparison underscores that ethanol options may have other climate tradeoffs. In addition to the aforementioned land-use GHG emissions that need to be accounted for, a large increase in ethanol production may also increase methane emissions. While Figure 3-59 does not account for the global warming potential of methane, the direction of the net GHG changes presented for each scenario would remain qualitatively similar after global warming potential was taken into account. Several of the cases reduce methane and CO_2, but Cases D and H (the electric vehicle scenarios) are most effective in reducing LDV emissions across the range of pollutants tracked. Nevertheless, we should be mindful that a large fraction of the energy for these cases would be generated by the electricity generation sector. These emissions are accounted for in the multi-sector meta-scenarios later in the report.

From the perspective of solely achieving CO_2 reductions, cases where a larger fraction of the LDV market was constrained generally achieved greater reductions. Figure 3-60 shows the temporally resolved trajectory for NYS LDV CO_2 emissions for each case. As the figure demonstrates, those scenarios with 50% of the LDV market or greater constrained were projected to achieve the greatest CO_2 reductions.

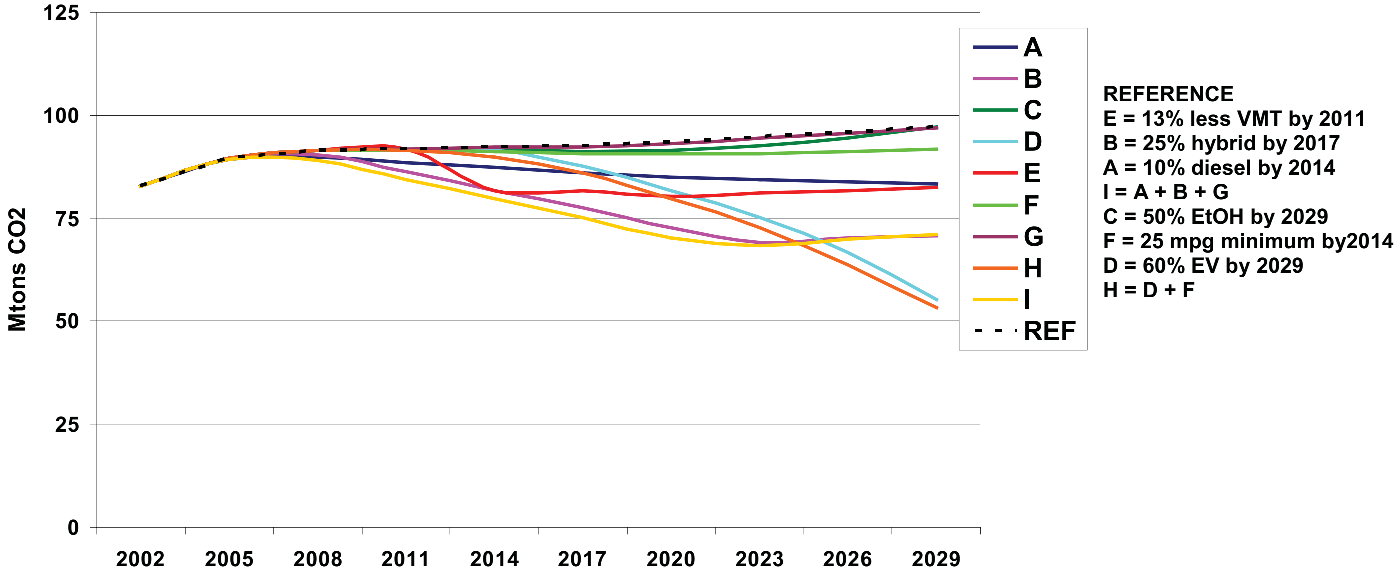

Figure 3-60. Net Change in Light Duty Vehicle CO_2 Emissions for Each Case.

The cost required to implement the cases varies widely. Figure 3-61 shows the projected net present value cost changes, relative to the Reference Case for each transportation case, broken down by capital cost, fixed and variable costs, and fuel costs. Case E represents a demand reduction and is clearly the most cost-effective. That is, if people drive less, then money is saved through reduced fuel consumption and potentially through the purchase of fewer cars, but it does not reflect the program costs that may be necessary to achieve this demand reduction. The other scenarios appear to pay for themselves with fuel savings, essentially outpacing any increases in technology costs (e.g., diesels, hybrids, efficiency standards). Cases C and D, however, led to projected increased cost relative to the Reference Case that were not recovered through fuel savings within the sector. The magnitude of such costs is small when compared to the overall cost of the energy-based economy.

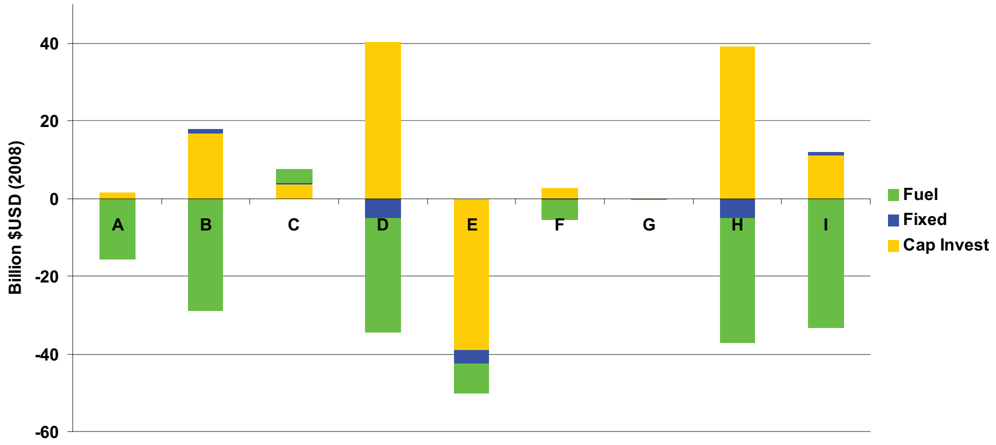

Figure 3-61. Projected Net Present Value Cost Change by Case.

Commercial and Residential Buildings. Nearly half of the energy consumed in NYS is used by residential and commercial buildings. A wide variety of end-use demands are responsible for this consumption, but heating, cooling, and lighting are the largest. Fossil fuels are consumed directly for space and water heating, and large quantities of electricity power serve most of the other appliances, equipment, and devices that are used in daily life. The analysis explored three technology cases aimed at heating and appliance efficiency, and one fuel strategy to reduce air pollution from residential, commercial, and industrial users of distillate and residual oil. These cases and their results are described below.

Case A: Increased Combined Heat and Power. Case A, the first residential and commercial sector policy examined, was a potential scenario in which 10% of heat and hot water demand for all residential and commercial sector buildings would be met by CHP systems. Figure 3-62 and Figure 3-63 show projected total energy consumption with and without the CHP requirement by fuel type for the commercial and residential sectors, respectively. Most of the CHP was projected to be used in the commercial sector.

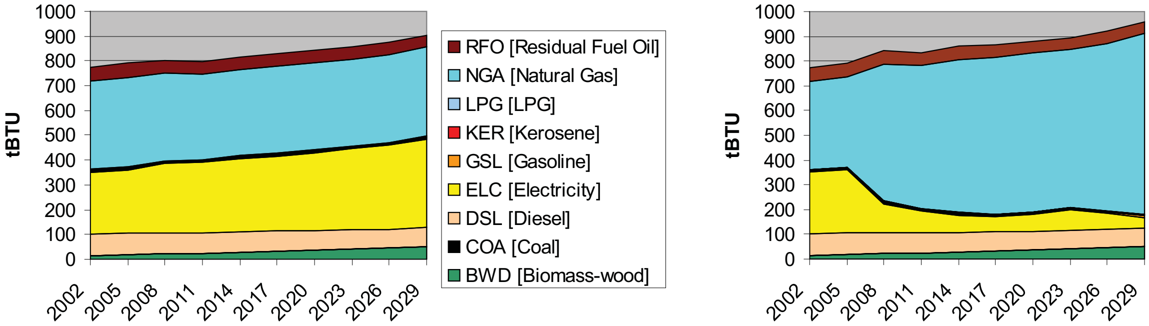

Figure 3-62. Projected Commercial Sector Energy Consumption for the Reference Case and Residential, Commercial, and Industrial Case A Simulations.

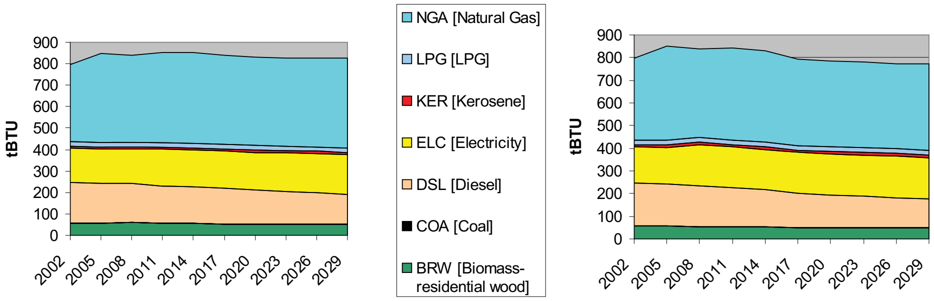

Figure 3-63. Projected Residential Sector Energy Consumption for the Reference Case and Residential, Commercial, and Industrial Case A Simulations.

Projected emissions changes under Case A assumptions were small, as shown in Table 3-37. The emissions changes associated with the introduction of CHP were primarily in the form of CO_2 reductions due to the greater efficiency of supplying heat and power simultaneously. Small reductions in CO, $PM_{2.5}$ and VOC were likely from the displacement of older, more polluting heating technologies.

Table 3-37. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case A.

Emission Changes relative to NYREF	**CO2 (Million Tons)**	**CO (Thousand tons)**	**NOx (Thousand tons)**	**P25 (Thousand tons)**	**SO2 (Thousand tons)**	**VOC (Thousand tons)**
Annual (2029)	-16 (-11%)	-14 (-3%)	-11 (-9%)	-1 (-2%)	-39 (-22%)	-11 (-5%)
Cumulative (2007-2030)	-467 (-13%)	-263 (-3%)	-9 (-0.3%)	-21 (-2%)	-25 (-0.5%)	-210 (-4%)

Table 3-38. Projected Residential and Commercial Cost Changes for Case A.

Cost Changes relative to NYREF (2008 $US)	**Change in capital costs**	**Change in fixed costs**	**Change in fuel costs**
Annual (2029)	+$1.9 B (+12%)	-$45 M (-1%)	-$11 B (-27%)
Cumulative (2008-2029)	+$10 B (+10%)	-$260 M (-1%)	-$69 B (-22%)

The large cost savings associated with CHP are evident in Table 3-38, which indicates nearly a 6:1 savings in annual expenses by 2029.

Case B: Energy Star™ Appliances. Case B examined appliance efficiency standards that would limit the market to appliances that meet current Energy Star efficiency ratings, starting in 2014. Figure 3-64 and Figure 3-65 show that ENERGY STAR® appliances play a more important role in the residential sector than in the commercial sector. This differs from Case A, where CHP systems played a larger role in the commercial sector.

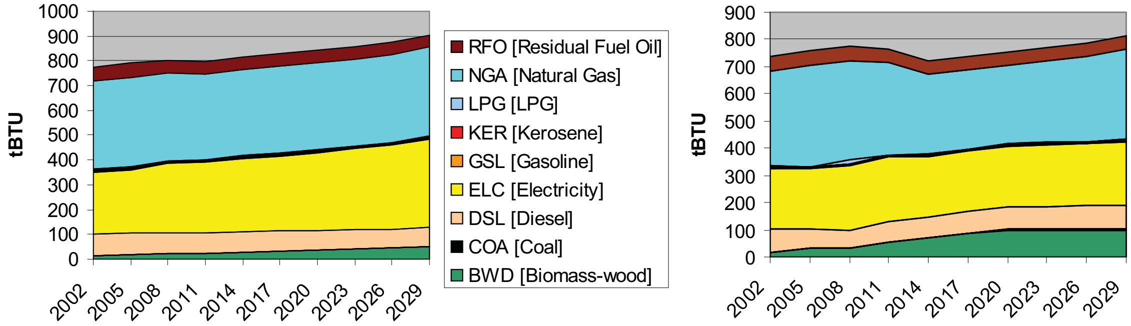

Figure 3-64. Projected Commercial Sector Energy Consumption for the Reference and Residential, Commercial, and Industrial Case B Simulations.

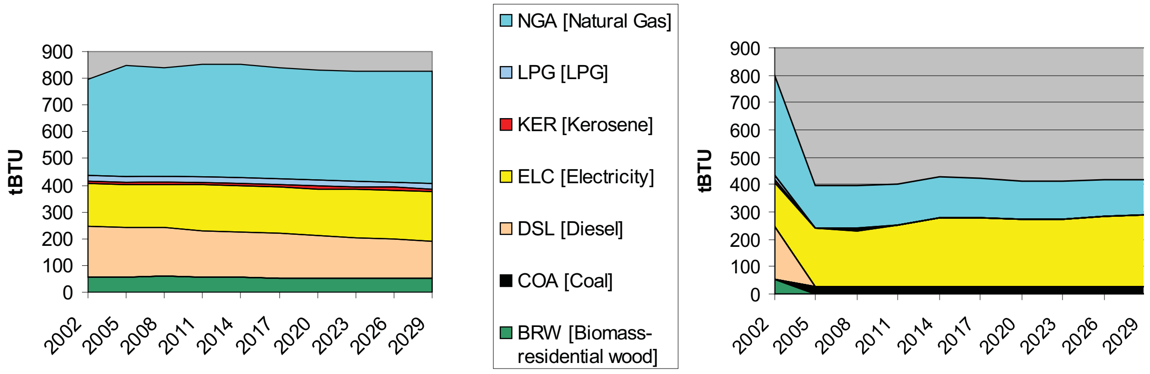

Figure 3-65. Projected Residential Sector Energy Consumption for the Reference Case and Residential, Commercial, and Industrial Case B Simulations.

Emissions changes under Case B assumptions indicated large reductions, as almost all residential sector demand was projected to shift to electricity. As with the transportation analyses, we need to account for any increased emissions captured in the power sector. The result is that almost all residential sector emissions were eliminated (though commercial and industrial emissions, which are included in these totals remain roughly constant), with the exception of some small continued natural gas heating. As shown in Table 3-39, this has large implications for emissions associated with Case B, especially CO, $PM_{2.5}$, and VOC.

Table 3-39. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case B.

Emission Changes relative to NYREF	CO2 (Million Tons)	CO (Thousand tons)	NOx (Thousand tons)	P2.5 (Thousand tons)	SO2 (Thousand tons)	VOC (Thousand tons)
Annual (2029)	-22 (-15%)	-254 (-63%)	-22 (-18%)	-33 (-73%)	-4.5 (-2.5%)	-200 (-98%)
Cumulative (2007-2030)	-530 (-15%)	-6400 (-65%)	-725 (-22%)	-847 (-75%)	-670 (-13%)	-5100 (-98%)

The projected costs of Case B, shown in Table 3-40, indicate that the substantial investment in energy efficient technologies would pay back through the large cost savings associated with fuel use.

Case C: Solar Thermal. Case C looked at increased deployment of solar thermal technologies that are capable of satisfying residential hot water heating demand using solar energy. A minimum constraint of 10% of all residential hot water heating demand was put in place, beginning in 2020. The response with respect to energy usage overall, even within the residential and commercial sectors, was relatively small. Nevertheless, Figure 3-66 shows that for residential hot water demand (the specific end-use demand that was constrained), energy savings on the order of the constraint were observed.

The projected emissions changes under Case C assumptions were correspondingly small, as shown in Table 3-41. Emissions reductions associated with a small introduction of solar thermal hot water systems could offset less than 1% of most emissions in the residential and commercial sectors, and could lead to a small increase of SO_2 emissions, if industrial CHP increases due to changes in electricity prices.

Table 3-40. Projected Residential and Commercial Cost Changes for Case B.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$5.1 B (+34%)	+$0.25 B (+5%)	-$11 B (-27%)
Cumulative (2008-2029)	+$41 B (+42%)	+$1.3 B (+3.5%)	-$60 B (-20%)

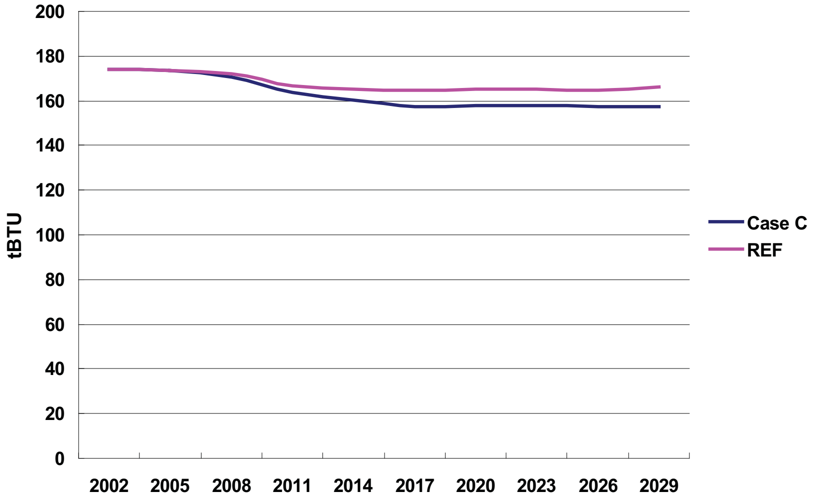

Figure 3-66. Projected Residential Hot Water Energy Use under Reference Case and Case C Assumptions.

Table 3-41. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case C.

Emission Changes relative to NYREF	CO2 (Million Tons)	CO (Thousand tons)	NOx (Thousand tons)	P25 (Thousand tons)	SO2 (Thousand tons)	VOC (Thousand tons)
Annual (2029)	-0.2 (-0.1%)	0 (<0.1%)	-0.8 (-0.7%)	0 (<0.1%)	+6.7 (+4%)	0 (<0.1%)
Cumulative (2007-2030)	-9 (-0.2%)	0 (<0.1%)	-9 (-0.3%)	0 (<0.1%)	+87 (+1.7%)	0 (<0.1%)

The cost to install the additional solar thermal capacity would eventually be recouped, but not immediately. The model projected that over the next two decades, roughly $5 billion would be needed to install and maintain the systems, which in turn would generate $3.4 billion in savings. Table 3-42 lists these costs and expenditures.

Table 3-42. Projected Residential and Commercial cost changes for Case C.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	+$0.75 B (+5%)	+38 M (+0.7%)	-$1.1 B (-3%)
Cumulative (2007-2030)	+$4.8 B (+5%)	+220 M (+0.6%)	-$3.4 B (-1%)

<u>Case D: Low-Sulfur Fuels.</u> Case D was neither technology-based nor focused on energy savings, but rather, a low-sulfur fuel standard. This scenario is currently being pursued, as appropriate, through the MANE-VU agreement among 11 northeast states, the District of Columbia and two native-American tribes.[26] The fuel standard requires that all distillate fuel achieve 15 ppm sulfur content or less by 2018. Heavier fuel blends are also limited in their sulfur content, but the majority of the reduction is intended to be achieved through the distillate component. Figure 3-67 shows the steep reduction in sulfur emissions projected from within the commercial and residential sectors, where distillate is a primary source of heating fuel.

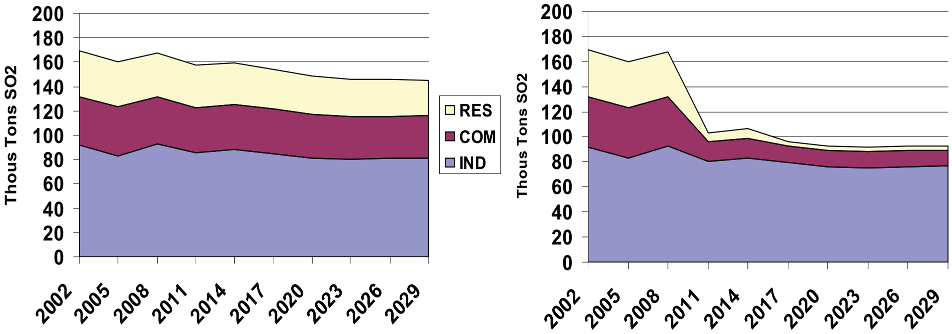

Figure 3-67. Projected Residential, Commercial, and Industrial Sector Emissions Under Reference and Case D Assumptions.

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[26] See: http://www.manevu.org/document.asp?fview=Formal%20Actions#

There are essentially no emissions changes under Case D other than the sulfur reductions. While there is expected to be a small efficiency increase (and therefore some reduction in CO_2 and CO) associated with the introduction of these cleaner fuels, such secondary effects would require developing additional emissions factors for residential and commercial technology assumptions, which is beyond the scope of this effort. The emissions changes presented in Table 3-43 therefore only account for the anticipated sulfur reductions.

Table 3-43. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case D.

Emission Changes relative to NYREF	**CO2 (Million Tons)**	**CO (Thousand tons)**	**NO_x (Thousand tons)**	**P25 (Thousand tons)**	**SO2 (Thousand tons)**	**VOC (Thousand tons)**
Annual (2029)	N/A	N/A	N/A	N/A	-55 (-31%)	N/A
Cumulative (2007-2030)	N/A	N/A	N/A	N/A	-1250 (-24%)	N/A

Table 3-44. Projected Residential, Commercial, and Industrial Sector Cost Changes for Case D.

Cost Changes relative to NYREF (2008 $US)	**Change in capital costs**	**Change in fixed costs**	**Change in fuel costs**
Annual (2029)	**N/A**	**N/A**	**$120 M (2.1%)**
Cumulative (2007-2030)	**N/A**	**N/A**	**$ 895 M (2%)**

The costs associated with the introduction of low-sulfur fuel are shown in Table 3-44. A small incremental increase in fuel cost drives up costs in 2029 by as much as $120 million per year. The incremental fuel costs used to generate these results were taken from analyses conducted by the Northeast Oilheat Research Association.[27] For 500 ppm fuel, the cost increment ranged from 5.4 to 6.8 cents per gallon; for 50 ppm fuel, the costs ranged from 3.8 and 7.6 cents per gallon; and for fuel less than 15 ppm, costs ranged from 4.6 and 8.9 cents per gallon. In each case, an average between the lower and upper bound of the incremental cost was used.

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[27] National Oilheat Research Alliance (2009). *Northeast Heating Oil.*

Industrial Sector. The industrial sector consumes about 15% of NYS's energy budget on an annual basis. NE-MARKAL does not have a highly detailed representation of the various industrial sectors that consume all of this fuel, but has a characterization of the primary service demands for five key industrial sectors of the New York economy: chemicals, metals, glass and cement, durables, and paper. Several processes common to these industries are explicitly represented in NE-MARKAL. These processes include: process heating; steam usage; electro-chemical devices; machine drives; and petro-chemical feed stocks. All other energy demands are aggregated into a generic "other industrial process" demand. At this point in time, policy analysis for the industrial sector is limited to the identified process demands, thus one case was developed that meets this criterion.

Case E: NO_x RACT. Case E assumes that all industrial boilers install NO_x controls at a level consistent with selective catalytic reduction (SCR) or greater. Figure 3-68 shows that, for this case, industrial sector emissions of NO_x were projected to be reduced by roughly 3,000 tons per year. Table 3-45 summarizes the projected emissions changes with respect to total emissions within all of the residential, commercial, and industrial sectors. While the 3,000 ton per year reduction represents only a 2% reduction relative to the total NO_x emissions from the residential, commercial and industrial sectors, these reductions are significant for shorter term attainment of air quality standards. This strategy does not result in emission reductions in other areas.

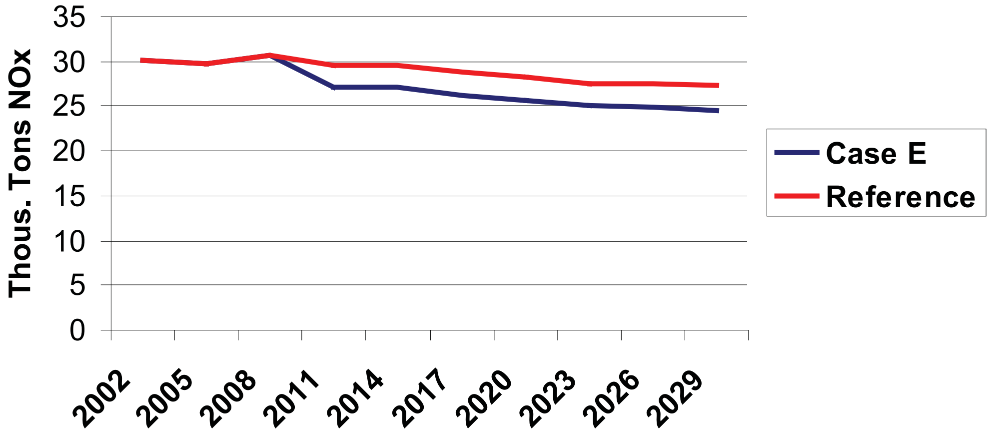

Figure 3-68. Projected NO_x Emissions for Residential, Commercial, and Industrial Sector under Reference Case and Case E Assumptions.

Table 3-45. Projected Residential, Commercial, and Industrial Sector Emissions Changes for Case E.

Emission Changes relative to NYREF	CO2 (Million Tons)	CO (Thousand tons)	NO_x (Thousand tons)	P25 (Thousand tons)	SO2 (Thousand tons)	VOC (Thousand tons)
Annual (2029)	N/A	N/A	-2.7 (-2.2%)	N/A	N/A	N/A
Cumulative (2007-2030)	N/A	N/A	-53 (-1.6%)	N/A	N/A	N/A

The costs associated with the new control equipment required to achieve this level of NO_x reduction have not been built into NE-MARKAL. An important next step for the use of NE-MARKAL is to incorporate characterizations of control technologies for criteria pollutants so that the energy efficiency and new technology options available to the model could be compared to retrofit costs for other criteria pollutant control options. This would principally include flue gas desulfurization (FGD) technology, SCR, and low NO_x burners, and could also include a wide range of other options, including low-sulfur or compliance coal and biomass co-firing. Similar characterizations are needed in the power generation sector, and would represent an important advance for more accurate simulation of criteria pollutant control options.

Table 3-46. Projected Residential, Commercial, and Industrial Sector Cost Changes for Case E.

Cost Changes relative to NYREF (2008 $US)	Change in capital costs	Change in fixed costs	Change in fuel costs
Annual (2029)	**+$.02 B (+.01%)**	**+$.04 B (+.01%)**	**N/A**
Cumulative (2007-2030)	**+$.2 B (+.03%)**	**+$.6 B (+.01%)**	**N/A**

Table 3-46 presents the incremental costs of installing NO_x controls on the State's industrial boilers. Overall, the costs are modest with respect to many of the other scenarios analyzed. In 2029, the annual incremental capital costs were estimated at roughly \$20 million, while the cumulative incremental costs over the 2008 to 2029 time period were at about \$200 million.[28]

Scenario Analyses and Results

The sector-specific policy levers discussed above examine the model responses to individual constraints within a given sector. Having verified that the model produces reasonable responses to these individual policy levers, five overarching policy scenarios were examined in a multi-sector context. These scenarios differed from the policy levers in that they were primarily designed to examine a combination of policies that would likely be enacted simultaneously to achieve multiple air quality and climate goals. In addition, the results were presented and evaluated across all sectors concurrently, rather than pollutant-by-pollutant and other specific, isolated impacts within each sector. This approach enabled the identification of cross-sectoral interactions of policies and synergistic effects of moving toward a low-carbon energy system.

Scenario 1: 52 x 30 Scenario.[29] The first scenario examined was identical to the power generation Case E (52% reduction by 2030 with conservation**)**. Here, however, we looked in greater detail and across multiple sectors. The emission reduction trajectory (See Figure 3-20) simulated represents one potential path for achieving the target of 80% CO_2 reduction by 2050. As discussed previously, this is not the only potential implementation pathway, and therefore this analysis should not be construed as reflective of State policy. While the prior policy lever analysis focused on power sector impacts, this scenario analysis examined a broad range of implications of achieving this target in the power, transportation sector, and residential, commercial and industrial sectors.

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[28] The data used to develop these cost estimated were from: *Applicability and Feasibility of NO_x, SO_2, and PM Emissions Control Technologies for Industrial, Commercial, and Institutional (ICI) Boilers.* NESCAUM 2009. Control cost data from Table 2-4 of that report were used to calculate average capital and fixed O&M costs across the range of boiler types in the NE-MARKAL system. For more information: http://www.nescaum.org/topics/air-pollution-control-technologies.

[29] The 52 x 30 scenario represents one of many pathways that could lead to substantial greenhouse gas reductions. This scenario differs from other potential climate scenarios, such as those developed in the context of the *NYS Interim Climate Action Plan (*www.dec.ny.gov/energy/80930.html). Scenarios and models differ in their approach to selecting types and quantities of measures, setting practical limits on implementation of strategies, and the assumptions used to quantify the economic impacts of strategies. For example, there can be substantial variance in assumptions for future costs of emerging technologies and net carbon impacts associated with changes in land use due to biomass development. Further, it is generally expected that scenarios based on less aggressive emission reduction goals for 2030 would be achievable at lower overall costs due to the ability to rely on measures that are more cost-effective.

Power generation Case E and this scenario allowed the model to exploit energy efficiency opportunities, including increased CHP for residential and commercial heating demands and other EE measures as surveyed by Optimal Energy for NYSERDA (NYSERDA, 2008) and represented in NE-MARKAL as conservation technologies. The comparison between the power generation Cases E and F demonstrated that including these efficiency opportunities can bring power sector costs down by nearly half (see comparison between case E and F in Figure 3-29).

The primary response of the power sector to the economy-wide carbon cap (as discussed previously and presented in Figure 3-20 through Figure 3-23 and Table 3-13 through Table 3-14), is to force a tremendous demand reduction through efficiency improvements in the demand sectors, followed by a large increase in renewable generation to satisfy a shift away from fossil fuel usage in other sectors.

Figure 3-69 examines the primary source of the increased demand, which comes from the transportation sector. There is a projected dramatic shift from gasoline and hybrid-electric light-duty vehicles to electric vehicles in order to reduce gasoline consumption. The result is that nearly 90% of the 2030 light-duty fleet would consist of pure electric vehicles.

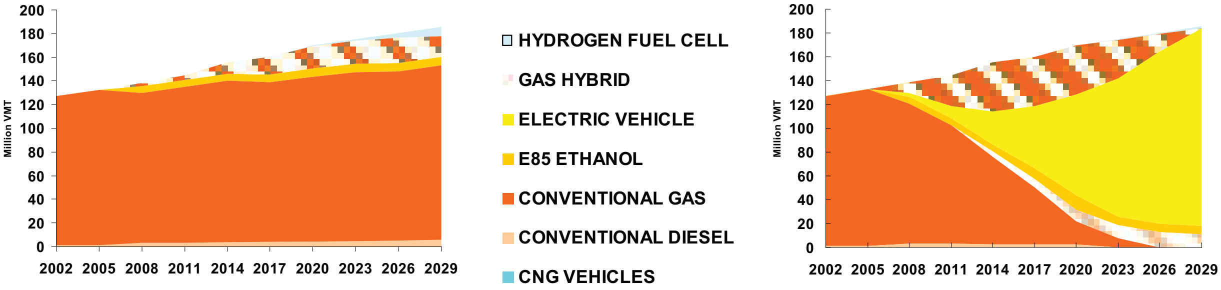


Figure 3-69. Projected Transportation Sector Technology Deployment under Reference Case and 52% CO_2 Reduction by 2030 Scenario.

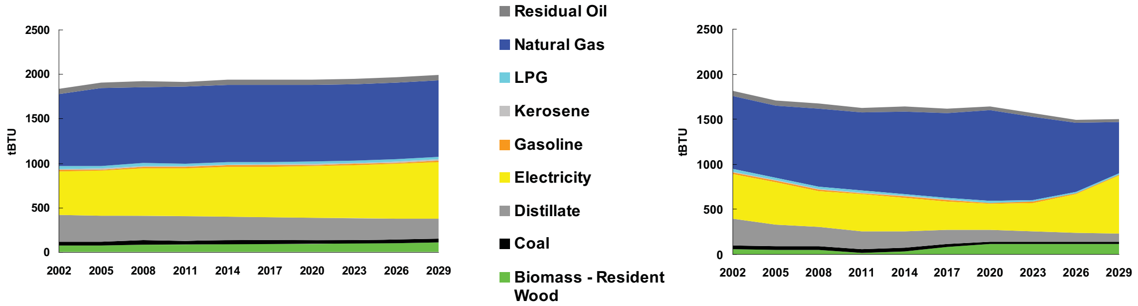


Figure 3-70. R/C/I Fuel Consumption under Reference Case and 52% CO_2 Reduction by 2030 Scenario.

Figure 3-70 presents combined results from the residential, commercial, and industrial sector to show the projected aggregate shift away from natural gas and distillate to electricity and wood. The shift to electricity is characterized by a decline in electricity early on, when the investment in more efficient technologies such as combined heat and power would lead to a demand reduction, followed by an increase in electricity consumption as heating demand would shift to more expensive heat pumps later in the period. Overall CO_2 reductions would also be achieved by switching to highly efficient gas furnaces and residential wood heat.

Scenario 2: Combination Scenario. The second scenario explored a specific combination of only the most effective policy levers at various levels of stringency. This scenario combined the following constraints:

> (1) NYS's current RPS (10,000 GWh of renewable generation by 2013, comprising 25% of forecast generation);
> (2) 25% of the 2030 light-duty vehicle fleet consist of electric vehicles;
> (3) an additional 25% of the light-duty fleet consists of gas-electric hybrid vehicles;
> (4) 100% of appliances sold after 2020 must meet the Energy Star standards for efficiency; and
> (5) fuel sulfur content of distillate and residual oil is restricted between 2017, consistent with regional agreements to achieve 15 ppm distillate and 0.5% sulfur content residual oil prior to 2018.

In addition, the following two constraints that were in place for the Reference Case were removed:

1. energy conservation technologies representing a collection of efficiency options identified by Optimal Energy for NYS (NYSERDA, 2008) may enter the solution up to their full technical potential; and
2. CHP may satisfy up to 20% of the residential and commercial sector heating demand.

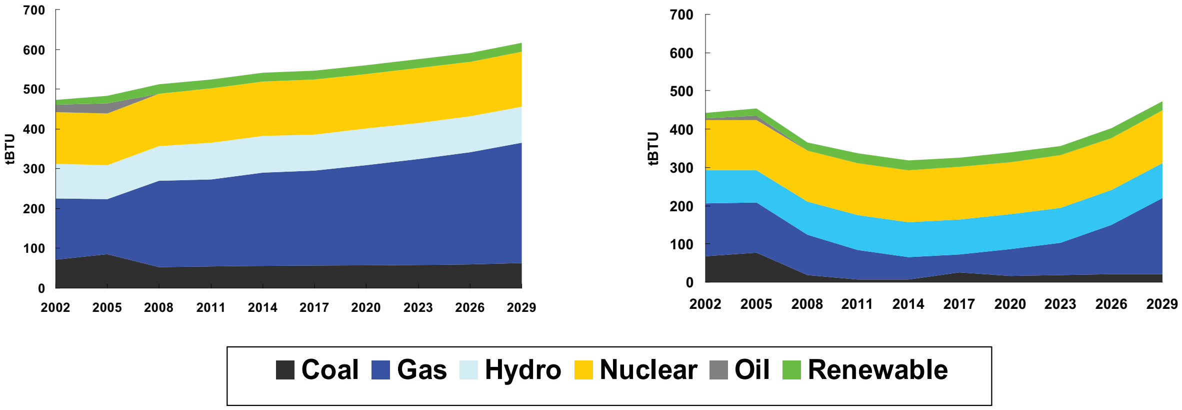


Figure 3-71. Projected Power Sector Technology Deployment under Reference Case and Combination Scenario consisting of the Most Effective Measures.

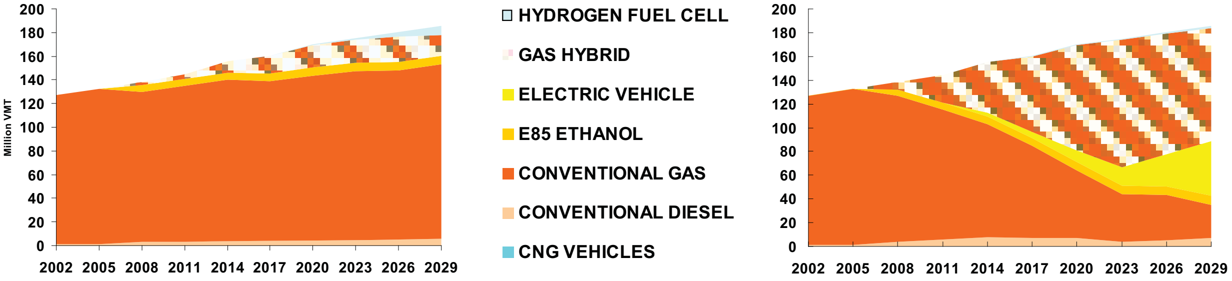


Figure 3-72. Projected Transportation Sector Technology Deployment under Reference Case and Combination Scenario Consisting of the Most Effective Measures.

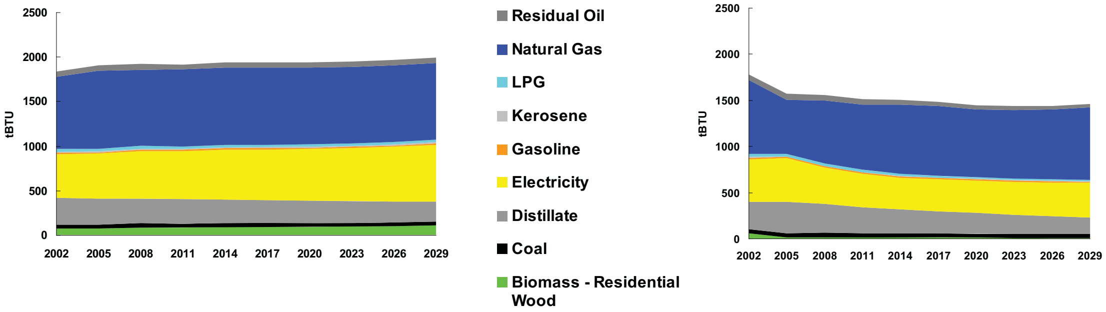


Figure 3-73. Projected R/C/I Fuel Consumption under Reference Case and Combination Scenario Consisting of the Most Effective Measures.

The results of this unique combination of policies are presented shown in Figure 3-71 through Figure 3-73. Figure 3-71 shows that the combination of requirements was projected to significantly reduce demand early on, as efficiency opportunities were exploited through the ENERGY STAR® appliance requirement and the availability of the conservation technologies and CHP. Demand is projected to rise in the later years, as the electric vehicle requirements bring the total level of demand back to 2005 levels by the end of the modeling period. Another significant finding is that an RPS of 10,000 GWh of renewable generation is essentially already being met, thus little additional renewable capacity would be needed to satisfy this requirement.

On the demand side, Figure 3-72 shows that forcing a moderate increase in hybrid-electric light-duty vehicles makes them more attractive to the model and, as a result, they achieve a greater than 25% share of fleet VMT in 2030. The electric vehicle requirement is considered expensive by comparison, and the model chooses to meet this constraint as late as possible while still satisfying the minimum criterion established for 2030. In the residential, commercial, and industrial sectors, the shift from traditional heat to CHP and energy efficiency investments is projected to reduce the overall energy use (Figure 3-73).

Scenario 3: Kitchen Sink Scenario. While Scenario 2 targeted investment in only the most effective strategies, Scenario 3, known as the Kitchen Sink Scenario, explored a combination of all the sector-specific policy lever analyses that were explored earlier. This approach required moderating the level of stringency for some of the measures such that deployment of each policy option was achieved at a reasonable level. The specific measures that constituted the Kitchen Sink Scenario were as follows:

(1) NYS's current RPS (10,000 GWh of renewable generation by 2013, comprising 25% of forecast generation);
(2) 25% of the 2030 light-duty vehicle fleet consists of electric vehicles;
(3) an additional 25% of the light-duty fleet consists of gas-electric hybrid vehicles;
(4) an additional 5% of the light-duty fleet consists of diesel vehicles;
(5) an additional 5% of the light-duty fleet consists of ethanol vehicles;
(6) a demand reduction in vehicle miles traveled of 5%;
(7) a minimum performance standard of at least 25 mpg for light-duty vehicles, starting in 2012;
(8) an overall 10% efficiency improvement in heavy-duty vehicle miles traveled corresponding with the NYS Smartways Program;
(9) a minimum of 10,000 MW of wind power generation by 2030 (not exclusive of the RPS);
(10) a 10% reduction in transmission and distribution (T&D) line losses for the electric grid;
(11) a 15% reduction in electric demand by 2015;
(12) 100% of appliances sold after 2020 must meet the ENERGY STAR® standards for efficiency;
(13) 10% of residential and commercial hot water demand must be met through solar thermal technologies;
(14) fuel sulfur content of distillate and residual oil is restricted between 2017, consistent with regional agreements to achieve 15 ppm distillate and 0.5% sulfur content residual oil prior to 2018; and
(14) Reasonably Achievable Control Technologies (RACT) must be applied to all industrial boilers to reduce NO_x emissions.

The following constraint relative to those in place for the Reference Case was removed:

- CHP may satisfy up to 20% of the residential and commercial sector heating demand.

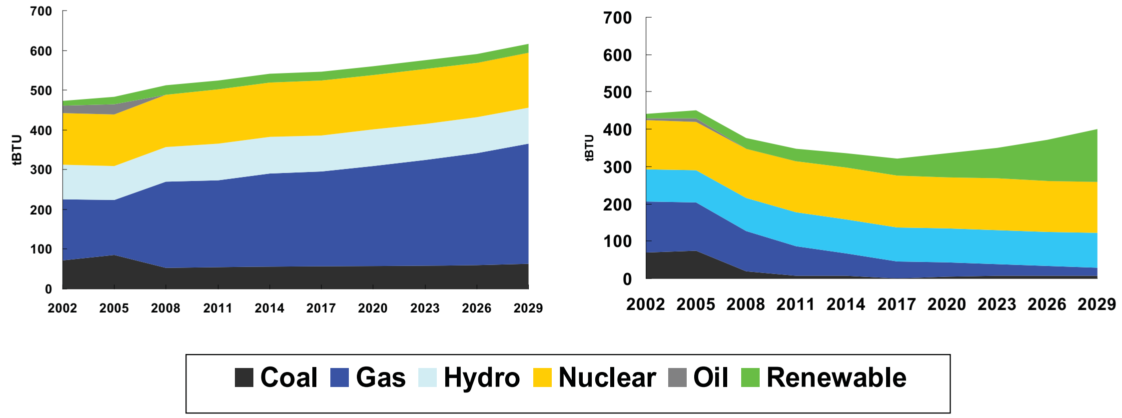


Figure 3-74. Projected Power Sector Technology Deployment under Reference Case and Kitchen Sink Scenario.

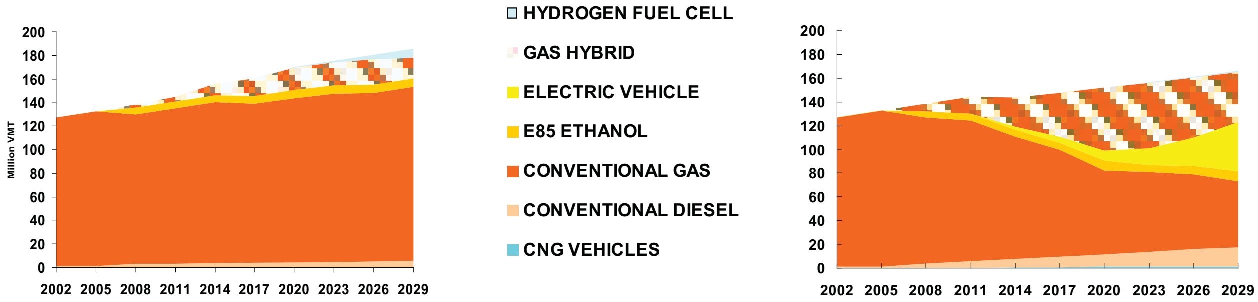


Figure 3-75. Projected Transportation Sector Technology Deployment under Reference Case and Kitchen Sink Scenario.

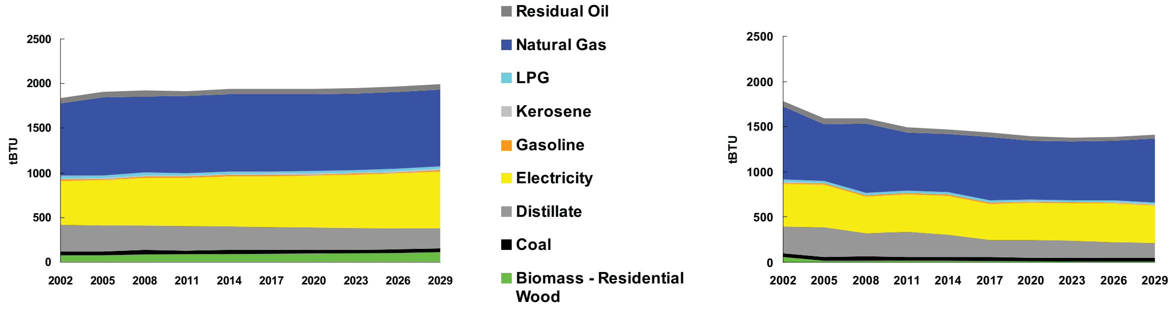


Figure 3-76. Projected R/C/I Fuel Consumption under Reference Case and Kitchen Sink Scenario.

The result of this combination of policies is shown in Figure 3-74 through Figure 3-76. Figure 3-74 indicates that the demand reduction policy and other measures that encourage efficiency are projected to lead to a reduction in electrical demand over time that would be eventually replaced as electric cars come on line in the 2020s. Gas and coal power generation would be scaled back as the demand is reduced and new wind generation is brought online to provide the new generation needed to satisfy the new transportation demand for electricity. Though the RPS is satisfied early on, the policy calling for wind power exclusively forces a large amount of additional wind capacity online.

Figure 3-75 shows the projected change in transportation technology deployment. The combination of electric vehicles, traditional hybrids, ethanol vehicles, and diesel vehicles would lead to a diverse light-duty fleet by 2030.

The entry of CHP, primarily in the commercial sector, combined with geothermal heat pumps to offset less efficient gas furnaces would lead to sharp decreases in natural gas usage and moderate reductions in electricity, giving rise to a lower combined total energy use for these sectors shown in Figure 3-76.

Scenarios 4 and 5: Fuel Cost Sensitivity and Technology Cost Sensitivity. Scenarios 4 and 5 were developed as sensitivity runs. The goal was to ensure that the solutions identified by NE-MARKAL were robust, given dramatically different conditions with respect to fuel price assumptions and technology costs. For the fuel price sensitivity, two simulations were conducted around the 52 x 30 Scenario (Scenario 1). For Scenario 4a, the 2030 price of oil and natural gas was roughly doubled, relative to the NYS Energy Plan price forecasts that had been used for the initial simulation of the Scenario 1. An annual average growth rate was calculated so that a smooth transition between 2008 State Energy Plan projections and the doubled 2030 projection could be achieved. For Scenario 4b, a similar process was undertaken to lead to 2030 price projections that were roughly half of the State Energy Plan price projections for petroleum and gas products.

As a sensitivity exercise, both of these scenarios are defensible. One can imagine price shocks in response to events like Hurricane Katrina in 2005, or dramatic shifts in offshore drilling policies in response to the 2010 Deepwater Horizon accident, or other geopolitical events that change import patterns. A doubling of the cost of fossil fuels is consistent with past events and could reoccur. While global agreement on strong GHG reduction policies does not seem imminent at present, one could imagine a sharp decline in demand for fossil fuels in response to global action on the order of the 52 x 30 Scenario being tested. Thus exploring a large price decrease over the coming two decades is also reasonable.

There are several key technologies that also determine how feasible and/or costly it may be to achieve the 52 x 30 targets. These include:

- 50 mile per gallon hybrid-electric vehicles
- 37 mile per gallon diesel vehicles

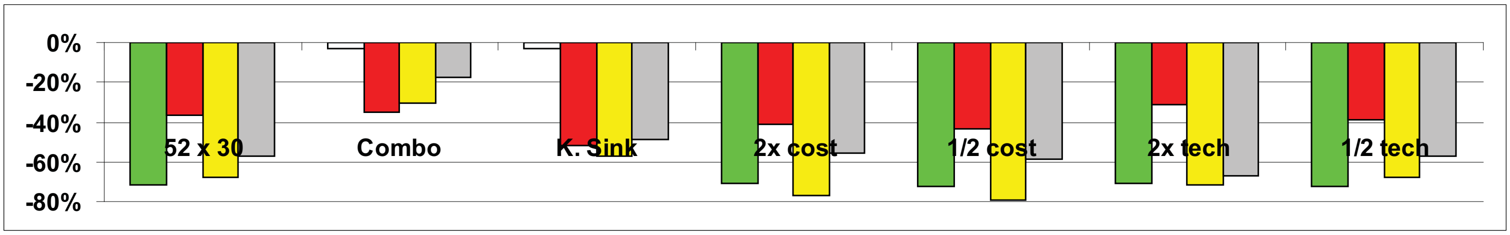
- full electric vehicles
- biomass-fired electric generation units (EGUs)
- landfill-gas fired EGUs
- solar power electrical generators
- wind power electrical generators
- solar-thermal water heating technologies
- ground-source heat pumps
- high efficiency lighting

For Scenario 5a, the capital investment cost for each of these technologies was replaced with a value reflecting twice current estimates. The exception was renewable energy technologies, where there was time dependent cost information from which annual average growth rates were developed that resulted in a doubling of cost by 2030, as had been done for Scenario 4. For Scenario 5b, the capital costs were cut in half or reduced via a declining annual average growth rate to achieve half the capital cost by 2030.

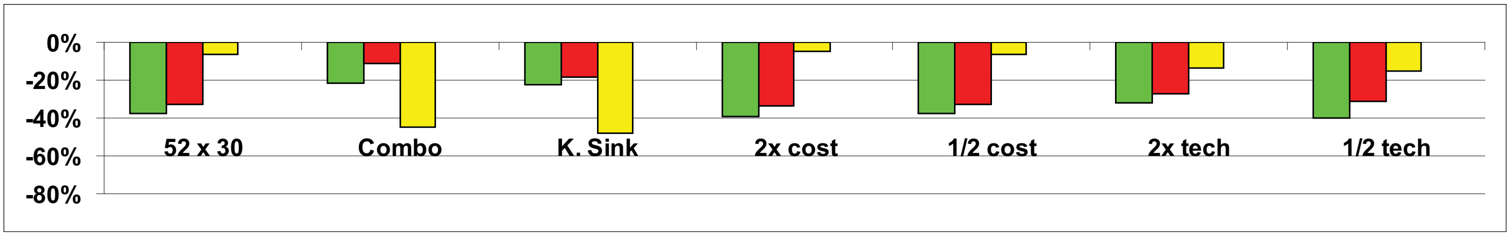
These assumptions reflect the inherent uncertainty in the assumed costs of future technologies and the rates of technological learning. If adopting stringent GHG regulation spurs research and development in other technological advances, prices could come down drastically as has been the case historically (NESCAUM, 2001). Projected costs for these technologies could rise if demand for them increases and there is not sufficient investment in expanded capacity or research and development. This scenario tests the conclusions about the costs of achieving NYS's policy goals as described by these specific scenarios in the context of altered cost assumptions. Different assumptions about interim targets or relative technology costs would result in varied results, and we reiterate that the 52 x 30 Scenario is not necessarily a recommended path for achieving NYS's GHG reduction goals.

Results for both of these scenarios are shown in Figure 3-77 for projected cumulative emissions changes between 2007 and 2030, and in Figure 3-78 for projected cumulative costs over the same time period. The results indicate that the emissions reductions that could be achieved under a 52 x 30 Scenario are robust and could be achieved, if mandated, through largely the same technological evolution. The cost of achieving this mandate, however, would vary with the cost of the technologies. The overall costs are driven by the transportation sector more than other sectors of the economy. Moreover, the costs are much more sensitive to the cost of electric vehicles in the future relative to the cost of a gallon of gasoline.

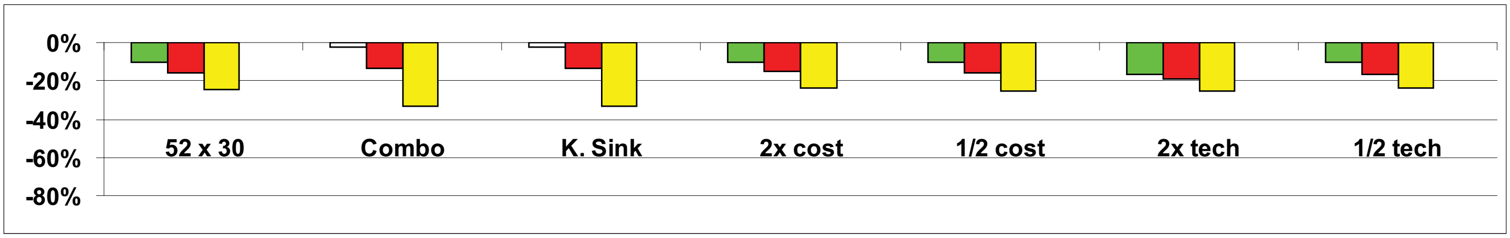
Power Sector.



Transportation Sector.



Residential, Commercial, and Industrial Sector.



Net Emissions Changes.

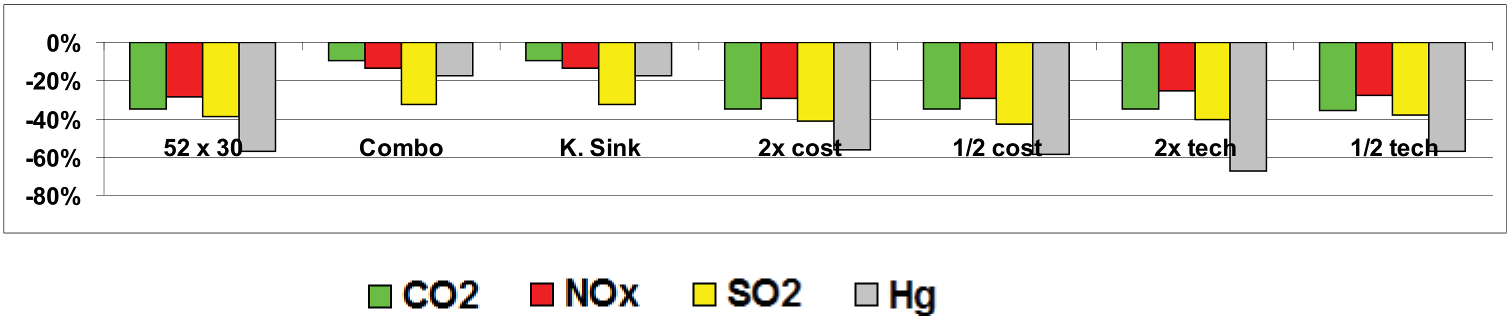
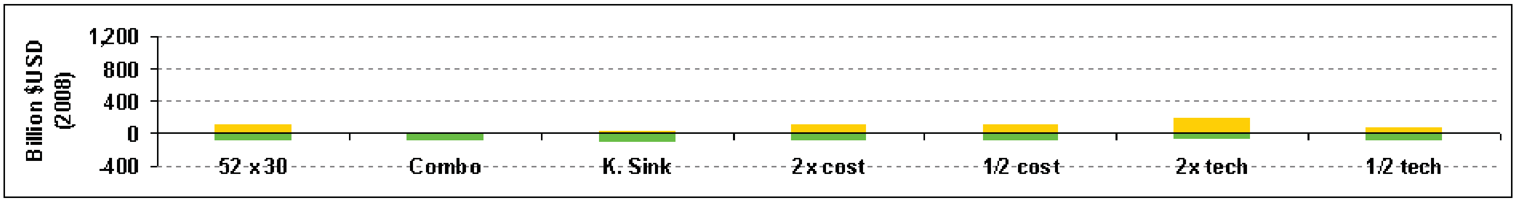
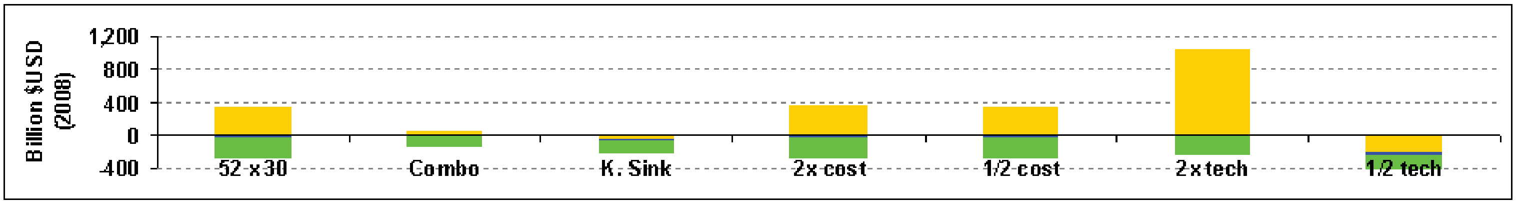


Figure 3-77. Projected Cumulative Emissions Changes between 2007 and 2030 by Sector under Five Scenarios.

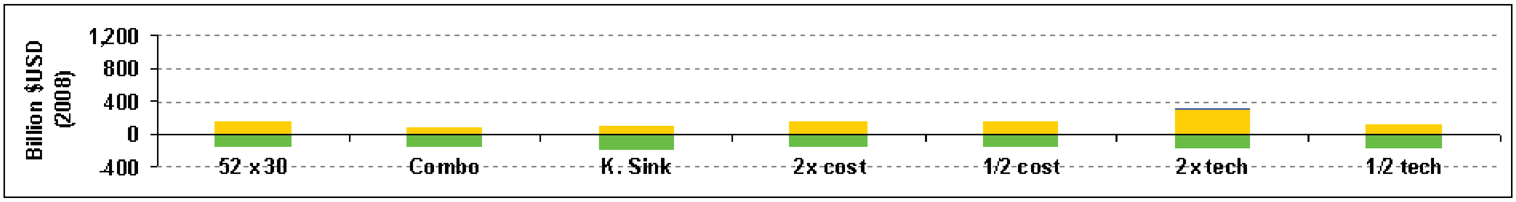
Power Sector.



Transportation Sector.



Residential, Commercial, and Industrial Sector.



Net Emissions Changes.

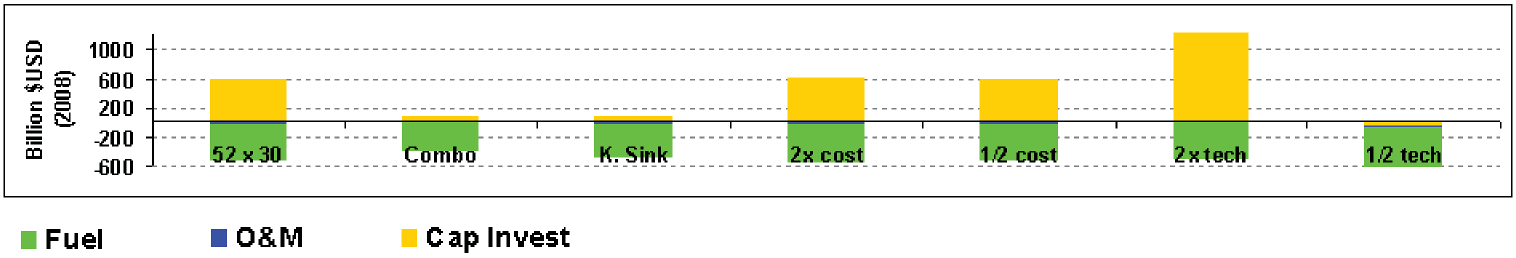


Figure 3-78. Projected Cumulative Cost Changes between 2007 and 2030 by Sector Under Five Scenarios.

__Cost and Emissions Summary__. Several scenarios were explored, including two price sensitivity scenarios. The results indicate that only seven key policy measures would be able to achieve more than half of the 52 x 30 Scenario reductions at substantial cost savings when accounting for reduced fuel consumption (See Figure 3-78). Many other policy approaches were examined that, when combined with these seven measures, were projected to lead to further savings and further emissions reductions.

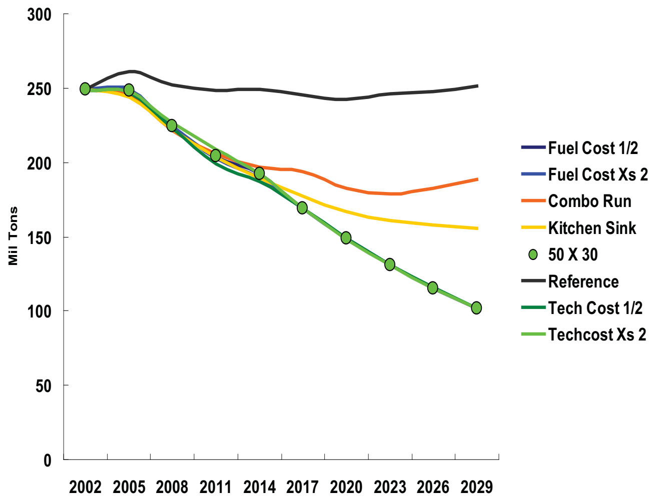


Figure 3-79. Projected GHG Reduction Pathways for Several Scenarios Explored through a Regional Integrated Assessment Framework.

Greenhouse gas reduction pathways for several scenarios are presented in Figure 3-79. The simulations presented here are based on assumptions that are already dated, i.e., based on 2008 patterns of energy consumption and GHG emissions. It would be prudent for the assumptions to be updated to reflect new economic and historical data prior to being used for shorter-term policy analysis. Notwithstanding, the longer term lessons regarding investment opportunities and intermediate reduction targets are useful to guide policy discussions.

The results further indicated that, while costs are different from one scenario to the next, the mandatory nature of the GHG reduction targets allowed for little flexibility in terms of overall emissions changes. Due to the nature of the constraint imposed on the system, simulations presented here had no choice but to achieve the targets, irrespective of cost.

Table 3-47 shows the projected cost implications of achieving the 52 x 30 Scenario targets under the Reference cost assumptions as compared to the combination of seven key measures or a combination of all policy measures explored.

Table 3-48 shows the same information for emissions reductions relative to the Reference Case.

Table 3-47. Projected Cost Changes relative to the Reference Case for Several Scenarios (Bill 2008 $s).

		Capital Costs	Fixed & Variable Costs	Fuel Costs
52 X 30	**Annual (2029)**	78.0	-44.5	-32.8
	% Change	*114%*	*-290%*	*-53%*
	Cumulative (2008-2029)	596.8	-32.8	-516.1
	% Change	*47%*	*-10%*	*-37%*
Combo	**Annual (2029)**	6.9	-45.4	-17.7
	% Change	*10%*	*-296%*	*-29%*
	Cumulative (2008-2029)	83.8	-20.5	-376.6
	% Change	*7%*	*-6%*	*-27%*
Kitchen Sink	**Annual (2029)**	6.6	-46.3	-22.1
	% Change	*10%*	*-302%*	*-36%*
	Cumulative (2008-2029)	77.1	-36.0	-448.5
	% Change	*6%*	*-11%*	*-32%*

Table 3-48. Projected Emission Changes relative to the Reference Case for Several Scenarios. (CO_2 – Mtons; NO_x/SO_2 – Thous. Tons; Hg – Tons)

		CO2	NOx	SO2	Hg
52 X 30	**Annual (2029)**	-148.8	-197.1	-135.0	-0.3
	% Change	*-59%*	*-50%*	*-58%*	*-75%*
	Cumulative (2008-2029)	-2072.8	-2673.0	-2189.0	-4.5
	% Change	*-35%*	*-29%*	*-39%*	*-57%*
Combo	**Annual (2029)**	-46.5	-72.7	-89.5	-0.1
	% Change	*-19%*	*-18%*	*-39%*	*-28%*
	Cumulative (2008-2029)	-576.6	-1260.5	-1849.8	-1.3
	% Change	*-10%*	*-13%*	*-33%*	*-17%*
Kitchen Sink	**Annual (2029)**	-51.3	-122.1	-117.1	-0.2
	% Change	*-20%*	*-31%*	*-51%*	*-61%*
	Cumulative (2008-2029)	-711.7	-1928.7	-2386.7	-3.8
	% Change	*-12%*	*-21%*	*-42%*	*-49%*

CMAQ Results: Air Quality Beefits Projections

CMAQ version 4.6 was run over the eastern United States for 2002 as well as two annual simulations of 2018 representing: (1) the NE-MARKAL Reference Case and (2) the Combination Scenario corresponding to a similarly named run of the NE-MARKAL model. CMAQ hourly surface concentration outputs were post-processed to generate $PM_{2.5}$ and O_3 spatial plots for multiple averaging periods and to generate text inputs for BenMAP.

2018 Reference Case

The 2018 Reference Case forms the basis against which alternate policy scenarios are compared and represents the possible evolution of the energy infrastructure in New York given certain baseline assumptions and constraints. While more detailed descriptions of the assumptions in this scenario and policy scenarios are contained earlier in this Section, key assumptions are reviewed here to provide insight into the emissions changes that needed to be represented through the SMOKE and CMAQ modeling process.

The key assumptions are:

- For the power sector, the RGGI was included, while a RPS was not included.
- In an effort to represent the consumer preference for SUVs and other inefficient light-duty vehicles, light-duty vehicle class shares were fixed in an effort to prevent NE-MARKAL from instituting a major shift of class shares to smaller, more efficient cars. The maximum penetration of CNG was limited to no more than 1% of total transportation sector fuel consumption because cost information on the associated necessary fueling infrastructure is not included in NE-MARKAL.
- Residential and commercial sector fuel shares were constrained such that they did not disrupt current regional fuel markets. Additionally, energy efficiency effects were constrained out of the Reference Case.

2018 Combination Scenario

The Combination Scenario was based on seven of the most effective strategies from the Kitchen Sink NE-MARKAL modeling scenario in an effort to demonstrate that the majority of reductions can result from just a few effective measures. These strategies included the following:

- NYS's current RPS (i.e., 10,000 GWh of renewable generation by 2013)
- Electric vehicles comprise at least 25% of the 2030 light-duty vehicle fleet
- Gas-electric hybrid vehicles comprise an additional 25% of the light-duty fleet
- 100% of appliances sold after 2020 must meet the ENERGY STAR® standards for efficiency
- Sulfur content of distillate and residual fuel is restricted to 15 ppm and 0.5%, respectively, by 2017
- Unrestricted conservation technologies
- Combined heat and power may satisfy up to 20% of the heating demand from residential and commercial sectors

Electricity demand was reduced between 2002 and 2017 due the Energy Star efficiency requirements and availability of CHP and conservation technologies from the residential, commercial, and industrial sectors. Later in the NE-MARKAL time horizon, demand increased due to the EV requirements. The RPS requirements were essentially already met by existing hydroelectric power, and as a result, little additional renewable capacity was necessary to meet the RPS constraint. In the transportation sector, there was a significant percentage of the light-duty vehicle fleet represented by hybrid vehicles by 2017, compared to the Reference Case.

While the focus in these NE-MARKAL runs is on NYS strategies, one should note that State scenario constraints may lead to significant impacts on the energy infrastructure of surrounding states. Impacts for all 11 states and the District of Columbia represented in NE-MARKAL were translated into spatially-resolved changes in the SMOKE modeling inventories for each scenario.

Results

Figure 3-80 and Figure 3-81 show the annual average $PM_{2.5}$ in micrograms per cubic meter ($\mu g/m^3$) and annual maximum 8-hour ozone surface concentration fields in parts per billion by volume (ppb) for 2002 and the 2018 Reference Case. $PM_{2.5}$ was estimated by summing the following species calculated by CMAQ: nitrate, ammonium, sulfate, elemental carbon, unspeciated fine mass, primary organic mass, and anthropogenic and biogenic secondary organic aerosol. Spatial patterns of $PM_{2.5}$ are similar between the two simulations, with urban centers clearly indicated. While the 2018 Reference Case led to a higher maximum annual average $PM_{2.5}$, in general, the 2018 Reference Case $PM_{2.5}$ was reduced compared to 2002. For annual maximum 8-hour O_3, the lowered concentrations in 2018 compared to 2002 are even more apparent. There are ubiquitous decreases in maximum 8-hour O_3 between the 2002 and 2018 Reference Case, with O_3 peaks often occurring in both cases downwind of urban centers after emissions have had time to be transformed by photochemistry.

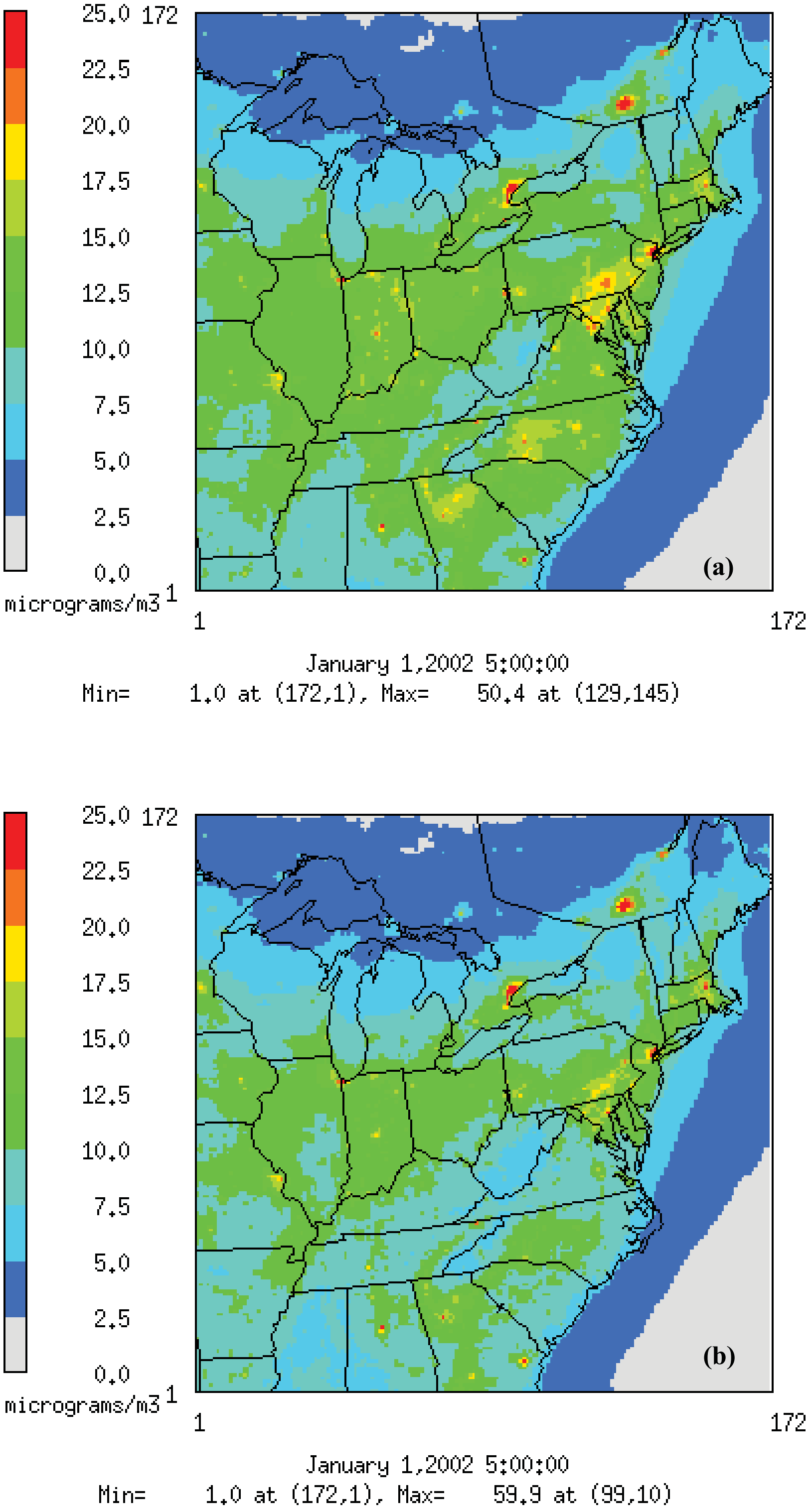


Figure 3-80. Annual Average PM$_{2.5}$ for (a) 2002 and (b) 2018 Reference Case.

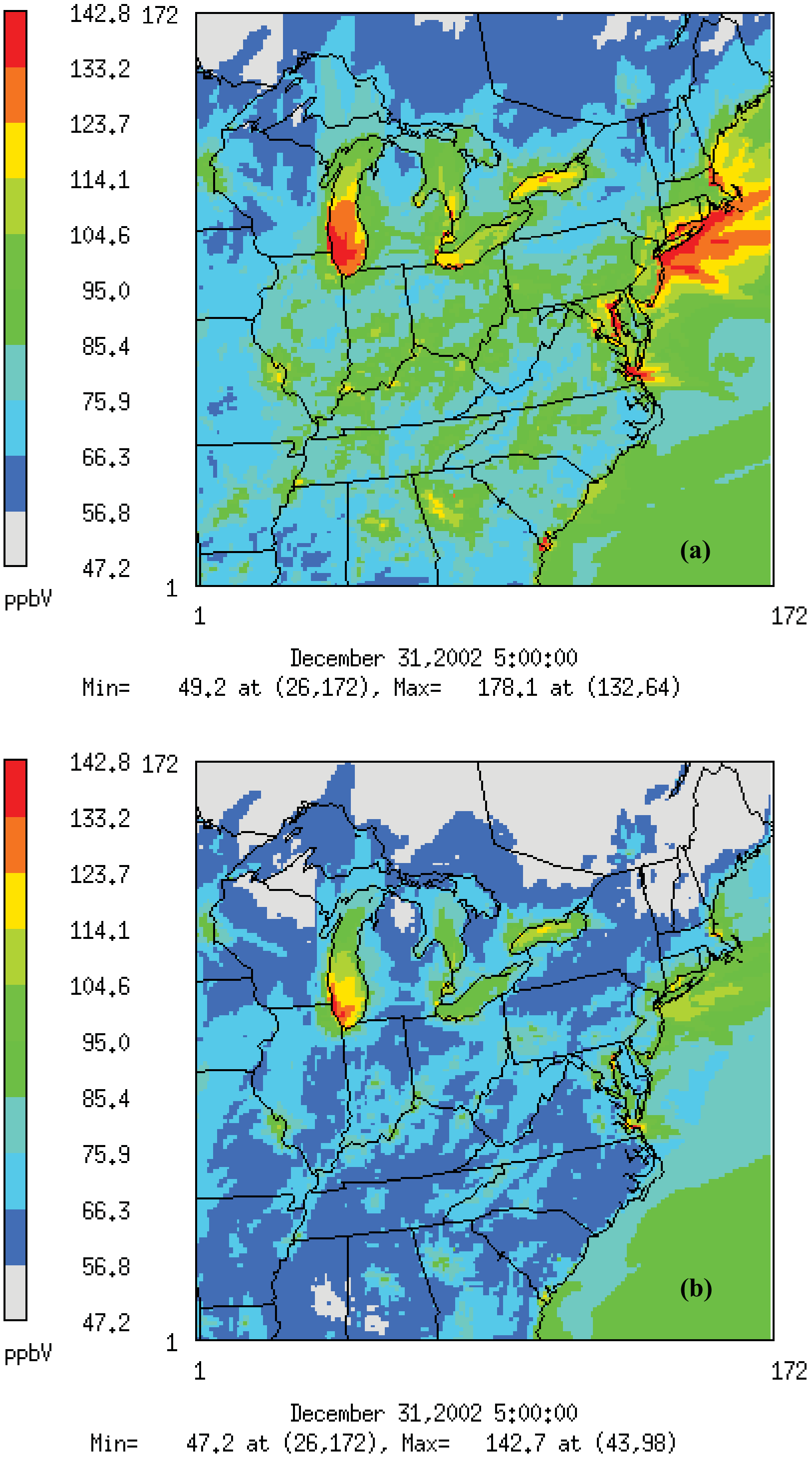


Figure 3-81. Annual Maximum 8-hour Ozone for (a) 2002 and (b) 2018 Reference Case.

Figure 3-82 shows the difference in annual average $PM_{2.5}$ and daily maximum 8-hour ozone between the 2018 Reference Case and the 2018 Combination Scenario. Recall that the NE-MARKAL Combination Scenario combined the most effective policy levers determined by previous analyses, in an effort to demonstrate that significant emissions reductions can come from just a few measures. To recap, these included the following:

- NYS's current Renewable Portfolio Standard (RPS) (10,000 GWh of renewable generation by 2013)
- Electric vehicles comprise at least 25% of the 2030 light-duty vehicle fleet
- Gas-electric hybrid vehicles comprise an additional 25% or more of the light-duty fleet
- 100% of appliances sold after 2020 must meet the ENERGY STAR® standards for efficiency
- Sulfur content of distillate and residual fuel is restricted to 15 ppm and 0.5%, respectively, by 2017[30]
- Unrestricted conservation technologies
- CHP may satisfy up to 20% of the heating demand from residential and commercial sectors

The negative values indicate a concentration increase between the Reference Case and Combination Scenario, and positive values a decrease. Table 3-49 includes a statistical summary of the absolute and percentage differences in annual average $PM_{2.5}$ and annual average daily maximum 8-hr O_3 for those cells with a State population ≥ 1. The gridded population values were generated with PopGrid for BenMAP processing. BenMAP and associated CMAQ post-processing are described in further detail below.

For NYS cells, the annual average $PM_{2.5}$ reduction between the Reference Case and the Combination Scenario was around 9% (0.8 $\mu g/m^3$). There was, however, a wide range in the percentage reductions, from ~-38% to ~20% (Table 3-49). The standard deviation was a bit higher here, so most cells fell in the 4.9% to 13.5% reduction range.

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[30] A low sulfur fuel correction was applied to the 2018 Combination Scenario area and point non-EGU emissions inventories as a post-processing step.

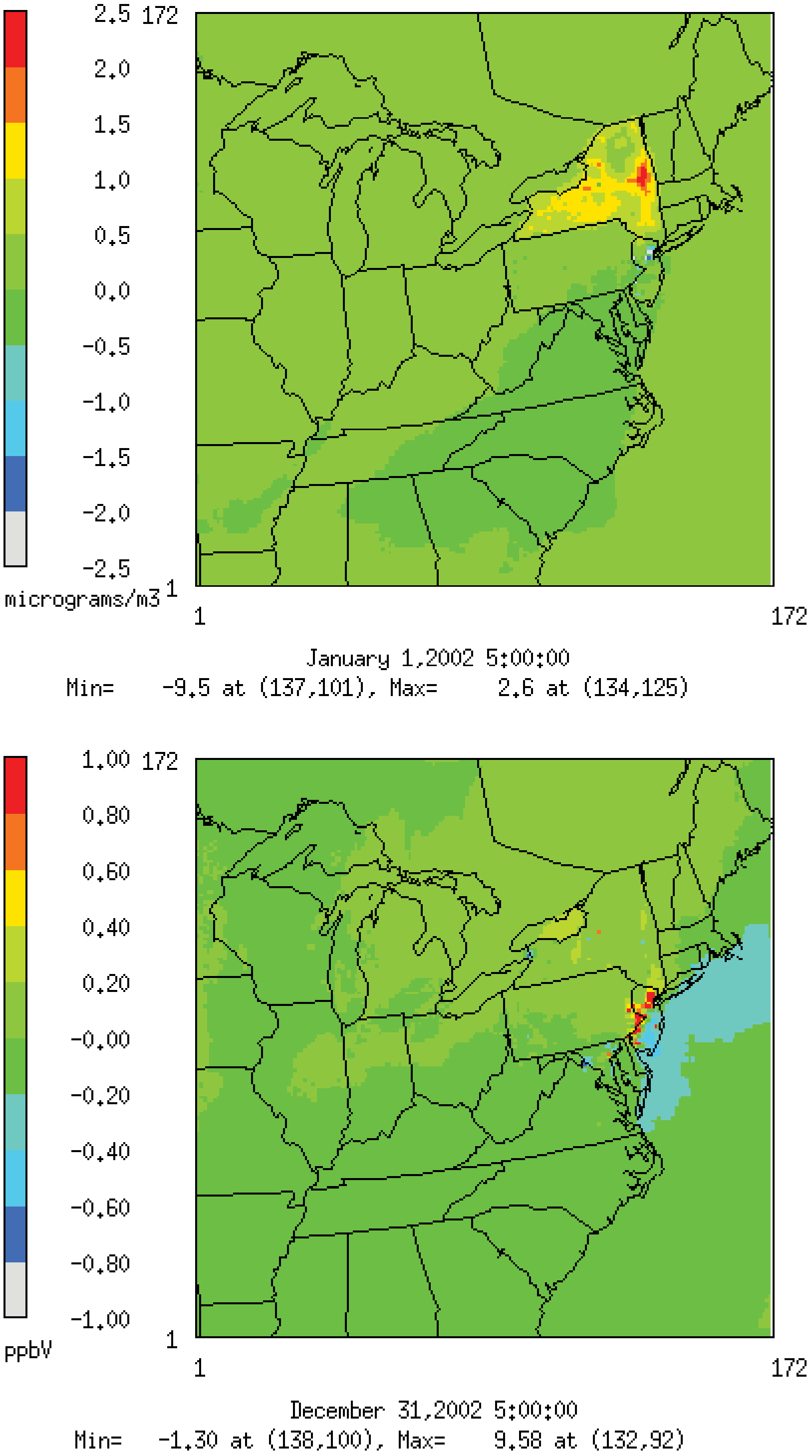

Figure 3-82. Difference between 2018 Reference Case and 2018 Combination Scenario for Annual Average (a) $PM_{2.5}$ and (b) Daily Maximum 8-hour Ozone.

Table 3-49. Difference in Annual Average PM2.5 (%, µg/m3) Annual average Daily maximum 8-hour O3 (%, ppb) between the 2018 Reference Case and the Combination Scenario over NYS.**

Statistic	Annual Average Daily Max 8-Hour O_3 (ppb)	Annual Average $PM_{2.5}$ (µg/m^3)	Annual Average Daily Max 8-Hour O_3 (%)	Annual Average $PM_{2.5}$ (%)
Mean Difference	0.15	0.8	0.4%	9.2%
Minimum Difference	-1.3	-9.5	-3.4%	-38.3%
Maximum Difference	9.3	2.6	30.5%	19.9%
Standard Deviation	0.4	0.6	1.2%	4.3%

****in cells with a State population of $\geq$ 1**

Annual average daily maximum 8-hour ozone saw a mean reduction across the State of around 0.4% (~0.15 ppb) between the Reference Case and the Combination Scenario. Still, there was a wider spread of the differences between the Reference Case and the Combination Scenario, with a larger standard deviation of 1.2% and a large range of values spanning from -3.4 to 30.5%. Figure 3-83 indicates that absolute differences on peak days (here the 8th highest daily average $PM_{2.5}$ and the 4th highest daily maximum 8-hr O_3) were considerably larger, depending on location. Table 3-50 summarizes the absolute and percentage differences in the 4th highest daily maximum 8-hour O_3 and 8th highest daily average $PM_{2.5}$ over all cells with a population ≥1. For annual average and 8th highest daily average $PM_{2.5}$, the percentage differences were similar, but because these are peak days, the absolute values were considerably higher. The mean difference in 8th highest daily average $PM_{2.5}$ across the State was around 2.0 µg/m^3 with a standard deviation of 1.5µg/m^3.

For O_3, the statewide average percentage differences between the Reference Case and the Combination Scenario were lower for the peak days (here, the 4th highest daily maximum 8-hour O_3 concentration) with only a 0.03% average increase between the cases. The standard deviation of 1.5 ppb was larger for the peak O_3 days compared to the average. The average was close to zero, so peak O_3 impacts between the cases depended strongly on location, with a range of -7.2 to 11.2 ppb.

It should be noted that while these State average statistics are helpful in characterizing the pollutant concentrations that occur over the State for alternate control scenarios, the health impacts and associated costs and benefits depend on the spatial variation of these concentration differences. While an average concentration difference over the State may be a fraction of a ppb, if the change is concentrated over a highly populated area, then the impacts will be far greater than one might anticipate from the low average concentration change for the State.

Table 3-50. Difference in 8th Highest Daily Average $PM_{2.5}$ ($\mu g/m^3$, %) 4th Highest Daily 8-hour O_3 (ppb, %) between the 2018 Reference Case and the Combination Scenario over NYS.**

Statistic	4th-highest Daily 8-Hour Max O_3 (ppb)	8th-highest Daily Average $PM_{2.5}$ ($\mu g/m^3$)	4th-highest Daily 8-Hour Max O_3 (%)	8th-highest Daily Average $PM_{2.5}$ (%)
Mean Difference	0.04	2.0	0.03%	8.0%
Minimum Difference	-7.2	-13.2	-9.0%	-23.1%
Maximum Difference	11.2	8.6	16.5%	23.8%
Standard Deviation	1.5	1.5	2.0%	4.7%

****in cells with a State population of ≥ 1**

As illustrated in Figure 3-82 (a) and Figure 3-83 (a), there was an obvious reduction in $PM_{2.5}$ over most of the State between the Reference Case and Combination Scenario, with the largest impacts near Albany. There was also a significant increase in $PM_{2.5}$ over New York City and parts of northern New Jersey (Figure 3-84). Figure 3-85 indicates that much of the total $PM_{2.5}$ average concentration difference comes from primary species. Annual emissions differences for NO_x, primary PM, and SO_x are shown in Figure 3-86 through Figure 3-88. There were primary PM emissions reductions near Albany that may have contributed to the $PM_{2.5}$ concentration differences in that area. Much of the area source emissions decrease in that area (Figure 3-89) came from a decrease in residential wood burning predicted by NE-MARKAL in response to more efficient residential heating alternatives available through the ENERGY STAR® requirement and the introduction of conservation technologies such as improved insulation and windows (Table 3-51). Note the significant PM and NO_x emissions differences over northern New Jersey and New York City in Figure 3-86 and Figure 3-87. The maximum negative concentrations occurred in cell (137, 101), the most populous cell in the northern New Jersey and New York City area.

Figure 3-90 indicates that NO_x emissions increased between the Reference Case and the Combination Scenario for nonEGU point and mobile sources. A closer look at these emissions sources in Figure 3-90 indicates that the nonEGU point source category was responsible for of the much of the emissions increases in northern New Jersey and New York City, including the cell with the largest emissions increase, (137,101). The total $PM_{2.5}$ emissions increase in July for this cell was around 150 tons, and the point source (not including major EGUs) emissions increase accounted for 149 of those tons. Similarly for NO_x, the total NO_x emissions increase for (137,101) in July was around 1596 tons, and the non-EGU point source emissions increase was 1452 tons. An examination of the emissions inventory for this source type in NYS and New Jersey indicated that the SCC code 20100201 (Internal Combustion Engines, Electric Generation, Natural Gas, Turbine) contributed the largest influx of additional NO_x emissions (see Table 3-52). These came from New Jersey, and the four New Jersey counties closest to New York City (Hudson, Essex, Union, and Middlesex) contributed about 34% of that total emissions increase. These emissions were grown according to NE-MARKAL aggregated combined cycle natural gas plants in New Jersey. Essentially, a policy change in NYS created a price incentive in the NE-MARKAL Combination scenario to import power from New Jersey. Due to the fact that the focus for this project was on New York strategies, the increased generation and emissions from New Jersey may not be realistic given electricity grid constraints. Such effects point to the need to extend state policy impact analyses beyond state boundaries.

For annual average daily maximum 8-hour ozone, there were reductions over most of NYS, with the largest reductions occurring over northern New Jersey and New York City. In Figure 3-91, a filter was applied to the annual average ozone difference fields to show more clearly where the negative values occurred. In this case, significant increases in overall NO_x emissions (Figure 3-86) lead to O_3 reductions over New York City due to a "localized NO_x scavenging" effect (Figure 3-82 (b) and Figure 3-83 (b)). In smaller urban areas of upstate New York, the opposite trend is evident where decreased NO_x at specific power plants leads to reduced NO_x scavenging and, therefore, small ozone increases in some localized regions. For much of the State outside these urban areas, however, there was an overall decrease in O_3 concentrations between the Reference Case and Combination Scenario. While the impacts on EGU emissions from the ENERGY STAR® constraints and unrestricted conservation technologies were visible in the CMAQ modeling emissions inputs (Figure 3-89 and Figure 3-90), as were the SO_2 decreases from the low-sulfur fuel oil measure, the impacts of these measures on average $PM_{2.5}$ and O_3 concentrations in New York City were dwarfed by the adverse impacts from the emissions of NO_x and PM in northern New Jersey for SCC code 20100201.

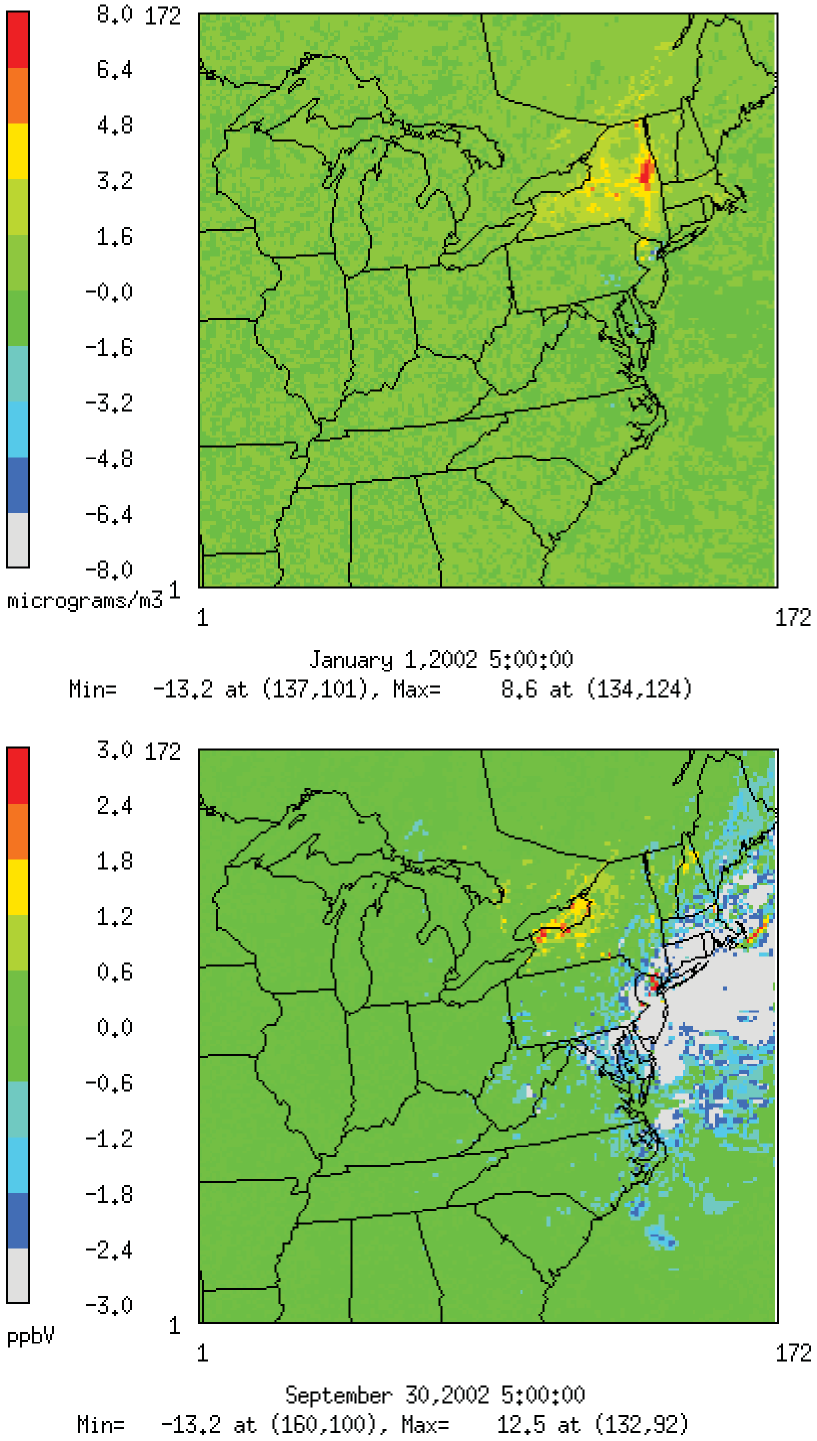

Figure 3-83. Difference between 2018 Reference Case and 2018 Combination Scenario for (a) 8th-highest Daily Average $PM_{2.5}$ and (b) 4th-highest Daily Maximum 8-hour Ozone.

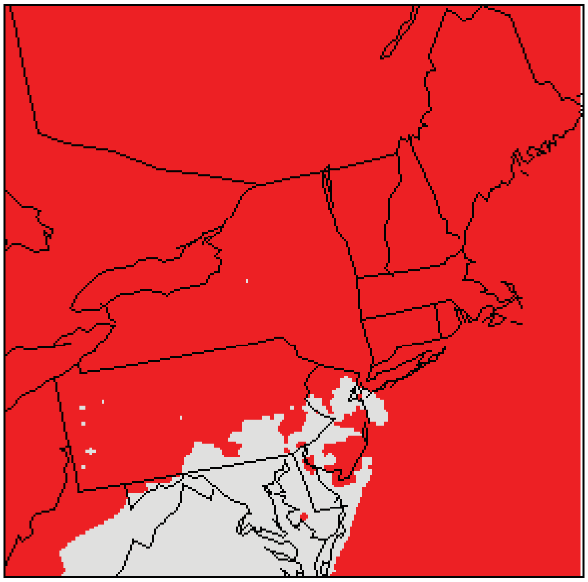

Figure 3-84. Annual Average $PM_{2.5}$ Difference: 2018 Reference Case – Combination Scenario (grey cells are < 0).

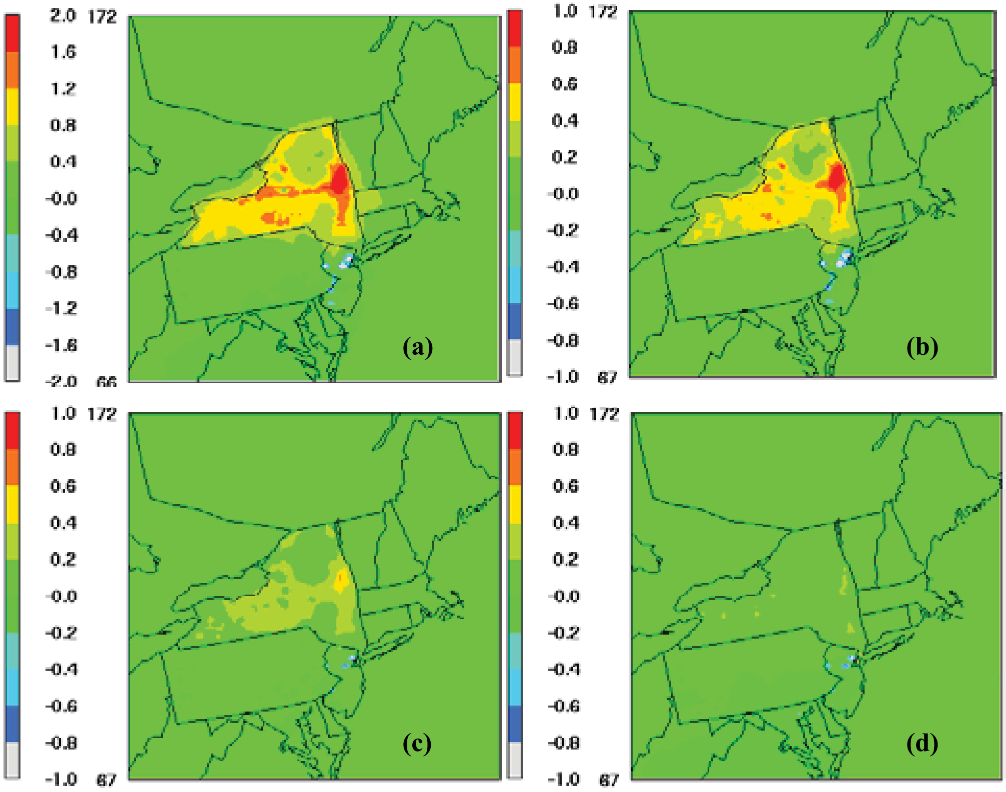

Figure 3-85. Annual Average Concentration Differences between 2018 Reference Case and 2018 Combination Scenario for (a) Total $PM_{2.5}$, (b) Primary Organic Aerosol, (c) Unspeciated “Other” $PM_{2.5}$, and (d) Sulfate.

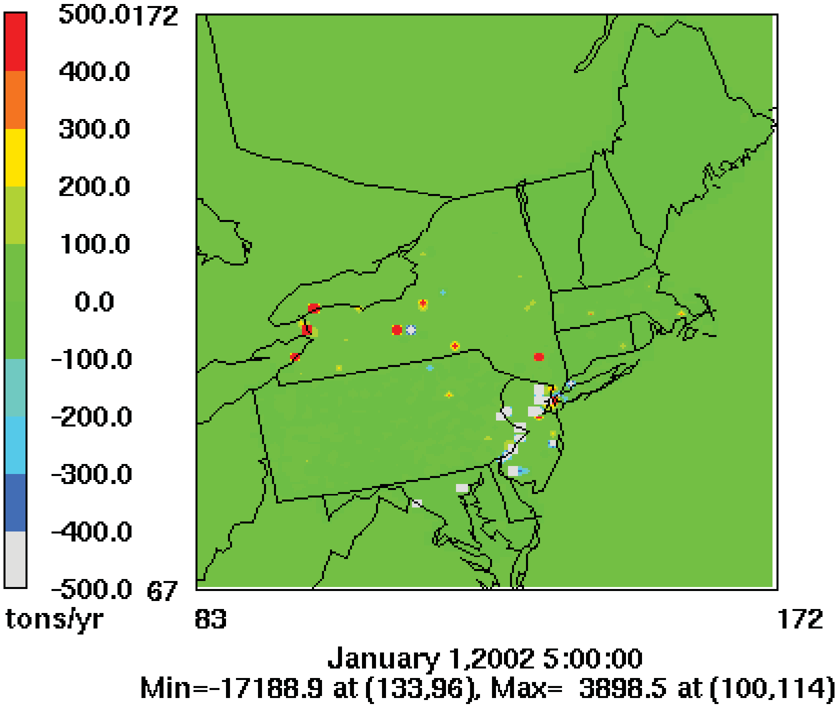

Figure 3-86. Annual NO$_x$ Emissions Differences between 2018 Reference Case and 2018 Combination Scenario.

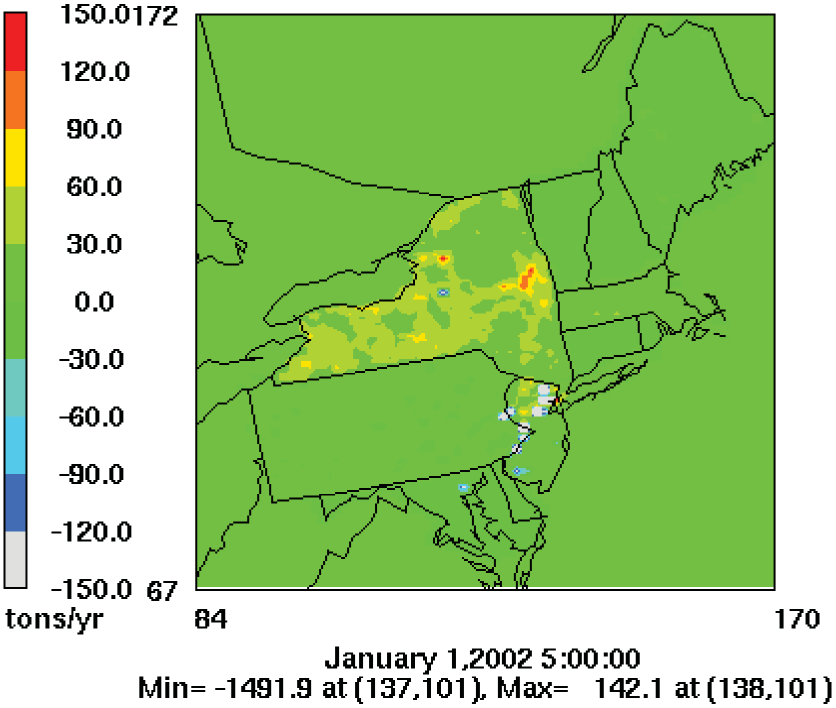

Figure 3-87. Annual PM Emissions Differences between 2018 Reference Case and 2018 Combination Scenario.

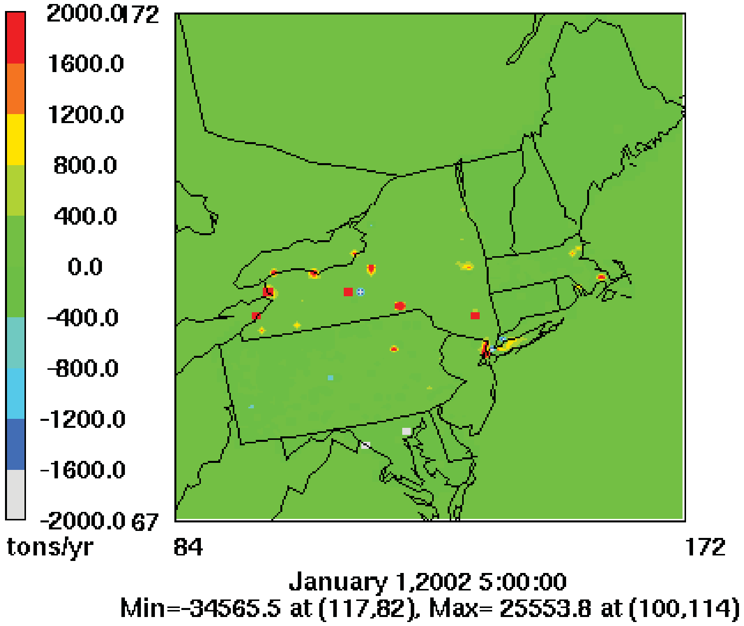

Figure 3-88. Annual SO_x Emissions Differences between 2018 Reference Case and 2018 Combination Scenario.

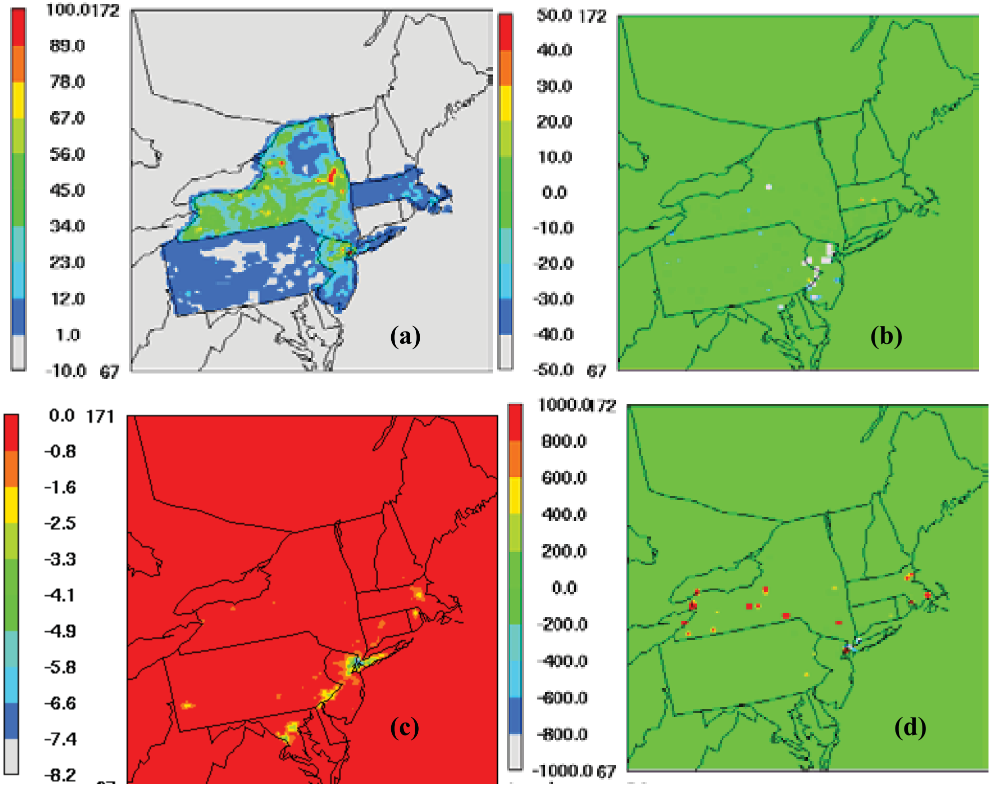

Figure 3-89. Annual Emissions Differences between 2018 Reference Case and 2018 Combination Scenario for PM from (a) Area sources, (b) Point sources other than Major EGUs, (c) Mobile Sources, and (d) SO_x from Major EGUs.

Table 3-51. Top Area $PM_{2.5}$ emissions Difference (2018 Reference Case – 2018 Combination Scenario) Contributions by SCC code for 9 Counties near Albany.**

County	SCC Code	Code Description (4th Level)***	$PM_{2.5}$ Difference
36 91	2104008001	Fireplaces: General	683.2217
36 115	2104008001	Fireplaces: General	577.7924
36 83	2104008001	Fireplaces: General	417.4231
36 113	2104008001	Fireplaces: General	369.6885
36 35	2104008001	Fireplaces: General	319.589
36 95	2104008001	Fireplaces: General	250.3703
36 91	2104008052	Non-catalytic Woodstoves: Low Emitting	241.3433
36 115	2104008052	Non-catalytic Woodstoves: Low Emitting	204.1014
36 1	2104008001	Fireplaces: General	182.6354
36 57	2104008001	Fireplaces: General	148.1444
36 83	2104008052	Non-catalytic Woodstoves: Low Emitting	147.4519
36 113	2104008052	Non-catalytic Woodstoves: Low Emitting	130.5903
36 35	2104008052	Non-catalytic Woodstoves: Low Emitting	112.8927
36 93	2104008001	Fireplaces: General	89.1364
36 95	2104008052	Non-catalytic Woodstoves: Low Emitting	88.4417
36 1	2104008052	Non-catalytic Woodstoves: Low Emitting	64.5148
36 91	2104008070	Outdoor Appliances	59.9317
36 57	2104008052	Non-catalytic Woodstoves: Low Emitting	52.331

** Albany, Fulton, Montgomery, Rensselaer, Saratoga, Schenectady, Schoharie, Warren, Washington Counties

*** The 1st, 2nd, and 3rd levels for the code description are: Stationary Source Fuel Combustion; Residential; and Wood.

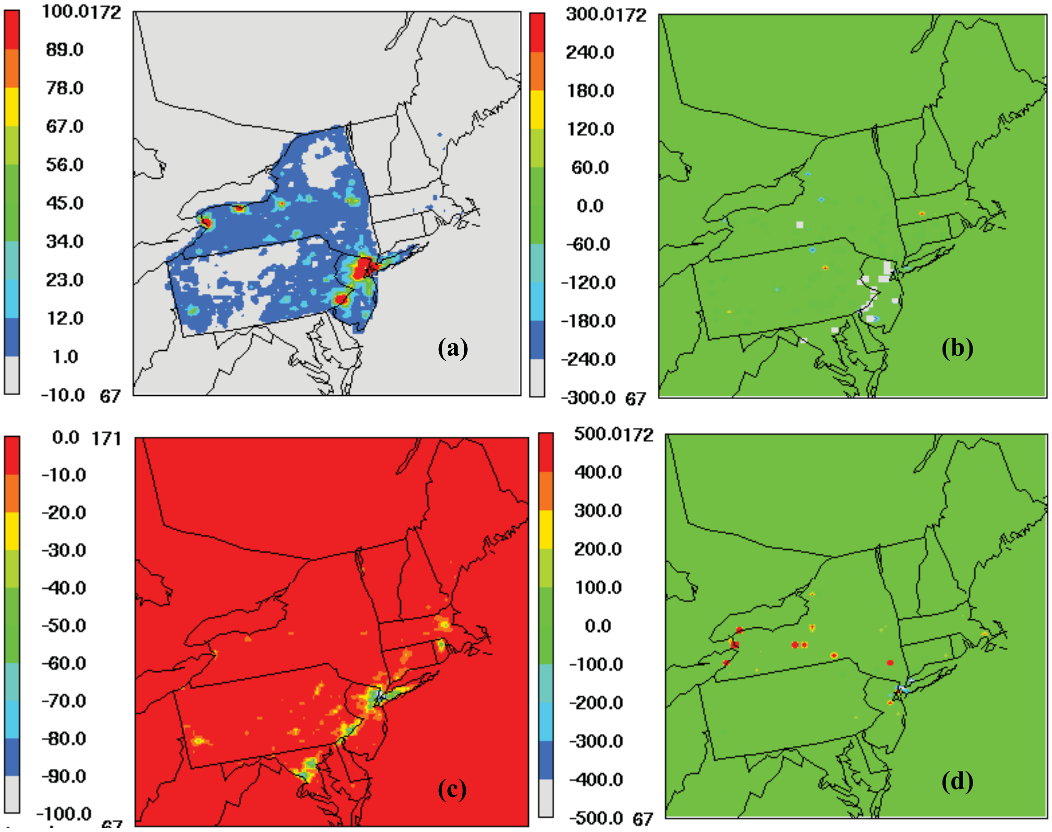

Figure 3-90. Annual NO_x Emissions Differences between 2018 Reference Case and 2018 Combination Scenario from (a) Area Sources, (b) Point Sources other than Major EGUs, (c) Mobile Sources, and (d) Major EGUs

Table 3-52. Sorted Statewide "Other" Point Annual NO_x Emissions Differences between the 2018 Reference Case and the Combination Scenario for SCC C with the Largest Absolute Differences. (Data for natural gas turbines is highlighted.)

SCC	Code Description	NO_x (T/year)
New York		
10100202	External Combustion Boilers; Electric Generation: Bituminous/Subbituminous Coal; Pulverized Coal: Dry Bottom (Bituminous Coal)	-3609.63
10300601	External Combustion Boilers; Commercial/Institutional; Natural Gas; >100 Million Btu/hr	-482.499
10100217	External Combustion Boilers; Electric Generation; Bituminous/Subbituminous Coal; Atmospheric Fluidized Bed Combustion: Bubbling Bed (Bituminous Coal)	-437.532
10300401	External Combustion Boilers; Commercial/Institutional; Residual Oil; Grade 6 Oil	165.341
10200203	External Combustion Boilers; Industrial; Bituminous/Subbituminous Coal; Cyclone Furnace	168.6042
20100201	Internal Combustion Engines; Electric Generation; Natural Gas; Turbine	244.1322
New Jersey		
20100201	Internal Combustion Engines; Electric Generation; Natural Gas; Turbine	-142.050
39000199	Industrial Processes; In-process Fuel Use; Anthracite Coal; General	-342.276
39000201	Industrial Processes; In-process Fuel Use; Bituminous Coal; Cement Kiln/Dryer (Bituminous Coal)	-9.999
20300101	Internal Combustion Engines; Commercial/Institutional; Distillate Oil (Diesel); Reciprocating	75.4535
10300402	External Combustion Boilers; Commercial/Institutional; Residual Oil; 10-100 Million Btu/hr	147.6228
10300602	External Combustion Boilers; Commercial/Institutional; Natural Gas; 10-100 Million Btu/hr	177.8844
Pennsylvania		
10300903	External Combustion Boilers; Commercial/Institutional; Wood/Bark Waste; Wood-fired Boiler – Wet Wood (>=20% moisture)	-314.614

10300102	External Combustion Boilers; Commercial/Institutional; Anthracite Coal; Traveling Grate (Overfeed) Stoker	-205.951
10300208	External Combustion Boilers; Commercial/Institutional; Bituminous/Subbituminous Coal; Underfeed Stoker (Bituminous Coal)	-200.308
10300602	External Combustion Boilers; Commercial/Institutional; Natural Gas; 10-100 Million Btu/hr	114.2436
20300201	Internal Combustion Engines; Commercial/Institutional; Natural Gas; Reciprocating	385.5916
10100101	External Combustion Boilers; Electric Generation; Anthracite Coal; Pulverized Coal	440.652

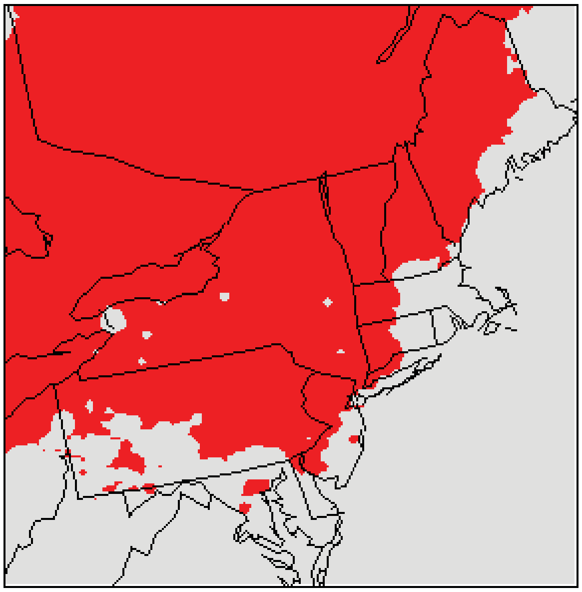

Figure 3-91. Annual Average 8-Hour Max O_3 Difference: 2018 Reference Case – Combination Scenario (grey cells are < 0).

Summary

As a crucial part of the Multi-pollutant Policy Analysis Framework, the Community Multi-scale Air Quality Modeling System (CMAQ) was used to simulate the impact of alternate emissions scenarios on spatially and temporally-varying criteria pollutant concentrations. The model was linked to NE-MARKAL through emissions projections. Fuel consumption and emissions projected by NE-MARKAL for multiple processes, technologies, and sectors, were linked to SCC codes and used to grow speciated 2002 MANE-VU emissions for those emissions categories represented in NE-MARKAL. Other emissions sources were grown according to the 2018 “Beyond on the Way” emissions inventories developed for previous regional haze modeling work.

Annual CMAQ simulations were run over the eastern U.S. for 2002 and two future cases: the 2018 Reference Case and the 2018 Combination Scenario. For the 2018 Combination Scenario, annual average $PM_{2.5}$ decreased over most of the State but increased over New York City. Annual average 8-hour maximum O_3 decreased over much of the state, including New York City. Both the increase in $PM_{2.5}$ and decrease of O_3 over New York City was linked to $PM_{2.5}$ and NO_x emissions increases from natural gas combined cycle plants in New Jersey. Such effects point to the need to extend state policy impact analyses beyond state boundaries. Because health benefit calculations are driven in part by population, statewide health benefits will be heavily influenced by the concentration impacts over New York City. We emphasize that due to the nature of ozone chemistry and the potential for long-range transport of NO_x emissions, the regional effect of the observed NO_x increases are not expected to be beneficial. While average concentration differences between the Reference Case and alternate control scenarios may not be large, these differences vary widely from cell to cell. As we will see in the following section, health impacts and their associated costs and benefits depend heavily on the spatial variation of concentration differences in relation to spatially variable population levels.

HEALTH BENEFITS (BENMAP) ASSESSMENT RESULTS

EPA’s Environmental Benefits Mapping and Analysis Program (BenMAP) version 4.0 was used to translate modeled pollutant concentration changes, as described in the previous section, to changes in population-weighted health impacts and their associated costs for the Combination Scenario described previously.

The BenMAP health impacts estimates were based on CMAQ model outputs from 2002 and two 2018 control scenarios – namely, the 2018 Reference Case and the 2018 Combination Scenario. A brief summary of each future year scenario is given below. Note that a more detailed description of these scenarios is contained in the NE-MARKAL part of Section 3.

Recap of 2018 Reference Case and Combination Scenario

The 2018 Reference Case forms the basis against which alternate policy scenarios are compared and represents the possible evolution of the energy infrastructure in NYS given certain baseline assumptions and constraints.

The key assumptions/constraints for the 2018 Reference Case are as follows:

- For the power sector, the RGGI was included, while a RPS was not included.
- In an effort to represent the consumer preference for SUVs and other inefficient light-duty vehicles, light-duty vehicle class shares were fixed in an effort to prevent NE-MARKAL from instituting a major shift of class shares to smaller, more efficient cars. The maximum penetration of compressed natural gas (CNG) was limited to no more than 1% of total transportation sector fuel consumption, because cost information on the associated necessary fueling infrastructure is not included in NE-MARKAL.
- Residential and commercial sector fuel shares were constrained such that they did not disrupt current regional fuel markets. Additionally, energy efficiency effects were constrained out of the Reference Case.

The Combination Scenario was based on seven of the most effective strategies from the Kitchen Sink NE-MARKAL modeling scenario in an effort to demonstrate that the majority of reductions can result from just a few effective measures. These strategies included the following:

- NYS's current RPS (i.e., 10,000 GWh of renewable generation by 2013)
- Electric vehicles comprise at least 25% of the 2030 light-duty vehicle fleet
- Gas-electric hybrid vehicles comprise an additional 25% of the light-duty fleet
- 100% of appliances sold after 2020 must meet the ENERGY STAR® standards for efficiency
- Sulfur content of distillate and residual fuel is restricted to 15 ppm and 0.5%, respectively, by 2017
- Unrestricted conservation technologies
- CHP may satisfy up to 20% of the heating demand from residential and commercial sectors

Electricity demand was reduced between 2002 and 2017 due to the Energy Star efficiency requirements and availability of CHP and conservation technologies from the residential, commercial, and industrial sectors. Later in the NE-MARKAL time horizon, demand increased due to the EV requirements. The RPS requirements were essentially already met by existing hydroelectric power, and as a result, little additional renewable capacity was necessary to meet the RPS constraint. In the transportation sector, there was a significant percentage of the light-duty vehicle fleet represented by hybrid vehicles by 2017, compared to the Reference Case.

As described above, these future year emissions scenarios were used to generate model-ready emissions files, and annual CMAQ model results were generated for each case. These model results were used in combination with monitoring data to generate the gridded O_3 and $PM_{2.5}$ concentration changes that drive the health impacts analysis in BenMAP.

Note that the high population density near New York City (See Figure 3-92) means that the concentration differences in that area will always have a heavy weight in BenMAP health-impact analyses.

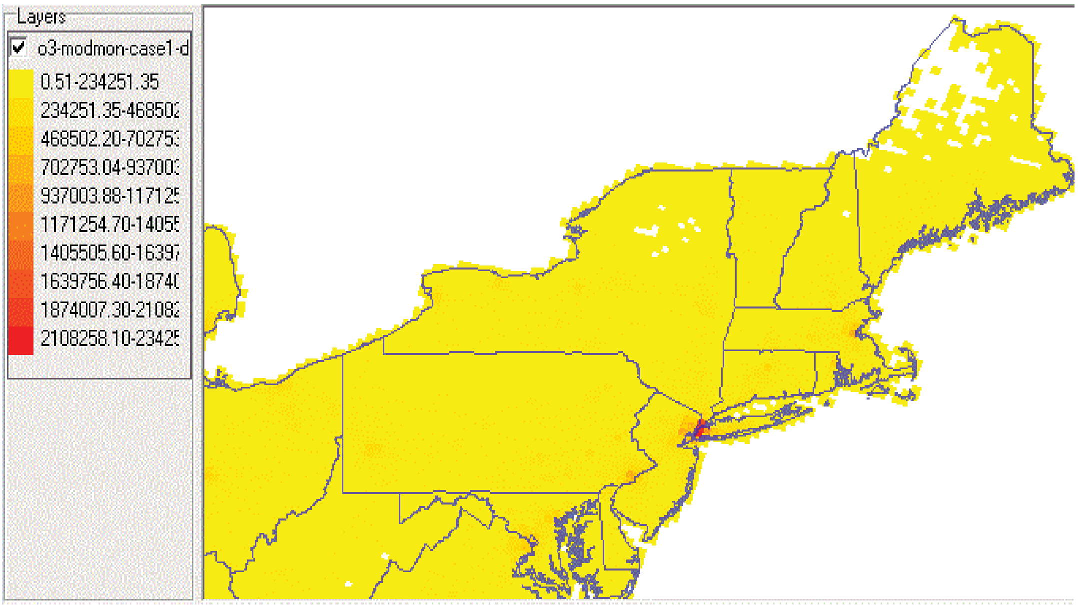

Figure 3-92. Total Population Levels from 2000 Census Data.

For all economic analyses presented here, the currency year is 2000, and valuation functions are adjusted to reflect increases in real income with an "income growth adjustment" to 2018. The tables include percentile estimates (~5th and ~95th) along with mean and standard deviation estimates of the health benefits/costs.

Results

Figure 3-93 and Figure 3-94 show the average Delta $PM_{2.5}$ and Delta O_3 air quality grids, respectively, representing the change in ambient concentrations between the 2018 Reference Case and the 2018 Combination Scenario. For $PM_{2.5}$, we see concentrations decreasing over much of the state between the Reference Case and the Combination Scenario, with large decreases near Albany. This is due in large part to decreases in residential wood burning. Still, there are areas where $PM_{2.5}$ concentrations increase in the Combination Scenario. There is, in fact, a large increase in $PM_{2.5}$ concentrations near New York City and northern New Jersey, and, while over only a small geographical area, this has a significant impact on aggregated health impacts due to the concentration change occurring in cells with large population densities. This $PM_{2.5}$ concentration increase is due to increased demand from aggregated combined cycle natural gas plants in New Jersey in the 2018 Combination Scenario. As mentioned in the prior section, due to the fact that the focus for this project was on NYS strategies, the increased generation and emissions from New Jersey may not be realistic depending on transmission capacity and other grid dynamics that should be further evaluated with a dispatch model. It will be worthwhile in future studies to do a reality-check on large emissions increases between runs, to make sure that the increases make sense and are not an artifact of the current emissions mapping methodology or other factors not assessed within the MPAF framework.

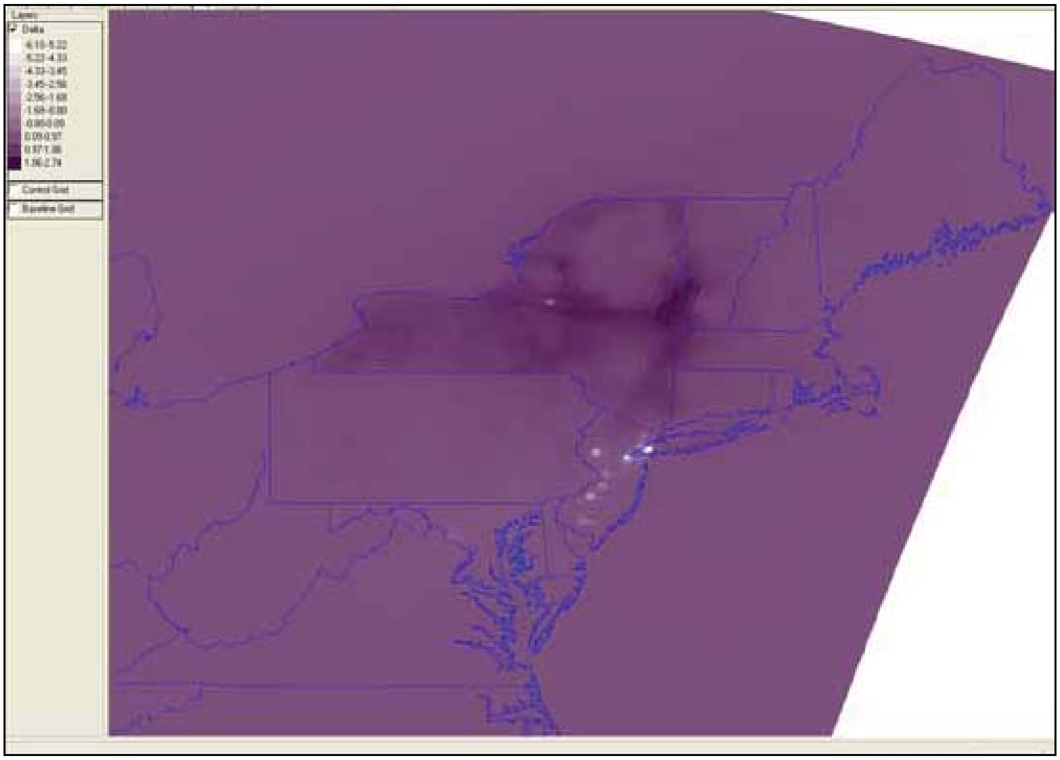

Figure 3-93. Average Delta $PM_{2.5}$ (monitor and model relative) between 2018 Reference Case and 2018 "Combination" Scenario ($\mu g/m^3$) (baseline – control).

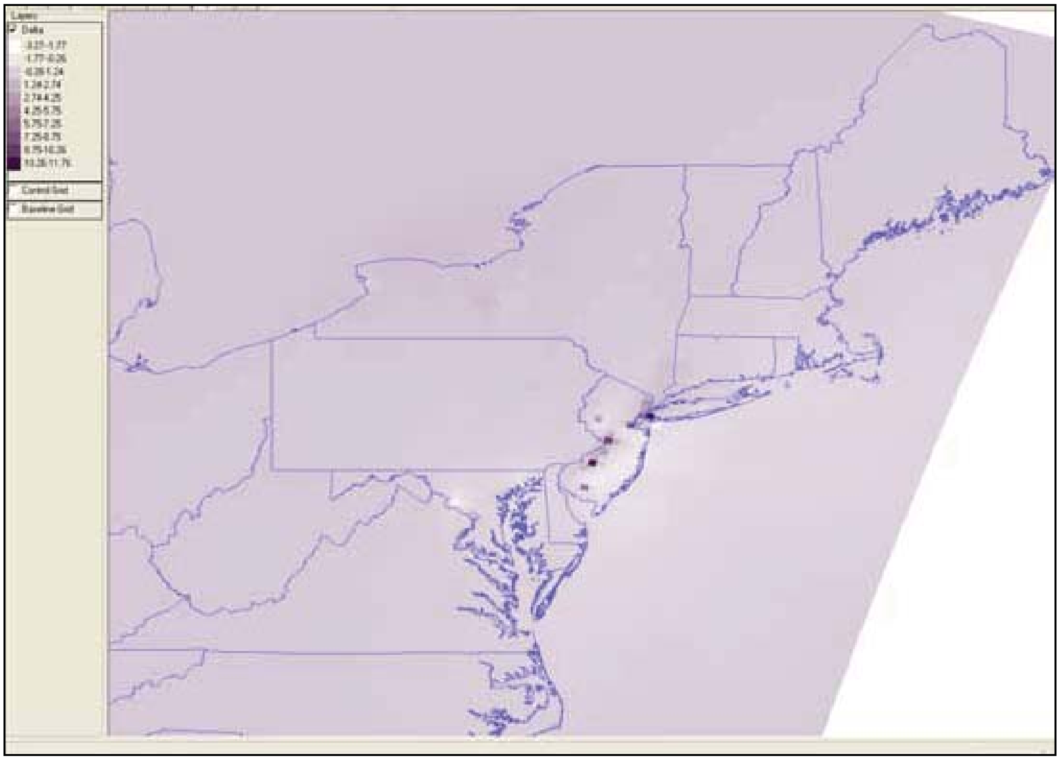

Figure 3-94. Average Delta O_3 (monitor and model relative) between 2018 Reference Case and 2018 Combination Scenario (ppb) (baseline – control).

Between the 2018 Reference Case and 2018 Combination Scenario, O_3 concentrations decrease over the state, with large decreases over New York City. There are large NO_x emissions increases in that area due to the increased demand from New Jersey combined cycle natural gas plants, the same mechanism that drives up the $PM_{2.5}$ concentrations in the same area. There is, however, a decreased O_3 concentration for the Combination Scenario due to the rising NO_x emissions. These statewide decreases in O_3 concentration, particularly the large decreases over highly-populated New York City, lead to net benefits over the state for O_3 in this case.

Table 3-53 gives the monetized health effects associated with $PM_{2.5}$ and O_3 concentration changes between the 2018 Reference Case and 2018 Combination Scenario. Corresponding health incidence impacts are given in Table 3-54. There are a wide range of costs/benefits depending on pollutant and health effect. There is a significant difference between the $PM_{2.5}$ and O_3 economic values, with a $PM_{2.5}$ disbenefit observed. Economic values associated with the change in O_3 concentrations are positive and represent "benefits," with nearly \$420 million associated with reduced mortality incidence alone. A \$25 million benefit was estimated for non-mortality health effects. The disbenefits from increased $PM_{2.5}$ concentrations over New York City for the most part dwarf the benefits seen with the drop in O_3 concentrations. The disbenefits from increased mortality exceed \$1 billion, and the disbenefits from increased incidence of non-mortality health effects is over $133 million. Here the currency year is 2000, and valuation functions are adjusted to reflect increases in real income with an "income growth adjustment" to 2018. The tables include percentile estimates (~5th and ~95th) along with mean and standard deviations of the health benefits.

Table 3-53. Health Costs/Benefits for the 2018 Combination Scenario (2000$).

Pollutant	**Endpoint Group**	**Endpoint**	**Age**	**Mean**	**Standard Deviation**	**Percentile 4.5**	**Percentile 5.5**	**Percentile 94.5**	**Percentile 95.5**
PM2.5	Mortality	Mortality, All Cause	<1	-1.567E+07	3.918E+07	-9.407E+07	-8.594E+07	3.752E+07	4.210E+07
			30-99	-1.320E+09	3.305E+09	-7.881E+09	-7.233E+09	3.212E+09	3.600E+09
	AMI	AMI, Nonfatal	18-24	-2.784E+04	3.657E+04	-1.248E+05	-9.479E+04	5.872E+03	2.879E+04
			25-44	-8.300E+05	1.710E+06	-5.327E+06	-3.798E+06	1.156E+06	2.539E+06
			45-54	-3.333E+06	5.007E+06	-1.650E+07	-1.218E+07	1.797E+06	5.694E+06
			55-64	-7.285E+06	1.362E+07	-3.952E+07	-2.809E+07	1.028E+07	1.930E+07
			65-99	-1.052E+07	2.213E+07	-6.959E+07	-4.975E+07	1.456E+07	3.252E+07
	Hospital Admissions, Respiratory	HA, Chronic Lung Disease	65-99	-2.224E+05	2.812E+05	-7.160E+05	-7.160E+05	2.702E+05	2.702E+05
		HA, Chronic Lung Disease (less Asthma)	18-64	-3.731E+04	1.155E+05	-2.402E+05	-2.402E+05	1.650E+05	1.650E+05
		HA, Pneumonia	65-99	-2.059E+05	1.360E+06	-2.598E+06	-2.598E+06	2.171E+06	2.171E+06
		HA, Asthma	0-64	-8.755E+05	3.701E+05	-1.526E+06	-1.526E+06	-2.283E+05	-2.283E+05
	Emergency Room Visits, Respiratory		0-17	-3.298E+05	1.210E+05	-5.448E+05	-5.283E+05	-1.285E+05	-1.272E+05
	Acute Bronchitis		8-12	-3.177E+05	4.537E+05	-1.146E+06	-1.121E+06	4.383E+05	4.484E+05
	Lower Respiratory Symptoms		7-14	-1.976E+06	1.410E+06	-4.498E+06	-4.419E+06	4.382E+05	4.460E+05
	Work Loss Days		18-64	-7.324E+06	1.634E+06	-1.019E+07	-1.019E+07	-4.462E+06	-4.462E+06
	Acute Respiratory Symptoms		18-64	-3.412E+07	8.890E+06	-4.971E+07	-4.900E+07	-1.917E+07	-1.886E+07
	Hospital Admissions, Cardiovascular		65-99	-2.016E+06	1.448E+06	-4.558E+06	-4.558E+06	5.223E+05	5.223E+05
			18-64	-2.015E+06	9.755E+05	-3.727E+06	-3.727E+06	-3.059E+05	-3.059E+05
	Asthma Exacerbation		6-18	-1.900E+06	2.416E+06	-6.170E+06	-6.029E+06	2.264E+06	2.317E+06
	Chronic Bronchitis**	Chronic Bronchitis	27-44	-3.601E+07	2.087E+07	-7.328E+07	-7.328E+07	-9.735E+04	-9.735E+04
			45-64	-2.327E+07	1.376E+07	-4.785E+07	-4.785E+07	4.290E+05	4.290E+05
			65-99	-1.266E+06	7.847E+05	-2.667E+06	-2.667E+06	8.527E+04	8.527E+04
O3	School Loss Days		5-17	4.214E+06	1.513E+06	1.688E+06	1.688E+06	7.187E+06	7.187E+06
	Emergency Room Visits, Respiratory		0-99	6.412E+04	5.464E+04	-2.781E+03	-2.753E+03	1.703E+05	1.737E+05
	Acute Respiratory Symptoms		18-64	1.827E+07	5.961E+06	7.910E+06	8.040E+06	2.827E+07	2.869E+07
	Hospital Admissions, Respiratory	HA, All Respiratory	0-1	8.727E+05	2.571E+05	4.164E+05	4.164E+05	1.318E+06	1.318E+06
			65-99	1.692E+06	8.259E+05	4.363E+05	4.363E+05	3.169E+06	3.169E+06
	Mortality	Pooled Mortality	0-99	4.199E+08	4.013E+08	3.495E+07	4.018E+07	1.221E+09	1.306E+09

Table 3-54. Health Incidence Changes between the 2018 Reference Case and the 2018 Combination Scenario.

Pollutant	Endpoint Group	Endpoint	Age	Mean	Standard Deviation	Percentile 5	Percentile 95
PM2.5	Mortality	Mortality, All Cause	<1	-2.10	4.27	-9.72	5.25
PM2.5	Mortality	Mortality, All Cause	30-99	-176.79	359.91	-810.60	451.72
PM2.5	AMI	AMI, Nonfatal	18-24	-0.42	0.40	-1.14	0.26
PM2.5	AMI	AMI, Nonfatal	25-44	-11.08	18.93	-44.95	21.43
PM2.5	AMI	AMI, Nonfatal	45-54	-42.08	51.54	-134.40	46.38
PM2.5	AMI	AMI, Nonfatal	55-64	-51.00	89.95	-211.97	103.52
PM2.5	AMI	AMI, Nonfatal	65-99	-159.68	265.93	-635.72	297.03
PM2.5	HA, Respiratory	HA, Chronic Lung Disease	65-99	-16.39	20.73	-52.78	19.92
PM2.5	HA, Respiratory	HA, Chronic Lung Disease (less Asthma)	18-64	-3.00	9.28	-19.30	13.25
PM2.5	HA, Respiratory	HA, Pneumonia	65-99	-11.43	75.46	-144.17	120.47
PM2.5	HA, Respiratory	HA, Asthma	0-64	-111.36	47.08	-194.15	-29.04
PM2.5	ER Visits, Respiratory		0-17	-1152.73	388.32	-1841.68	-479.73
PM2.5	Acute Bronchitis		8-12	-800.99	1137.72	-2868.40	1122.01
PM2.5	Lower Respiratory Symptoms		7-14	-9959.78	7058.96	-22524.29	2233.88
PM2.5	Work Loss Days		18-64	-52271.82	11659.25	-72734.35	-31842.78
PM2.5	Acute Respiratory Symptoms		18-64	-328502.31	82881.73	-474083.53	-183394.03
PM2.5	HA, Cardiovascular		65-99	-94.56	67.94	-213.80	24.50
PM2.5	HA, Cardiovascular		18-64	-88.07	42.63	-162.90	-13.37
PM2.5	Asthma Exacerbation		6-18	-11469.69	14492.92	-36953.70	13876.78
PM2.5	Chronic Bronchitis	Chronic Bronchitis	27-44	-192.95	111.81	-392.66	-0.52
PM2.5	Chronic Bronchitis	Chronic Bronchitis	44-64	-192.97	114.14	-396.77	3.56
PM2.5	Chronic Bronchitis	Chronic Bronchitis	65-99	-94.49	58.56	-199.02	6.36
O3	School Loss Days		5-17	56186.13	20168.93	22507.71	95828.35
O3	ER Visits, Respiratory		0-99	224.16	186.80	-10.39	641.59
O3	Acute Respiratory Symptoms		18-64	175906.08	56215.63	76937.24	274100.44
O3	HA, Respiratory	HA, All Respiratory	0-1	111.42	32.82	53.16	168.27
O3	Mortality		0-99	56.38	32.66	12.30	114.09
O3	HA, Respiratory		65-99	91.17	44.49	23.50	170.71

Summary

Elevated PM$_{2.5}$ and O$_3$ levels can have significant adverse impacts on human health, and, as a result, it is important to incorporate an estimate of these health impacts in NESCAUM's MPAF. NESCAUM employed the Environmental Benefits Mapping and Analysis Program (BenMAP) to estimate health impacts and associated economic costs arising from PM$_{2.5}$ and O$_3$ concentration changes between the baseline and a control scenario. Here, we estimated the costs/benefits associated with the concentration changes between the 2018 Reference Case and 2018 Combination Scenario. For the Combination Scenario, an increase in electricity imports from New Jersey (and an associated increase in emissions) led to adverse impacts on PM$_{2.5}$ concentrations over northern New Jersey/ New York City and a net PM$_{2.5}$ health disbenefit (-$1.3 billion due to increased mortality and ~-$134 million due to other adverse non-mortality health impacts). This is in spite of the fact that PM$_{2.5}$ concentration decreases were widespread over much of the State. For O$_3$, these same emissions increases of NO$_x$ in New Jersey led to O$_3$ decreases over New York City and an associated O$_3$ health benefit over the state (~$420 million benefit from avoided mortality and $25 million due to other non-mortality health impacts).

The large influence of highly populated urban areas on statewide health benefits indicates that additional analysis and focus should be paid to these areas, and that sometimes targeted controls or alternative policies may be necessary in addition to regional and statewide policies. In addition, as evidenced by the large adverse impacts over New York City due to increased emissions from New Jersey natural gas plants (Reference Case - Combination Scenario), it is crucial to extend policy impact analyses and policy development beyond state boundaries when addressing complex air quality problems.

MACROECONOMIC ASSESSMENT (REMI) RESULTS

Several multi-sector, multi-pollutant policy scenarios were selected for analysis based on policy goals that attempt to shift a variety of energy technologies toward more environmentally benign (and cost-effective) options. These alternatives were projected by the NE-MARKAL energy model, and for one scenario – the Combination Scenario – the technology shifts were analyzed from the perspective of their associated emissions changes using the CMAQ chemical transport model, and their associated public health consequences as projected by the BenMAP tool.

For the macroeconomic assessment, impacts on the New York economy in response to two multi-pollutant scenarios were analyzed, as shown in Table 3-55 and Table 3-56, for 2018 and 2029. Economic impacts related to the health outcomes were limited to the 2018 Combination Scenario for which BenMAP results were calculated; however, the direct economic consequences of shifts in energy technologies and associated fuels in response to the Combination Scenario and the 52 x 30 Scenario were analyzed based on the NE-MARKAL output directly. While these are snapshot impacts, they are derived from within a CGE context (imparted by the REMI model structure) and reflect scenario-induced adjustments from preceding years. Impacts emerging from the scenarios are shown in terms of total employment (EMP) and gross state product (GSP) economy-wide.

Table 3-55. Employment (EMP) and Gross State Product (GSP) Impacts of the 52 x 30 Multi-Pollutant Strategy (MPS) Scenario relative to Base Case, (*No* Health Outcome Considerations).

MPS target sector	*differences*				*percent*			
	EMP (units)		**GSP (B2000$)**		EMP		GSP	
	2018	2029	2018	2029	2018	2029	2018	2029
Power producing sector	-2332	-161060	-0.221	-22.221	-0.02	-1.14	-0.02	-1.10
Transportation sector	-54,892	-169,000	-3.938	-15.181	-0.43	-1.20	-0.27	-0.75
Residential	7,952	-7,757	0.335	-1.051	0.06	-0.06	0.02	-0.05
Comm & Indstrl	-8,501	-58,161	-0.542	-10.016	-0.07	-0.41	-0.04	-0.49
all sectors	*-57,773*	*-395,978*	*-4.366*	*-48.469*	*-0.46*	*-2.81*	*-0.30*	*-2.39*

Table 3-56. Employment (EMP) and Gross State Product (GSP) Impacts from the Combination Multi-Pollutant Strategy (MPS) Scenario relative to Base Case (*before* Health Outcome Considerations).

MPS target sector	*differences*				*percent*			
	EMP (units)		**GSP (B2000$)**		EMP		GSP	
	2018	2029	2018	2029	2018	2029	2018	2029
Power producing sector	-22036	-20281	-2.26	-2.528	-0.17	-0.14	-0.16	-0.12
Transportation sector	8,262	9,637	0.899	1.283	0.07	0.07	0.06	0.06
Residential	32,813	37,154	1.309	2.076	0.26	0.26	0.09	0.10
Comm & Indstrl	-12,841	-54,129	-1.045	-9.094	-0.10	-0.38	-0.07	-0.45
all sectors	*6,198*	*-27,619*	*-1.097*	*-8.263*	*0.05*	*-0.20*	*-0.08*	*-0.41*

The MARKAL requirements of a 52 x 30 multi-pollutant strategy scenario translate into a set of economic conditions in both 2018 and 2029 that depress the state's economy.[31] This is explained predominantly by the pattern and magnitude of direct effects on sector-specific participants portrayed in Table 2-9a (refer to Section 2 for the MARKAL estimated values that define the direct effects).

MARKAL's predicted investment for capital goods that support multi-pollutant objectives needs to be considered from two perspectives: first, it represents a change in the dollar amount and composition of equipment relative to the base case (non-multi-pollutant setting), and second, the added cost of purchasing equipment with advanced technology attributes has to be fully absorbed (in the absence of subsidy/incentive mechanisms) by vehicle owners, worksites, households, and presumably, energy customers. When NYS households incur added cost to operate their homes, or buy higher tech, clean vehicles, it reduces what can be spent on other consumer goods. Depending on the relative local fulfillment of any of these household compliance purchases, the shift in goods purchased may lead to more dollars leaving the State economy to where products are made. The shift would not be economically stimulative. When State businesses incur a change in their cost of doing business (whether from capital investment or changes to fuels purchases or O&M budgets) it will have an inverse effect on their ability to make sales at home, and exports to elsewhere in the U.S. and rest of the world.

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[31] The 52 x 30 scenario represents one of many pathways that could lead to substantial greenhouse gas reductions. This scenario differs from other potential climate scenarios, such as those developed in the context of the *NYS Interim Climate Action Plan (*www.dec.ny.gov/energy/80930.html). Scenarios and models differ in their approach to selecting types and quantities of measures, setting practical limits on implementation of strategies, and the assumptions used to quantify the economic impacts of strategies. For example, there can be substantial variance in assumptions for future costs of emerging technologies and net carbon impacts associated with changes in land use due to biomass development. Further, it is generally expected that scenarios based on less aggressive emission reduction goals for 2030 would be achievable at lower overall costs due to the ability to rely on measures that are more cost-effective.

The Combination Scenario (see Table 3-56) leads to macroeconomic effects on the State that are employment positive in 2018, negative by 2029, and overall, less burdensome on economic activity than the 52 x 30 Scenario shown in the prior table. MARKAL projects technology shifts in the transportation and residential sectors in the Combination Scenario in a way that is not adverse to economic activity. For instance, the transportation sector compliance would be achieved with extra capital cost that is just 1/10th that required in 52 x 30, and with fuel and O&M savings that are 53% of those in the 52 x 30 Scenario. By 2029 however in the Combination Scenario, the C/I sector compliance from MARKAL had already incurred a ramp in capital cost (investment) outlays that exceeded the level of O&M spending reductions, and as a result, statewide employment and GSP are lower than in the base case by 0.20% and 0.41% respectively.

Health outcome induced macroeconomic effects are explored for 2018 where the BenMAP model was applied to air quality modeling results (the Combination Scenario). These are not included in the bottom-line scenario results of Table 3-56, but are shown below in Table 3-57. The Combination Scenario is linked to aggregate health disbenefits from BENMAP, resulting in more patronage at health care service centers, and an added 320 jobs in New York (an actual increase of 520 in the health care services industries but lost productivity as an increase in worker absentee days increase chisels away other jobs away through lost competitiveness for NYS businesses.)

Table 3-57. Combination Scenario 2018 Economic Impacts from BENMAP Health Outcomes relative *to* Base Case.

2018 REMI Macro Impacts for NYS*								
SCENARIO	*NET BENEFIT / DISBENEFIT*	$ AMOUNT for Select *BENMAP 2018 IMPACTS (mil 2000$)*	**Jobs**	*Private-sector Jobs*	**Health Services Jobs**	% of the private-sector impact	GSP (mil 2000$)	Output (mil 2000$)
COMBINATION	***DISBENEFIT***	-$108	320	340	520	*NA*	-$30	-$60

** Excludes the ENDPOINT categories associated with willingness-to-pay as these are SOCIAL Benefits, not REMI conformable*

Sensitivity Analysis of Complementary Fiscal Policies

A sensitivity analysis was conducted for the 52 x 30 Scenario, focused on improving the self-supply for new demand for products from NAICS 335 – *Electrical equipment, Appliance & Components manufacturing*. This sector of the New York economy provides components into various technologies from all four sector strategies, particularly electric, hybrid or fuel cell powered vehicles, battery technology applications, some power generation technologies (RE and traditional) and aspects of industrial O&M spending. The NYS REMI model indicates that currently, this small sector (0.2% of NYS output in 2010) fulfills 13% of State demand for such goods from in-state suppliers (the balance being imported.) The base case in the model predicts, however, that this share will shrink to 9% by 2030 based in part on in-state competitiveness for manufacturers, and the national trend (-30%) expected for this sector. The sensitivity analysis assumes a doubling of the current in-state fulfillment (from 13% to 26%) on such demand due to complementary economic policies that could be implemented in parallel with the environmental policies comprising our multi-pollutant scenario. The result is that adverse macroeconomic impacts of the 52 x 30 Scenario would be mitigated by 13% for employment and 16.5% for GSP. Results are shown in Table 3-58.

Table 3-58. 52 x 30 Scenario: "*NAICS 335 Doubling In-state Fulfillment for new Demand*," Economic Impacts relative to Base Case (no Health Outcome Considerations).

52 x 30	*differences*				
	EMP (units)			**GSP (B2000$)**	
MPS target sector	2018	2029		2018	2029
Power producing sector	-2364	-157740		-0.225	-21.496
Transportation sector	-50017	-160113		-3.315	-13.618
Residential	8355	-6273		0.382	-0.81
Comm & Indstrl	-8633	-20984		-0.556	-4.572
all sectors	*-52,659*	*-345,110*		*-3.714*	*-40.496*

Implications

A key ramification from examining pollution policy from a macroeconomic context is that without an *a priori* emphasis on economic development promotion within the pollution policy, it is not unlikely that requirements on businesses and households to use different technology (for transportation, or for daily operations) will leak away the potential stimulative effects of shifting investment demand and leave the State's constituents with the costs to bear. It is not surprising that a large investment in new clean technology – if not balanced by complementary economic policies – will not be fully offset by the fuel savings. We also see that a large fraction of the economic impacts can theoretically be avoided if complementary fiscal policies are successful at retaining or growing clean-tech market share within NYS.

Also, as has been seen before, pure macroeconomic frameworks are not a suitable setting for introducing "improvements to health," as the foregone wage-levels and local linkages tied to the health care spending cannot be replaced by increased household spending since the general consumer basket (retail activities) has a higher reliance on imported (non-NYS) content. The quality of life benefits associated with reduced incidence of air pollution related illness are among some of the traditional externalities that are not well characterized by classical economic frameworks. Nonetheless, reducing the incidence of cardiac and pulmonary disease through air quality improvement remains an important societal goal. This finding is reminiscent of the notorious cost-benefit analysis done by Arthur D. Little for the Czech Republic (financed by Phillip Morris) showing the economic benefits of smoking on government spending. Government health care expenses do decline dramatically when smokers continue their habit – but it is primarily due to premature deaths, which limit health care expenses relative to a scenario under which they quit their habit, but continue to live with impaired health.

Section 4

THE MULTI-POLLUTANT NARRATIVE: PULLING THE PIECES TOGETHER

This project demonstrates a proof-of-concept of several multi-pollutant planning analytical tools, and identifies how state agencies can build capacity to use these tools. It describes the policy benefits and challenges that accompany shifting to a multi-pollutant planning paradigm, and suggests recommendations for moving forward based on lessons learned. The tools used are part of NESCAUM's Multi-Pollutant Policy Analysis Framework (MPAF), and were examined in Section 2. Analytical results were presented in a step-by-step evaluation of each individual component of the framework in Section 3. The importance of using an energy model such as NE-MARKAL for air quality planning purposes is its ability to begin the air-energy integration process. The range of outputs it provides, including multi-pollutant emissions changes and costs, is far broader -- and may be more useful to high-level state decision-makers -- than the more traditional air quality analytical tools. The larger value of an integrated assessment process, such as the one conducted using NESCAUM's MPAF, is the integration and synthesis of information across the multiple tools to provide a meta-analysis with greater context than can be derived from any one component alone.

For this proof-of-concept exercise, we conducted the meta-analysis using the Combination Scenario. Using the full breadth of information derived from the full set of MPAF tools as described in the prior sections, a narrative emerges of how each set of policy choices results in technology shifts as well as economic costs and savings that lead to changes in emissions, air quality, public health outcomes, and macroeconomic indicators. This information is presented in the context of cross-sectoral interactions and environmental tradeoffs that would not otherwise be available in an analysis limited to an individual component of the integrated assessment framework.

THE MULTI-POLLUTANT NARRATIVE

Description of the Combination Scenario

The Combination Scenario combined the seven most effective policy levers from prior analyses, demonstrating that a significant fraction of the reduction potential would come from just a few measures. Measures analyzed in this run included a requirement that at least 25% of the light-duty automobile fleet be hybrid-electric vehicles by 2030 and that another 25% be electric vehicles. In addition, Reference Case restrictions on energy efficiency opportunities and combined heat and power for residential and commercial users were removed to simulate the role of state incentives for efficiency programs under the "15 x 15" or similar strategies. NYS's RPS was required to be met, corresponding to 10,000 GWh of generation by

2013. It was assumed that all appliances sold in NYS would meet ENERGY STAR® or better efficiency levels by 2020, and the State's low-sulfur fuel program would be met by 2017.

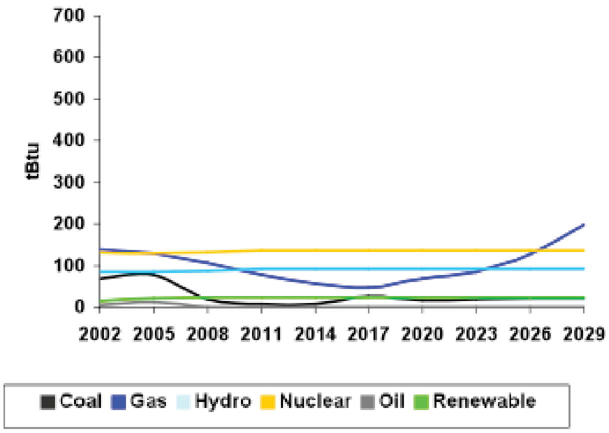


Figure 4-1. Power Generation Technology Projections under a Combination Scenario Consisting of Seven Highly Effective Policy Measures. The energy efficiency measures suppress demand early in the period and relatively weak RPS and EV mandates do not result in a large renewable energy mandate or increased electric demand like other scenarios examined in Chapter 4.

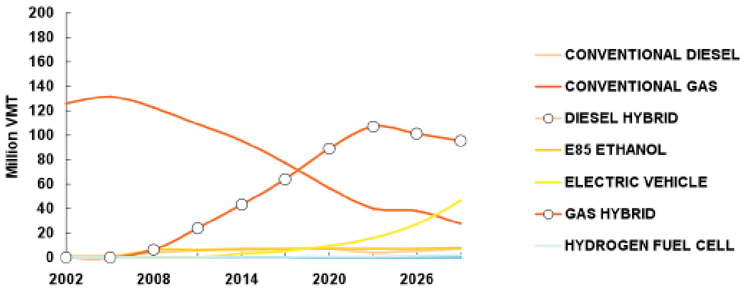
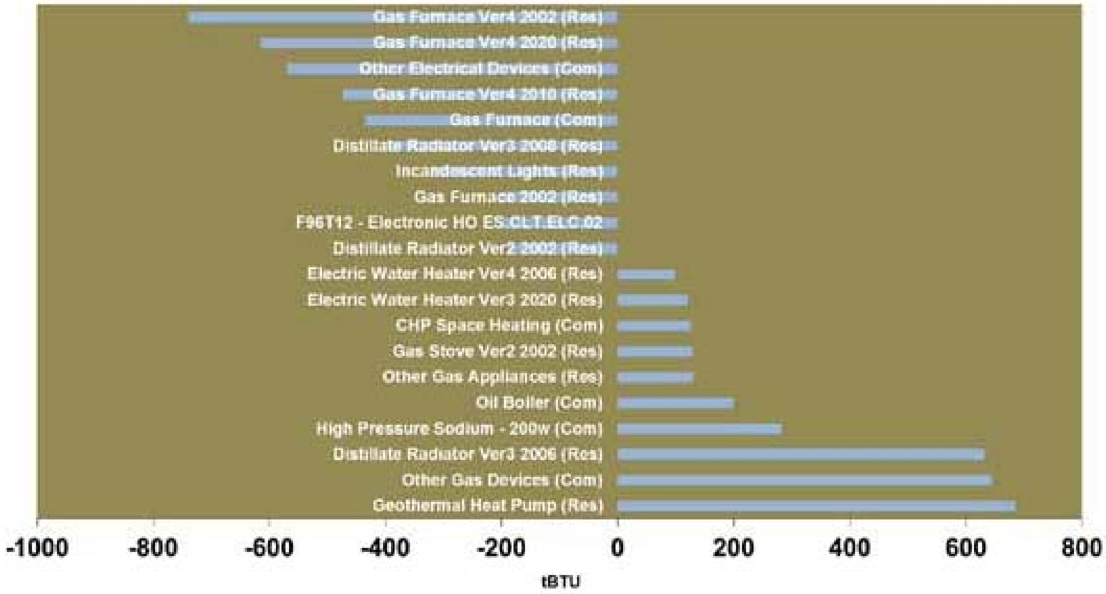


Figure 4-2. Transportation Technology Projections under a Combination Scenario. The mandate for 25 percent electric vehicles is just met in 2030, whereas the similar mandate for 25 percent hybrid-electric vehicles is found to be more economically attractive and leads to over-compliance with the requirement.

MPAF Phase 1: Projected Emissions and Technology Changes

The NE-MARKAL analysis shows that, using these assumptions, high levels of pollution reductions could be achieved with the seven selected strategies with relatively few technological hurdles and at reasonable cost. The analysis further indicated that fuel savings would offset a portion of the capital expense incurred. In most cases, the fuel savings would more than compensate for the capital expense, thus resulting in overall cost savings.

Figure 4-1 through Figure 4-3 and Table 4-1 present the key results from the NE-MARKAL model simulations for this scenario.



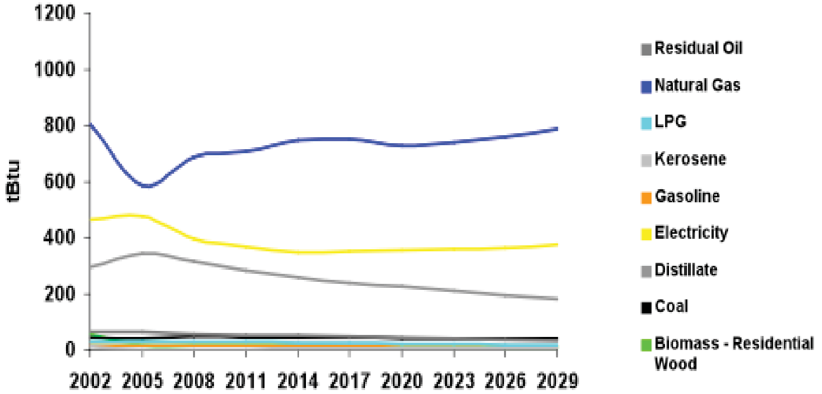
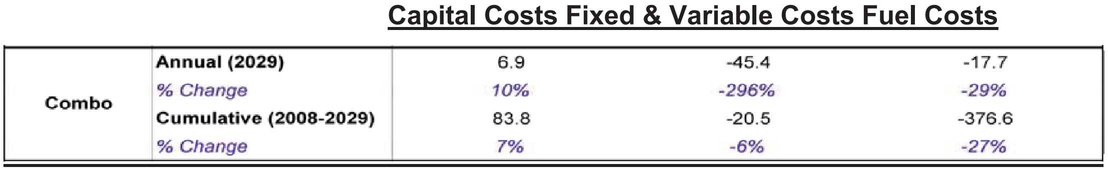


Figure 4-3. Residential, Commercial, and Industrial Technology Projections under a Combination Scenario. This analysis shows that demand reductions resulting from efficiency options lead to shifts in fuel use (less wood and oil) across these sectors in 2018.

Here, we recall from Section 3 that the introduction of conservation technologies, Energy Star appliances, and the increased availability of combined heat and power for residential and commercial heating demand could reduce the market share of residential heating from biomass such as wood. In addition, the large amount of existing hydro capacity satisfies the RPS requirements, while the Energy Star requirements and conservation technologies could lead to a decline in electric demand by 2020 with an increase in demand toward 2030 in response to greater transportation demand for electricity.

Table 4-1. 2030 Annual and Cumulative Changes in Capital Investment, Operations and Maintenance, and Fuel Costs for the Combination Scenario relative to a Reference Case. (2008 $billion).



		Capital Costs	Fixed & Variable Costs	Fuel Costs
Combo	**Annual (2029)**	6.9	-45.4	-17.7
	% Change	*10%*	*-296%*	*-29%*
	Cumulative (2008-2029)	83.8	-20.5	-376.6
	% Change	*7%*	*-6%*	*-27%*

MPAF Phase 2: Air Quality Effects

Due to availability of an air-quality modeling platform for the calendar year 2018, the air quality implications of the technology changes identified by the NE-MARKAL model were investigated for NYS during that year. Emissions projections from the NE-MARKAL model were used to develop growth and control factors for air quality modeling simulations carried out with the CMAQ model.

The projected emissions changes associated with the Combination Scenario reflect the technology shifts described above, as shown in Figure 4-4 and Figure 4-5 (which re-prints Figure 3-89 and Figure 3-90 from earlier sections). Here we see that emissions differences of $PM_{2.5}$ are large in the several counties surrounding Albany (and still moderate over much of the state) reflecting the statewide decline in residential heating with wood. This is a direct result of the increased efficiency and least-cost preference for alternative heating systems relative to current wood heat. Note in Figure 4-4(d) the overall decline in power plant SO_2 emissions at a number of facilities, reflecting a general decline in electricity demand in 2018 due to ENERGY STAR® programs and conservation technologies. In Figure 4-5, we see the same trend for power plant emissions of NO_x as SO_2 within NYS. Note, however, that both $PM_{2.5}$ and NO_x emissions increase in neighboring New Jersey as a result of lowered demand, thus making imported power from New Jersey more cost-competitive. The imports typically come from aggregated combined cycle gas turbines that ramp up as transmission capacity becomes available. Ideally, additional energy analysis tools, such as dispatch modeling, would be helpful in assessing the availability of the additional transmission from northern New Jersey, notwithstanding the apparent cost advantage identified by MARKAL.

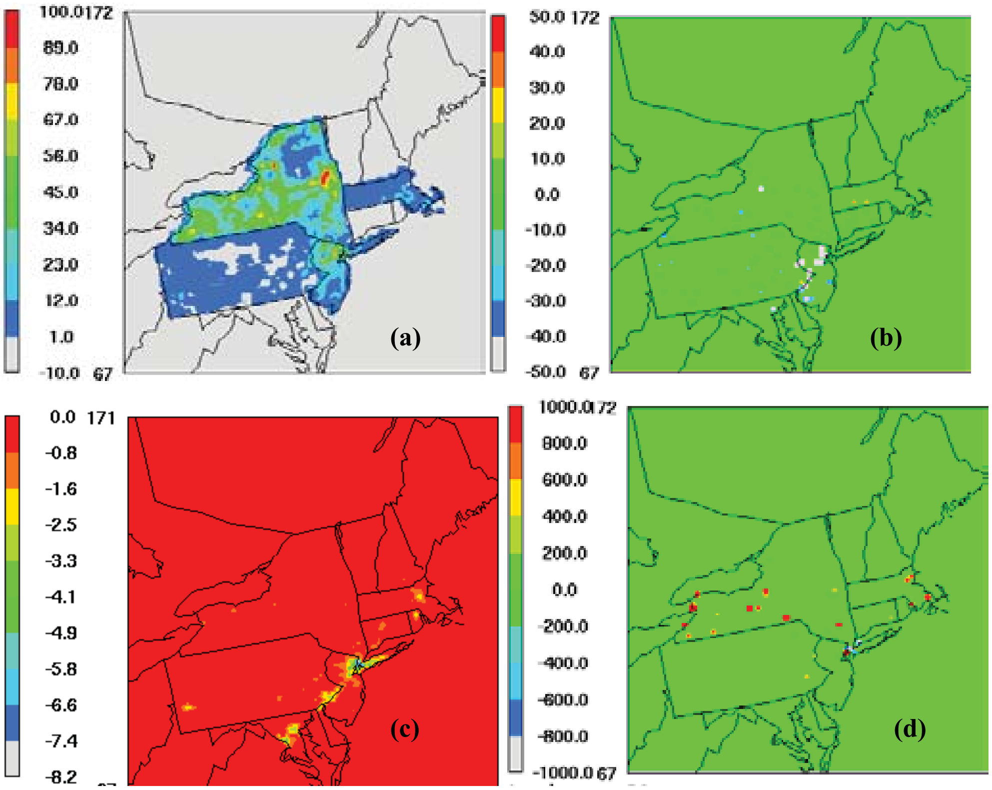


Figure 4-4. Annual Modeled Emissions Differences between 2018 Reference Case and 2018 Combination Scenario for PM from (a) Area Sources, (b) Point Sources other than Major EGUs, (c) Mobile Sources, and (d) SO_x from Major EGUs using CMAQ.

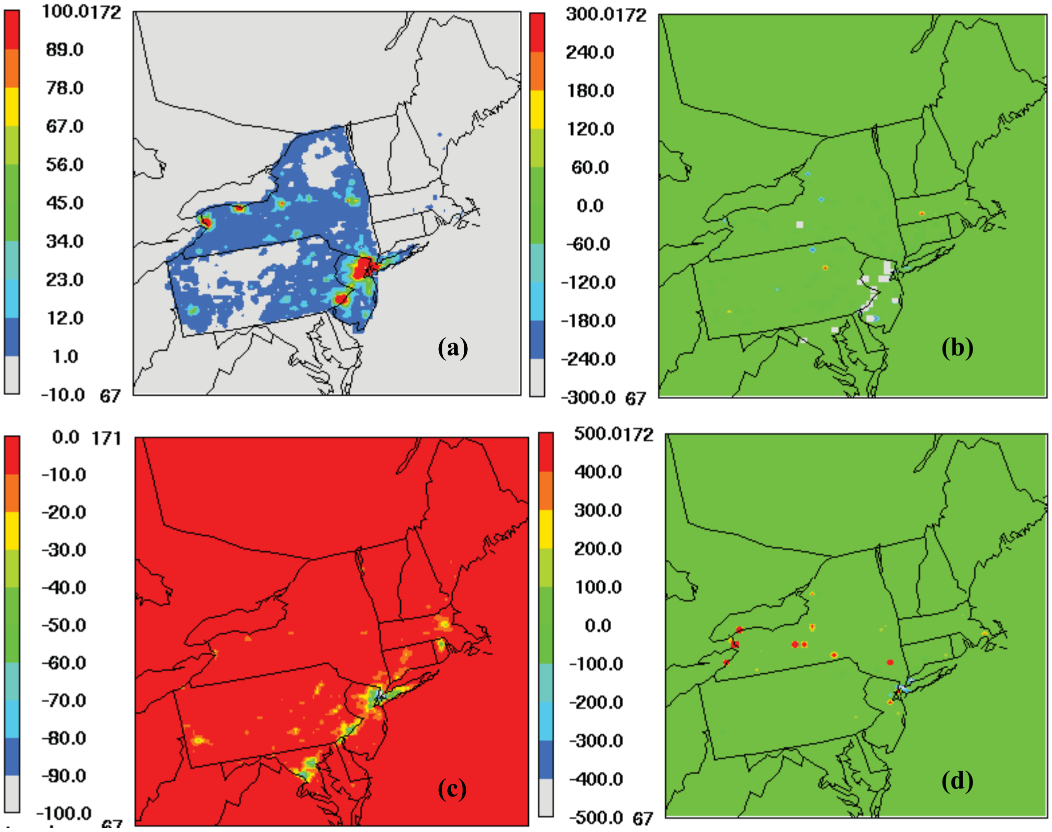


Figure 4-5. Annual Modeled NO_x Emissions Differences between 2018 Reference Case and 2018 Combination Scenario from (a) Area Sources, (b) Point Sources other than Major EGUs, (c) Mobile Sources, and (d) Major EGUs using CMAQ.

While not attributed to a technology transition, the low-sulfur fuel program could also lead to emission reduction due to a fuel transition, as shown in Figure 4-6. While not as large as the $PM_{2.5}$ emission reductions from the standpoint of primary $PM_{2.5}$, the lower SO_2 emissions play a role in lowering secondary $PM_{2.5,}$ formation across the State, with less than half the SO_2 emissions in the Combination Scenario relative to the Reference Case.

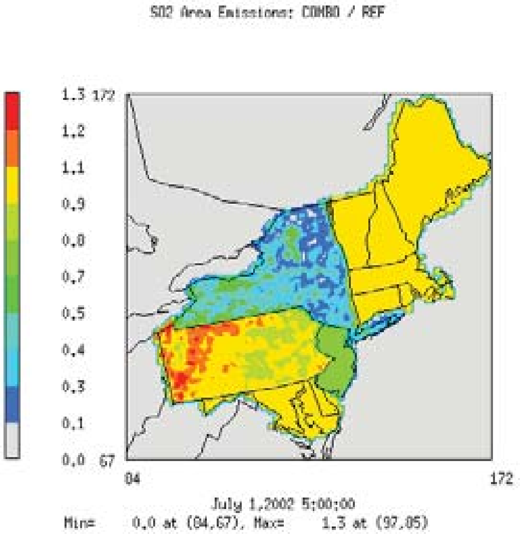


Figure 4-6. Ratio of Combination Scenario SO_2 Emissions to Reference Case Emissions. Reductions of more than half across the state are due, in large part, to area source reductions due to the low-sulfur heating oil program.

When these emission changes are simulated in the CMAQ chemical transport model, we find, as expected, that air quality responds to the changes. The air quality response is documented in Figure 3-83a from Section 3, which shows projected statewide reductions in annual average $PM_{2.5}$ on the order of 1 µg/m^3, and much larger reductions (~2-2.5 µg/m^3) in the Albany area. A review of the speciated components of the modeled $PM_{2.5}$ indicates that the majority of the $PM_{2.5}$ reduction in and around the Albany area is due to the primary organic aerosol reduction associated with the reduced residential wood heating. Broader statewide $PM_{2.5}$ reductions are due in part to less wood burning, but also to a 4 to 10% reduction in sulfate from the combination of reduced SO_2 emissions from residential heating oil, and reduced SO_2 from power plants due to lowered general electricity demand.

Ozone concentrations under the Combination Scenario (see Figure 3-83b) are projected to decrease over much of the State on the order of about 0.1-0.2 ppb. This is due to decreased NO_x emissions from power plants and residential heating sources (areas sources) as more efficient heating and conservation measures are deployed as well as NO_x reductions from transportation programs in the early stages of implementation in 2018. The New York City metropolitan area, however, shows larger decreases in ozone, observed on the order of 1 ppb. Realistic or not, the analyzed Combination Scenario reflects increased electricity imports from northern New Jersey gas turbines that result in increases in local NO_x, which increase NO_x scavenging of ozone and thus result in local ozone decreases. We have not examined the impact of the increased NO_x farther downwind in New England. To do so would warrant a comprehensive analysis of regional air quality. The phenomenon, however, is opposite to the trend in smaller urban areas of upstate

New York, where decreased NO_x at specific power plants lead to reduced NO_x scavenging and small ozone increases in some localized regions.

As demonstrated above, we note that because the components of this scenario can be directly tied back to constraints imposed in NE-MARKAL, we have the capability to more easily identify the influences and interactions of an individual policy lever with the other levers in the suite of policies that are modeled. This is strength of the MPAF framework.

MPAF Phase 3: Evaluating Health Benefits

The emissions and air quality findings, described above, feed into the third stage of employing the MPAF to evaluate health benefits. The changes in ambient air quality values projected for the Combination Scenario were input to the BenMAP model to estimate specific increases and decreases in incidence of five ozone-associated health endpoint groups[32] and 11 PM-related health endpoint groups[33] associated with the ambient air pollutants tracked by the CMAQ model. Gridded ambient air quality projections for 2018 were used with the 2018 Reference projection to calculate projected changes in ambient air quality monitors. These were then translated into monetized public health impacts.

Table 4-2. Monetized Public Health Benefits (costs) (in $US million) from the BenMAP Tool for the Combination Scenario.

Pollutant	Mortality (willingness to pay)	Morbidity (health expenses/services)
Fine Particle Pollution	**(1,300)**	**(134)**
Ozone	**420**	**25**

Results are presented in Table 4-2. Note that the monetized results are driven by the nearly $1.3 billion of mortality costs associated with $PM_{2.5}$ increases in metropolitan New York City. While these are large dollar values, they represent monetized estimates of societal “willingness to pay” valuations, not actual damages, and therefore have not been included in the subsequent macroeconomic analysis. Notwithstanding, the results indicate monetized morbidity costs of $PM_{2.5}$ of approximately $134 million. This is due to increased incidence of cardiac and pulmonary non-mortality health endpoints in and around greater New York City and is associated with local increases in $PM_{2.5}$ in northern New Jersey from projected gas turbine utilization.

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[32] Ozone endpoints analyzed in BenMAP were: mortality, school loss days, emergency room visits (respiratory), acute respiratory symptoms, and hospital admissions (respiratory).

[33] PM endpoints analyzed in BenMAP were: mortality, acute myocardial infarction, hospital admissions (respiratory), emergency room visits (respiratory), acute bronchitis, lower respiratory symptoms, work loss days, acute respiratory symptoms, hospital admissions (cardiovascular), asthma exacerbation, and chronic bronchitis.

For O_3, the same emissions increases of NO_x in New Jersey lead to O_3 decreases over New York City and associated O_3 net health benefits that dominates statewide impacts (~$420 million from avoided mortality and $25 million due to other non-mortality health impacts). Statewide, there are observed reductions in both $PM_{2.5}$ and O_3 and associated health benefits. The local increases in pollution over New York City, however, lead to large monetized health costs relative to the rest of the state, owing to the population differences. The net health effect is increased statewide healthcare costs and associated work and school day losses by $109 million per year. These represent real spending increases that are passed on to the macro economy.

MPAF Phase 4: Macroeconomic Analysis

For the fourth stage of employing the MPAF, the monetized health benefits (and not the "willingness to pay"-based mortality benefits) were used with estimated capital investment, fuel savings, and operations and maintenance costs from the NE-MARKAL analysis to feed macroeconomic simulations of the NYS economy using the REMI model.

For the Combination Scenario, projected economic benefits included more than 6,000 new jobs in 2018, but a decrease in employment by 2029. Initial employment gains projected may be due to conservation technologies and residential efficiency opportunities that are taken up quickly. Later technology shifts are related to transportation requirements, where new investment and technology development are occurring out-of-state, with fewer in-state employment benefits. Gross state product (GSP) effects are not stimulative overall, but residential sector and transportation sector policies result in greater fuel and O&M savings relative to capital outlays. In the commercial and industrial sector, the added expense of compliance is not repaid by 2029, resulting in GSP effects that are negative, but within 1% of the Reference Case projections. A sensitivity analysis of economic results, however, shows significantly better economic outcomes due to an assumed doubling of the current in-state fulfillment (from 13% to 26%) for demand in just one economic sector – electrical equipment manufacturing. This assumption attempts to simulate complementary economic policies that could be implemented in parallel with the environmental policies comprising the multi-pollutant scenario. These results suggest that a package of policies targeting multiple economic green/clean technology sectors could lead to significantly improved economic outcomes.

The health costs derived from the BENMAP analysis lead to mixed results, with increased employment attributed in large part to the health services sector, and a small negative impact on gross state product resulting from the reduced household disposable income of those who incurred greater health spending as a result of the increased $PM_{2.5}$ over New York City.

Section 5

LESSONS LEARNED AND IMPLICATIONS FOR FUTURE PLANNING

PLANNING AND PROCESS ASPECTS: SUCCESSES, CHALLENGES, AND LESSONS LEARNED

Given that this effort was a proof-of-concept exercise, NESCAUM interviewed key project participants on the successes and challenges of employing the Multi-pollutant Policy Analysis Framework. Participants were asked to reflect on the process in terms of what worked and did not work, what exceeded expectations, what were the greatest challenges, how might the results be used, and what suggested improvements could be made. The goal was to document lessons learned in order to inform future multi-pollutant planning efforts elsewhere in the region or the U.S. Findings are summarized below.

Broadening Planning Horizons

When this project was first conceived, the State had multiple areas that were classified as nonattainment for various criteria air pollutants. Such status provided an incentive to explore the potential of integrated multi-pollutant planning. NYSDEC engaged in this project knowing that it was a new, groundbreaking venture, and expected to encounter challenges as the staff explored a different way to approach air quality planning and use new analytical tools.

This project broadened NYSDEC staff's perspectives as air quality planners by providing them with hands-on experience on how energy and climate programs can provide opportunities to help meet air quality goals. Using the NE-MARKAL model, they were able to examine and address energy and climate issues as well as a host of key air pollutants. NYSDEC staff view the NE-MARKAL model as a primary avenue for integrating multi-disciplinary (i.e., air-energy-climate), multi-pollutant planning analyses going forward. Without using NE-MARKAL, the planners would otherwise have continued to employ their standard pollutant-by-pollutant planning approach.

The NE-MARKAL analyses provided NYSDEC with projections of air quality co-benefits resulting from implementing specific energy programs. Such emissions reduction information has not been readily available in the past. NYSDEC staff expects this type of analysis to be even more valuable to states as they seek emissions reductions to comply with more protective National Ambient Air Quality Standards (NAAQS) in the future.

This exercise broadened the air planners' perspective by framing the effort, i.e., contextualizing the proposed control measures, within NYDEC's broader priority areas. Normally, the air quality planners would have proceeded solely within the context of the federal Clean Air Act and state air program goals.

Working within a new planning horizon presented a new set of policy questions. The NE-MARKAL model uses a planning horizon different from that used for SIP planning, accommodating and presenting results over a 20 year period rather than the three to six years typically encountered in SIPs. The resultant benefits were both long- and short-term. Some of the climate strategies yielded significant air benefits, but not for 10 or 20 years. This encouraged thinking about longer-term air quality needs, which is not typically fostered through the current, shorter Clean Air Act deadlines. Air planning staff were able to consider questions such as what programs could address a future, more stringent NAAQS, or whether it would be appropriate to invest now for longer term air quality benefits.

By employing a different planning approach, the project helped expand staff's vision of how various programs might be effective and yield benefits in air and non-air quality arenas. Furthermore, it motivated air quality planners to think about how to integrate SIP planning into multi-pollutant planning, and vice versa. For example, in past planning efforts, programs not within the NYSDEC Air Bureau's jurisdiction were typically not considered for inclusion in the SIP or relevant to air quality goals. This exercise provided an approach that allowed for truly integrated air-energy-climate planning that yielded analyses on a suite of energy- and climate-driven programs, many of which yielded air quality benefits. Moreover, the exercise allowed the air planners to concretely consider how the resulting analyses could be used within a SIP context as well as within general policy planning.

NYSDEC's climate staff was impressed with the abilities of the NE-MARKAL model, and came to understand how the model could inform air and climate planning. The model indicated that, from a policy perspective, carbon would be a dictating factor, and in order to meet the State's climate goals, all sectors must be involved. While the model did not predict or project at the electricity sub-station level, it provided projections on the magnitude of the reductions (i.e., megawatts generation capacity) needed, and information on the cost-effectiveness of various options. Climate staff indicated that NE-MARKAL's ability to analyze the needed reductions in megawatts if cost-effectiveness were changed is a great function of the tool. They see it as a useful upper management level tool that will not specifically place resources, but can project which resources would be economic.

Climate and air staff agreed that this exercise helped show how integrated planning could be done at a level much higher and be more encompassing than pollutant-by-pollutant SIP planning. While it will be a challenge to shift away from the current approach to air quality planning that has developed in response to requirements within the Clean Air Act, the expectation is that, over time, the multi-pollutant approach will be adopted as a new way of doing business. The intent is that longer-term, integrated planning will be able to directly inform and address Clean Air Act planning requirements as well as climate and energy planning.

All parties agreed that the process was the most important aspect of the project. Engaging in this type of integrated planning exercise was a valuable learning experience for the participants. The group understood the possibilities, as well as the limitations, of the NE-MARKAL model and NESCAUM's MPAF framework. They gained an appreciation for the iterative nature of the NE-MARKAL calibration and modeling processes. Going through the progression of steps and learning as a group how to use the MARKAL model was important, and gave everyone a better understanding of the NYS energy system and the ever-changing issues that will arise during such a modeling exercise. All have a better understanding of MARKAL as a tool in the planning process and how to use it in a planning process. As they continue with similar analyses in future, less work effort up front is anticipated, and all are better prepared to address issues as they arise.

Data Collection and Management Decisions and Process

Preparatory work with data for model inputs is a formidable task. It is even more complicated when there are multiple end-users. Calibrating the Reference Case was a labor intensive, iterative process. It was a cornerstone of the project as it provided the basis for all subsequent analyses. During the process, weekly discussions focused on review of results for various sectors until agreement was reached that the sectors were appropriately calibrated. NESCAUM was able to calibrate the NE-MARKAL model to the NYS energy system and output projections that were extremely close to the State's energy plan without having to make any unusual assumptions. A similar, iterative process was employed for scenario development and results.

Several suggestions were made as to how the process could be improved in the future in terms of finalizing data inputs. First, up-front briefings on how the NE-MARKAL model uses data, including a hypothetical reference case, would have better positioned all parties to assess the data at the appropriate levels of detail (e.g., directionality, order of magnitude). Second, some strategic data decisions might have been reached more easily had there been more face-to-face meetings to close out certain phases of the data processing. For example, it would have helped to hold a meeting to specifically discuss data needs, and a one- to two-day meeting specifically to lock down the data inputs. This would have allowed all parties to be together with all the supporting materials as well as computer access, so that the decision-makers could review materials, ask questions, and come to closure on issues together.

Third, it would be prudent in future to plan time into the project schedule, after generating initial reference case results, to evaluate those results, ensure the inputs are appropriate, and assess whether and how the model might be constrained to further calibrate the reference case. NESCAUM's initial work plan did not consider this need at the outset.

Fourth, it was recommended that NESCAUM establish a shared electronic directory and/or site that would house the project data and documents during the project. Lacking an FTP site, a weekly email would suffice indicating what and when updates were completed, and a link to the most recent documents. Such efforts would easily provide a documented appendix on how the data were collected, how things were changed or constrained, and how data issues were addressed.

Some identified data entry errors resulted in the need for NESCAUM to re-run the CMAQ analysis. Given that the various models within the MPAF are connected and rely on each others' outputs, it is critical that very rigorous QA/QC protocols are implemented. It underscores the importance that states who wish to undertake analyses employing the full suite of MPAF tools have access to robust modeling capacity with rigorous QA/QC protocols.

Information Gaps and Research Needs

Observations were made about information gaps and research needs. For this study, NE-MARKAL primarily used 2002 data sets. Much has changed over the past seven years, especially in light of utility deregulation, and the resource and generation mix have also changed. Identifying a way to update the model on a routine basis would be helpful for future efforts. It was recommended that the next NE-MARKAL baseline developed should be based in a consortium activity, rather than a state-by-state effort, with air and energy agencies working together with NESCAUM. This approach would be particularly useful, as different agencies use different data sets, and often those data sets do not match well.

Another suggestion for future efforts is to conduct some research into power plant capacity factors. These data are apparently not routinely compiled, and it would be helpful to gather that historical and current information. These data would assist in model calibration. More information on capacity ratings was also recommended: such information would be useful especially with a shift to natural. Expanding the efficiency choices in NE-MARKAL was also suggested for future research efforts. Such expansion, with technologies built into the model, would be helpful.

Clearer definitions on how sectors are defined would have been useful to have at the outset. For example, issues around hydropower came up purely due to nomenclature; NYSDEC staff viewed hydropower as a renewable, whereas it may have initially been categorized differently.

Building Capacity in NYS

A key lesson learned for future efforts, particularly with states that have never used the model before, is the importance of clearly communicating expectations on how the data will be used and transformed through the models. This could be addressed in future by NESCAUM spending significant time at the front end of the project guiding state staff through examples of the NE-MARKAL model outputs, before initially reviewing default inputs. While staff understood the process conceptually, without prior experience with NE-MARKAL they did not fully grasp what the outputs were going to look like on a practical level. They therefore did not fully comprehend the relative importance of various data sets until initial modeled outputs were available and presented. As a result, additional data reviews and model iterations were needed later on in the project, requiring more time than anticipated prior to finalizing data inputs for the Reference Case.

In terms of building capacity in-house, an initial hands-on, more advanced training on using the MARKAL model for the NYSDEC data manager would have been beneficial. While an introductory training session was provided near the beginning of the project, it was not rigorous enough. Future efforts would best be served with an up-front comprehensive training that fully explains the differences, data-wise, between the sectors and the categories within the sectors. It should include aspects of the database structure, the data management process, and general computational algorithms. Such training would be best done face-to-face. It should explain, step-by-step, how data are input and output for each sector and category, specifically identifying the input data needed and their attributes, as well as the output attributes. For the electricity generation sector, for example, this would include explaining and answering questions on what specific data and units are input (e.g., fuel, kWh generated), and what units are output. Having such knowledge ahead of time would ensure efforts are focused on the appropriate sectors and data.

Other suggested training topics for future consideration include: (1) an explanation of how the NE-MARKAL model can be constrained and tweaked to calibrate the reference case and scenario runs; and (2) up-front, in-house NE-MARKAL simulations using a hypothetical reference case. This would assist in better understanding not only the structure, inputs, outputs and operation of the model, but also the nuanced ways in which the model responds.

Education and Outreach

During the project period, NESCAUM and NYSDEC engaged with regional and national groups to discuss the project's goals, effort, and preliminary findings. The primary purpose of these efforts was to start discussions with higher level policy makers and planners on the benefits of engaging in multi-pollutant planning by leading with energy-related policies. Preliminary results were presented and used as examples of outputs from NE-MARKAL.

Presentations were made at the Ontario Ministry of the Environment's Emissions, Modeling, and Policy Workshop in May 2008; the National Association of Clean Air Agencies (NACAA) at its membership meeting in September 2009; the Northeast States for a Clean Air Future at its September 2009 Board meeting; the Ozone Transport Commission at its membership meeting in October 2009, the NESCAUM Board meeting in October 2009, at various program offices of the U.S. Environmental Protection Agency in August through December 2009; and at NYSERDA's Environmental Monitoring, Evaluation, and Protection conference in October 2009 . In 2010, presentations were made at the NACAA Spring meeting and the Mid-Atlantic Regional Air Managers Association's (MARAMA's) SIP Coordination Workshop. In 2011, NYSDEC staff presented at the Energy, Utility and Environment Conference (EUEC) and the National Air Quality Conference. Sample presentations are in Appendix B.

There is also international interest in this effort. In October 2010, during a visit to China, U.S. EPA Administrator Lisa Jackson referenced this project as an example of how addressing air quality and climate change goals can be very beneficial. She noted that NYS was combining air quality measures with improvements in energy efficiency, allowing for reductions in traditional pollutants as well as GHGs. A briefing on this project was held for the Tsinghua University School of Environment in Beijing in late 2011. This report is intended to be used to communicate to other audiences about the process involved in and the outputs of this effort.

PLACING THE RESULTS INTO THE POLICY CONTEXT

This is an opportune time to develop and implement tools that can assist states to conduct multi-pollutant planning. The 2004 report on Air Quality Management by the National Research Council underscored the need for a multi-pollutant, cross-sector approach that simultaneously seeks reductions in pollutants posing the most significant risks.[34] In 2007, the U.S. EPA Clean Air Act Advisory Committee's Air Quality Management Subcommittee recommended that states move to an integrated multiple pollutant approach to air quality through comprehensive air quality management plans (AQMPs). [35] In 2007, EPA launched pilot projects with two states (New York and North Carolina) and one locality (St. Louis, MO and IL) to develop multi-pollutant Air Quality Management Plans.[36] In 2011, EPA published a study of a multi-pollutant, risk-based approach that was employed in Detroit, Michigan.[37] The challenge of addressing global climate change has been a catalyst for the northeastern states in recognizing the limits of the existing air quality management framework with respect to lowest cost emission reductions, and the importance of moving to a more holistic, multi-pollutant, multi-source sector, economy-wide approach.

The concept of multi-pollutant planning has varied definitions. Some view multi-pollutant planning as merely considering more than one pollutant at a time. NESCAUM developed its MPAF based on the principles that an effective multi-pollutant process must be able to: (1) address multiple criteria and climate change pollutants, including SO_2, NO_x, CO_2, $PM_{2.5}$, and Hg; (2) highlight tradeoffs and co-benefits; (3) analyze not only the environmental implications of various planning options, but provide economic impacts as well; and (4) allows for multi-sector analyses. Placing the energy-based NE-MARKAL model as the

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[34] National Research Council of the National Academies. Air Quality Management in the United States, 2004, p. 130. See: http://www.nap.edu/openbook.php?isbn=0309089328

[35] See: http://www.epa.gov/air/caaac/aqm.html

[36] See: http://www.epa.gov/air/oaqps/aqmp/

[37] Fann, N., H. A. Roman, C. M. Fulcher, M. A. Gentile, B. J. Hubbell, K. Wesson, J. I. Levy. Maximizing Health Benefits and Minimizing Inequality: Incorporating Local-Scale Data in the Design and Evaluation of Air Quality Policies. *Risk Analysis*, June 2011, v. 31, #6, 908-922. (See: http://onlinelibrary.wiley.com/doi/10.1111/j.1539-6924.2011.01629.x/full)

centerpiece of the framework has essentially provided a hard-wired integration of air and energy at the outset of its use.

The NE-MARKAL outputs provide ideas about technology evolution that can inform future policy discussions. This approach, and the resultant data, is new to air quality planners at the state level. Notwithstanding that some of the models currently used in air quality planning are also least-cost optimization models (i.e., the Integrated Planning Model (IPM)), using energy efficiency technology evolution as a basis for assessing changes in emissions is new to the traditional air quality assessment framework and requires an essential shift in the planning paradigm. As with any model, the appropriate uses are in part based on the robustness of the underlying input data. The NE-MARKAL model outputs interface with and can be input into the CMAQ photochemical model, which is currently the cornerstone of U.S. EPA's photochemical modeling requirements for SIPs. At this point in time, the MPAF results and its accompanying CMAQ modeling are best used as a larger weight-of-evidence analysis that augments the traditional SIP analytical requirements. This will hold true until the robust quality assurance and quality control of the underlying data sets can provide states with the confidence to use this system as a primary driver for inventory growth and control factors in the context of a SIP. The primary value of the MPAF results is that they provide analyses that are not currently available to SIP planners through typical SIP planning efforts, i.e., (1) a multi-pollutant, multi-programmatic view of emissions impacts, including tradeoffs ; (2) an economic analysis of the modeled programs; (3) an assessment of health benefits for the modeled programs; and (4) specific information on program characteristics (from the technology evolution analyses) that can be used directly in regulation development and SIP program planning analyses. As such, the MPAF has significant value as planning and screening tools towards developing more refined SIP and climate plan products.

The focus of this exercise was to launch the first comprehensive application of NESCAUM's MPAF, provide example data for multi-pollutant planning purposes, and assess how to improve the framework. The effort enabled the State to understand how various factors and programs interact. The analyses introduced the reality of co-benefits and tradeoffs through data, and provided illustrative results of the relative importance of various modeled strategies. For example, by showing the strong potential role of combined heat and power in commercial and industrial applications, the modeling indicated where NYSDEC might need to continue to address particular criteria pollutants. This type of analysis can aid policy makers in scaling single pollutant programs to the levels needed to meet their air quality goals.

The agencies involved in this effort agree that a multi-pollutant planning approach is a critical path forward, and find the MPAF to be a useful set of tools. The work produced by this project has been the cornerstone of NYSDEC's AQMP submittal to EPA, and the agency plans to use the results in a broader weight-of-evidence context in developing its future SIPs. In order to fully realize this vision, additional tools (i.e., grid simulation models and/or dispatch models) may be needed to ensure that the projections produced by NE-MARKAL are realistic from an operational standpoint.

In addition, the database underlying the current version of NE-MARKAL, while adequate for a proof-of-concept exercise, will need updating to more recent demand projections and technology data prior to serving as a basis for more refined policy deliberations. Current SIP and energy planning efforts at the state level are conducted continuously, by a staff greater than this project team, within two larger individual regulatory settings. With this relatively modest effort, we engaged in a process to help evolve state planning programs to a new mode of operation. Such an activity is, in hindsight, too ambitious for a single project. Successful evolution to multi-pollutant planning will likely involve the coordination and integration of several functions from at least two state programs over a period of several years. Notwithstanding, this project has shown the way toward achieving these goals. A key element of this transition involves a routine process for collecting, organizing and incorporating energy and emissions data into the NE-MARKAL database with review and quality assurance of results. Such efforts require a significant data-development component of the program.

IMPLICATIONS FOR FUTURE AIR PLANNING

These results demonstrate the power of an integrated platform that allows air quality planners to go beyond their traditional air quality planning world and examine energy and climate strategies and their potential emission reduction benefits with respect to air quality and climate simultaneously. This is a proof-of-concept exercise. The focus of this exercise was to launch the first comprehensive application of NESCAUM's MPAF, provide useful data for multi-pollutant planning purposes, and assess how to improve the framework. The effort enabled the State to understand how various factors and programs interact. It allowed a state air program to examine a realistic package of potential policies from the multi-faceted perspective of environment, energy, public health, and economy. Most important, the MPAF exercise allowed policy makers to follow the consequences of various policy choices through a linked modeling framework to better understand the comprehensive set of consequences and interactions between economic sectors, technology choices, and environmental trade-offs. The analyses introduced the reality of co-benefits and tradeoffs through data, and provided illustrative results of the relative importance of various modeled strategies. For example, by showing the strong potential role of combined heat and power in commercial and industrial applications, the modeling indicated where NYSDEC might want to continue to address particular criteria pollutants. These types of analyses can aid policy makers in scaling single pollutant programs to the levels needed to meet their air quality goals.

This effort helped to distill NYSDEC's paradigm for multi-pollutant planning. The staff concluded that working at a higher planning level, i.e., by not having the SIP be the sole planning driver, but rather, expanding the planning exercise to longer temporal horizons, and working from an energy platform, was critical to developing a series of products that could satisfy multiple program goals. Instead of being solely a SIP planning exercise, this effort was a multi-pollutant exercise that yielded several products, of which some could be incorporated into a SIP. While this was a resource intensive project, a better basis for comparison is that it could be viewed as an extremely cost-effective process compared to the typical SIP and energy planning processes. It produced products that can be helpful to not only the SIP process, but to programs outside of the Air Bureau. These products are also meaningful to high-level policy makers including and beyond the air quality realm within the State.

Currently, there are disincentives within the U.S. EPA's guidance and the overall SIP construct that have made it challenging for states to conduct integrated air quality planning. These analyses will assist the NYSDEC air planners in developing a new, robust weight-of -evidence approach for relevant programs that they may want to have considered in the next round of ozone, $PM_{2.5}$, or regional haze SIPs.

The planning and analysis processes of this project, and the iterative nature of reviewing results, helped identify key dynamics that policy makers should be aware of in developing their environmental plans. It emphasized the importance of tools that can observe cross-sectoral impacts and consider technology evolution as well as assess emissions reductions in evaluating programs. It underscored the need for to evaluating the effectiveness of programs through the lens of fostering renewable energy and energy efficiency while working to meet air quality, climate, and energy goals simultaneously.

States will continue to play a significant role in evolving the tools to conduct more rigorous multi-pollutant analyses and planning. Future pilot projects, including those that include regional analyses, will help to build capacity in other states. Briefings and discussions with the U.S. EPA should occur, not only to develop possible guidance with respect to SIP submittals that include MPAF analyses, but to explore the potential for EPA to expand its current version of MARKAL, the USr9 model, as a multi-pollutant analytical tool that states could use. In order to maximize use of these tools, the staff in the air and energy agencies must continue to work together to ensure that the input data are appropriately quality assured. Collaboration between EPA and the U.S. Department of Energy on data collection activities could significantly reduce the hurdle for state agencies. Shifting to a multi-pollutant paradigm is challenging for any state regulatory agency, as it requires significant up-front commitment to understand and work with staff from other agencies and other disciplines that have different legislative and regulatory requirements and agendas. Notwithstanding, this process has fostered a new understanding of multi-pollutant relationships and provided critical data that will help inform future policy and planning endeavors.

APPENDIX A: NE-MARKAL INPUT ASSUMPTIONS FOR NYS

INTRODUCTION

This document presents the input assumptions that were used to calibrate the NE-MARKAL modeling in preparing for analysis. For purposes of this effort, 2002 was used as the operative base year. All data specific to the NYS Reference Case energy system are presented below. Figure A-1 presents the Final Energy Consumption Snapshot for 2002.

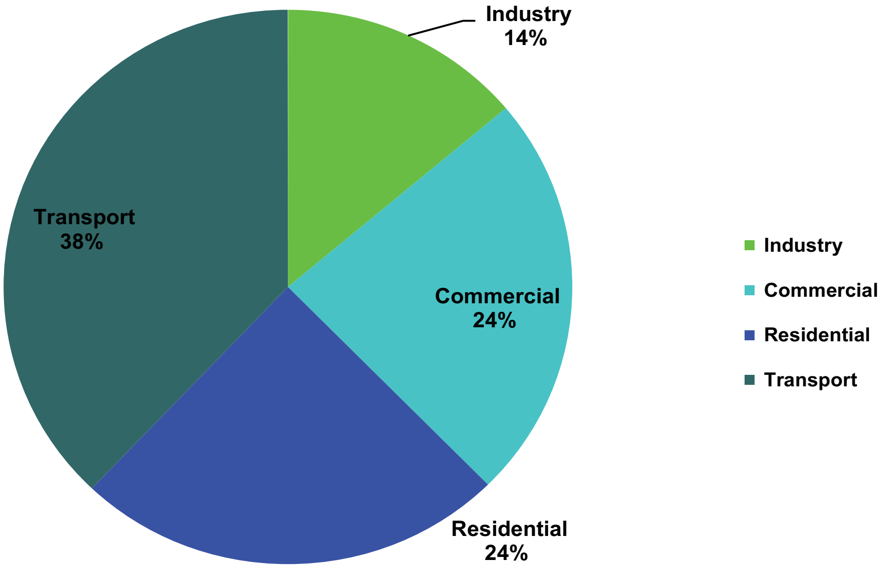

Figure A-1. NYS 2002 Final Energy Consumption Snapshot.

BUILDING SECTOR INPUT ASSUMPTIONS & REFERENCE CASE RESULTS

Commercial/Residential Demand Projections

In the NE-MARKAL modeling framework, the energy infrastructure is configured to meet the estimated demand for energy using the most cost effective technologies and fuel sources. Energy demand for the commercial and residential sectors (presented in Figure A-2 and Table A-1) was estimated outside of the MARKAL framework and represents a significant model input.

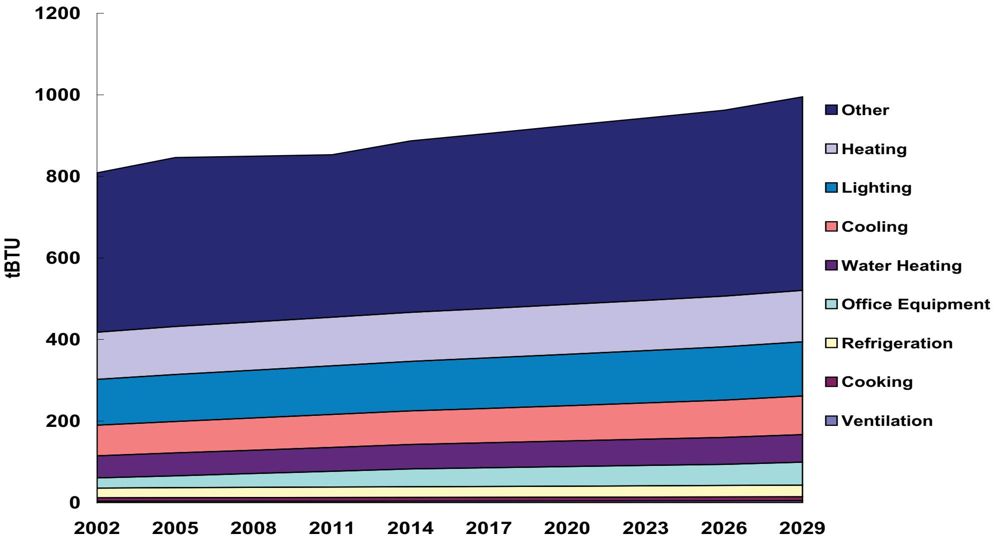

Figure A-2. Commercial Sector Demand Projections.

Table A-1. Commercial Demand Growth.

	Average Annual Growth 2002-2029	% 2002 Demand
Office Equipment	8.6%	3.1%
Cooling	2.3%	9.3%
Ventilation	2.3%	0.4%
Water Heating	2.2%	6.7%
Other/Non-Building	2.0%	48.3%
Cooking	1.9%	1.0%
Refrigeration	1.8%	3.0%
Lighting	1.7%	13.9%
Heating	0.8%	14.3%

The residential demand projections and average annual growth trends are presented in Figure A-3 and Table A-2, respectively. While the electrical demands experience the highest growth rates, these demands represent a relatively small portion of overall demand in 2002. Space heating demand was by far the largest demand sector, representing over 50% of the demand for energy in the base year.

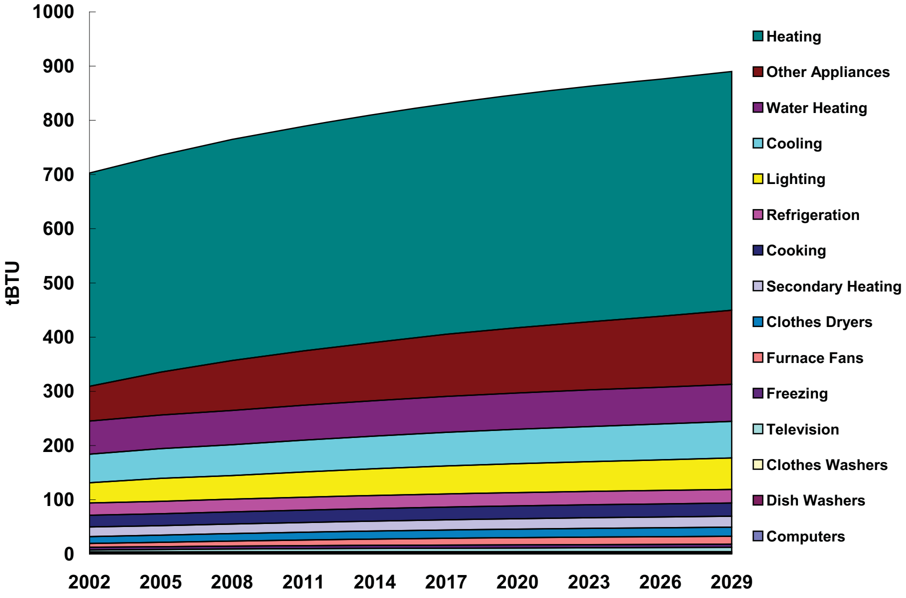

Figure A-3. Residential Demand Projections.

Table A-2. Residential Demand Growth.

	Average Annual Growth 2002-2029	% 2002 Demand
Furnace Fans	7.9%	1.0%
Other Appliances	7.9%	9.1%
Television	7.8%	0.5%
Lighting	4.6%	5.3%
Clothes Dryers	2.8%	1.8%
Cooling	2.4%	7.5%
Dish Washers	1.9%	0.2%
Freezing	1.7%	0.7%
Secondary Heating	1.4%	2.5%
Clothes Washers	1.3%	0.2%
Water Heating	1.1%	8.7%
Personal Computers	1.1%	0.1%
Cooking	1.1%	3.1%
Heating	1.1%	56.0%
Refrigeration	0.9%	3.2%

Demand Projection Methodology

Demand drivers were developed using data from the U.S. Department of Energy's (DOE's) *Annual Energy Outlook (*AEO) 2006 forecast of useful energy demand for the Northeast. After calculating the growth in useful energy demand relative to 2002, which is NE-MARKAL's base year, these growth factors were used to project the demand for energy in the commercial and residential sectors out to 2029. DOE's *National Energy Modeling System* (NEMS) provided a forecast of useful energy demand for the commercial sector and was used directly to develop the commercial demand drivers. NEMS does not provide a forecast of useful energy demand for the residential sector, so we constructed a customized forecast of residential energy demand based on AEO 2006 projections of device units in the residential equipment stock, final energy consumption by type of device, and the average base year efficiency of residential devices in each residential demand category.

Building Sector Demand Technologies

Table A-3 and Table A-4 outline key assumptions made in NE-MARKAL regarding building technologies in the residential and commercial sectors. Technological and market innovation was represented by introducing more efficient or less expensive technologies over time. In Table A-3, the investment cost and efficiency ranges were prepared by comparing all technologies of a given type over the entire model timeframe. The tables below provide a sense for our assumed range of market and technical innovation.

Table A-3. Commercial Technologies.

		Efficiency		Investment Cost $/Mbtu	
Commercial Technology	**# Technologies**	**Min**	**Max**	**Min**	**Max**
Electric Range	2	0.70	0.80	37	43
Gas Range	2	0.45	0.60	26	36
Beverage Machine	10	0.70	1.08	1,488	1,632
Centralized Refrigeration	10	1.82	1.95	947	955
Ice Machine	8	0.44	0.48	2,281	2,505
Reach in Freezer	10	0.56	0.69	2,206	2,832
Reach in Refrigerator	8	0.48	0.63	3,518	4,104
Refrigerated Vending Machine	11	0.48	0.65	3,487	3,692
Walk in Cooler	12	1.99	3.59	760	959
Walk in Freezer	10	0.73	1.09	2,498	2,788
Cooling Air Src HP	7	2.78	5.51	97	194
Centralized AC	7	2.81	5.86	45	143
Centrifugal Chiller	7	4.60	7.30	28	56
Cooling Ground Src HP	5	3.96	8.06	175	300
Gas Fired Chiller	6	1.00	2.20	52	75
Gas Heat Pump	3	0.62	0.70	181	181
Gas Rooftop AC	5	0.59	1.10	96	150
Electric Rooftop AC	6	2.60	4.40	61	80
Reciprocating Chiller	6	2.50	3.80	74	101
Wall Room AC	6	2.40	3.52	17	80
Air Src HP	7	1.88	3.17	97	194
Oil Boiler	4	0.73	0.84	17	19
Oil Furnace	3	0.76	0.80	9	10
Electric Boiler	2	0.94	0.94	20	22
Other Electric Packaged Sys	2	0.93	0.96	16	21
Ground Src HP	5	3.40	5.10	175	300
Natural Gas Boiler	5	0.70	0.85	20	37
Natural Gas Furnace	7	0.70	0.90	9	14
Gas HP	3	1.30	1.50	181	181
7000 CFM System	5	0.56	0.61	3,143	3,217
15000 CFM System	11	0.22	0.36	4,008	4,928
30000 CFM System	10	0.24	0.56	3,150	3,761
50000 CFM System	10	0.26	0.67	3,792	4,229
Oil Water Heater	2	0.73	0.78	27	41
Electric Water Heater	2	0.95	0.97	14	19
Natural Gas Water Heater	4	0.74	0.97	11	19

Table A-4. Residential Technologies.

		Efficiency		Investment Cost $/Mbtu	
Residential Technology	**# Technologies**	**Min**	**Max**	**Min**	**Max**
Electric Clothes Dryer	5	1.07	1.19	90.55	104.13
Gas Clothes Dryer	5	0.94	1.05	101.74	115.32
Electric Clothes Dryer	2	1.00	1.00	341.30	341.30
LPG Range	2	1.00	1.00	341.30	341.30
Gas Range	2	1.00	1.00	341.30	341.30
Electric Range	8	0.68	1.82	1124.69	2322.74
Electric Dish Washer	10	1.05	2.72	200.34	772.75
Electric Freezer	4	1.12	1.92	192.52	252.65
Florescent Light	4	3.68	3.68	1.84	2.03
Incandescent Light	2	0.99	0.99	0.24	0.24
Solid State Light	3	6.62	6.62	10.46	85.85
Electric Refrigeration	9	1.19	1.96	215.44	492.24
Central AC	11	2.93	5.86	411.02	1233.05
Air Src HP	14	2.93	5.51	273.33	503.49
Ground Src HP	10	13.80	27.50	604.19	1035.76
Gas HP	3	0.62	0.70	251.75	431.57
Room AC	6	2.87	3.52	59.60	164.41
Oil Furnace	5	0.80	0.86	30.79	37.63
Oil Radiator	7	0.80	0.97	47.89	62.43
Air Src HP	14	1.99	3.17	42.25	77.82
Electric Radiator	1	1.00	1.00	25.66	25.66
Ground Src HP	10	3.40	5.10	93.38	160.09
Kerosene Furnace	3	0.80	0.86	35.10	72.12
LPG Furnace	9	0.78	0.97	25.66	171.03
Natural Gas Furnace	9	0.78	0.97	25.66	171.03
Gas Heat Pump	3	1.30	1.50	38.91	66.70
Natural Gas Radiator	7	0.80	0.97	47.89	62.43
Wood Stove	1	1.00	1.00	29.08	29.08
Oil Water Heater	2	0.55	0.58	73.74	79.26
Electric Water Heater	18	0.86	2.40	33.87	174.20
LPG Water Heater	12	0.54	0.86	33.19	213.78
Natural Gas Water Heater	13	0.54	0.86	33.19	213.78

Technology/Fuel Share Constraints

In Table A-3 and Table A-4, efficiency is defined differently, depending on the technology type. The efficiency of devices such as radiators or furnaces is defined in the typical way as energy output divided by energy input. Lighting efficiency is defined as billion lumens per trillion British thermal units (tBtu). Heat pumps and air conditioners are characterized by their coefficient of performance (COP).

Technology-specific penetration rates and fuel consumption shares were developed to ensure that initial year fuel consumption levels calibrated well with the historical 2002 values reported in AEO 2006. These calibration constraints were relaxed modestly over time to allow for some degree of fuel-switching and increased adoption of high efficiency technologies. These “relaxation factors” have a large impact on how flexible each of the sectors can be when deciding which technologies and energy sources are implemented to meet the demand for energy. When assessing stringent environmental policies, the model requires the freedom to explore scenarios that are very different from current energy consumption patterns. In these cases, the constraints in Table A-5 and Table A-6 must be relaxed. Between 2002 and 2029, the value of the constraint decreases or increases linearly depending on whether the constraint is being relaxed or tightened.

Table A-5. Commercial Calibration/Technology Constraints.

	2002	2029	Relaxation Factor
* Space Heating			
Lower limit of electricity use in commercial space heating	11.0%	9.9%	90.0%
Lower limit of natural gas use in commercial space heating	64.8%	51.8%	80.0%
Lower limit of distilate oil use in commercial space heating	24.3%	17.0%	70.0%
Advanced technology limit for commercial space heating	0.0%	20.0%	Not Used
Technology upper limit for commercial GSHP	0.3%	20.0%	Not Used
* Space Cooling			
Lower limit of electricity use in commercial space cooling	98.4%	88.6%	90.0%
Lower limit of natural gas use in commercial space cooling	1.6%	1.2%	80.0%
Advanced technology limit for commercial space cooling	0.0%	20.0%	Not Used
Technology upper limit for window AC	16.0%	12.8%	80.0%
Technology upper limit for rooftop AC	53.4%	42.7%	80.0%
* Water Heating			
Upper limit of solar use in commercial water heating	15.2%	0.0%	Not Used
Upper limit of heat pump use in commercial water heating	15.2%	0.0%	Not Used
Lower limit of electricity use in commercial water heating	15.2%	13.6%	90.0%
Lower limit of natural gas use in commercial water heating	61.2%	49.0%	80.0%
Lower limit of distilate oil use in commercial water heating	23.6%	16.5%	70.0%
Advanced technology limit for commercial water heating	0.0%	20.0%	Not Used
* Ventilation			
Advanced technology limit for commercial ventilation	0.0%	20.0%	Not Used
Upper limit of small ventilation eq	50.5%	45.5%	90.0%
Lower limit of medium ventilation eq	6.6%	5.9%	90.0%
Upper limit of large ventilation eq	36.7%	33.1%	90.0%
* Cooking			
Lower limit of electricity use in commercial cooking	14.2%	12.8%	90.0%
Lower limit of natural gas use in commercial cooking	85.8%	77.2%	90.0%
Advanced technology limit for commercial cooking	0.0%	20.0%	Not Used
* Lighting			
Technology share for commercial lighting - Incandescent	17.6%	0.0%	0.0%
Technology share for commercial lighting - Fluorescent	71.5%	71.5%	Not Used
Technology share for commercial lighting - HID	11.0%	11.0%	Not Used
Advanced technology limit for commercial lighting	8.0%	25.0%	Not Used
* Refrigeration			
Technology share for commercial refrigeration - Centralized	65.3%	65.3%	Not Used
Technology share for commercial refrigeration - Walk-in Cooler	18.9%	18.9%	Not Used
Technology share for commercial refrigeration - Walk-in Freezer	5.6%	5.6%	Not Used
Technology share for commercial refrigeration - Reach-in Refrigerator	1.4%	1.4%	Not Used
Technology share for commercial refrigeration - Reach-in Freezer	2.0%	2.0%	Not Used
Technology share for commercial refrigeration - Ice Machine	1.6%	1.6%	Not Used
Technology share for commercial refrigeration - Beverage Merchandiser	2.0%	2.0%	Not Used
Technology share for commercial refrigeration - Rfg. Vending Machine	3.2%	3.2%	Not Used
Advanced technology limit for commercial refrigeration	0.0%	20.0%	Not Used

Table A-6. Residential Calibration/Technology Constraints.

	2002	2029	Relaxation Factor
*** Space Heating**			
Lower limit of electricity use in residential space heating	4.5%	4.0%	90.0%
Lower limit of natural gas use in residential space heating	49.8%	42.3%	85.0%
Upper limit of kerosene use in residential space heating	1.8%	2.0%	110.0%
Lower limit of LPG use in residential space heating	1.3%	1.2%	90.0%
Lower limit of distilate oil use in residential space heating	31.4%	28.3%	90.0%
Lower limit of woody biomass use in residential space heating	11.3%	10.2%	90.0%
Technology upper limit for residential GSHP	0.0%	5.0%	Not Used
Advanced technology limit for residential space heating	2.0%	10.0%	Not Used
*** Space Cooling**			
Lower limit of electricity use in residential space cooling	100.0%	90.0%	90.0%
Lower limit of natural gas use in residential space cooling	0.0%	0.0%	Not Used
Advanced technology limit for residential space cooling	0.0%	20.0%	Not Used
Technology upper limit for room AC	32.0%	50.0%	Not Used
Technology upper limit for heat pumps	5.6%	10.0%	Not Used
*** Clothes Washers**			
Advanced technology limit for residential clothes washers	0.0%	20.0%	Not Used
*** Dish Washers**			
Advanced technology limit for residential dishwashers	0.0%	10.0%	Not Used
*** Water Heating**			
Upper limit of solar use in residential water heating	0.0%	25.0%	Not Used
Lower limit of LPG use in residential water heating	1.2%	1.1%	90.0%
Lower limit of electricity use in residential water heating	15.7%	14.2%	90.0%
Lower limit of natural gas use in residential water heating	55.5%	44.4%	80.0%
Lower limit of distilate oil use in residential water heating	27.5%	19.3%	70.0%
Advanced technology limit for residential water heating	0.0%	20.0%	Not Used
*** Cooking**			
Lower limit of electricity use in residential cooking	15.7%	14.1%	90.0%
Lower limit of natural gas use in residential cooking	75.9%	68.3%	90.0%
Lower limit of LPG use in residential cooking	8.4%	7.6%	90.0%
Advanced technology limit for residential cooking	0.0%	10.0%	Not Used
*** Drying**			
Lower limit of electricity use in residential clothes drying	64.1%	57.7%	90.0%
Lower limit of natural gas use in residential clothes drying	35.9%	32.3%	90.0%
Advanced technology limit for residential clothes drying	0.0%	10.0%	Not Used
*** Refrigeration**			
Advanced technology limit for residential refrigeration	0.0%	20.0%	Not Used
*** Freezing**			
Advanced technology limit for residential freezing	0.0%	10.0%	Not Used
*** Lighting**			
Technology share for residential lighting - Incandescent	91.2%	70.0%	Not Used
Technology share for residential lighting - Fluorescent	8.8%	25.0%	Not Used
Advanced technology limit for residential lighting	0.0%	2.0%	Not Used
*** Secondary Heating**			
Lower limit of natural gas use in residential secondary heating	0.3%	0.3%	90.0%
Lower limit of electricity use in residential secondary heating	18.0%	16.2%	90.0%
Lower limit of LPG use in residential secondary heating	2.5%	2.0%	80.0%
Lower limit of distilate oil use in residential secondary heating	10.5%	7.4%	70.0%
Upper limit of kerosene use in residential secondary heating	3.0%	3.0%	Not Used
Upper limit of coal use in residential secondary heating	0.8%	0.8%	Not Used
Lower limit of woody biomass use in residential secondary heating	65.0%	58.5%	90.0%

Residential & Commercial Sector Fuel Price Projections

Figure A-4 and Figure A-5 represent the 2009 AEO and NYS Energy Plan Reference Case price forecasts used in the analysis. Biomass resource supply curves are presented in a later section. Electricity price predictions were made within the NE-MARKAL framework, and thus are not included in these figures.

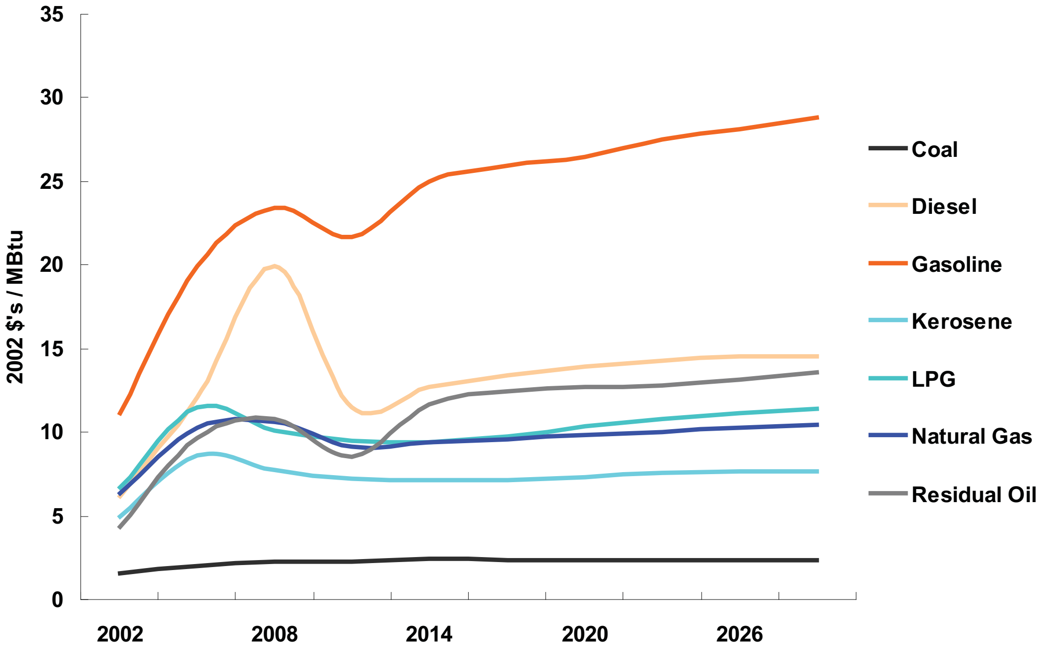

Figure A-4. Commercial Sector Fuel Price Projections.

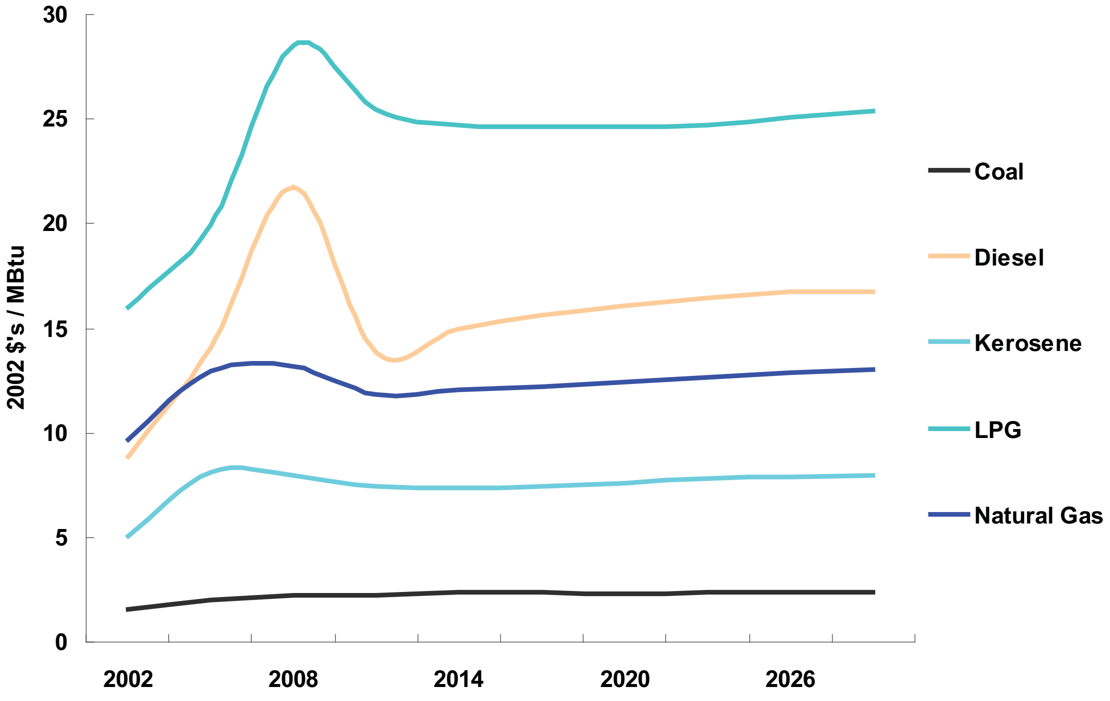

Figure A-5. Residential Sector Fuel Price Projections.

Commercial Sector Reference Case Energy Consumption Trends

The energy consumption trends in the commercial sector, depicted in Figure A-6, were predicted to remain stable over the modeling timeframe. The lack of any environmental policies targeted at the commercial sector in the Reference Case explained the limited amount of fuel switching.

Natural gas, electricity and diesel were projected to account for over 90% of the energy consumption in the commercial sector over the 2002-2029 timeframe. Table A-7 summarizes commercial sector energy consumption changes over the modeling timeframe. On an average annual basis, electricity consumption was projected to increase by approximately 0.5% relative to 2002 by 2029. Overall commercial energy consumption appeared to decline modestly, at an average annual rate of 0.1%.

Total commercial energy consumption calibrated well to the most recent data from the U.S. DOE Energy Information Administration's (EIA's) *State Energy Data System (SEDS)*. The calibration is summarized in Table A-8. Each of the modeled years for which data are available projected energy consumption is within 1% in absolute terms of the consumption level reported in the SEDS data. The 2002 calibration was very good for all of the major fuels. Wood, an obvious outlier in 2002 and 2005, accounted for less than 2% of commercial energy consumption, and was not a primary focus in the calibration process. The 2005 calibration was mostly very good for the major commercial energy sources. Projected natural gas consumption in 2005 was 8% higher than reported in SEDS, while predicted electricity consumption fell short of the SEDS data by 15%. The discrepancy between observed and predicted natural gas and electricity consumption in 2005 was deemed not serious enough to have a significant impact on emissions growth rates, and thus no further calibration was attempted.

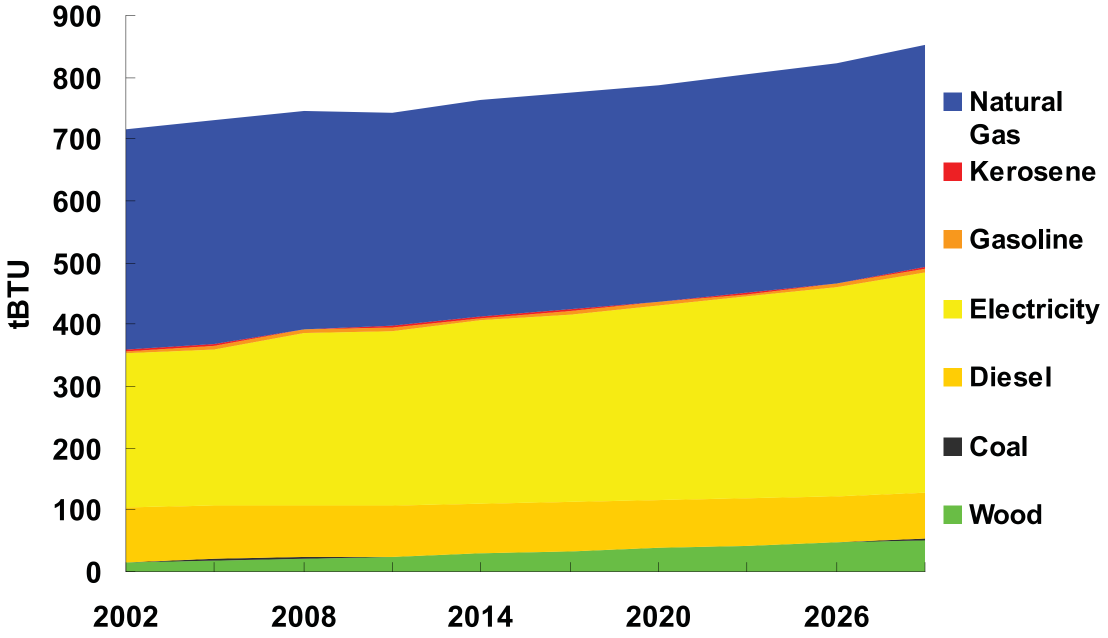

Figure A-6. Projected Commercial Sector Fuel Consumption.

Table A-7. Commercial Energy Consumption Shares

	2002	2029	AAC*
Natural Gas	46.0%	41.3%	-0.5%
Electricity	32.3%	37.0%	0.4%
Diesel	11.3%	9.3%	-0.8%
Residual Fuel	7.1%	9.1%	0.9%
Wood	1.9%	1.6%	-0.7%
Gasoline	0.6%	0.5%	-0.3%
LPG	0.4%	0.4%	-0.3%
Kerosene	0.4%	0.5%	0.9%
Coal	0.1%	0.3%	3.4%
Total	~~	~~	-0.1%

* AAC = Average Annual Change 2002-2029

Table A-8. Commercial Energy Consumption Calibration Results.

		Difference From SEDS
Wood	2002	44.8%
	2005	19.3%
Coal	2002	-1.4%
	2005	<.1%
Diesel	2002	-0.4%
	2005	<.1%
Electricity	2002	<.1%
	2005	-15.6%
Motor gasoline	2002	-0.1%
	2005	206.7%
Kerosene	2002	0.1%
	2005	-0.1%
LPG	2002	<.1%
	2005	-6.5%
Natural Gas	2002	<.1%
	2005	8.2%
Residual oil	2002	<.1%
	2005	<.1%
Total	**2002**	**0.5%**
Total	**2005**	**-1.8%**

Residential Sector Reference Case Energy Consumption Trends

Table A- 9 summarizes commercial sector energy consumption changes over the modeling timeframe. In the Reference Case, no climate and or air quality goals were specifically targeted at the residential sector. As a result, the projected energy consumption trends, presented in Figure A-7, remained stable throughout the time horizon. Natural Gas, diesel fuel, and electricity accounted for the largest share of residential energy consumption over the modeled timeframe. Together, the three fuels represented over 90% of the sectors energy consumption between 2002 and 2029. There was a small decrease observed in the importance of diesel fuel oil relative to other residential fuels over time, as shown in the last column of Table A-9 (see average annual change in fuel consumption between 2002 and 2029). The consumption of all residential fuel types except diesel grew at a modest average annual rate. The decline associated with diesel oil was most likely associated with the high price of diesel fuel oil relative to other residential energy sources, as depicted in Figure A-5

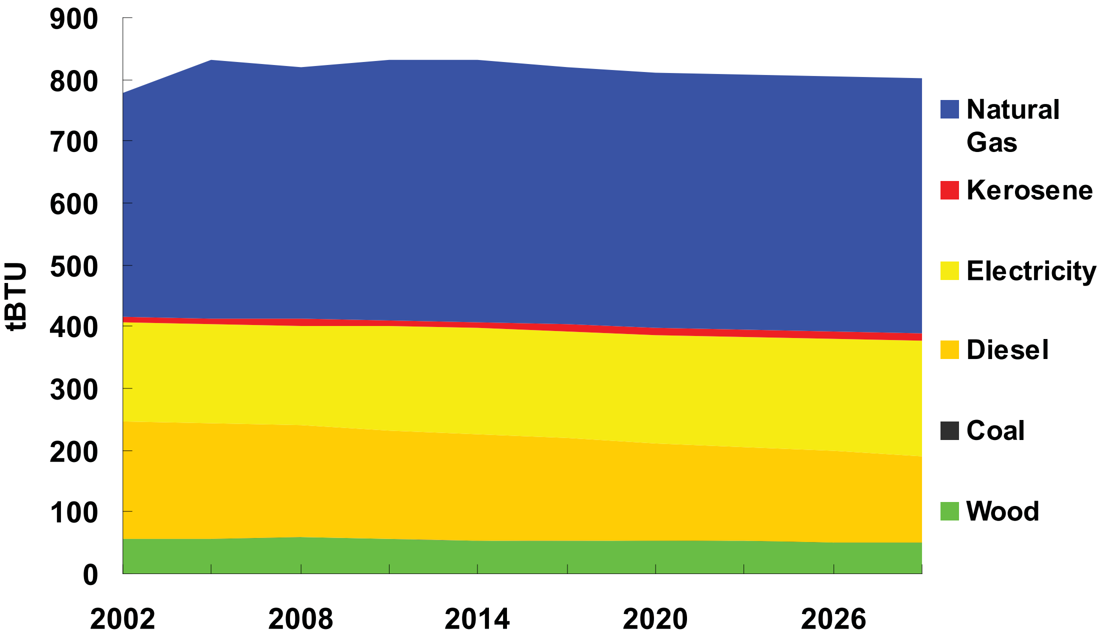

Figure A-7. Projected Residential Sector Fuel Consumption.

Table A-9. Energy Consumption Shares.

	2002	2029	AAC*
Natural Gas	41%	44%	0.4%
Diesel	26%	19%	-1.0%
Electricity	25%	28%	0.6%
Wood	4%	5%	0.6%
LPG	3%	3%	0.2%
Kerosene	1%	1%	0.8%
Coal	0%	0%	0.1%
Total	~~	~~	0.1%

* AAC = Average Annual Change 2002-2029

Residential energy consumption in NYS calibrated well to the most recent data available from SEDS. The full set of calibration results are presented in Table A-10. Most fuels were brought under the 1% difference threshold in absolute terms after the calibration process. Total residential energy consumption reported in NE-MARKAL for 2002 was just 0.2% higher than SEDS, while in 2005, the NE-MARKAL reported total energy consumption was 1% lower than SEDS. While electricity and liquefied petroleum gas (LPG) were outliers, both were within less than 10% of the EIA data. LPG represented only 3% of residential energy consumption, and therefore modest effort was expended on the 2005 calibration for this fuel type. Reported 2005 electricity consumption was nearly 6% below SEDS. A likely source of the small discrepancy is the simplified representation of the electricity grid in NE-MARKAL, specifically the absence of peak times of electricity demand. As the difference was small, no further effort was deemed necessary for the 2005 electricity sector calibration.

Table A-10. Residential Energy Consumption Calibration Results.

		Difference From SEDS
Wood	2002	<1%
	2005	<1%
Coal	2002	<1%
	2005	<1%
Diesel	2002	<1%
	2005	<1%
Electricity	2002	<1%
	2005	-5.75%
Kerosene	2002	<1%
	2005	<1%
LPG	2002	7.5%
	2005	7.5%
Natural Gas	2002	<1%
	2005	<1%
Total	**2002**	**0.2%**
	2005	**-1.0%**

TRANSPORTATION SECTOR INPUT ASSUMPTIONS

For light duty vehicles (LDV), heavy trucks, and buses, 2002 state-level vehicle miles traveled (VMT) were derived from report files from the Mid-Atlantic/Northeast Visibility Union's (MANE-VU's) MOBILE modeling. The demands were based on the MOBILE model's size classes, and were mapped to the NE-MARKAL size classes: small car, large car, small truck, large truck, and mini-vans. The NE-MARKAL size classes were defined to take advantage of technical and economic data in a detailed study of currently available and emerging GHG reduction technologies. [38]

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[38] Reducing Greenhouse Gas Emissions from Light-duty Motor Vehicles, Northeast States Center for a Clean Air Future (NESCCAF), Boston, MA (September 2004). Available online at: http://www.nescaum.org/documents/reducing-greenhouse-gas-emissions-from-light-duty-motor-vehicles-technical-support-study/

Transportation Demand Projections

Demand projections, presented in Figure A-8, for LDVs, trucks, and buses were based on VMT projections extracted by NESCAUM from the MANE-VU[39] inventory data for 2009 and 2018, which were based on state-provided VMT projections. Table A-11 summarizes the assumptions used in this analysis to drive VMT growth for all of the size classes. A uniform average annual growth rate of 1.4% was applied across classes.

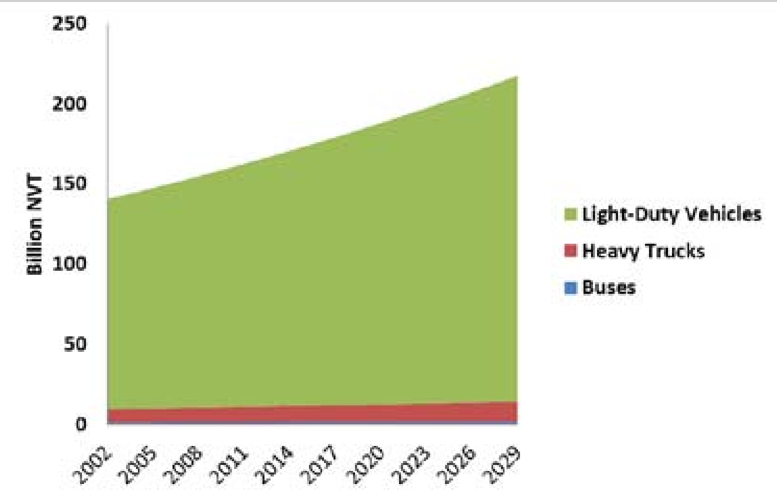

Figure A-8. VMT Demand Projections.

Table A-11. VMT Demand Growth.

	Average Annual Growth 2002-2029	% of 2002 Demand
Light Duty Vehicles	1.4%	93.9%
Heavy Trucks	1.4%	5.1%
Buses	1.4%	1.0%

For the fuel-based other demands presented in Figure A-9, growth projections were derived from the growth of the consumption of these fuels in AEO 2006 regional results. The exception was for Other Diesel because AEO diesel consumption is dominated by heavy trucks, a demand we tracked explicitly. The growth rate for Other Diesel was the AEO annual growth rate for the sum of freight rail and domestic

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[39] MARAMA, Documentation of the 2002 Mobile Emissions Inventory for the MANE-VU States, Mid-Atlantic Regional Air Management Association, Baltimore MD (2006). Available online at: http://www.marama.org/visibility/Inventory%20Summary/final_mob_manevu_rpt.pdf

shipping, the two largest components of diesel consumption after heavy trucks. This is a national average growth rate. The full set of average annual growth rate trends are presented in Table A-12.

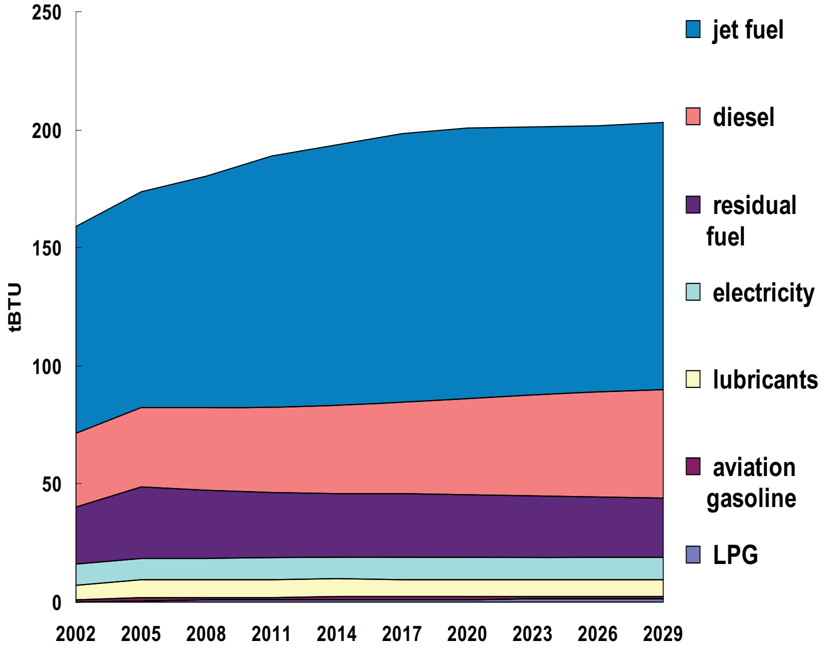

Figure A-9. Other Transportation Fuel Demands.

Table A-12. Other Transportation Demand Growth.

	Unit	Average Annual Growth 2002-2029	% 2002 Demand
LPG	tBTU	21.3%	0.1%
Diesel	tBTU	3.9%	19.7%
Jet Fuel	tBTU	2.6%	55.0%
Lubricants	tBTU	1.6%	3.8%
Aviation Gasoline	tBTU	1.6%	0.6%
Electricity	tBTU	0.8%	5.6%
Residual Fuel	tBTU	0.4%	15.2%

Transportation Sector Technology Characteristics

Each of the major vehicle classes represented in Table A-13 and Table A-14 contains more than one technology, depending on the model year. These tables list the range of costs and efficiencies associated with technologies in the transportation sector over the modeling timeframe. In cases where the minimum and maximum values are identical, the technology class includes only one vintage.

Table A-13. HDV Technical Characteristics.

	Min MPG	Max MPG	Min Cost (2002$/mi/yr)	Max Cost (2002$/mi/yr)	Life
CNG Bus	4.3	8.6	5.0	11.4	15
Diesel Bus	3.9	4.7	3.5	11.4	15
Electric Bus	4.3	9.3	5.0	11.4	15
Gasoline Bus	7.1	11.1	4.7	11.4	15
Heavy Diesel Truck	5.8	6.9	2.9	11.3	25
Heavy Diesel Truck Adv	7.0	8.3	3.0	3.3	25
Heavy Gasoline Truck	5.8	5.8	2.9	11.3	25
Medium Diesel Truck	7.8	9.4	1.7	6.8	25
Medium Diesel Truck Adv	9.5	11.3	1.8	2.0	25
Medium Gasoline Truck	7.8	7.9	1.7	6.8	25

Table A-14. LDV Technical Characteristics.

	Min MPG	Max MPG	Min Cost (2002$/mi/yr)	Max Cost (2002$/mi/yr)	Life
CNG Minivan	17.2	17.2	2.2	2.3	15
Diesel Hybrid Minivan	42.7	42.7	2.7	2.7	15
Diesel Minivan	23.2	23.2	2.2	2.2	15
Electric Minivan	68.8	68.8	3.3	3.7	15
Ethanol Minivan	20.7	23.0	2.1	2.2	15
Gasoline Hybrid Minivan	31.1	36.2	2.4	2.6	15
Gasoline Minivan	17.2	23.6	2.1	2.3	15
Hydrogen FC Minivan	40.9	47.3	2.5	2.7	15
Large CNG Car	19.7	19.7	2.5	2.5	15
Large CNG Truck	13.3	13.3	2.4	2.5	15
Large Diesel Car	26.0	26.0	2.3	2.3	15
Large Diesel Hybrid Car	49.0	49.0	3.0	3.0	15
Large Diesel Hybrid Truck	33.5	33.5	3.1	3.1	15
Large Diesel Truck	17.7	17.7	2.5	2.5	15
Large Electric Car	78.9	78.9	4.1	4.1	15
Large Electric Truck	17.0	53.2	2.3	3.5	15
Large Ethanol Flex Car	21.1	23.8	2.3	2.4	15
Large Gasoline Car	19.7	30.1	2.1	2.6	15
Large Gasoline Hybrid Car	35.7	41.6	2.6	2.8	15
Large Gasoline Hybrid Truck	23.8	27.7	2.6	2.9	15
Large Gasoline Truck	13.3	19.0	2.2	2.6	15
Large Hydrogen FC Car	47.9	54.6	2.8	3.1	15
Large Hydrogen FC Truck	28.1	36.9	2.7	3.2	15
Small CNG Car	23.3	23.3	2.0	2.0	15
Small CNG Truck	15.2	15.2	1.9	1.9	15
Small Diesel Car	35.5	35.5	2.1	2.1	15
Small Diesel Truck	23.4	25.2	1.8	1.8	15
Small Electric Car	93.1	93.1	3.4	3.4	15
Small Electric Truck	17.7	61.0	1.7	2.8	15
Small Ethanol Flex Car	25.9	27.4	1.8	1.8	15
Small Ethanol Truck	18.3	19.3	1.8	1.8	15
Small Gasoline Car	23.3	33.0	1.7	2.0	15
Small Gasoline Truck	15.2	21.8	1.7	1.9	15
Small Hybrid Diesel Car	59.4	59.4	2.4	2.4	15
Small Hybrid Diesel Truck	37.1	37.1	2.3	2.3	15
Small Hybrid Gasoline Car	42.2	49.1	2.1	2.2	15
Small Hybrid Gasoline Truck	27.1	31.5	1.9	2.1	15
Small Hydrogen FC Car	60.1	65.9	2.2	2.5	15
Small Hydrogen FC Truck	30.5	45.7	2.1	2.3	15

Table A-15 presents the default assumptions for the evolution of the fleet technology mix for NYS in the NE-MARKAL model. These share constraints change linearly between 2005 and 2029. They govern the extent to which the fleet technology mix is allowed to change over time. As with the share constraints in both of the building sectors, these constraints govern how flexible the technology choices in the transportation sector are in response to climate and environmental policy scenarios.

Table A-15. Technology Share Constraints.

	2005	2029
Minimum Share of Big Car in Transportation LDV	30.2%	19.2%
Minimum Share of Large Truck in Transportation LDV	14.2%	16.7%
Minimum Share of Min Van in Transportation LDV	6.1%	13.0%
Minimum Share of Small Car in Transportation LDV	25.7%	16.3%
Minimum Share of Small Truck in Transportation LDV	22.8%	33.8%
Max Share of CNG Bus in Transportation Buses	7.6%	8.4%
Min Share of Diesel Bus in Transportation Buses	84.4%	67.5%
Max Share of Gasoline Bus in Transportation Buses	6.0%	6.6%
Min Share of Gasoline Truck in Transportation Heavy Trucks	54.5%	51.8%
Min Share of Heavy Truck in Transportation Heavy Trucks	31.2%	29.7%
Max Share of CNG LDV in Transportation LDV	0.1%	1.0%
Max Share of DSL LDV in Transportation LDV	2.0%	10.0%

The transportation sector price projections in the NE-MARKAL model for NYS are presented in Figure A-10 below. These projections represent our input assumptions about fuel price trends over the model timeframe. The 2009 AEO and the 2009 NYS Energy Plan were the basis for the projections.

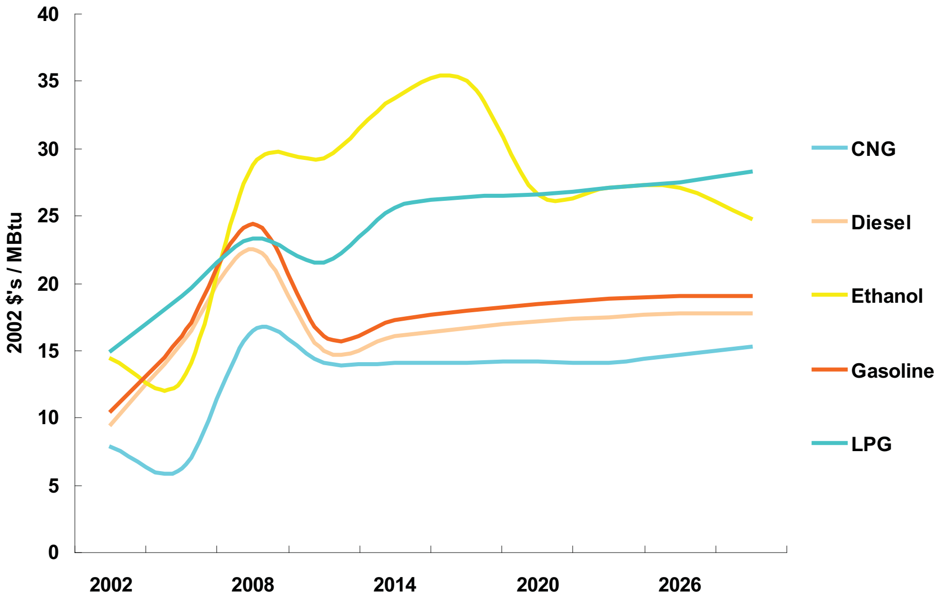

Figure A-10. Transportation Sector Fuel Price Projections.

Transportation Sector Reference Case Results

Figure A-11 and Table A-16 summarize the Reference Case energy consumption trends within the transportation sector. Aside from the current federal Corporate Average Fuel Economy (CAFE) standard on light duty vehicles, there were no explicit transportation sector environmental policies modeled. Gasoline remained the most significant source of energy in the transportation sector over the modeling horizon. A share of overall energy consumption gasoline declined from roughly 80% to 48%, as diesel and compressed natural gas (CNG) shares rose. There was a notable increase in the share of CNG consumption projected. By 2029 it was projected to represent the third most intensively consumed transportation fuel. Most of the increase in CNG consumption, however, is accounted for by new CNG busses and trucks. Diesel fuel was projected to represent close to 20% of the transportation sector's overall consumption by the end of the modeling period. Secondary fuel consumption trends (i.e., lubricants, LPG, and aviation gasoline) remained mostly unchanged.

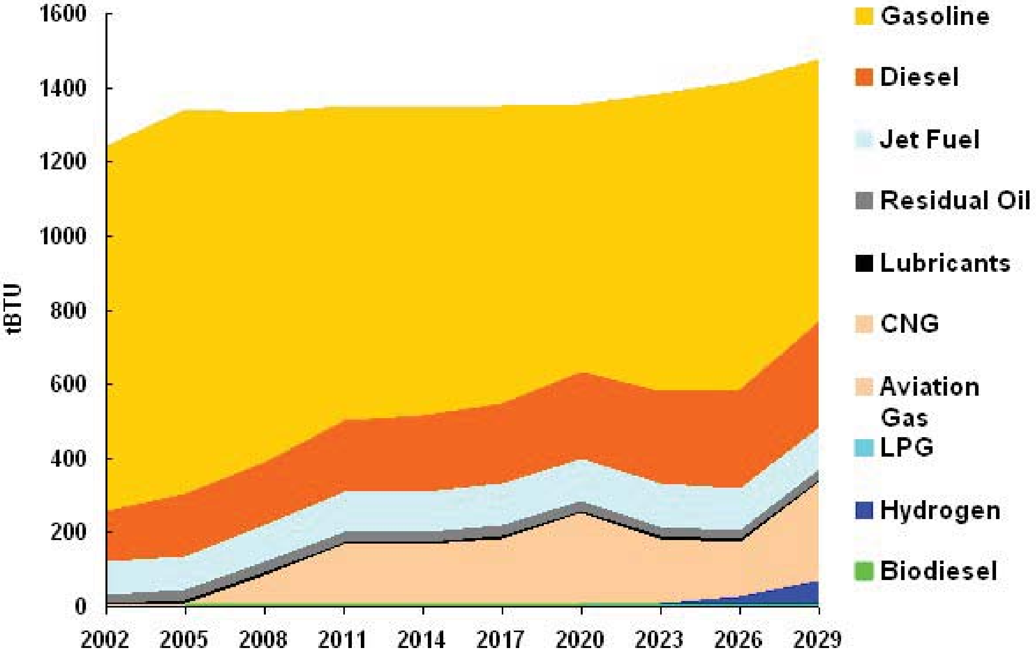

Figure A-11. Projected Transportation Energy Consumption by Fuel.

Table A-16 also indicates the projected average annual consumption growth rate of each fuel. The average annual growth rate for each of the top four transportation fuels was projected to remain within 2% in absolute terms. As noted above, CNG was projected to become a much more significant fuel, especially for heavy duty vehicles, with an average annual consumption growth rate of nearly 20%.

Table A-16. Transportation Consumption Shares.

	2002	2029	AAC*
Biodiesel	0.0%	0.3%	0.0%
Hydrogen	0.0%	4.5%	51.0%
LPG	0.0%	0.1%	2.9%
Aviation Gas	0.1%	0.1%	-0.4%
CNG	0.2%	17.8%	19.8%
Lubricants	0.5%	0.5%	-0.4%
Residual Oil	1.9%	1.7%	-0.7%
Jet Fuel	7.0%	7.6%	0.8%
Diesel	11.1%	19.4%	2.0%
Gasoline	79.2%	48.1%	-1.4%

* AAC = Average Annual Change 2002-2029

INDUSTRIAL SECTOR INPUT ASSUMPTIONS

Industry Sector Demand Projections

Industrial sector demand covers a generic set of process technologies in the manufacturing industries, and is depicted in Figure A-12.[40] The DOE's *Manufacturing Energy Consumption Survey* (MECS) was used to map industrial energy consumption reported in the AEO 2006 forecast into a set of processes common to all industries modeled. These processes include process heating, steam usage, electro-chemical devices, machine drives, petro-chemical feed stocks, and other industrial process demands. Table A-17 presents the average annual demand growth rates for the major industrial industries represented. The average annual rate changes were modest, with declines occurring in three of the six industrial sectors.

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[40] The National Energy Modeling System (NEMS) reports energy consumption by North American Industrial Classification System (NAICS) code for the manufacturing sector. Paper 322, Metal 3311-3313, Chemicals 325, Durables 332-336, Glass & Cement 3272-3273, and Other Manufacturing 339.

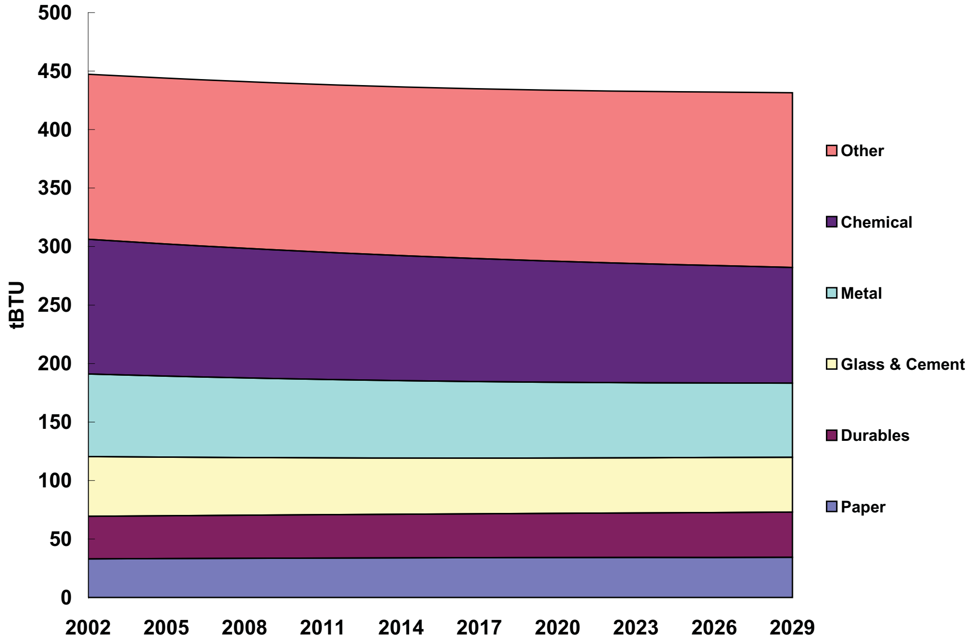

Figure A-12. Industry Demand.

Table A-17. Industry Demand Growth.

	Average Annual Growth 2002-2029	% 2002 Demand
Durables	0.6%	8.2%
Other	0.6%	31.5%
Paper	0.4%	7.4%
Glass & Cement	-0.8%	11.4%
Metal	-1.1%	15.8%
Chemical	-1.5%	25.7%

Demand Projection Methodology

Unlike energy demand in the buildings sector, industrial demand drivers were based on AEO 2006 projections of final energy consumption, rather than useful energy output. The drivers were constructed in a manner that would result in relatively flat industrial demand projections.

Industrial Sector Fuel Share Constraints

Table A-18 through Table A-23 outline the fuel share constraints that calibrated industrial sector fuel consumption to baseline 2002 data sources. Tables are also included describing how these constraints were relaxed over time to allow for fuel- and technology-switching. The shares indicate the minimum proportion of each fuel category consumed by each industrial process.

Table A-18. Chemical Sector Fuel Share Constraints.

		Boilers	CHP	Machine Drive	Other Processes	Petro-Chemical Processes
Coal	2002	2.72%	11.32%		0.11%	
	2029	1.63%	10.19%		0.07%	
Diesel	2002	5.35%	1.03%	0.43%	0.16%	
	2029	3.74%	0.92%	0.30%	0.11%	
Electricity	2002	0.88%		96.25%	14.44%	
	2029	0.88%		96.25%	14.44%	
Low Temp Heat	2002	34.42%				
	2029	34.42%				
LPG	2002				0.00%	5.56%
	2029				0.00%	5.00%
MSW	2002	0.32%				
	2029	0.32%				
Natural Gas	2002	47.57%	86.65%	3.31%	3.30%	11.66%
	2029	38.06%	77.99%	2.65%	2.64%	9.33%
Other Petroleum	2002				81.26%	
	2029				65.01%	
Petro-Chemical Feedstocks	2002					82.78%
	2029					66.22%
Residual Oil	2002	8.74%			0.72%	
	2029	6.99%			0.58%	

Table A-19. Metal Manufacturing Sector Fuel Share Constraints.

		Boilers	Machine Drive	Other Processes	Process Heat
Coal	2002			3.51%	12.30%
	2029			2.11%	7.38%
Diesel	2002		1.33%	0.43%	0.64%
	2029		0.93%	0.30%	0.44%
Electricity	2002	2.07%	94.00%	4.46%	21.41%
	2029	2.28%	94.00%	4.91%	23.55%
Low Temp Heat	2002	29.81%			
	2029	29.81%			
LPG	2002			0.00%	
	2029			0.00%	
Natural Gas	2002	68.12%	4.67%	4.92%	65.66%
	2029	54.49%	3.73%	3.93%	52.52%
Other Petroleum	2002			86.54%	
	2029			86.54%	
Residual Oil	2002			0.14%	
	2029			0.10%	

Table A-20. Durable Goods Manufacturing Sector Fuel Share Constraints.

		Boilers	CHP	Machine Drive	Other Processes	Process Heat
Coal	2002	47.67%	68.49%		4.75%	
	2029	47.67%	61.64%		2.85%	
Diesel	2002	1.02%			2.14%	
	2029	0.72%			1.50%	
Electricity	2002			98.49%	57.90%	35.00%
	2029			98.49%	46.32%	35.00%
Low Temp Heat	2002	5.49%				
	2029	5.49%				
LPG	2002				0.00%	
	2029				0.00%	
Natural Gas	2002	34.11%	14.60%	1.51%	31.54%	65.00%
	2029	27.29%	13.14%	1.21%	25.23%	52.00%
Residual Oil	2002	1.75%			3.67%	
	2029	1.40%			2.93%	
Wood	2002	9.96%	15.91%			
	2029	9.96%	14.32%			

Table A-21. Paper Manufacturing Sector Fuel Share Constraints.

		Boilers	CHP	Machine Drive	Other Processes	Process Heat
Coal	2002	3.12%	15.66%	1.14%	8.19%	
	2029	1.87%	14.09%	0.68%	4.91%	
Diesel	2002	0.24%	0.91%		1.59%	0.92%
	2029	0.17%	0.82%		1.12%	0.65%
Electricity	2002	0.18%		89.98%	36.35%	3.39%
	2029	0.19%		89.98%	32.71%	3.73%
Low Temp Heat	2002	58.19%				
	2029	58.19%				
LPG	2002				0.00%	0.00%
	2029				0.00%	0.00%
MSW	2002	0.98%				
	2029	0.98%				
Natural Gas	2002	20.18%	24.77%	7.43%	46.90%	70.50%
	2029	16.15%	22.29%	5.95%	37.52%	56.40%
Pulping Liquor	2002		42.87%			
	2029		38.58%			
Residual Oil	2002	7.61%	11.36%	1.45%	6.97%	25.19%
	2029	6.08%	10.23%	1.16%	5.58%	20.15%
Wood	2002	9.50%	3.43%			
	2029	9.50%	3.09%			

Table A-22. Glass & Cement Sector Fuel Share Constraints.

		Boilers	Machine Drive	Other Processes	Process Heat
Coal	2002				54.75%
	2029				32.85%
Diesel	2002	44.31%	5.85%	1.23%	0.96%
	2029	31.02%	4.10%	0.86%	0.67%
Electricity	2002		93.12%	1.96%	6.67%
	2029		93.12%	2.16%	7.34%
Low Temp Heat	2002	7.17%			
	2029	7.17%			
Natural Gas	2002	48.52%	1.03%	1.43%	37.62%
	2029	38.82%	0.82%	1.15%	30.10%
Other Petroleum	2002			94.43%	
	2029			94.43%	
Residual Oil	2002			0.94%	
	2029			0.76%	

Table A-23. Other Industrial Sectors Fuel Share Constraints.

		Boilers	CHP	Machine Drive	Other Processes	Process Heat
Coal	2002	1.63%	17.45%		0.05%	0.02%
	2029	0.98%	15.70%		0.03%	0.01%
Diesel	2002	16.74%	15.03%	13.27%	15.34%	2.60%
	2029	11.72%	13.53%	9.29%	10.74%	1.82%
Electricity	2002			86.18%	51.90%	18.31%
	2029			86.18%	57.09%	20.14%
Gasoline	2002				16.81%	
	2029				16.81%	
Low Temp Heat	2002	6.83%				
	2029	6.83%				
LPG	2002				0.00%	
	2029				0.00%	
Natural Gas	2002	56.54%	52.86%	0.56%	15.25%	76.91%
	2029	45.23%	47.58%	0.44%	12.20%	61.53%
Residual Oil	2002	3.59%	4.14%		0.64%	2.15%
	2029	2.87%	3.73%		0.51%	1.72%
Wood	2002	14.67%	9.52%			
	2029	14.67%	8.56%			

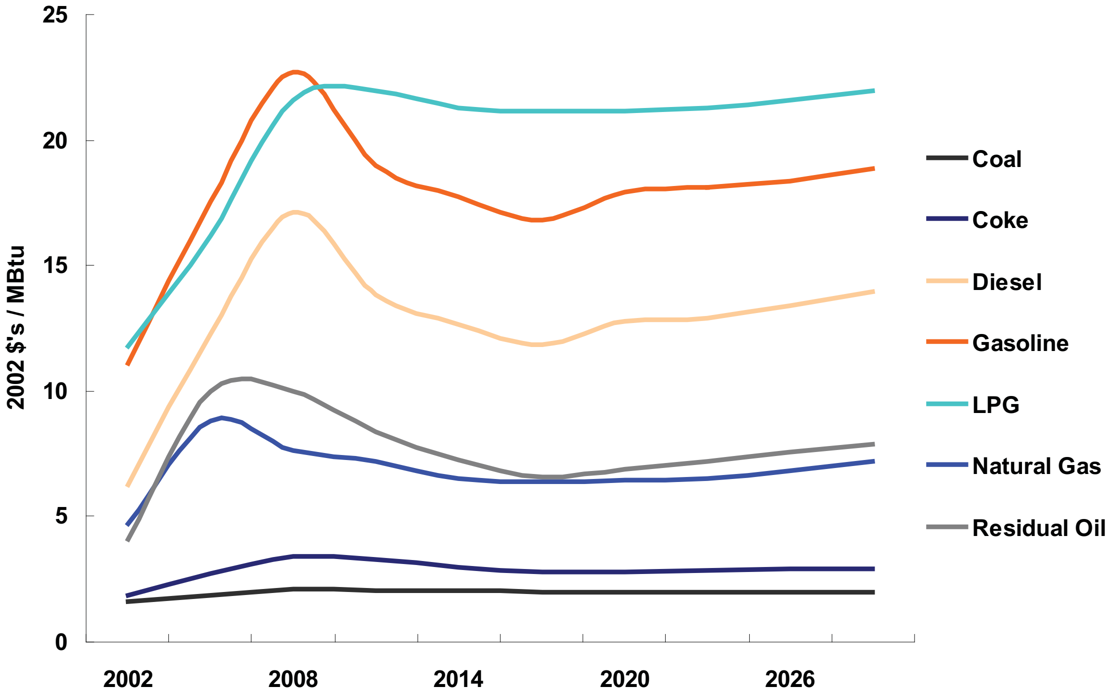

Figure A-13. Industrial Sector Price Projections.

As with other sectors, the industrial fuel price projections presented in Figure A-13 were generated using input from the AEO 2009 and NYSERDA.

Industrial Sector Reference Case Results

Figure A-14 and Table A-24 summarize Reference Case industrial energy consumption trends. There was no significant level of fuel switching projected in the industry sector. The relatively stable energy consumption trends are an artifact of how the industrial sector input fuel constraints were set up. The industrial technologies were primarily used as fuel accounting processes. They do not represent devices as in the commercial, residential and transportation sectors. In sectors where technologies were modeled at an appropriate level of detail, there is a wide degree of flexibility for the model to switch between various fuels. In the industrial sector, where this level of technological detail is not available (due to the lack of data sources), more stringent limits on fuel switching were imposed. This is highlighted by the modest average annual consumption growth rate of each industrial fuel (e.g., municipal solid waste (MSW) represented only 0.1% of industrial consumption).

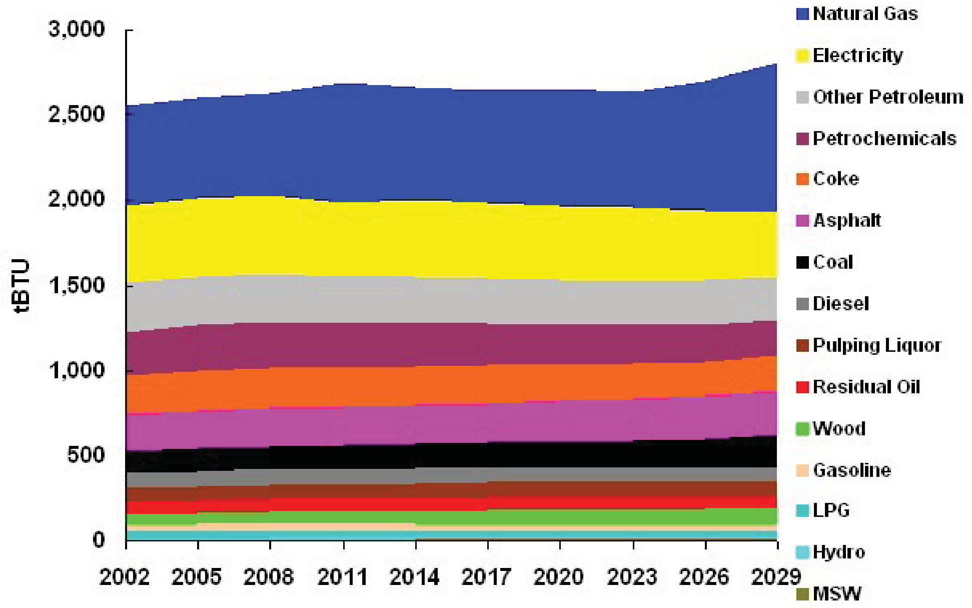

Figure A-14. Projected Industrial Energy Consumption.

Table A-24. Industry Consumption Shares.

	2002	2029	AAC 2002-2029
Natural Gas	23.0%	31.3%	1.5%
Electricity	17.8%	13.6%	-0.6%
Other Petroleum	11.3%	9.1%	-0.5%
Petrochemicals	10.0%	7.4%	-0.8%
Coke	8.9%	7.2%	-0.4%
Asphalt	8.4%	9.1%	0.6%
Coal	4.9%	7.2%	1.8%
Diesel	3.8%	2.8%	-0.8%
Pulping Liquor	2.9%	3.2%	0.7%
Residual Oil	2.9%	2.4%	-0.4%
Wood	2.5%	3.4%	1.5%
Gasoline	1.6%	1.5%	0.2%
LPG	1.6%	1.1%	-1.0%
Hydro	0.4%	0.4%	0.0%
MSW	0.1%	0.3%	5.9%

* AAC = Average Annual Change

Natural gas and electricity remained the most intensively consumed industrial fuels over the modeling timeframe, together representing over 40% of industrial energy consumption. Other petroleum products, such as still gas, pentanes, waxes, special naphthas, and a wide range of blending components, were also a significant category of industrial energy consumption.

POWER SECTOR INPUT ASSUMPTIONS & REFERENCE CASE RESULTS

For electricity-only power plants, the NE-MARKAL modeling approach is to represent individual plants down to a minimum size threshold, and aggregate the smaller plants below that threshold. Technical and economic data were taken from EIA reports, NEMS, and EPA's Emissions & Generation Resource Integrated Database (eGRID).

There are two types of combined heat and power (CHP) applications considered in NE-MARKAL. The first is independent or merchant CHP plants that primarily sell electricity to the grid and are not integrated into industrial processes. The heat (usually steam) they produce can be used in a range of low- to medium-temperature applications, including district heating, commercial/institutional buildings, and industrial manufacturing. These plants were modeled in the electricity sector in the same manner as the electricity generation technologies.

The second class of plants is industrial CHP plants. These plants are more tightly integrated with the industrial processes they serve and often (but not always) use by-product fuels from industrial processing. The fuel consumption and residual capacity of these plants (and on-site generation) were extracted from the NEMS industrial database and apportioned to the states according the SEDS data, similar to the other industrial energy consumption data. The CHP end-use shares were derived from the MECS data, and specific CHP technologies were defined according to the fuel input. Technology characteristics were derived from the *System for the Analysis of Global Energy Markets* (SAGE) industrial technology database.

Existing Power Plants

The data sources for electricity generation plants and independent CHP generation technologies available in the 2002 NE-MARKAL energy system were EIA Forms 860 (existing and planned units), 767, and 759/906. These data sources collectively list generating unit capacity, prime mover, fuel sources, location, plant operation and equipment design (including environmental controls), and fuel consumption and quality. For the larger investor-owned plants, these data sources also include non-fuel operating costs. Each EIA form covers a unique universe of units and collectively characterizes the power sector in the first model year. The key input assumptions derived from the EIA data for all existing NYS plants are presented in Table A-25 through Table A-29.

The NYS Independent System Operator (NYISO) Load and Capacity Reports for 2005 and 2008 were used to update the base year data to include any capacity changes – down ratings and up ratings – and unit retirements. Making these updates required a mapping between the EIA ORSPL facility codes and the NYISO PTID identifiers. In many cases, there was a clear mapping between the EIA and the NYISO facility identifiers. Rows in Table A-25 through Table A-29 that contain data irregularities – possibly a result of errors in the mapping process – are bolded. Two types of data irregularities were encountered. First, rows bolded in blue did not contain data for 2008 capacity. In the analysis, these units were assumed to go off-line in 2008. Second, rows bolded in red did not contain 2005 data, and in those cases the 2008 unit capacity was used to fill in the missing 2005 data (which assumes that, if a plant had capacity in 2002 and in 2008, then there was also capacity in 2005). With the second data irregularity, the magnitude of the 2008 capacity was very close to the 2002 level with three notable exceptions in Table A-26, Table A-28, and Table A-29, respectively.

Because the EIA forms list every plant regardless of size, small plants were aggregated to an appropriate level to obtain a manageable number of technologies that still adequately represent the diversity of existing plants and their differential use in the system. All existing generation units above a specified capacity threshold were represented as individual technologies, retaining all unit-specific information. This threshold is currently set at 25 megawatts (MW), but can be adjusted to obtain the desired level of detail in the sector.

Plants below the capacity threshold were aggregated using the following characteristics[41] to define a plant type:

- Fuel input type
- Plant type (taken from the Electricity Capacity Planning (ECP) designations in NEMS)
- State/Region

For each grouping of aggregated plants, data for the representative MARKAL technology was derived by calculating a capacity weighted average of selected fields from the EIA forms and totaling other fields. The following fields were averaged:

- Heat rate
- Annual capacity additions (added to fixed operating and maintenance (O&M) costs)
- Fixed O&M
- Variable O&M
- Capacity factor
- Availability
- Scrubber efficiency
- NO_x emission rate

The following fields were totaled:

- Summer capacity
- Winter capacity (used by adjusting the Annual Availability Factor by season)

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[41] Note that ECP designations separate coal units with and without scrubbers and by vintage. In addition, for coal units, the coal supply region providing the fuel input was used to further distinguish between units for aggregation purposes.

Table A-25. Existing Power Plants #1

Unit Name	ORSPL	Start	Fuel	2002 Capacity (MW)	2005 Capacity (MW)	2008 Capacity (MW)	Efficiency	Avalability
Danskammer Generatin 4	2480	1967	Coal / Biomass	236	234	239	33.7%	82.0%
Danskammer Generatin 3	2480	1959	Coal / Biomass	133	133	147	33.7%	82.0%
Danskammer Generatin 2	2480	1954	Oil / Gas	64	64	74	32.7%	80.0%
Danskammer Generatin 1	2480	1951	Oil / Gas	63	63	72	32.7%	80.0%
Arthur Kill Generati 3	2490	1969	Gas	501	503	536	32.6%	85.6%
Arthur Kill Generati 2	2490	1959	Gas	350	350	376	32.6%	85.6%
Charles Poletti 6	2491	1977	Residual	847	886	883	32.8%	45.0%
East River 7	2493	1955	Residual	183	183	200	32.8%	45.0%
East River 2	2493	2005	Gas		189	189	52.5%	85.6%
East River 1	2493	2005	Gas		185	185	52.5%	85.6%
East River 6	2493	1951	Residual	135	135	156	32.8%	45.0%
Hudson Avenue 10	2496	1951	Residual	65	65	65	32.8%	45.0%
Indian Point 2	**2497**	**2003**	**Nuclear**	**1030**	**990**		**34.1%**	**92.0%**
Ravenswood 3	2500	1965	Oil / Gas	969	969	1027	32.7%	80.0%
Ravenswood 2	2500	1963	Gas	394	394	400	32.6%	85.6%
Ravenswood 1	2500	1963	Gas	387	387	400	32.6%	85.6%
Ravenswood CC 04	2500	2004	Gas		263	250	52.5%	85.6%
Ravenswood 2-4	2500	1970	Gas	48	48	43	25.8%	65.0%
Ravenswood 3-1	2500	1970	Gas	48	48	43	25.8%	65.0%
Ravenswood 2-3	2500	1970	Gas	47	47	43	25.8%	65.0%
Ravenswood 2-1	2500	1970	Gas	47	47	43	25.8%	65.0%
Ravenswood 3-2	2500	1970	Gas	46	46	43	25.8%	65.0%
Ravenswood 3-3	2500	1970	Gas	45	45	43	25.8%	65.0%
Ravenswood 3-4	2500	1970	Gas	45	45	43	25.8%	65.0%
Ravenswood 2-2	2500	1970	Gas	44	44	43	25.8%	65.0%
Ravenswood 9	**2500**	**1970**	**Gas**	**25**	**25**		**25.8%**	**65.0%**
Waterside 6	**2502**	**1941**	**Oil / Gas**	**69**	**69**		**32.7%**	**80.0%**
Waterside 8	**2502**	**1949**	**Oil / Gas**	**50**	**50**		**32.7%**	**80.0%**
Waterside 9	**2502**	**1949**	**Oil / Gas**	**49**	**49**		**32.7%**	**80.0%**
E F Barrett 1	2511	1956	Oil / Gas	200	200	188	32.7%	80.0%
E F Barrett 2	2511	1963	Oil / Gas	198	198	188	32.7%	80.0%
E F Barrett 12	2511	1971	Oil / Gas	51	51	51	33.0%	80.0%
E F Barrett 11	2511	1971	Oil / Gas	49	49	49	33.0%	80.0%
E F Barrett 10	**2511**	**1971**	**Oil / Gas**	**52**	**52**		**33.0%**	**80.0%**
E F Barrett 9	**2511**	**1971**	**Oil / Gas**	**51**	**51**		**33.0%**	**80.0%**
Far Rockaway 4	2513	1953	Oil / Gas	112	112	100	32.7%	80.0%
Glenwood 5	2514	1954	Gas	120	120	114	32.6%	85.6%
Glenwood 4	2514	1952	Gas	119	119	114	32.6%	85.6%
Glenwood 3	2514	1972	Diesel	66	66	55	25.8%	65.0%
Glenwood 2	2514	1972	Diesel	65	65	55	25.8%	65.0%
Northport 4	2516	1977	Oil / Gas	391	391	387	32.7%	80.0%
Northport 2	2516	1968	Residual	391	391	387	32.8%	45.0%
Northport 3	2516	1972	Oil / Gas	384	384	387	32.7%	80.0%
Northport 1	2516	1967	Oil / Gas	383	383	387	32.7%	80.0%
Port Jefferson 4	2517	1960	Residual	196	196	188	32.8%	45.0%
Port Jefferson 3	2517	2002	Gas	50	190	188	40.1%	85.6%
Port Jefferson 2	2517	2002	Gas	45	45	53	40.1%	85.6%
Port Jefferson 1	2517	1993	Residual	44	44	44	25.8%	65.0%
Shoreham 1	2518	1971	Diesel	64	64	53	25.8%	65.0%
West Babylon 4	2521	1971	Diesel	64	64	52	25.8%	65.0%
AES Westover 7	2526	1943	Coal / Biomass	44	44	75	33.7%	82.0%
AES Westover 8	2526	1951	Coal / Biomass	84	84	44	33.7%	82.0%
AES Greenidge LLC 4	2527	1953	Coal / Biomass	105	108	112	33.7%	82.0%
AES Greenidge LLC 3	2527	1950	Coal / Biomass	54	54	50	33.7%	82.0%
AES Hickling LLC 2	2529	1952	Coal / Biomass	40	40	40	33.7%	82.0%
AES Hickling LLC 1	2529	1948	Coal / Biomass	30	30	30	33.7%	82.0%
AES Jennison LLC 2	2531	1950	Coal / Biomass	30	30	30	33.7%	82.0%

Table A-26. Existing Power Plants #2.

Unit Name	ORSPL	Start	Fuel	2002 Capacity (MW)	2005 Capacity (MW)	2008 Capacity (MW)	Efficiency	Avalability
AES Jennison LLC 1	2531	1945	Coal / Biomass	30	30	30	33.7%	82.0%
AES Cayuga 1	2535	1955	Coal / Biomass	153	154	167	33.7%	82.0%
AES Cayuga 2	2535	1955	Coal / Biomass	153	155	155	33.7%	82.0%
PSEG Albany Generati 1	**2539**	**1952**	**Residual**	**95**	**893**	**893**	**32.8%**	**45.0%**
PSEG Albany Generati 3	2539	1953	Oil / Gas	96	96	96	32.7%	80.0%
PSEG Albany Generati 4	2539	1954	Residual	94	94	94	32.8%	45.0%
PSEG Albany Generati 2	2539	1952	Residual	94	94	94	32.8%	45.0%
C R Huntley Generati 68	2549	1958	Coal / Biomass	218	218	218	33.7%	82.0%
C R Huntley Generati 67	2549	1957	Coal / Biomass	218	218	218	33.7%	82.0%
Huntley 68	2549	1958	Coal	202	202	218	33.7%	82.0%
Huntley 67	2549	1957	Coal	194	194	218	33.7%	82.0%
C R Huntley Generati 66	2549	1954	Coal / Biomass	100	100	100	33.7%	82.0%
C R Huntley Generati 65	2549	1953	Coal / Biomass	100	100	100	33.7%	82.0%
C R Huntley Generati 64	2549	1948	Coal / Biomass	100	100	100	33.7%	82.0%
C R Huntley Generati 63	2549	1942	Coal / Biomass	80	80	80	33.7%	82.0%
Huntley 66	**2549**	**1954**	**Coal**	**85**	**85**		**33.7%**	**82.0%**
Huntley 65	**2549**	**1953**	**Coal**	**85**	**85**		**33.7%**	**82.0%**
Dunkirk Generating S 3	2554	1959	Coal / Biomass	200	208	200	33.7%	82.0%
Dunkirk Generating S 4	2554	1960	Coal / Biomass	197	200	200	33.7%	82.0%
Dunkirk Generating S 2	2554	1950	Coal / Biomass	96	101	80	33.7%	82.0%
Dunkirk Generating S 1	2554	1950	Coal / Biomass	95	94	80	33.7%	82.0%
Nine Mile Point Nucl 2	2589	1969	Nuclear	1159	1160	1259	34.1%	92.0%
Nine Mile Point Nucl 1	2589	1969	Nuclear	621	621	642	34.1%	92.0%
Oswego Harbor Power 5	2594	1975	Residual	853	853	902	32.8%	45.0%
Oswego Harbor Power 6	2594	1979	Gas	836	836	902	32.6%	85.6%
Spier Falls 9	2612	1930	Hydro	46	46	46	100.0%	75.1%
Stark 1	2613	1957	Hydro	26	26	26	100.0%	75.1%
Stewarts Bridge 1	2614	1952	Hydro	35	35	35	100.0%	75.1%
Bowline Point 1	2625	1972	Gas	572	588	555	32.6%	85.6%
Bowline Point 2	2625	1974	Residual	567	503	555	32.8%	45.0%
Hillburn 1	2628	1972	Oil / Gas	47	47	47	33.0%	80.0%
Lovett 5	2629	1969	Coal / Biomass	191	190	201	33.7%	82.0%
Lovett 4	**2629**	**1966**	**Coal / Biomass**	**172**	**176**		**33.7%**	**82.0%**
Lovett 3	**2629**	**1955**	**Oil / Gas**	**69**	**69**		**32.7%**	**80.0%**
Shoemaker 1	2632	1972	Oil / Gas	42	43	42	33.0%	80.0%
Rochester 7 4	2642	1957	Coal / Biomass	80	81	82	33.7%	82.0%
Rochester 7 3	2642	1953	Coal / Biomass	65	57	63	33.7%	82.0%
Rochester 7 2	**2642**	**1950**	**Coal / Biomass**	**65**	**60**		**33.7%**	**82.0%**
Rochester 7 1	**2642**	**1948**	**Coal / Biomass**	**47**	**47**		**33.7%**	**82.0%**
Freeport CT 2	2679	2004	Gas		50	61	40.1%	85.6%
S A Carlson 7	**2682**	**2001**	**Gas**	**47**	**47**	**47**	**40.1%**	**85.6%**
Hillburn GT	2682	1971	Gas	51	51	47	40.1%	85.6%
Jamestown 5	2682	1951	Coal	29	29	29	33.7%	82.0%
Jamestown 6	2682	1951	Coal	25	25	25	33.7%	82.0%
Blenheim Gilboa 1	**2691**	**1973**	**Hydro**	**264**	**265**		**100.0%**	**75.1%**
Blenheim Gilboa 2	**2691**	**1973**	**Hydro**	**264**	**264**		**100.0%**	**75.1%**
Blenheim Gilboa 3	**2691**	**1973**	**Hydro**	**264**	**264**		**100.0%**	**75.1%**
Blenheim Gilboa 4	**2691**	**1973**	**Hydro**	**264**	**264**		**100.0%**	**75.1%**
Robert Moses Niagara 5	2693	2002	Hydro	222	222	222	100.0%	75.1%
Robert Moses Niagara 7	2693	2002	Hydro	222	222	222	100.0%	75.1%
Robert Moses Niagara 6	2693	2001	Hydro	222	222	222	100.0%	75.1%
Robert Moses Niagara 13	2693	1962	Hydro	222	222	222	100.0%	75.1%
Robert Moses Niagara 2	2693	1962	Hydro	222	222	222	100.0%	75.1%
Robert Moses Niagara 3	2693	1961	Hydro	222	222	222	100.0%	75.1%
Robert Moses Niagara 4	2693	1961	Hydro	222	222	222	100.0%	75.1%
Robert Moses Niagara 1	2693	1961	Hydro	166	166	166	100.0%	75.1%
Robert Moses Niagara 11	2693	1962	Hydro	150	150	150	100.0%	75.1%

Table A-27. Existing Power Plants #3.

Unit Name	ORSPL	Start	Fuel	2002 Capacity (MW)	2005 Capacity (MW)	2008 Capacity (MW)	Efficiency	Avalability
Robert Moses Niagara 12	2693	1962	Hydro	150	150	150	100.0%	75.1%
Robert Moses Niagara 10	2693	1961	Hydro	150	150	150	100.0%	75.1%
Robert Moses Niagara 8	2693	1961	Hydro	150	150	150	100.0%	75.1%
Robert Moses Niagara 9	2693	1961	Hydro	150	150	150	100.0%	75.1%
St Lawrence - FDR	2694	1958	Hydro	850	855	912	100.0%	75.1%
AES Somerset LLC 1	6082	1984	Coal / Biomass	682	682	655	33.7%	82.0%
James A Fitzpatrick 1	6110	1976	Nuclear	856	849	882	34.1%	92.0%
R. E. Ginna Nuclear 1	6122	1970	Nuclear	499	499	612	34.1%	92.0%
Spier Falls 2	6527	1930	Hydro	42	42	38	100.0%	75.1%
Stewarts Bridge	6527	1930	Hydro	34	34	30	100.0%	75.1%
Wading River 3	7146	1989	Diesel	100	100	80	25.8%	65.0%
Wading River 1	7146	1989	Diesel	98	98	80	25.8%	65.0%
Wading River 2	7146	1989	Diesel	97	97	80	25.8%	65.0%
Richard M Flynn 1	7314	1994	Oil / Gas	113	165	164	41.7%	80.0%
Richard M Flynn 2	7314	1994	Diesel	52	52	52	31.0%	65.0%
Allegany GT	7784	1995	Gas	42	42	42	52.5%	85.6%
Allegany Cogen 1	**7784**	**1994**	**Gas**	**40**	**40**		**52.5%**	**85.6%**
Vernon Boulevard 2	7909	2001	Gas	40	46	47	40.1%	85.6%
Vernon Boulevard 3	7909	2001	Gas	40	45	47	40.1%	85.6%
Gowanus 5	7910	2001	Gas	47	47	47	40.1%	85.6%
Gowanus 6	7910	2001	Gas	47	47	47	40.1%	85.6%
Joseph J. Seymour Po 2	7910	2001	Gas	40	40	40	40.1%	85.6%
Joseph J. Seymour Po 1	7910	2001	Gas	40	40	40	40.1%	85.6%
Brentwood 1	7912	2001	Gas	47	47	47	40.1%	85.6%
Hell Gate 1	7913	2001	Gas	40	47	47	40.1%	85.6%
Hell Gate 2	7913	2001	Gas	40	46	47	40.1%	85.6%
Harlem River Yard 1	7914	2001	Gas	40	47	47	40.1%	85.6%
Harlem River Yard 2	7914	2001	Gas	40	46	47	40.1%	85.6%
North 1st 1	7915	2001	Gas	47	47	47	40.1%	85.6%
Roseton Generating S 1	8006	1974	Residual	605	611	621	32.8%	45.0%
Roseton Generating S 2	8006	1974	Residual	604	611	621	32.8%	45.0%
Holtsville 10	8007	1975	Diesel	67	67	57	25.8%	65.0%
Holtsville 7	**8007**	**1975**	**Diesel**	**70**	**70**		**25.8%**	**65.0%**
Holtsville 9	**8007**	**1975**	**Diesel**	**67**	**67**		**25.8%**	**65.0%**
Holtsville 6	**8007**	**1975**	**Diesel**	**64**	**64**		**25.8%**	**65.0%**
Holtsville 3	**8007**	**1974**	**Diesel**	**64**	**64**		**25.8%**	**65.0%**
Holtsville 5	**8007**	**1974**	**Diesel**	**64**	**64**		**25.8%**	**65.0%**
Holtsville 2	**8007**	**1974**	**Diesel**	**64**	**64**		**25.8%**	**65.0%**
Holtsville 4	**8007**	**1974**	**Diesel**	**64**	**64**		**25.8%**	**65.0%**
Holtsville 1	**8007**	**1974**	**Diesel**	**63**	**63**		**25.8%**	**65.0%**
Holtsville 8	**8007**	**1975**	**Diesel**	**61**	**61**		**25.8%**	**65.0%**
Pouch 1	8053	2001	Gas	47	47	47	40.1%	85.6%
Astoria Generating S 4	8906	1961	Oil / Gas	375	376	387	32.7%	80.0%
Astoria Generating S 5	8906	1962	Oil / Gas	373	372	387	32.7%	80.0%
Astoria Generating S 3	8906	1958	Oil / Gas	372	372	376	32.7%	80.0%
Astoria Generating S 2	8906	1954	Gas	178	181	180	32.6%	85.6%
Indian Point 3 3	8907	2003	Nuclear	994	994	1012	34.1%	92.0%
TransCanada Power Ca 1	10190	1992	Oil / Gas	47	73	72	41.7%	80.0%
Black River Generati 1	10464	1989	Coal / Biomass	50	53	58	33.7%	82.0%
CH Resources Beaver 1	10617	1995	Oil / Gas	58	81	108	41.7%	80.0%
CH Resources Beaver 2	10617	1995	Oil / Gas	37	37	37	41.7%	80.0%
South Glens Falls En 1	**10618**	**1999**	**Oil / Gas**	**47**	**67**		**41.7%**	**80.0%**
Carthage Energy LLC 1	10620	1991	Oil / Gas	47	65	63	41.7%	80.0%
CH Resources Syracus 1	10621	1994	Oil / Gas	65	90	103	41.7%	80.0%
CH Resources Syracus 2	10621	1994	Oil / Gas	37	37	37	41.7%	80.0%
American Ref-Fuel of 1	10642	1989	Waste	72	74	79	32.5%	85.0%
Selkirk Cogen Partne 3	10725	1994	Oil / Gas	275	275	275	41.7%	80.0%

Table A-28. Existing Power Plants #4.

Unit Name	ORSPL	Start	Fuel	2002 Capacity (MW)	2005 Capacity (MW)	2008 Capacity (MW)	Efficiency	Avalability
Selkirk Cogen Partne 4	10725	1994	Oil / Gas	104	104	104	41.7%	80.0%
Selkirk Cogen Partne 5	10725	1994	Oil / Gas	104	104	104	41.7%	80.0%
Selkirk Cogen Partne 2	**10725**	**1992**	**Oil / Gas**	**51**	**325**		**41.7%**	**80.0%**
Selkirk Cogen Partne 1	**10725**	**1992**	**Oil / Gas**	**84**	**112**		**41.7%**	**80.0%**
Ogdensburg Power 1	10803	1993	Oil / Gas	79	79	79	41.7%	80.0%
Ogdensburg Power 3	10803	1993	Gas	29	29	29	52.5%	85.6%
Ogdensburg Power 2	10803	1993	Oil / Gas	29	29	29	41.7%	80.0%
Cogen Tech-Linden	**50006**	**1992**	**Gas**	**96**	**96**		**52.5%**	**85.6%**
WPS Power Niagara 1	**50202**	**1991**	**Coal / Biomass**	**53**	**56**	**56**	**33.7%**	**82.0%**
Bethpage 3	50292	2005	Gas		96	96	52.5%	85.6%
Bethpage	50292	1989	Gas	60	60	84	52.5%	85.6%
Bethpage GT4	**50292**	**0**	**Gas**	**50**	**50**		**40.1%**	**85.6%**
Indeck Silver Spring 1	50449	1991	Oil / Gas	45	60	57	41.7%	80.0%
Indeck Oswego Energy 1	50450	1990	Gas	38	60	57	52.5%	85.6%
Indeck Yerkes Energy 1	50451	1989	Oil / Gas	38	58	60	41.7%	80.0%
Indeck Corinth Energ 1	50458	1995	Oil / Gas	88	133	147	41.7%	80.0%
Indeck Corinth Energ 2	50458	1995	Gas	55	55	55	52.5%	85.6%
NRG Ilion LP 1	**50459**	**1993**	**Oil / Gas**	**42**	**65**		**41.7%**	**80.0%**
Glen Park Assoc.	**50512**	**1986**	**Hydro**	**42**	**42**		**100.0%**	**75.1%**
Trigen Syracuse Ener 1	50651	1991	Coal / Biomass	79	85	101	33.7%	82.0%
Onondaga County	50662	1994	Waste	33	33	40	32.8%	45.0%
Sterling Power Plant 1	**50744**	**1991**	**Gas**	**48**	**65**		**52.5%**	**85.6%**
Onondaga Cogeneratio 1	50855	1993	Oil / Gas	54	88	106	41.7%	80.0%
Wheelabrator Westche 1	50882	1984	Waste	53	52	75	32.5%	85.0%
Carr Street Generati 1	50978	1993	Oil / Gas	42	106	123	41.7%	80.0%
Carr Street Generati 2	50978	1993	Oil / Gas	42	42	42	41.7%	80.0%
Trigen Nassau Energy 1	52056	1991	Oil / Gas	45	45	45	41.7%	80.0%
Rensselaer Cogen 1	54034	1993	Oil / Gas	56	79	104	41.7%	80.0%
Rensselaer Cogen 2	54034	1993	Oil / Gas	32	32	32	41.7%	80.0%
Lockport Energy Asso 4	54041	1992	Gas	75	75	75	52.5%	85.6%
Lockport Energy Asso 1	**54041**	**1992**	**Oil / Gas**	**51**	**49**	**49**	**41.7%**	**80.0%**
Lockport Energy Asso 2	**54041**	**1992**	**Oil / Gas**	**51**	**49**	**49**	**41.7%**	**80.0%**
Lockport Energy Asso 3	**54041**	**1992**	**Oil / Gas**	**51**	**49**	**49**	**41.7%**	**80.0%**
Indeck Olean Energy 1	54076	1994	Oil / Gas	42	83	91	41.7%	80.0%
Indeck Olean Energy 2	54076	1994	Gas	45	45	45	52.5%	85.6%
KIAC GT 02 (JFK)	54114	1995	Gas	47	47	47	52.5%	85.6%
Kennedy Internationa 1	54114	1994	Gas	51	45	47	52.5%	85.6%
Kennedy Internationa 3	54114	1995	Oil / Gas	28	28	27	41.7%	80.0%
Kennedy Internationa 2	**54114**	**1994**	**Gas**	**50**	**45**		**52.5%**	**85.6%**
Fortistar North Tona 1	**54131**	**1993**	**Oil / Gas**	**44**	**55**	**55**	**41.7%**	**80.0%**
Fulton Cogen	**54138**	**0**	**Gas**	**47**	**47**		**52.5%**	**85.6%**
Stony Brook Cogen Pl 1	54149	1995	Oil / Gas	47	21	47	41.7%	80.0%
Project Orange 2	54425	1992	Gas	46	46	49	40.1%	85.6%
Project Orange 1	54425	1992	Gas	45	45	49	40.1%	85.6%
Sithe Independence S 1	**54547**	**1994**	**Gas**	**180**	**1254**	**1254**	**52.5%**	**85.6%**
Sithe Independence S 5	54547	1994	Oil / Gas	205	205	205	41.7%	80.0%
Sithe Independence S 6	54547	1994	Oil / Gas	205	205	205	41.7%	80.0%
Sithe Independence S 2	54547	1994	Gas	180	180	180	52.5%	85.6%
Sithe Independence S 3	54547	1994	Gas	180	180	180	52.5%	85.6%
Sithe Independence S 4	54547	1994	Gas	180	180	180	52.5%	85.6%
Saranac Facility 1	54574	1994	Gas	87	80	95	52.5%	85.6%
Saranac Facility 2	54574	1994	Gas	86	80	95	52.5%	85.6%
Saranac Facility 3	54574	1994	Gas	85	80	95	52.5%	85.6%
International Paper - Curtis	54580	1986	Hydro	30	30	30	100.0%	75.1%
Massena Power Plant 1	**54592**	**1992**	**Oil / Gas**	**56**	**102**	**102**	**41.7%**	**80.0%**
Massena Power Plant 2	54592	1992	Oil / Gas	35	35	35	41.7%	80.0%
Batavia Power Plant 1	**54593**	**1992**	**Gas**	**46**	**67**	**67**	**52.5%**	**85.6%**

Table A-29. Existing Power Plants #5.

Unit Name	ORSPL	Start	Fuel	2002 Capacity (MW)	2005 Capacity (MW)	2008 Capacity (MW)	Efficiency	Avalability
Brooklyn Navy Yard C 1	54914	1996	Oil / Gas	110	295	322	41.7%	80.0%
Brooklyn Navy Yard C 2	54914	1996	Oil / Gas	110	110	110	41.7%	80.0%
Brooklyn Navy Yard C 3	54914	1996	Oil / Gas	38	38	38	41.7%	80.0%
Brooklyn Navy Yard C 4	54914	1996	Oil / Gas	38	38	38	41.7%	80.0%
Adir HY-Hudson Falls	**54953**	**1995**	**Hydro**	**44**	**44**		**100.0%**	**75.1%**
Astoria Gas Turbines 4-4	55243	1970	Gas	41	49	47	40.1%	85.6%
Astoria Gas Turbines 3-2	55243	1970	Gas	41	48	47	40.1%	85.6%
Astoria Gas Turbines 4-3	55243	1970	Gas	41	48	47	40.1%	85.6%
Astoria Gas Turbines 4-1	55243	1970	Gas	41	48	47	40.1%	85.6%
Astoria Gas Turbines 3-4	55243	1970	Gas	41	48	47	40.1%	85.6%
Astoria Gas Turbines 3-3	55243	1970	Gas	41	47	47	40.1%	85.6%
Astoria Gas Turbines 4-2	55243	1970	Gas	41	47	47	40.1%	85.6%
Astoria Gas Turbines 2-2	55243	1970	Gas	41	47	47	40.1%	85.6%
Astoria Gas Turbines 2-3	55243	1970	Gas	41	47	47	40.1%	85.6%
Astoria Gas Turbines 3-1	55243	1970	Gas	41	47	47	40.1%	85.6%
Astoria Gas Turbines 2-1	55243	1970	Gas	41	47	47	40.1%	85.6%
Astoria Gas Turbines 2-4	55243	1970	Gas	41	46	47	40.1%	85.6%
Astoria GT 10	55243	1971	Diesel	31	31	32	25.8%	65.0%
Astoria GT 13	55243	1971	Diesel	30	30	32	25.8%	65.0%
Astoria GT 11	55243	1971	Diesel	29	29	32	25.8%	65.0%
Astoria GT 12	55243	1971	Diesel	27	27	32	25.8%	65.0%
Astoria Energy 3	55375	2007	Gas	188	188	188	52.5%	85.6%
Astoria Energy 1	55375	2006	Gas	188	188	188	52.5%	85.6%
Astoria Energy 2	55375	2006	Gas	188	188	188	52.5%	85.6%
Astoria Energy 4	55375	2006	Gas	188	188	188	52.5%	85.6%
Athens 1	55405	2004	Gas		405	441	52.5%	85.6%
Athens 2	55405	2004	Gas		405	441	52.5%	85.6%
Athens 3	55405	2004	Gas		405	441	52.5%	85.6%
Binghamton Cogen 1	55600	1992	Gas	47	50	48	40.1%	85.6%
Bloomfield Generatin 1	55615	2006	Gas	49	49	49	40.1%	85.6%
Bloomfield Generatin 2	55615	2006	Gas	49	49	49	40.1%	85.6%
Bloomfield Generatin 1	55616	2006	Gas	49	49	49	40.1%	85.6%
Bloomfield Generatin 2	55616	2006	Gas	49	49	49	40.1%	85.6%
Bayswater Peaking Fa 1	55699	2002	Gas	57	58	60	40.1%	85.6%
PPL Edgewood Energy 1	55786	2002	Gas	49	49	49	40.1%	85.6%
PPL Edgewood Energy 2	55786	2002	Gas	49	49	49	40.1%	85.6%
Shoreham GT3	55787	2002	Gas	49	49	50	40.1%	85.6%
Shoreham GT4	55787	2002	Gas	49	49	50	40.1%	85.6%
PPL Shoreham Energy 1	55787	2002	Diesel	49	49	49	25.8%	65.0%
PPL Shoreham Energy 2	55787	2002	Diesel	49	49	49	25.8%	65.0%
Fenner Wind 1	55790	2001	Wind	30	30	30	100.0%	75.1%
Greenport GT1	55969	2003	Gas	55	55	54	40.1%	85.6%
Freeport CT 1	56032	2004	Gas		50	60	40.1%	85.6%
Bethlehem Energy Cen 4	56042	2005	Gas	273	273	273	52.5%	85.6%
Bethlehem Energy Cen 1	56042	2005	Gas	176	176	176	52.5%	85.6%
Bethlehem Energy Cen 2	56042	2005	Gas	176	176	176	52.5%	85.6%
Bethlehem Energy Cen 3	56042	2005	Gas	176	176	176	52.5%	85.6%
Far Rockaway GT2	56141	2003	Gas	57	57	60	40.1%	85.6%
Pinelawn Power LLC 1	**56188**	**2005**	**Gas**	**50**	**82**	**82**	**52.5%**	**85.6%**
500MW CC 1	56196	2005	Gas	188	188	188	52.5%	85.6%
500MW CC 2	56196	2005	Oil / Gas	170	170	170	41.7%	80.0%
Maple Ridge Wind Far 1	56290	2005	Wind		231	231	100.0%	75.1%
Maple Ridge 2	56290	2007	Wind			91	100.0%	75.1%
Astoria East Energy CC1	EP1	2006	Gas		448	448	52.5%	85.6%
Astoria CC 1	EP2	2006	Gas		288	288	52.5%	85.6%
Astoria CC 2	EP3	2006	Gas		288	288	52.5%	85.6%
Astoria East Energy CC2	EP4	2006	Gas		192	192	52.5%	85.6%
Munnsville Wind Power	EP5	2007	Wind			35	100.0%	75.1%
Ontario New York	EP6	2002	Wind	138	138	138	100.0%	75.1%

Table A-30 summarizes the overall installed generating capacity in NYS through the year 2008. The total installed capacity agreed well with the data in the NYISO Load and Capacity Reports. The decline in capacity in 2008 was an artifact of removing the capacity from the plants in Table A-25 through Table A-29 bolded in blue. If deemed appropriate for future analyses this capacity could be added back.

Table A-30. Summary of Installed Capacity by Fuel Type.

	Fuel	2002	2005	2008
Units 25 MW+	Coal	620	620	490
	Coal / Biomass	3,980	3,998	3,711
	Oil	6,238	6,226	6,490
	Hydro	4,672	4,677	3,583
	MSW	158	159	193
	Gas	9,327	12,931	13,952
	Nuclear	5,158	5,113	4,407
	Oil / Gas	7,450	8,341	7,725
	Wind	168	524	524
25 MW+ Total		**37,770**	**42,588**	**41,075**
Units 25 MW-	Wood	37	37	37
	Coal / Biomass	55	55	55
	Oil	845	845	845
	Hydro	1,000	1,000	1,000
	MSW	124	124	124
	Gas	1,430	1,430	1,430
	Oil / Gas	350	350	350
	Wind	18	18	18
25 MW- Total		**3,859**	**3,859**	**3,859**
Total		**41,629**	**46,447**	**44,934**

New Power Plants

New conventional fossil and nuclear plants were characterized using NEMS data. Table A-31 presents the key parameter assumptions associated with new conventional generation technologies in NE-MARKAL. Investment cost and efficiency ranges represent the assumed decline in cost and efficiency increase over the modeling horizon.

Table A-31. New Power Plant Characteristics.

	$ / Kw				
	Investment Cost	**Var O&M**	**Fix O&M**	**Efficiency**	**Availability**
Scrbd Pulverized Coal 2010	1,305 - 1374	1.2	23.9	39 - 40 %	85%
Integrated Gas Comb Cycle 2010	1,313 - 1,561	0.7	33.5	43 - 47 %	85%
IGCC w/Sequestration 2010	1,589 - 2,279	1.1	39.5	35%	85%
Gas/Oil Steam Turbine 2005	1,024	0.5	32.2	36%	82%
Conv Combustion Turbine 2007	375 - 400	0.9	10.5	31%	92%
Adv Combustion Turbine 2007	315 - 379	0.8	9.1	38 - 40 %	92%
Conv Gas/Oil Comb Cycle 2008	548 - 585	0.5	10.8	47%	87%
Adv Gas/Oil Comb Cycle 2008	503 - 576	0.5	10.1	52 - 54 %	87%
Adv CC w/Sequestration 2010	864 - 1,149	0.7	17.3	40%	87%
Fuel Cells 2005	4,304	12.2	4.9	43%	87%
Advanced Nuclear 2013	1,990 - 2,255	0.1	63.6	33%	90%
Pumped Storage 2005	2,180	0.8	17.1	97%	10%
Distributed Generation-Base 2005	818	1.8	13.9	35%	50%
Distributed Generation-Peak 2005	982	1.8	13.9	32%	5%

The power sector price projections presented in Figure A-15 were also from the AEO 2009 Reference Case results and represented the input assumptions for the projected price of power sector energy sources.

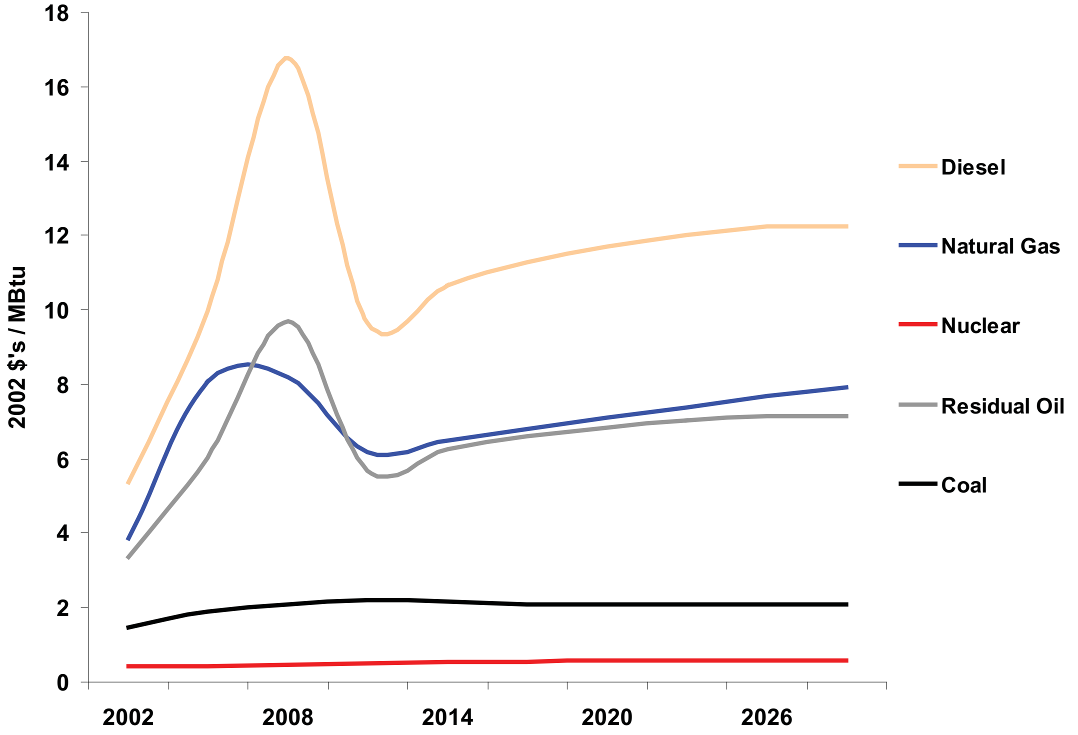

Figure A-15. Power Sector Price Projections.

Power Sector Reference Case Results

Figure A-16 and Table A-32 summarize Reference Case power sector results. The projected decrease in coal and large increase in natural gas generation was the result of strong demand for new generation coupled with the Regional Greenhouse Gas Initiative (RGGI) requirements for low carbon capacity. The State's renewable portfolio standards (RPS), which were not included in the Reference Case, requires 30% of statewide electricity generation to come from renewable sources by 2015, and was analyzed in a separate policy scenario.

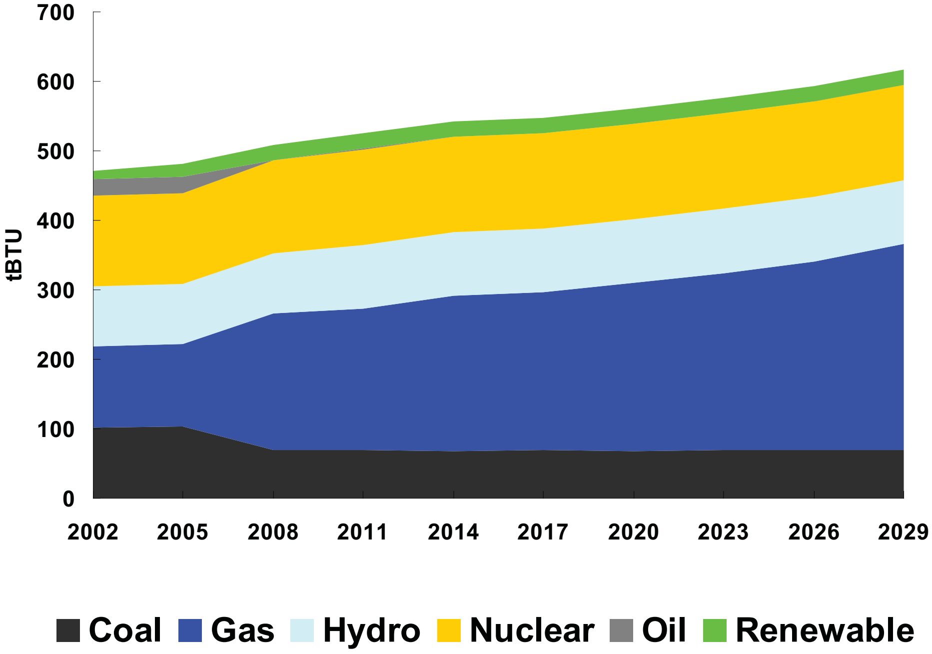

Figure A-16. Electricity Generation by Fuel Type.

Table A-32 summarizes the electricity generation shares depicted in Figure A-16. There was a significant decline in generation from coal between 2002 and 2008, consistent with the annual record, but it remained constant thereafter at 69 tBTU. By 2029, coal generation was projected to represent only 11% of the State's generation due to overall growth in generation. The base loaded nuclear and hydro shares were projected to remain stable over the modeling timeframe. The most significant change was the large increase in gas generation that was ramped up at approximately 2% per year to meet increased demand.

Table A-32. Electricity Generation Shares.

	2008 Shares	% Change 2008-2029	Ann. Av. Growth Rate
Coal	14%	0.0%	0.0%
Gas	39%	50.5%	2.0%
Hydro	17%	5.8%	0.3%
Nuclear	26%	3.4%	0.2%
Oil	0%	0.0%	0.0%
Renewable	4%	-3.1%	-0.1%
Total	100%		

Renewable Resource Assumptions Wind Resources.

The National Renewable Energy Lab (NREL) provided NESCAUM with wind potentials for on- and off-shore resources and as a function of wind class (3 through 7) and distance from grid transmission lines. NREL processed its standard state-level wind resource maps and transmission line data from PowerMap [42] for lines between 69 - 345 kV, buffered to identify raw wind resource potential for 0-5, 5-10, 10-20, and >20 mile distance bands. The standard environmental, land use, and other exclusion criteria were then applied to the data to produce a developable resource potential. These criteria are provided in Table A-33.

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[42] Special analysis performed by Walter Short at NREL for NESCAUM using the WNDS model, 2006.

Table A-33. Criteria for Defining Available Windy Land (numbered in the order they are applied).

Environmental Criteria	***Data/Comments:***
2) 100% exclusion of National Park Service and Fish and Wildlife Service managed lands	USGS Federal and Indian Lands shapefile, Jan 2005
3) 100% exclusion of federal lands designated as park, wilderness, wilderness study area, national monument, national battlefield, recreation area, national conservation area, wildlife refuge, wildlife area, wild and scenic river or inventoried roadless area.	USGS Federal and Indian Lands shapefile, Jan 2005
4) 100% exclusion of state and private lands equivalent to criteria 2 and 3, where GIS data is available.	State/GAP land stewardship data management status 1, from Conservation Biology Institute Protected Lands database, 2004
8) 50% exclusion of remaining USDA Forest Service (FS) lands (incl. National Grasslands)	USGS Federal and Indian Lands shapefile, Jan 2005
9) 50% exclusion of remaining Dept. of Defense lands	USGS Federal and Indian Lands shapefile, Jan 2005
10) 50% exclusion of state forest land, where GIS data is available	State/GAP land stewardship data management status 2, from Conservation Biology Institute Protected Lands database, 2004
Land Use Criteria	
5) 100% exclusion of airfields, urban, wetland and water areas.	USGS North America Land Use Land Cover (LULC), version 2.0, 1993; ESRI airports and airfields (2003)
11) 50% exclusion of non-ridgecrest forest	Ridge-crest areas defined using a terrain definition script, overlaid with USGS LULC data screened for the forest categories.
Other Criteria	
1) Exclude areas of slope > 20%	Derived from elevation data used in the wind resource model.
6) 100% exclude 3 km surrounding criteria 2-5 (except water)	Merged datasets and buffer 3 km
7) Exclude resource areas that do not meet a density of 5 km^2 of class 3 or better resource within the surrounding 100 km^2 area.	Focalsum function of class 3+ areas (not applied to 1987 PNL resource data)

Note - 50% exclusions are not cumulative. If an area is non-ridgecrest forest on FS land, it is just excluded at

This developable wind resource data were converted into state-level upper resource bounds for eight distinct wind technologies. These technologies and some indicative data are shown in Table A-34. Onshore-1 corresponds to less than 20 miles to a 68 kV or higher transmission line, and the cost of this technology was based on a recent assessment of wind farm costs compiled by Navigant Consulting[43] and used in the RGGI Integrated Planning Model (IPM) analysis. Onshore-2 corresponds to greater than 20 miles to a high voltage transmission line and imposes an incremental investment cost on the wind technology based on the transmission line cost for an average 50 mile line length. Offshore-1 corresponds to 5 to 20 nautical miles (nm) from shore (Note, there is a 100% exclusion for 0 to 5 nm from shore). Offshore-2 corresponds to 20 to 100 nm from shore. The investment cost for the Offshore-2 wind technologies also contains an incremental transmission line cost.

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[43] "New Jersey Renewable Energy Market Assessment," Navigant Consulting, August 2004.

Table A-34. Wind Resource Data.

				Resource Upper Bound in 2020 (MW)								
Type	**Wind Class**	**2002 Investment Cost $/Mbtu**	**2029 Investment Cost $/Mbtu**	**CT**	**MA**	**ME**	**NH**	**RI**	**VT**	**NJ**	**NY**	**PA**
Onshore -1	5-Apr	1268	633	51	570	1,710	587	30	1,374	83	**1,553**	970
Onshore -1	7-Jun	1532	897	0	123	720	149	0	0	0	**30**	1
Onshore -2	5-Apr	1268	633	0	32	716	117	0	366	0	**121**	38
Onshore -2	7-Jun	1532	897	0	10	193	16	0	0	0	**1.4**	0
Offshore -1	5-Apr	2006	1583	223	717	793	173	304	0	2,791	**5,282**	980
Offshore -1	7-Jun	2270	1846	0	0	0	0	0	0	68	**39**	0
Offshore -2	5-Apr	2006	1583	0	10,612	8,647	194	1,345	0	2,065	**4,377**	0
Offshore -2	7-Jun	2270	1846	0	48,733	9,142	103	3,823	0	21,715	**19,470**	0

Capacity factor data for each wind technology were derived at the census division level from NEMS data and used for each at the state level. Growth constraints of 10% per year and hurdle rates of 25% were added to represent siting, financing, and other considerations expected to slow penetration of wind in the Reference Case.

PV Capacity Factors. For solar photovoltaic (PV) systems, the technical potential of the resource is tremendous and does not provide a meaningful limit on the amount of resource that can be used. The capacity factor for PV systems is the most meaningful parameter affecting performance. These were provided by NREL for each day/season time slice, and are shown in Table A-35 for central PV systems for grid electricity generation. This technology was assumed to use one-axis tracking. Two other PV technologies were developed – for residential rooftops and commercial rooftops – and have capacity factors based on a fixed tilt orientation.

Table A-35. Capacity Factors for Central Solar PV Systems.

Region	Intermediate Day	Intermediate Night	Summer Day	Summer Night	Winter Day	Winter Night
CT	0.333	0	0.423	0	0.219	0
MA	0.34	0	0.443	0.001	0.224	0
ME	0.345	0	0.444	0.001	0.234	0
NH	0.333	0	0.434	0.001	0.232	0
RI	0.341	0	0.454	0	0.223	0
VT	0.322	0	0.437	0.001	0.2	0
NJ	0.334	0.001	0.411	0.008	0.226	0
NY	**0.316**	**0.002**	**0.418**	**0.011**	**0.205**	**0**
PA	0.329	0.003	0.415	0.011	0.209	0

Solar Investment Cost Assumptions. Solar cost assumptions over the modeling timeframe are presented in Table A-36. The principal constraint on PV systems is the growth rate that the industry can sustain over time. Thus, each PV technology contains an annual growth rate constraint. Based on historical growth rates, these were set at 10%, 20%, and 30% respectively for central, commercial, and residential PV technologies.

Table A-36. PV Investment Cost Projections.

	2002 Investment Cost $/Mbtu	2029 Investment Cost $/Mbtu
Centralized PV	5,803	3,292
Commercial PV	6,197	3,353
Residential PV	7,291	4,171

Renewable energy cost and resource bounds. Oak Ridge National Lab (ORNL) has estimated the availability and delivered price of six types of biomass resources for the U.S. [44] For agricultural residues, the delivered price includes the cost of collecting the residues, the premium paid to farmers to encourage participation, and transportation costs. Woody biomass and agricultural wastes were combined as one aggregated biomass resource, as the technology differences for application of these two biomass types are not significant.

Four biomass resource supply steps, described in Table A-37 and Table A-38, were developed for each state, corresponding to each price step in the ORNL data. The first three price steps start in 2002, as they correspond to existing supplies of forest and urban wood waste residues. The final step corresponds to energy crops, which ORNL assumed are available by 2010. The final step was constructed so that half the potential energy crop supply is available in 2008, and the full energy crop potential is available in 2011.

Most of the increase, at $50/dry ton, was due to energy crops, which the ORNL data assume is all switch grass because of its higher productivity. Such a significant role for energy crops, however, may not be the best assumption for NYS. The ORNL methodology assumes that agricultural lands are used for energy crops, and does factor in some competition between food production and energy crops. We did not review the validity of these and the other assumptions in ORNL's analysis to assess how adequately they characterized NYS's potential for energy crops. For future analyses, additional input and data would be welcomed to better understand and characterize the likely supply and suitability of switch grass, poplar, and other energy crops in NYS.

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[44] Walsh, M.E., R.L. Perlack, A. Turhollow, D. de la Torre Ugarte, D.A. Becker, R.L. Graham, S.E. Slinsky, D.E. Ray. Biomass Feedstock Availability in the United States: 1999 State Level Analysis, Oakridge National Laboratory, updated January 2000.

Data on MSW feedstocks were derived from the report "BioCycle, The State of Garbage in America, April 2006."[45] Initial biomass pulping liquor resource bounds were developed using SEDS data and then relaxed slowly over the model timeframe. Both MSW and pulping liquor are currently consumed at no cost. Residential wood had a high cost, to prevent any large degree of fuel-switching into the resource. Hydrogen supply curves were developed based on a forecast[46] of regional hydrogen production and investment costs out to 2050. Biodiesel supply and cost characteristics were constructed directly from the 2006 Annual Energy Outlook.

Table A-37. Renewable Energy Cost Assumptions.

		Million 2002$ / tBTU		
	Start	**Initial Cost**	**Cost 2029**	**% Change**
Woody Biomass @ 20$/dt	2002	1.5	1.5	0.0%
Woody Biomass @ 30$/dt	2002	2.3	2.3	0.0%
Woody Biomass @ 40$/dt	2002	3.3	3.3	0.0%
Woody Biomass @ 50$/dt	2008	4.2	4.2	0.0%
Residential Wood	2002	15*	15*	0.0%
MSW**	2002			
Pulping Liquor**	2002			
Biodiesel Supply Curve 1	2005	5.0	6.1	22.1%
Biodiesel Supply Curve 2	2005	6.8	7.9	16.3%
Hydrogen Supply Curve 1	2011	30.3	24.0	-20.9%
Hydrogen Supply Curve 2	2020	55.0	58.5	6.4%

Table A-38. Renewable Energy Resource Bounds (Trillion Btu).

		tBTU		
	Start	**Initial Upper Bound**	**Upper Bound 2029**	**% Change**
Woody Biomass @ 20$/dt	2002	16.1	16.1	0.0%
Woody Biomass @ 30$/dt	2002	29.8	29.8	0.0%
Woody Biomass @ 40$/dt	2002	8.5	8.5	0.0%
Woody Biomass @ 50$/dt	2008	29.0	58.1	100.0%
Residential Wood	2002	111.9	111.9	0.0%
MSW**	2002	46.6	53.4	14.4%
Pulping Liquor**	2002	7.3	9.0	22.1%
Biodiesel Supply Curve 1	2005	0.32	0.33	2.3%
Biodiesel Supply Curve 2	2005	0.18	0.18	2.3%
Hydrogen Supply Curve 1	2005	0.012	215.1	>> 100%
Hydrogen Supply Curve 2	2020	0.4	16.4	>> 100%

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[45] Simmons, P., N. Goldstein, S.M. Kaufman, N.J. Themelis, J. Thompson Jr., The State of Garbage in America. *Biocycle*. April 2006, Vol. 47, No. 4, 26-43, available at: http://www.p2pays.org/ref/22/21411.pdf.

[46] Hydrogen Demand, Production, and Cost by Region to 2050. Argonne National Laboratory, ANL/ESD/05-2.

STATE/REGIONAL POLICIES AND REGULATIONS

State RPS

Existing State RPS requirements were analyzed as one of the policy scenarios. NYS's RPS is depicted in Figure A-17. The implementation represents the requirements as they are "on the books," without adjustment for the possibility that they might not be met on the ground.

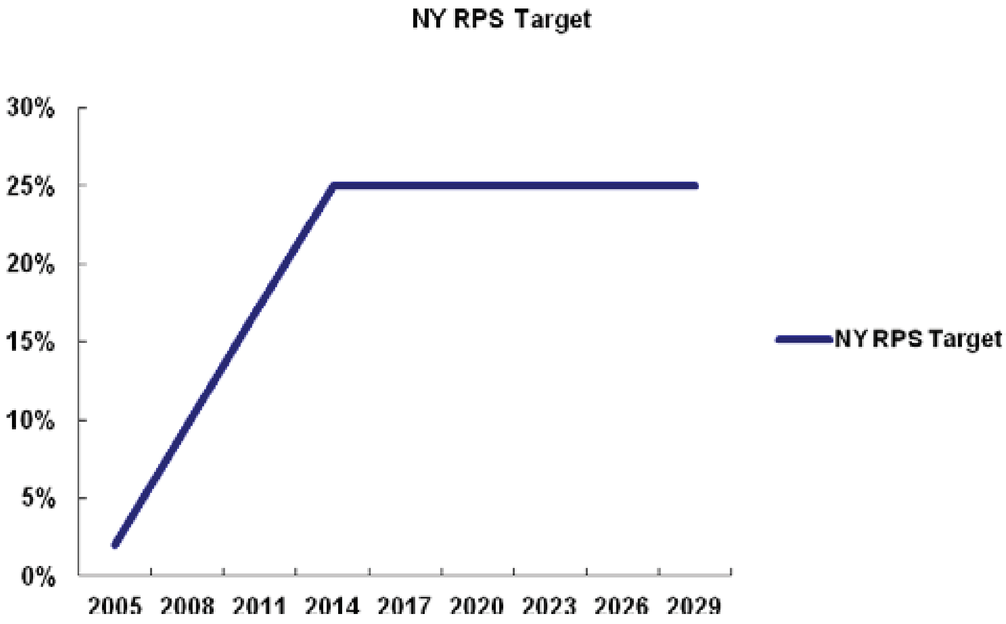

Figure A-17. NYS Renewable Portfolio Standards.

NYS RGGI Characterization

The RGGI cap for NYS was represented in the Reference Case using the same assumptions as were used for the IPM analysis of RGGI. NYS's annual CO_2 equivalent (CO_2e) budget under the RGGI program[47] is presented in Table A-39. In the model, we represented this budget by introducing a power sector-wide constraint on CO_2 emissions consistent with the data in Table A-39.

---

[47] Assumption Development Document: Regional Greenhouse Gas Initiative Analysis, Prepared by ICF Consulting for Regional Greenhouse Gas Initiative (RGGI) Staff Working Group and Stakeholders, August 2006.

Table A-39. RGGI CO2e Limits by State over Time.

Thousand tons CO2

	2008	2011	2014	2017	2020	2023	2026	2029
CT	9,702	9,702	9,622	8,975	8,732	8,732	8,732	8,732
DE	6,858	6,858	6,801	6,344	6,172	6,172	6,172	6,172
ME	5,397	5,397	5,352	4,992	4,857	4,857	4,857	4,857
MD	34,019	34,019	33,736	31,468	30,617	30,617	30,617	30,617
MA	24,186	24,186	23,984	22,372	21,767	21,767	21,767	21,767
NH	7,820	7,820	7,755	7,234	7,038	7,038	7,038	7,038
NJ	20,768	20,768	20,595	19,210	18,691	18,691	18,691	18,691
NY	58341.8	58341.8	57855.62	53966.16	52507.62	52507.62	52507.62	52507.62
RI	2,412	2,412	2,392	2,231	2,171	2,171	2,171	2,171
VT	1,112	1,112	1,103	1,029	1,001	1,001	1,001	1,001

For the modeling exercise, the reductions were derived assuming that 2020 levels would be at 10% below 2008 levels. We assumed that the RGGI cap remained in place for the remainder of the modeling horizon (i.e., through 2029) at 2020 levels.

APPENDIX B: SAMPLE OUTREACH PRESENTATION

INTRODUCTION

Over the course of the project, NESCAUM and NYSDEC engaged with various regional and national multi-state organizations to discuss the project's goals, effort, and preliminary findings. The primary purpose of these efforts was to begin discussions with higher level policy makers and planners on the benefits of engaging in multi-pollutant planning by leading with energy-related policies. Below is a presentation provided to the Ozone Transport Commission at its Fall Meeting in Baltimore, Maryland on November 5, 2009.

Power Point Presentation

Moving States Towards Multi-Pollutant Air Quality Planning

NESCAUM

Leah Weiss
Senior Policy Advisor

Gary Kleiman
Science & Technology Program Manager

OTC Fall Meeting

Baltimore, MD

November 5, 2009

Acknowledgements

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  - Sandi Meier - Carl Mas
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  - Bob Bielawa - Dave Gardner
  - Ona Papageorgiou - Scott Griffin
  - Kevin Civerolo - Kevin Watz
  - Carlos Mancilla
- **Massachusetts:**
  - Nancy Seidman - Vivek Mohta
- **Maryland:**
  - Tad Aburn - Diane Franks
  - Brian Hug - Mary Jane Rutkowski

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Take-Away Message

- An integrated multi-pollutant planning approach, supported by a technical framework, can enable states to:
  - meet air quality objectives
  - reduce greenhouse gases
  - meet electricity demand through reliable and diverse supplies

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Traditional Air Planning Approach is Becoming Less Effective

- Climate Change has moved to center stage on the policy agenda
- Single pollutant programs can’t solve all air quality problems, and can create or exacerbate other problems
- States have many competing needs, e.g., economic, environmental, energy, security

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Multi-Pollutant Planning Makes Sense

- Energy and air quality are linked -- programs that reduce greenhouse gases can also reduce PM and ozone precursors
- Can be a more cost-effective approach, using state resources effectively and efficiently
- Can identify potential tradeoffs and provide information for policy makers to make informed decisions
- Can result in equal and better environmental results overall

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NESCAUM's View of Multi-Pollutant Planning

- Addresses multiple pollutants, including SO_2, NO_X, CO_2, PM, and Hg
- Highlights tradeoffs and co-benefits
- Analyzes the economic and environmental implications of various planning options
- Allows for multi-sector analyses

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Need to Change Planning Paradigm

- Move to a broader, longer term multi-pollutant planning approach, from which the SIP can be developed
- SIP is no longer the sole driver, but one of several drivers and components
- Work with/align various state offices in a new planning exercise to identify common solutions

Need to Modify Planning Horizons

- Air quality agenda requires multiple plans and regulations on relatively short-term planning cycles (typically three to nine years)
- Energy and Climate programs work under longer term planning cycles
- Possible to plan for longer cycles while meeting shorter term goals

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NESCAUM's Goals

- Enable state multi-pollutant planning through replicable, consistent and predictable protocols
- Foster integrated environmental and energy planning by leading with energy
- Refine tools that can support integrated, multi-pollutant work, and can be applied on a national scale
- Ensure that results from this approach can be used in SIPs and by energy planners to develop their Integrated Resource Plans (IRPs)

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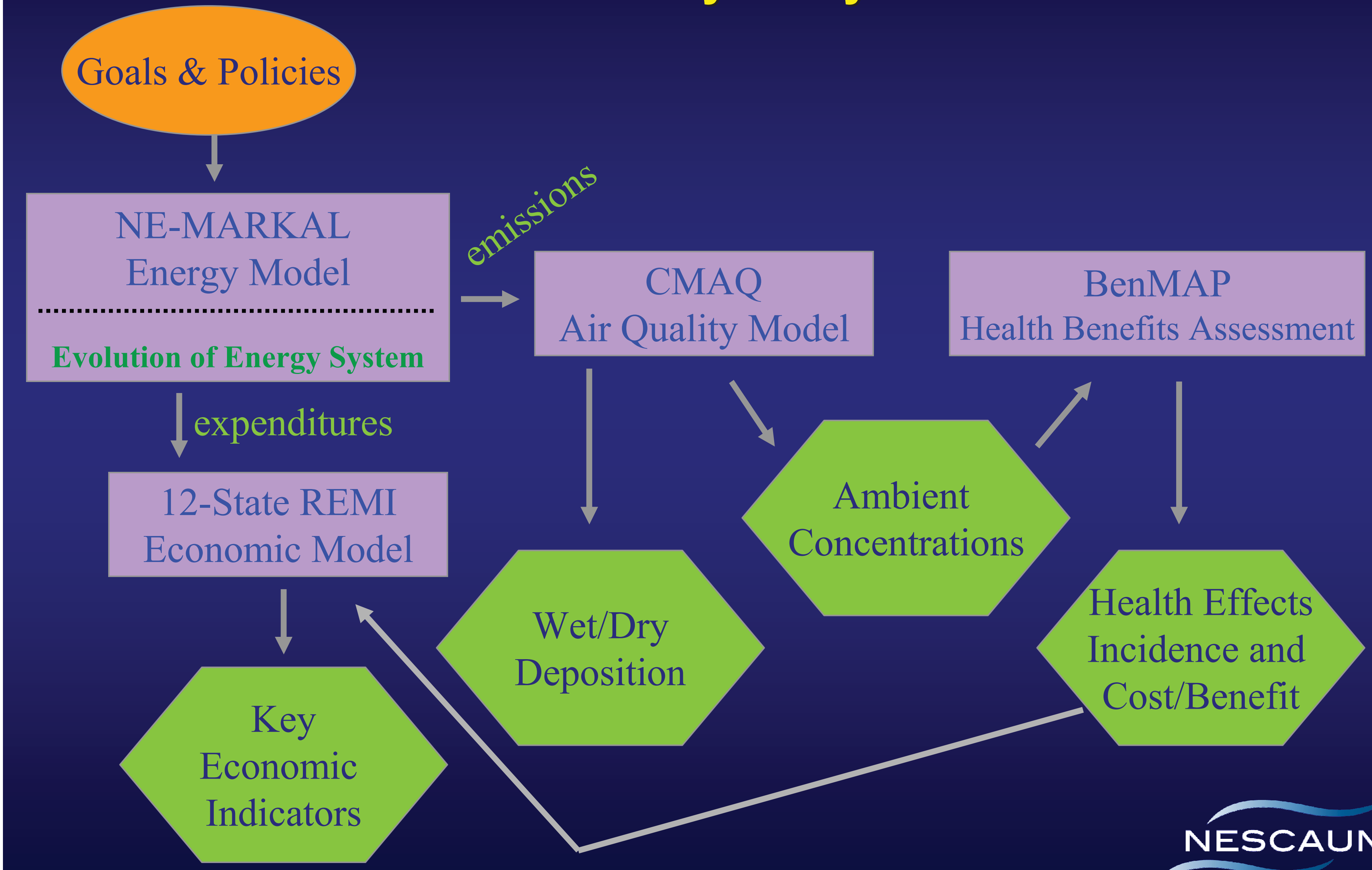
NESCAUM's Multi-Pollutant Policy Analysis Framework (MPAF)

NESCAUM's
Multi-Pollutant Policy Analysis Framework



Goals & Policies

NE-MARKAL
Energy Model

Evolution of Energy System

emissions

CMAQ
Air Quality Model

BenMAP
Health Benefits Assessment

expenditures

12-State REMI
Economic Model

Ambient
Concentrations

Wet/Dry
Deposition

Health Effects
Incidence and
Cost/Benefit

Key
Economic
Indicators

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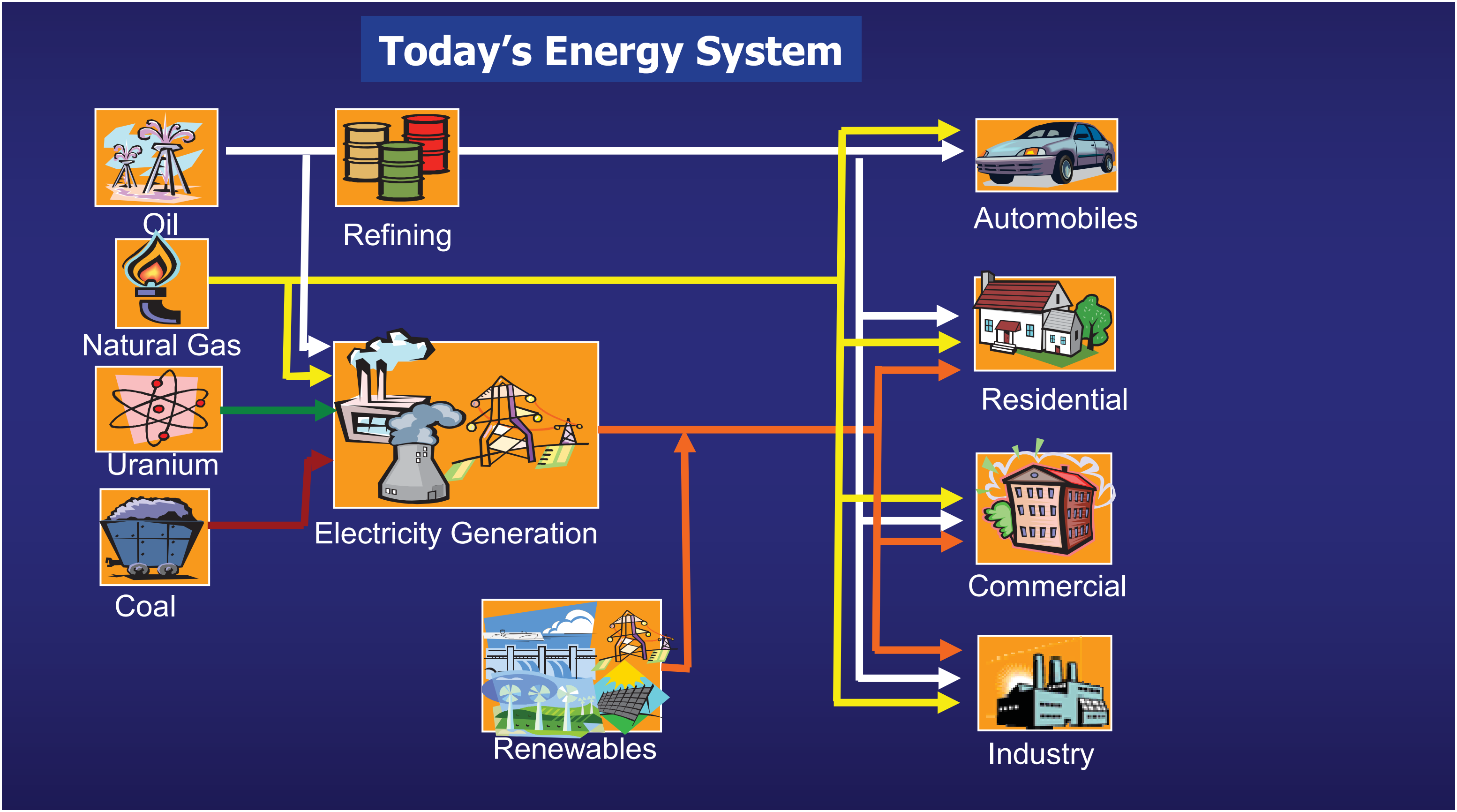
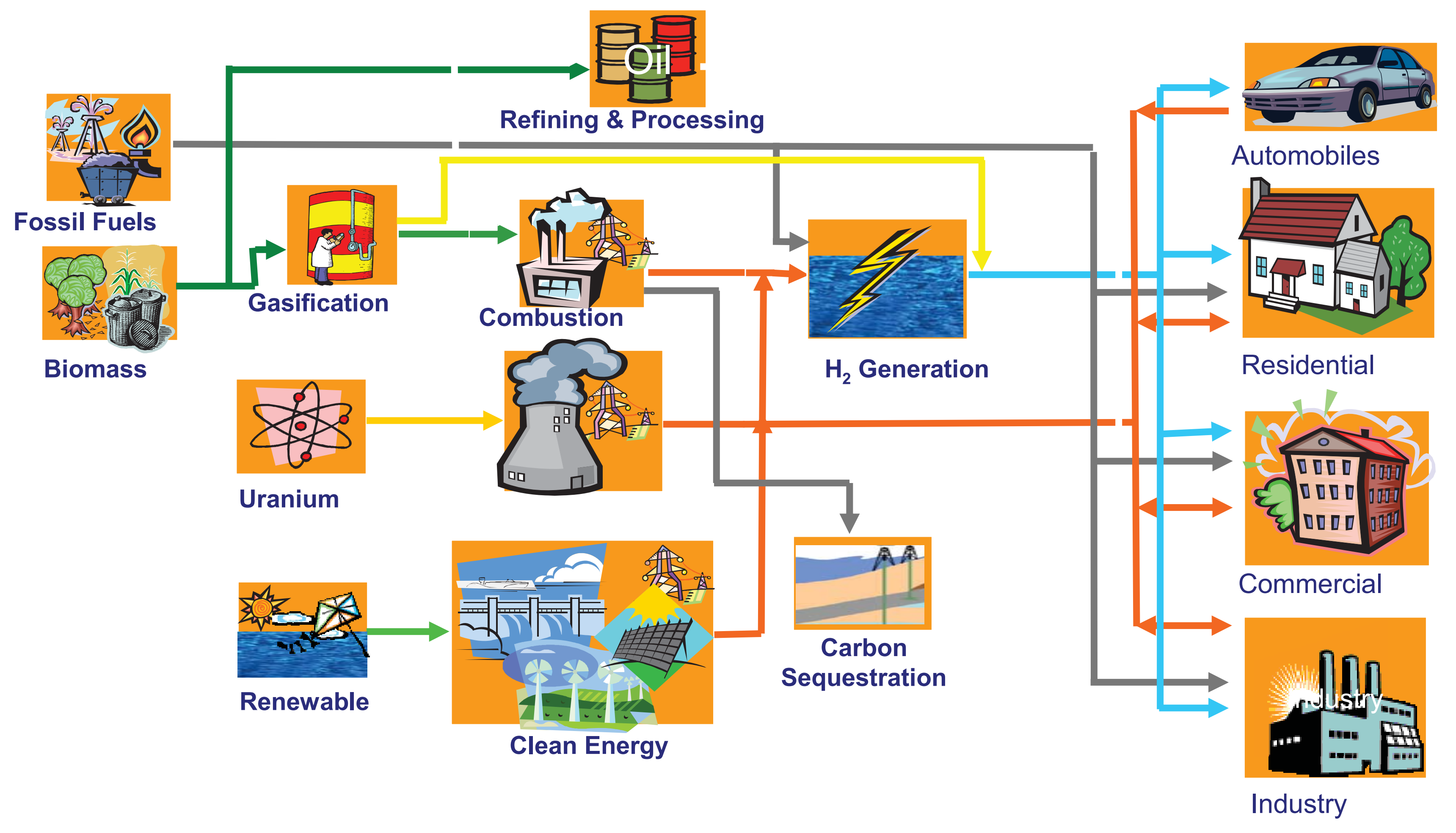
NE-MARKAL:
Energy Model as Centerpiece



Source: EPA ORD

NE-MARKAL:
Energy Model as Centerpiece



Source: EPA ORD

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Example of Results

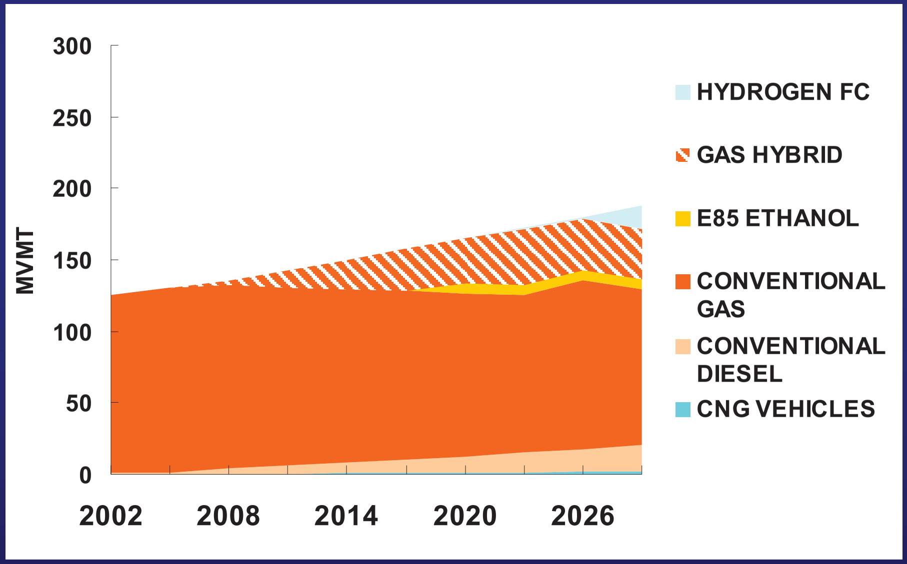
Transportation Example

- Fuel and Technology Deployment
- Emissions
- Costs

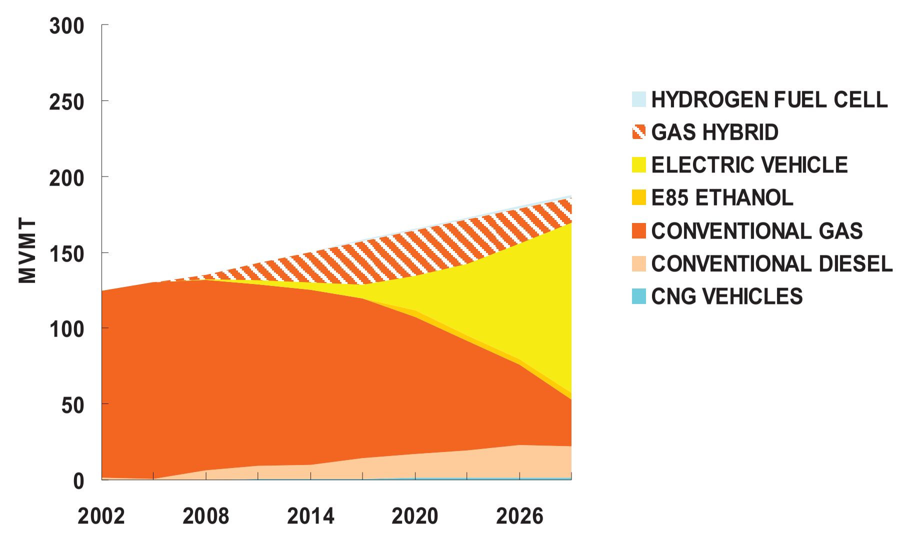
Example Transportation Policy (state-specific projections)

Technology Deployment Changes with EV Mandate

Reference



With Policy



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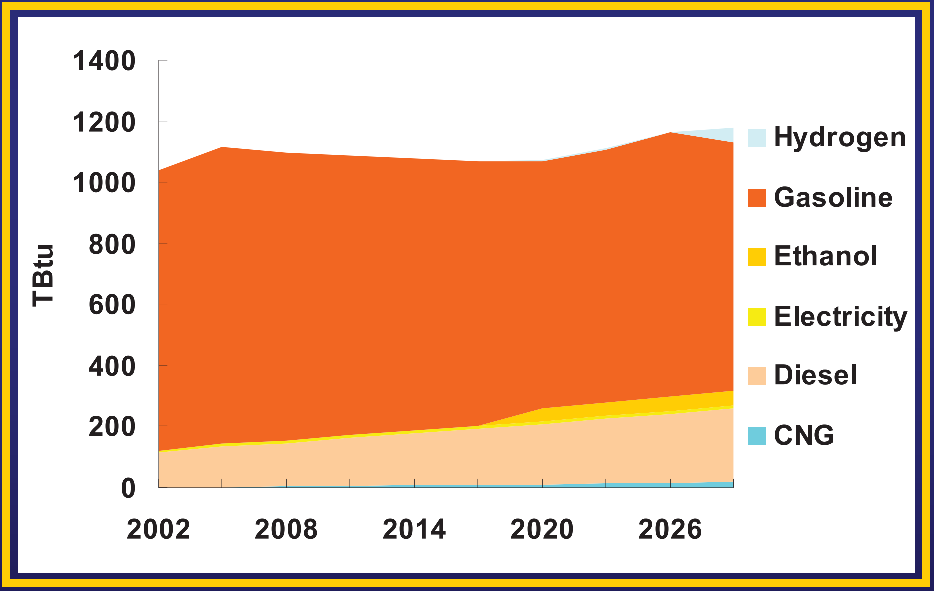
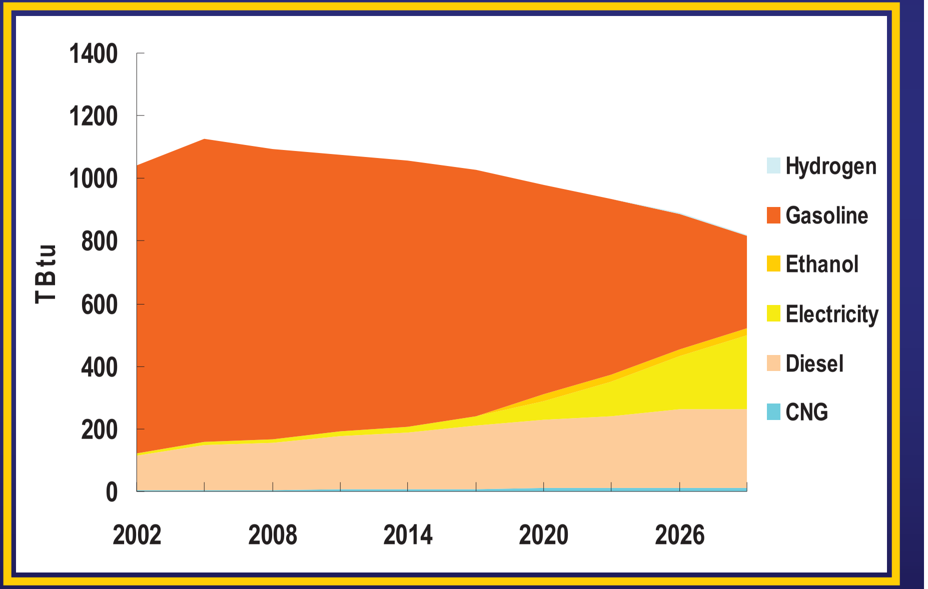
Example Transportation Policy (state-specific projections)

Fuel Consumption Changes with EV Mandate





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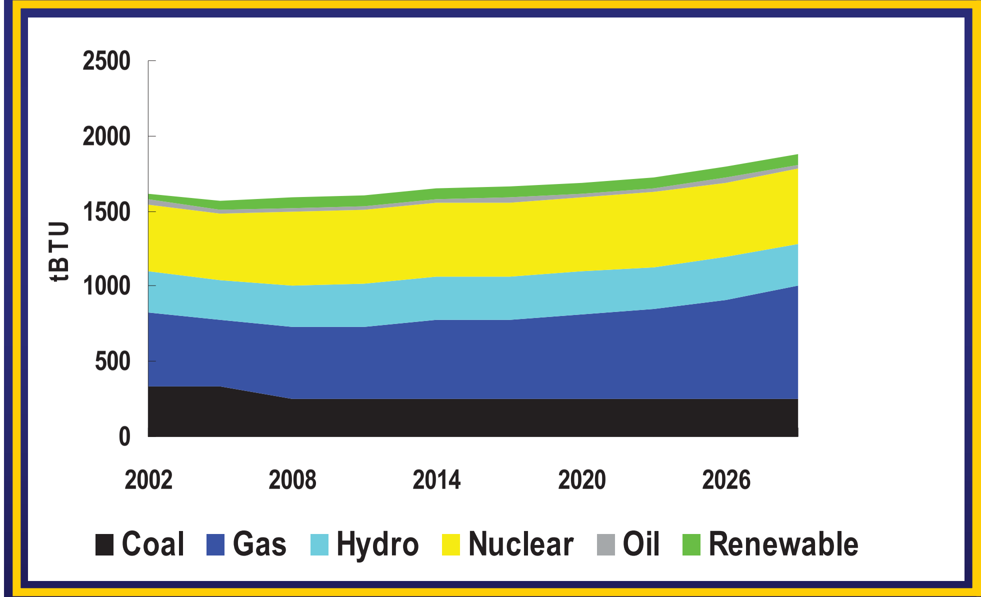
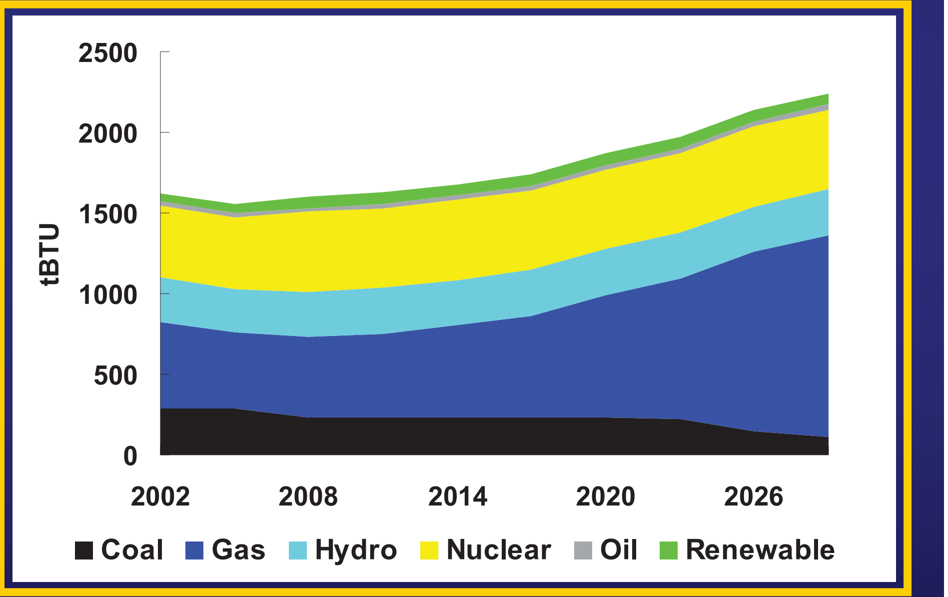
Example Transportation Policy (state-specific projections)

Power Generation Changes with EV Mandate





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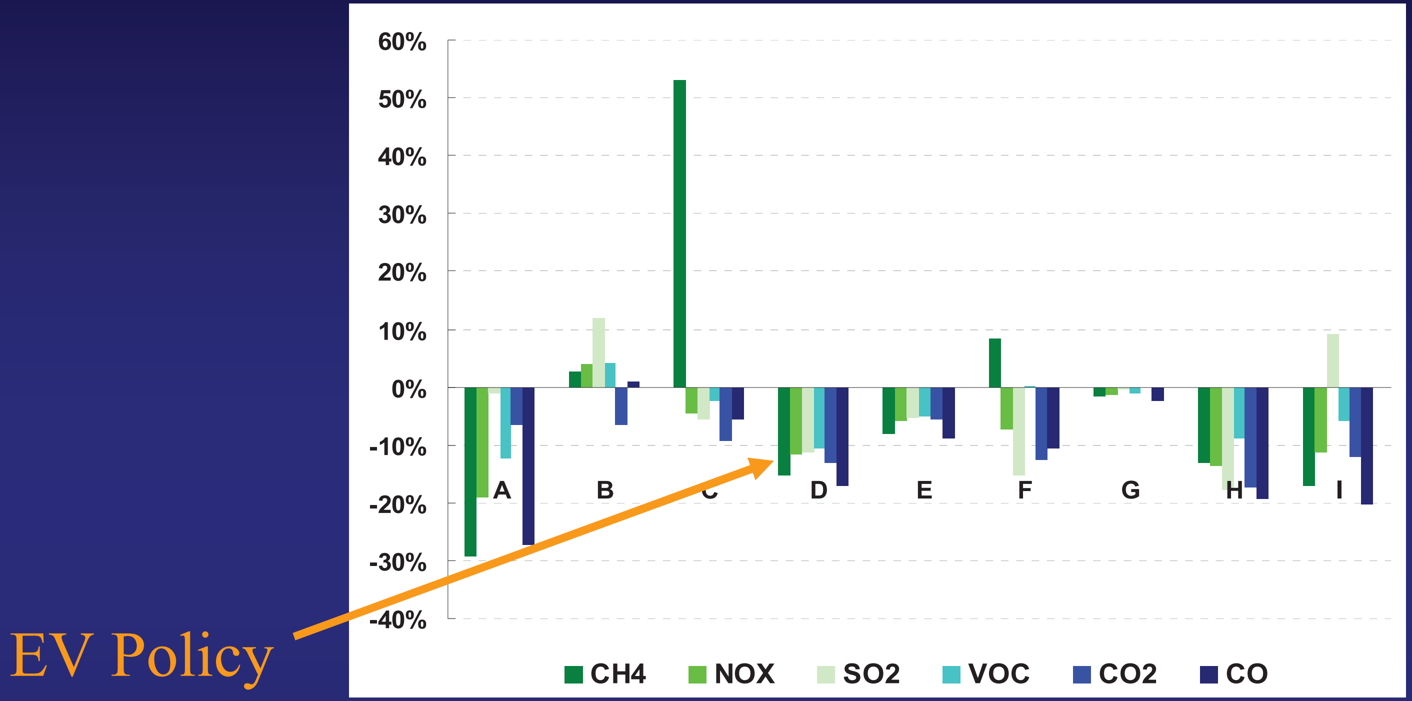
GHG & Criteria Pollutant Emission Reductions (state-specific projections)



EV Policy

- Climate focused policies can help to meet short- and long-term criteria pollutant goals.
- Near-term criteria pollutant goals, however, play only a small role in achieving long term climate goals.
- The multi-pollutant approach provides the opportunity to simultaneously address criteria and climate pollutant goals more efficiently than a pollutant by pollutant approach.

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Change in Total System Cost (analysis done for one state)

EV Policy →

	NPV Cost Change Relative to Reference	Run Type
A	-1.2%	Constraint
B	-0.3%	Constraint
C	0.2%	Constraint
D	1.4%	Constraint
E	-4.3%	Demand Reduction
F	-0.5%	Constraint
G	-0.1%	Constraint
H	1.2%	Constraint
I	-1.4%	Constraint

- The multi-pollutant approach also allows decision makers to weigh cost against environmental benefits for multiple scenarios, multiple pollutants, multiple sectors

Air Quality, Public Health, and Economic Analyses

- Emissions projections are inputs for air quality models
- Traditional estimates of monetized mortality/morbidity impacts are calculated from projected air quality changes
- Monetized health impacts can be fed back into regional economic model to estimate scenario-specific projected economic impacts on Gross State Product, labor income, and jobs

Advantages to Using NE-MARKAL

- Quick to run and turn around results
- Relatively inexpensive to use
- Transparent to review
- Detailed enough to assess a wide range of climate, air quality and energy policies
- Can analyze at different levels (state/regional), as well as multiple and/or single strategies
- Outputs can link to other models – REMI, CMAQ, BenMAP
- Is a multi-pollutant model. Outputs include: emissions changes in CO2, NOx, PM; Hg for power sector, and; SO2, VOC, CO for transportation sector
- Shows trade-offs
- Is an energy model – its use by air regulators starts the integration between air and energy

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Limitations to Using NE-MARKAL

- While expansive in its coverage, it will not provide perfect representation of all sectors and technologies
- Should be used for comparative policy analysis, not energy dispatch or forecasting
- Does not simulate behavior or consumer response

How This is Different

- Broader planning horizons, bigger picture, multi-disciplinary
- The planning happens first, results then feed into various plans (i.e., SIP, IRP)
- An iterative process – the model must first be tailored to state-specific conditions before it can be used to inform decisions
- Requires policy-makers to look at tradeoffs
- NE-MARKAL outputs can be used as inputs to other models; results are useful to state policy makers
- Outputs can inform air, energy, and economic policy (and vice versa)

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The Time is Ripe for Multi-Pollutant Planning

- Has the potential to align various state offices in a new planning exercise and identify common solutions.
- Can enable states to meet air quality objectives, reduce greenhouse gases, and meet electricity demand through reliable and diverse supplies
- Can identify potential tradeoffs and provides information for policy makers to make informed decisions.
- Tools are out there and available. NESCAUM's framework leads with energy and can help air regulators move toward multi-pollutant planning.

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THANK YOU!

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Energy. Innovation. Solutions.

Applying the Multi-Pollutant Policy Analysis Framework to New York: An Integrated Approach to Future Air Quality Planning

Final Report
May 2012

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