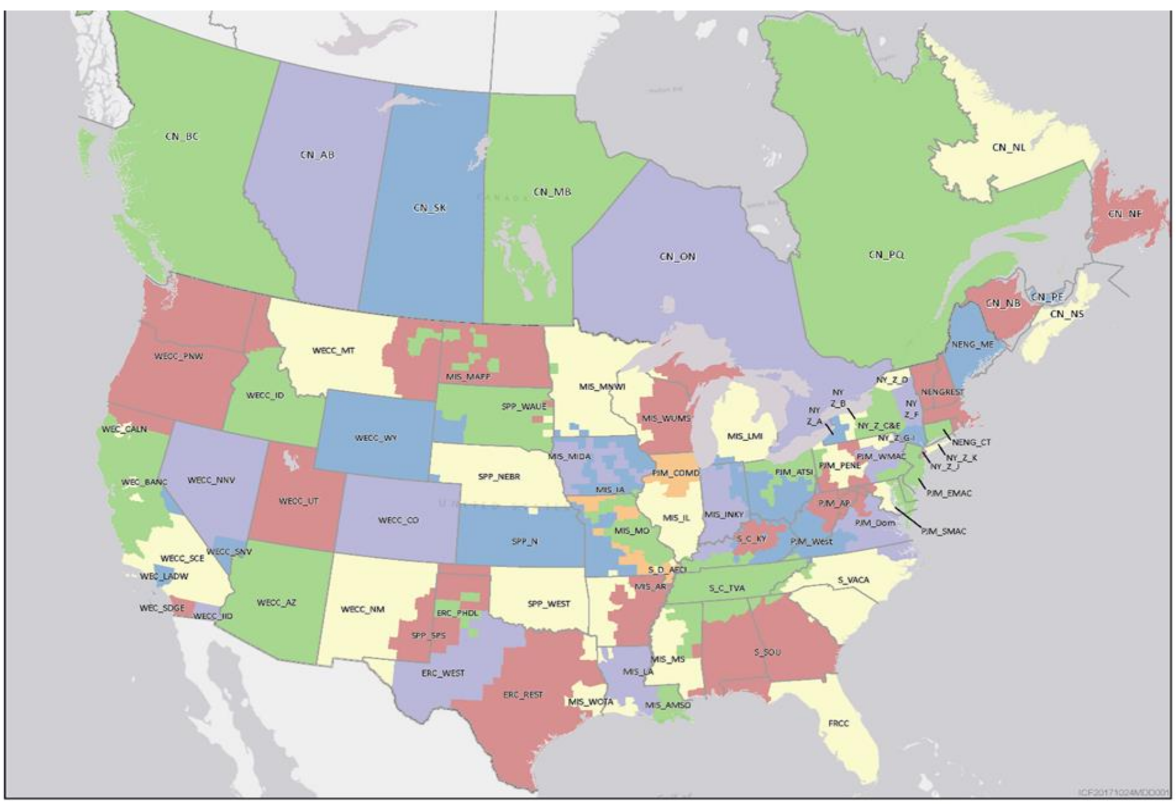
United States
Environmental Protection
Agency

Air and
Radiation
(6204J)

April 2024
“2023 Reference
Case”

Documentation for EPA’s Power Sector Modeling Platform 2023 Using the Integrated Planning Model 2023 Reference Case



Cover: EPA's Power Sector Modeling Platform is used by the U.S. Environmental Protection Agency as a platform to conduct various scenario and sensitivity analysis on the key drivers of the power sector behavior and to project the impact of emissions policies on the electric power sector in the 48 contiguous states and the District of Columbia in the lower continental U.S. Representation of the electric power sector in Canada is also included for purposes of integrated projections. The map appearing on the cover shows the 67 model regions used to characterize the operation of the U.S. electric power system in the lower continental U.S. and 11 model regions in Canada. EPA's Power Sector Modeling Platform using the Integrated Planning Model (IPM®) was developed by EPA's Clean Air Markets Division with technical support from ICF, Inc. The IPM is a product of ICF, Inc. and is used in support of its public and private sector clients. IPM® is a registered trademark of ICF Resources, L.L.C.

Documentation for EPA's Power Sector Modeling Platform Using the Integrated Planning Model 2023 Reference Case

U.S. Environmental Protection Agency
Clean Air Markets Division
1200 Pennsylvania Avenue, NW (6204J)
Washington, D.C. 20460
(www.epa.gov/airmarkets)

April 2024
"2023 Reference Case"

Acknowledgment

This document was prepared by U.S. EPA's Clean Air Markets Division, Office of Air and Radiation. ICF Incorporated, an operating company of ICF, provided technical support under EPA Contract 68HE0C18D0001.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

1. Introduction

1.1 Executive Summary

This document describes the nature, structure, and capabilities of the Integrated Planning Model (IPM) and the assumptions underlying the EPA's Power Sector Modeling Platform 2023 Reference Case (EPA 2023 Reference Case) that was developed by the U.S. Environmental Protection Agency (EPA) with technical support from ICF, Inc. IPM is a multi-regional, dynamic, and deterministic linear programming model of the U.S. electric power sector. The model provides projections of least-cost capacity expansion, electricity dispatch, and emission control strategies while meeting energy demand, environmental, transmission, dispatch, and reliability constraints. IPM can be used to evaluate the cost and emissions impacts of proposed policies to limit emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), mercury (Hg), and hydrogen chloride (HCl) from the electric power sector.

This introduction chapter summarizes the key modeling capabilities and major data elements that are described in greater detail in the subsequent chapters.

EPA 2023 Reference Case incorporates various data updates using the latest vintages of data available as of December 2023 with respect to the previous version (Post-IRA IPM 2022). This version maintains previously implemented updates to the model architecture, such as the detailed representation of the load segments and seasons. In addition, this reference case improves the representation of the Inflation Reduction Act (IRA) of 2022. Further, this updated version of EPA 2023 Reference Case uses demand projections from the Energy Information Agency's (EIA) Annual Energy Outlook (AEO) 2023 for the non-Electric Vehicle (EV) portion of the demand and incorporates EV demand provided by EPA's Office of Transportation and Air Quality (OTAQ), implementing a total demand reflecting EPA's view (see Attachment 3-1). EPA 2023 Reference Case reflects on-the-books rules and regulations as of December 2023; it does not reflect any rules that are under reconsideration or at the proposal stage.

This documentation includes assumptions and data values used to produce the EPA 2023 Reference Case. For subsequent runs that examine various alternative futures and policy analysis, we include separate documentation that makes clear where any assumptions or data values differ from the 2023 Reference Case conditions shown in this core documentation. When policy analysis is conducted using 2023 Reference Case, relevant assumptions and documentation will be provided elsewhere accordingly.

EPA 2023 Reference Case is a projection of electricity sector activity that considers only those Federal and state air emission laws and regulations, and legislations whose provisions were either in effect or enacted as documented in Section 3.10. Section 3.10 contains a detailed discussion of the environmental regulations included in EPA 2023 Reference Case, which are summarized below.

- Inflation Reduction Act of 2022
- Final Good Neighbor Plan (GNP) of 2023, a federal regulatory measure affecting EGU emissions from 22 states to address transport under the 2015 National Ambient Air Quality Standards (NAAQS) for ozone. For states in which the GNP is the most recently promulgated ozone-season program, the GNP limitations replace those from these prior programs, namely The Revised Cross-State Air Pollution Rule (CSAPR), CSAPR Update Rule, and the Revised CSAPR Update Rule,
- The Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units[1] through rate limits.

[1] 80 FR 64510

- The Mercury and Air Toxics Rule (MATS),[2] which was finalized in 2011. MATS establishes National Emissions Standards for Hazardous Air Pollutants (NESHAP) for the "electric utility steam generating unit" source category.
- Current and existing state regulations. A summary of these state regulations can be found in Table 3-29.
- Current and existing Renewable Portfolio Standards and Clean Energy Standards (see Section 3.10.10)
- EPA 2023 Reference Case reflects the latest actions EPA has taken to implement the Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations Final Rule[3]. The regulation requires states to submit revised State Implementation Plans (SIPs) that include (1) goals for improving visibility in Class I areas on the 20% worst days and allowing no degradation on the 20% best days and (2) assessments and plans for achieving Best Available Retrofit Technology (BART) emission targets for sources placed in operation between 1962 and 1977. Since 2010, the EPA has approved SIPs or, in a few cases, put in place regional haze Federal Implementation Plans for several states. The BART limits approved in these plans (as of summer 2020) that will be in place for EGUs are represented in the EPA 2023 Reference Case (see Table 3-34).
- EPA 2023 Reference Case reflects California AB 32 CO_2 allowance price projections and the Regional Greenhouse Gas Initiative (RGGI) rule (see Section 3.10.5).
- EPA 2023 Reference Case also includes three non-air federal rules affecting EGUs: National Pollutant Discharge Elimination System-Final Regulations to Establish Requirements for Cooling Water Intake Structures at Existing Facilities and Amend Requirements at Phase I Facilities, Hazardous, and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; and the Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category. (See Section 3.10.6)

Table 1-1 lists key updates included in EPA 2023 Reference Case with the corresponding data sources. The updates are listed in the order in which they appear in the documentation.

Table 1-1 Key Updates and Specifications in the EPA 2023 Reference Case

Description	For More Information
Modeling Framework	
The model time horizon extends to 2059 with seven model run years: 2028, 2030, 2035, 2040, 2045, 2050, and 2055.	Table 2-1
Power System Operation	
Power system operations are updated based on recent data from EIA, NERC, and FERC.	Chapter 3
The electricity demand projection is based on AEO 2023 for the non-EV portion with added EV demand provided by EPA's Office of Transportation and Air Quality (OTAQ) reflecting on the book rules as of end of 2023 that are not captured in the AEO 2023 demand projections.	Section 3.2 and Attachment 3-1
The reserve margins are updated to NERC 2022 Long-Term Reliability Assessment levels.	Section 3.6
Inventory of state emission regulations is updated.	Section 3.10

[2] 82 FR 16736

[3] 70 FR 39104

Description	For More Information
IRA Provisions (2022), GNP (2023), MATS (2011), and BART are reflected. IRA credits are phased out after first run year in which the CO_2 emissions from the power sector reduce by 75% below 2022 levels.	Section 3.10.4, Section 4.5
Inventory of RPS and CES standards are updated.	Table 3-18, Table 3-20
Generating Resources	
NEEDS planned units, retirements, and emission control configurations are updated based on 2021 EIA Form 860, January 2023 EIA Form 860M, August 2023 EIA Form 860M, AEO 2023, and AMPD 2019.	Table 4-1
Minimum capacity factor requirements of 10% are applied to existing coal steam units, and 2% are applied to existing oil/gas steam units and C2G retrofits, in regions without capacity markets	Section 3.5.2
Cost and performance characteristics for potential (new) units are updated based on AEO 2023 and NREL ATB 2023.	Table 4-12 and Table 4-15
Wind and solar technologies have revised cost and resource base estimates based on NREL ATB 2023.	Section 4.4.5
Energy storage options of both 4-hour and 10-hour durations are based on NREL ATB 2023.	Section 4.4.5
Tax credit extensions from the Inflation Reduction Act of 2022 are implemented for wind, solar, hydro, geothermal, landfill gas, energy storage, biomass, and 45Q.	Section 4.4.5
Emission Control Technologies	
Pipeline lateral costs for coal-to-gas-retrofits and natural gas co-firing retrofits are updated	Section 5.7.2
Carbon Capture, Transport, and Storage	
45Q is modeled in the 2030 and 2035 run years.	Section 3.12
Cost and performance assumptions for CCS controls are updated. Capital cost reductions are implemented over time for CCS retrofits	Section 6.1.2
Cost of geologic storage of carbon dioxide is updated using the GeoCAT 2.0 model. The update includes the quantity (in metric tons of capacity) and cost (in dollars per metric ton of CO_2) of potential geologic storage of carbon dioxide by location (generally defined as that portion of a geologic basin contained within one state) and by geologic storage type.	Section 6.2
CO_2 transportation cost adders reflect a transport cost algorithm that is based on a single, separate pipeline being used for each power plant all the way from the source to the sink.	Section 6.3
Natural Gas	
Natural gas assumptions as of the end of 2021 (with LNG export assumptions from AEO 2023) are modeled through annual gas supply curves and IPM region-level seasonal basis differentials.	Chapter 8
Other Fuels	
A hydrogen fuel price of 9.64 $/MMBtu is assumed.	Chapter 9
Financial assumptions	
Cost adder for new non-peaking fossil units associated with future CO_2 emissions is no longer applied.	

Table 1-2 lists the types of plants included in the EPA 2023 Reference Case.

Table 1-2 Plant Types in the EPA 2023 Reference Case

Conventional Technologies
Coal Steam
Oil/Gas Steam
Combustion Turbine
Combined-Cycle Combustion Turbine
Integrated Gasification Combined-Cycle (IGCC) Coal
Ultra-Supercritical Coal with and without Carbon Capture
Fluidized Bed Combustion
Nuclear
Renewables and Non-Conventional Technologies
Hydropower
Pumped Storage
Energy Storage
Biomass
Onshore Wind
Offshore Wind
Fuel Cells
Distributed Solar Photovoltaics
Solar Photovoltaics
Solar Thermal
Geothermal
Landfill Gas
Other[1]

Note:

[1] Included are fossil and non-fossil waste plants.

Table 1-3 lists the emission control technologies available for meeting emission limits in EPA 2023 Reference Case.

Table 1-3 Emission Control Technologies in the EPA 2023 Reference Case

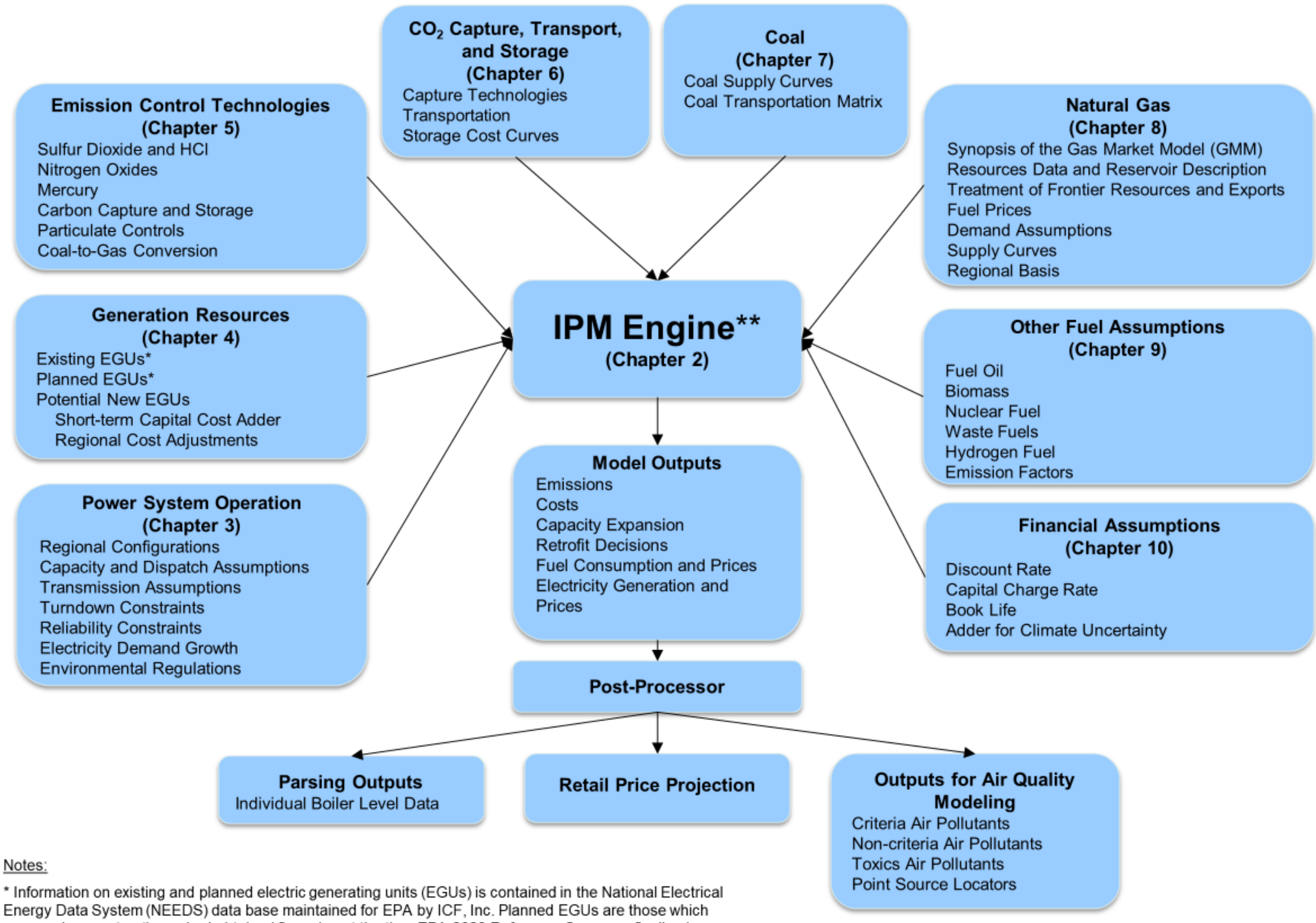
Sulfur Dioxide (SO_2)
Limestone Forced Oxidation (LSFO) Lime Spray Dryer (LSD)
Nitrogen Oxides (NO_x)
Combustion controls Selective catalytic reduction (SCR) Selective non-catalytic reduction (SNCR)
Mercury (Hg)
Combinations of SO_2, NO_x, and particulate control technologies Activated Carbon Injection
Hydrogen Chloride (HCl)
Dry Sorbent Injection (with milled Trona)
Carbon Dioxide (CO_2)
Coal-to-gas Carbon Capture and Sequestration Natural Gas Cofiring Hydrogen Cofiring

Notes:

Fuel switching between coal types is also a compliance option for reducing emissions in EPA 2023 Reference Case.

Figure 1-1 provides a schematic of the components of the modeling and data structure used for EPA 2023 Reference Case. The document contains separate chapters devoted to all the key components shown in Figure 1-1. Chapter 2 provides an overview of IPM's modeling framework (also referred to as the IPM Engine), highlighting the mathematical structure, notable features of the model, programming elements, and model inputs and outputs. The remaining chapters are devoted to different aspects of EPA 2023 Reference Case. Chapter 3 covers the operating characteristics of the power system. Chapter 4 explores the characterization of electric generation resources. Emission control technologies and carbon capture, transport, and storage are discussed in chapters 5 and 6. The next three chapters discuss the representation of and assumptions for fuels. Coal is covered in chapter 7, natural gas in chapter 8, and other fuels (i.e., fuel oil, biomass, nuclear fuel, and waste fuels) in chapter 9 (along with fuel emission factors). Finally, chapter 10 summarizes the financial assumptions.

Figure 1-1 Modeling and Data Structures in the EPA 2023 Reference Case



Notes:

* Information on existing and planned electric generating units (EGUs) is contained in the National Electrical Energy Data System (NEEDS) data base maintained for EPA by ICF, Inc. Planned EGUs are those which were under construction or had obtained financing at the time EPA 2023 Reference Case was finalized.

**IPM Engine is the model structure described in Chapter 2

1.2 Review and Ongoing Improvement of the Integrated Planning Model

A customized, fully documented version of the data assumptions underlying IPM has been developed and used by EPA to help inform power plant air regulatory and legislative efforts for more than 25 years, following the enactment of the Clean Air Act Amendments of 1990. The model has been tailored to meet the unique environmental considerations important to EPA, while also fully capturing the detailed and complex economic and electric dispatch dynamics of power plants across the country. EPA's goal is to explain and document the agency's use of the model in a transparent and publicly accessible manner, while also providing for concurrent channels for improving the model's assumptions and representation by soliciting constructive feedback to improve the model. This includes making all inputs and assumptions to the model, as well as output files from the model, publicly available on EPA's website (and, when applied to inform a rulemaking, in the relevant publicly accessible regulatory docket).

EPA's use of IPM depends upon a variety of environmental, policy, and regulatory considerations. EPA's version of the model input assumptions has undergone significant updates and architectural improvements every 2-4 years to best reflect the evolving dynamics of the power sector, and smaller ongoing updates (1-2 times a year) to reflect changes in fleet composition (retirements, new capacity builds, and installed retrofits). Currently, EPA's implementation of IPM is in its sixth major version, not including Coal and Electric Utility Model (CEUM), the model used by EPA before its use of IPM.

Federal Regulatory efforts:

EPA has used IPM for many regulatory efforts affecting the power sector, including:

- The NO_x SIP Call, the Clean Air Interstate Rule (2004-2006), the Clean Air Visibility Rule, the Clean Air Mercury Rule (2005), the Cross-State Air Pollution Rule and Updates, Good Neighbors Plan (2010-2023), the Mercury and Air Toxics Rule (2012), the Clean Power Plan (2015), Affordable Clean Energy Rule (2019) and various Ozone, PM NAAQS, and regional haze regulatory efforts.

National Legislative efforts:

EPA has used IPM to support legislative efforts that affect the power sector, including:

- The Clear Skies Act (2002-2005), the Clean Air Planning Act (2002-2005), the Clean Power Act (2002-2005), the Climate Stewardship and Innovation Act (2007), the Low Carbon Economy Act (2007-2008), the Lieberman-Warner Climate Security Act (2007-2008), and the American Clean Energy and Security Act (2008-2009).

Notable Versions and Updates/Improvements/Enhancements:

EPA Base Case using IPM - 1996

- Designed for projections covering the US with 4 run years
- Disaggregated the US into 17 IPM model regions
- Modeled coal and gas markets through coal and gas supply curves

EPA Base Case using IPM – 1998

- Updated unit inventory of power plants
- Increased the number of IPM model regions covering the US from 17 to 21
- Disaggregated New York into 4 IPM model regions
- Increased the number of run years from 4 to 6

EPA Base Case 2000 using IPM Version 2.1 (2000-2003)

- Updated unit inventory of power plants
- Increased the number of IPM model regions covering the US from 21 to 26
- Increased the modeling time horizon to 2030
- Increased the overall number of emission control technology options modeled
- Incorporated Activated Carbon Injection (ACI) retrofit options for mercury control modeling
- Expanded coal supply representation

EPA Base Case 2004 using IPM Version 2.1.9 (2004)

- Updated unit inventory of power plants
- Improved the characterization of SO_2 and NO_x emissions
- Revised coal choice assumptions for individual coal units
- Updated natural gas supply curves, incorporating recommendations from the natural gas peer review

EPA Base Case 2006 using IPM Version 3 (2005-2009)

- Updated unit inventory of power plants
- Improved environmental pollution control retrofit assumptions
- Increased the number of IPM model regions covering the US from 26 to 32 to enhance regional representation
- Increased the number of load segments from 5 to 6 to enhance electric load representation
- Updated natural gas supply curves based on ICF's North American Natural Gas Systems Analysis (NANGAS) model
- Updated coal supply curves
- Enhanced electric transmission capabilities and imports/exports
- Enhanced power plant representation detail

EPA Base Case using IPM Version 4.10 (2010-2013)

- Updated unit inventory of power plants
- Integrated Canada into the modeling framework
- Incorporated HCl emissions and Dry Sorbent Injection retrofit options
- Improved resolution of carbon capture and storage modeling by including regional storage representation and transportation network
- Updated coal supply modeling with significantly more resolution of coal mine data
- Incorporated natural gas resource model for North America to reflect emerging shale resource
- Enhanced power plant representation detail to support toxic air pollutant emissions and controls

EPA Base Case using IPM Version 5 (2014-2017)

- Updated unit inventory of power plants
- Doubled the number of IPM model regions from 36 to 64
- Revised environmental pollution control retrofit assumptions for conventional pollutants and toxic emissions
- Incorporated additional technology options for new power plants
- Overhauled coal supply assumptions, with even further resolution to reflect mine-by-mine geography and coal characteristics
- Improved coal transportation network by modeling each individual coal plant as its own coal demand region
- Updated gas modeling assumptions to reflect natural gas shale supply/trends and pipeline capacity expansion

EPA Base Case using IPM Version 6 (2017-2023)

- Updated unit inventory of power plants
- Revised environmental pollution control retrofit assumptions for conventional pollutants and toxic emissions
- Increased the number of seasons from 2 to 3 and the number of load segments for each season from 6 to 24
- Aggregated hours in load segments based on predefined time of day categories.
- Inputs for generation profiles for wind and solar technologies at an hourly level.
- Implemented capacity credit assumptions for wind, solar, and energy storage units that deteriorate with an increase in their penetration.
- Performed a comprehensive update of coal and natural gas supply and transportation assumptions.
- Updated generation technology costs
- Enabled functionality to model endogenous transmission builds
- Implemented capability to model operating reserves

- Revised the model time horizon to 2028-2059
- Implemented the impact of Inflation Reduction Act of 2022

EPA 2023 Reference Case using IPM (2024)

- Maintained structural and capability updates from the previous version
- Updated unit inventory, natural gas supply, demand, generation technology cost and performance assumptions, environmental regulations, implementation of IRA
- Increased the number of seasons from 3 to 4
- Implemented a comprehensive update of the CO_2 storage cost curve development methodology.

Background on EPA Base Case using IPM Review:

Peer Reviews:

EPA conducts periodic peer review of the EPA Base Case application of IPM. The reviews have included separate expert panels on the model itself and on EPA's key modeling input assumptions. For example, separate panels of independent experts have been convened to review the EPA Base Case application of IPM's coal supply and transportation assumptions, natural gas assumptions, and model formulation.

EPA IPM v6 Reference Case Peer Review

In September 2019, EPA commissioned a peer review of EPA's v6 Reference Case. An independent contractor facilitated a formal peer review process in compliance with EPA's *Peer Review Handbook* (U.S. EPA, 2006). A panel of peer reviewers with extensive expertise in energy policy, power sector modeling and economics reviewed the EPA Version 6 Reference Case and provided feedback in the form of a report.[4] The peer reviewers evaluated the adequacy of the framework, assumptions, and supporting data used in the EPA Version 6 Reference Case using IPM, and they suggested potential improvements. Overall, the panel found much to commend EPA; stating that the modeling platform:

- lends itself well to EPA analyses of air policy focused on the power sector
- includes significant detail related to electricity supply and demand
- includes data-rich representation both across different geographic areas and across time
- provides a reasonable representation of power sector operations, generating technologies, emissions performance and controls, and markets for fuels used by the power sector
- is well suited to assess the costs and emissions impacts
- documentation is well-written, clearly organized, and detailed in its presentation of most model characteristics

EPA has posted a response document to this Peer Review Report detailing the latest improvements in capabilities and documentation, and potential future improvements.

EPA Base Case v5.13 Data Assumption Review

In 2015, an independent peer review panel provided expert feedback on whether the analytical framework, assumptions, and applications of data in IPM were sufficient for the EPA's needs in estimating the economic and emissions impacts associated with the power sector. The panel identified several strengths associated with the model and underlying data and assumptions. For example, the report stated that EPA's platform exceeds other model capabilities in providing a relevant feedback mechanism between the electric power model and key fuel inputs that drive simulation results.[5]

[4] https://www.epa.gov/power-sector-modeling/ipm-peer-reviews

[5] https://www.epa.gov/power-sector-modeling/ipm-peer-reviews

Other strengths the panel identified include:

- The detail with which pollution control technology options and costs are represented
- The level of detail at which federal Clean Air Act (CAA) regulations are represented
- The ability of the model to allow for the detailed representation of a variety of potential changes in energy and environmental policies, including important features of market-based programs
- The accuracy of the emissions control costs and their relationship to retirement decisions
- The expansion of model regions from 32 to 64, which allows the model to better represent current power market operations and existing transmission bottlenecks even within regional transmission organization (RTO) regions
- Continuous updates of the representation of domestic coal and natural gas market conditions

The peer review panel has also provided several areas for investigation and additional recommendations for the EPA's consideration, including:

- Improved documentation of the input assumptions
- Changes to certain cost functions and financial assumptions
- Consideration of certain improvements to the Base Case architecture (additional seasonal representation, representation of electric demand, transmission considerations, and renewable energy representation, among others)

The EPA 2023 Reference Case using IPM addresses many of the recommendations (seasons, renewable energy representation, regional representation, etc.). The peer review has also led to additional work at EPA to further understand and better represent some of the emerging issues in the power sector. EPA intends to add more capabilities and continue to refine the modeling platform to reflect these comments and adopt those changes at an appropriate time after further research and testing of the model.

Coal Market Assumptions Review

In 2003, a group of experts in the field of cost, quality, reserves, and availability of coal was selected as peer reviewers to assess whether the choice, use, and interpretation of data and methodology employed in the derivation of the IPM coal supply curves were appropriate and analytically sound. The peer reviewers were charged with:

- Evaluating the appropriateness of the overall methodology used to develop the new coal supply curves
- Assessing the adequacy of the individual components employed in building the coal supply curves in terms of both the approach and data used
- Assessing the technical soundness of the resulting coal supply curves for each coal type and supply region in terms of the cost/quantity relationship and the characteristics associated with the coal (e.g., sulfur, heat, and mercury content)
- Assessing the appropriateness of the use of this set of supply curves for use in production cost models in general (of which IPM is a particular example)

The review process produced useful and specific recommendations for improving and updating the coal supply information represented in IPM, which were subsequently incorporated into the model.

Gas Market Assumptions Review

In 2003, a peer review of the natural gas supply assumptions implemented in EPA Base Case using IPM v.2.1.6 (2003) was performed. The peer reviewers were charged with evaluating the following:

- The appropriateness of the representation of all the key natural gas market fundamentals in NANGAS

- The reasonableness of the natural gas supply curves, non-electricity demand assumptions and transportation adders
- The reasonableness of the iteration process between NANGAS and IPM

The review commended the comprehensiveness of the approach used to generate the gas supply curves implemented in the EPA Base Case. The review further identified assumptions that could be revised in generating a new set of natural gas supply curves, as well as nonelectric-sector gas demand curves, for the next update of the EPA Base Case.

IPM Formulation Review

Conducted in 2008, this peer review focused on IPM's core mathematical formulation. The objective of the review was to obtain expert feedback on the adequacy of the formulation in representing the economic and operational behavior of the power sector over a modeling time horizon of 20-50 years.

The panel identified several strengths of IPM, including:

- The model's ability to compute optimal capacity that combined short-term dispatch decisions with long-term investment decisions
- The model's integration of relevant markets, including the electric power, fuel, and environmental markets, into a single modeling framework
- And the model's ability to represent a very detailed level of data regarding the emissions modeling capability

The peer review panel also provided several areas for investigation and recommendations for the EPA's consideration. These peer reviews led to changes, enhancements, and updates to the IPM framework to better represent the power sector and related markets (i.e., fossil fuels).

Regulatory Review:

The formal rulemaking process provides an opportunity for expert review and comment by key stakeholders. Formal comments as part of a rulemaking are reviewed and evaluated, and changes and updates are made to IPM where appropriate. Stakeholders to EPA regulatory efforts are a diverse group, including regulated entities and impacted industries, fuel supply companies, states, environmental organizations, developers of other models of the U.S. electricity sector, and others. The feedback provides a highly detailed review of input assumptions, model representation, and model results.

Other Uses and Reviews:

- IPM has been used by many regional organizations for regulatory support, including the Regional Greenhouse Gas Initiative (RGGI), the Western Regional Air Partnership (WRAP), and the Ozone Transport Assessment Group (OTAG). IPM has also been used by other Federal agencies (e.g., FERC, USDA), environmental groups, and many electric utilities.
- The Science Advisory Board reviewed EPA's application of IPM as part of the CAAA Section 812 prospective study 1997-1999.
- The President's Council of Economic Advisors (2002-2003) performed head-to-head comparison of IPM and EIA's NEMS system for use in multi-pollutant control analysis.
- IPM has been used in several comparative model exercises sponsored by Stanford University's Energy Modeling Forum and other organizations.

EPA 2023 Reference Case using IPM represents a major iteration of EPA's application of IPM, with notable structural and platform improvements and enhancements, as well as universal updates to reflect the most current set of data and assumptions, coupled with continuous routine input data and assumption updates.

2. Modeling Framework

ICF developed the Integrated Planning Model (IPM) to support analysis of the electric power sector. The EPA, in addition to other state air regulatory agencies, utilities, and public and private sector entities, has used IPM extensively for various air regulatory analyses, market studies, strategy planning, and economic impact assessments.

IPM is a long-term capacity expansion and production-costing model of the electric power sector. Its mathematical formulation is based on a Linear Programming (LP) structure. The structure provides several advantages, one of which is the guarantee of a globally optimal solution. Fast and efficient commercial solvers exist to solve LP models. The solved dual variables (also known as shadow prices) of each constraint modeled in IPM inform EPA rulemaking or policy analysis process in regard to the marginal cost pricing of energy, capacity, fuels, and emission allowances. Also, reasonable solution times for an LP model allow EPA to gain insights by modeling a large number of scenarios in a relatively short period of time.

The first section of this chapter provides a brief overview of the model's purpose, capabilities, and applications. The following sections are devoted to describing the IPM's model structure and formulation (2.2), key methodological characteristics (2.3), and programming features (2.4), including its handling of model inputs and outputs. Readers may find some overlap between sections. For example, transmission decision variables and constraints are covered in the discussion of model structure and formulation in section 2.2, and transmission modeling is covered as a key methodological feature in section 2.3.7. The different perspectives of each section are designed to provide readers with information that is complementary rather than repetitive.

2.1 IPM Overview

IPM is a well-established model of the electric power sector designed to help government and industry analyze a wide range of issues related to this sector. The model represents economic activities in key components of energy markets – fuel markets, emission markets, and electricity markets. Since the model captures the linkages in electricity markets, it is well suited for developing integrated analyses of the impacts of alternative regulatory policies on the power sector. In the past, applications of IPM have included capacity planning, environmental policy analysis and compliance planning, wholesale price forecasting, and power plant asset valuation.

2.1.1 Purpose and Capabilities

IPM is a dynamic linear programming model that generates optimal decisions under the assumption of perfect foresight. It determines the least-cost method of meeting energy and peak demand requirements over a specified period. In its solution, the model considers a number of key operating or regulatory constraints that are placed on the power, emissions, and fuel markets. The constraints include, but are not limited to, emission limits, transmission capabilities, renewable generation requirements, and fuel market constraints. The model is designed to accommodate complex treatment of emission regulations involving trading, banking, and special provisions affecting emission allowances (e.g., bonus allowances and progressive flow control), as well as traditional command-and-control emission policies.

IPM represents power markets through model regions that are geographical entities with distinct operational characteristics. The model regions are largely consistent with the North American Electric Reliability Council (NERC) assessment regions and with the organizational structures of the Regional Transmission Organizations (RTOs) and the Independent System Operators (ISOs) that handle dispatch on most of the U.S. grid. IPM represents the least-cost arrangement of electricity supply (capacity and generation) within each model region to meet assumed future load (electricity demand) while constrained by a transmission network of bulk transfer limitations on interregional power flows. All utility-owned existing electric generating units, including renewable resources, as well as independent power producers and cogeneration facilities selling electricity to the grid, are modeled.

IPM provides a detailed representation of new and existing resource options. These include fossil, nuclear, renewable, storage, and non-conventional options. Fossil options include coal steam, oil/gas steam, combined cycles, and simple cycle combustion turbines. Renewable options include wind, landfill gas, geothermal, solar thermal, solar photovoltaic, and biomass. Storage options include pump storage and battery storage. Non-conventional options include fuel cells.

IPM can incorporate a detailed representation of fuel markets and can endogenously forecast fuel prices for coal, natural gas, and biomass by balancing fuel demand and supply for electric generation. The model also includes detailed fuel quality parameters to estimate emissions from electric generation.

IPM provides estimates of air emission changes, regional wholesale energy and capacity prices, incremental electric power system costs, changes in fuel use, and capacity and dispatch projections.

2.1.2 Applications

IPM's structure, formulation, and set-up make it adaptable and flexible. The necessary level of data, modeling capabilities exercised, and computational requirements can be tailored to the strategies and policy options being analyzed. This adaptability has made IPM suitable for a variety of applications. These include:

<u>Air Regulatory Assessment:</u> Since IPM contains extensive air regulatory modeling features, state and federal air regulatory agencies have used the model extensively in support of air regulatory assessment.

<u>Integrated Resource Planning:</u> IPM can be used to perform least-cost planning studies that simultaneously optimize demand-side options (load management and efficiency), renewable options and traditional supply-side options.

<u>Strategic Planning:</u> IPM can be used to assess the costs and risks associated with alternative utility and consumer resource planning strategies as characterized by the portfolio of options included in the input database.

<u>Options Assessment:</u> IPM allows industry and regulatory planners to screen alternative resource options and option combinations based on their relative costs and contributions to meeting customer demands.

<u>Cost and Price Estimation:</u> IPM produces realistic estimates of energy prices, capacity prices, fuel prices, and allowance prices. Industry and regulatory agencies have used these cost reports for due diligence, planning, litigation, and economic impact assessment.

2.2 Model Structure and Formulation

IPM employs a linear programming structure that is particularly well-suited for analysis of the electric sector to help decision-makers plan system capacity and model the dispatch of electricity from individual units or plants. The model consists of three key structural components:

- A linear objective function
- A series of decision variables
- A set of linear constraints
- The sections below describe the objective function, key decision variables, and constraints included in IPM for the EPA 2023 Reference Case.

2.2.1 Objective Function

IPM's objective function is to minimize the total, discounted net present value of the costs of meeting demand, power operation constraints, and environmental regulations over the entire planning horizon. The objective function represents the summation of all the costs incurred by the electricity sector on a net present value basis. These costs, which the linear programming formulation attempts to minimize, include the cost of new plant and pollution control construction, fixed and variable operating and maintenance costs, and fuel costs. Many of these cost components are captured in the objective function by multiplying the decision variables by a cost coefficient. Cost escalation factors are used in the objective function to reflect changes in cost over time. The applicable discount rates are applied to derive the net present value for the entire planning horizon from the costs obtained for all years in the planning horizon.

2.2.2 Decision Variables

Decision variables represent the values for which the IPM model is solving, given the cost-minimizing objective function described in Section 2.2.1 and the set of electric system constraints detailed in Section 2.2.3. The model determines values for these decision variables that represent the optimal least-cost solution for meeting the assumed constraints. Key decision variables represented in IPM are described in detail below.

<u>Generation Dispatch Decision Variables:</u> IPM includes decision variables representing the generation from each model power plant.[6] For each model plant, a separate generation decision variable is defined for each possible combination of fuel, season, model run year, and segment of the seasonal load duration curve applicable to the model plant. (See Section 2.3.5 below for a discussion of load duration curves.) In the objective function, each plant's generation decision variable is multiplied by the relevant heat rate and fuel price (differentiated by the appropriate step of the fuel supply curve) to obtain a fuel cost. It is also multiplied by the applicable variable operation and maintenance (VOM) cost rate to obtain the VOM cost for the plant.

<u>Capacity Decision Variables:</u> IPM includes decision variables representing the capacity of each existing model plant and capacity additions associated with potential (new) units in each model run year. In the objective function, the decision variables representing existing capacity and capacity additions are multiplied by the relevant fixed operation and maintenance (FOM) cost rates to obtain the total FOM cost for a plant. The capacity addition decision variables are multiplied by the investment cost and capital charge rates to obtain the annualized capital cost associated with the capacity addition.

<u>Operating Reserve Decision Variables:</u> IPM includes decision variables representing each model plant's contribution to meeting operating reserve requirements. While a model plant can contribute to both energy and operating reserve requirements, its total contribution is limited by its total capacity.

<u>Transmission Decision Variables:</u> IPM includes decision variables representing the electricity transmission along each transmission link between model regions in each run year. In the objective function, these variables are multiplied by variable transmission cost rates to obtain the total cost of transmission across each link.

<u>Emission Allowance Decision Variables:</u> For emission policies where allowance trading applies, IPM includes decision variables representing the total number of emission allowances for a given model run year that are bought and sold in that or subsequent run years. In the objective function, these year-differentiated allowance decision variables are multiplied by the market price for allowances prevailing in

[6] Model plants are aggregate representations of real-life electric generating units. They are used by IPM to model the electric power sector. For a discussion of model plants in EPA 2023 Reference Case, see Section 4.2.6.

each run year. This formulation allows IPM to capture the inter-temporal trading and banking of allowances.

Fuel Decision Variables: For each type of fuel and each model run year, IPM defines decision variables representing the quantity of fuel delivered from each fuel supply region to model plants in each demand region. Coal decision variables are further differentiated according to coal rank (bituminous, sub-bituminous, and lignite), sulfur grade, chlorine content, and mercury content. These fuel quality decision variables do not appear in the IPM objective function but in constraints that define the types of fuel that each model plant is eligible to use and the supply regions that are eligible to provide fuel to each specific model plant.

2.2.3 Constraints

Model constraints are implemented in IPM to accurately reflect the characteristics of, and the conditions faced by, the electric sector. Among the key constraints included in EPA 2023 Reference Case are:

Reserve Margin Constraints: Regional reserve margin constraints capture system reliability requirements by defining a minimum margin of reserve capacity (in megawatts) per year beyond the total capacity needed to meet future peak demand that must remain in service to that region. These reserve capacity constraints are derived from reserve margin targets that are assumed for each region based on information from NERC, RTOs, or ISOs. If the existing plus planned capacity is not sufficient to satisfy the annual regional reserve margin requirement, the model will build the required level of new capacity. Section 3.6 further discusses reserve margin assumptions.

Operating Reserve Constraints: These constraints specify the operating reserve requirements by product type and region that the power system must meet.

Demand Constraints: The model categorizes regional annual electricity demand into seasonal load curves, which are used to form winter (December 1 – February 28), spring (March 1 – April 30), fall (October 1 – November 30), and summer (May 1 – September 30) load duration curves (LDC). The seasonal load segments, when taken together, represent all the hourly electricity load levels that must be satisfied in a particular region, season, and model run year. As such, the LDC defines the minimum amount of generation required to meet the region's electricity demand during the specific season. These requirements are specified by demand constraints.

Capacity Factor Constraints: These constraints specify how much electricity each plant can generate, given its capacity and seasonal availability.

Turn Down Constraints: The model uses turn down constraints to account for the cycling capabilities of generation resources, i.e., whether they can be shut down at night or on weekends, must operate at all times, or must operate at least at some minimum capacity level. The constraints ensure that the model reflects the distinct operating characteristics of peaking, cycling, and base-load units.

Emissions Constraints: IPM can endogenously consider an array of emissions constraints for SO_2, NO_x, HCl, mercury, and CO_2. Emission constraints can be implemented on a plant-by-plant, regional, or system-wide basis. The constraints can be defined in terms of a total tonnage cap (e.g., tons of SO_2) or a maximum emission rate (e.g., lb/MMBtu of NO_x). The emission constraints' scope, timing, and definition depend on the required analysis.

Transmission Constraints: IPM can simultaneously model any number of regions linked by transmission lines. The constraints define either a maximum capacity on each link or a maximum level of transmission on two or more links (i.e., joint limits) to different regions.

Fuel Supply Constraints: These constraints define the types of fuel that each model plant is eligible to use and the supply regions that are eligible to provide fuel to each specific model plant. A separate constraint is defined for each model plant.

2.3 Key Methodological Features of IPM

IPM is a flexible modeling tool for obtaining short- and long-term projections of production activity in the electric generation sector. The projections obtained using IPM are not statements of what will happen. Rather, they are estimates of what might happen, given the assumptions and methodologies used. Chapters 3 to 10 contain detailed discussions of the cost and performance assumptions specific to EPA 2023 Reference Case. The present section provides an overview of the essential methodological and structural features of IPM that extend beyond the assumptions that are specific to EPA 2023 Reference Case.

2.3.1 Model Plants

Model plants are a central structural component that IPM uses: (1) to represent aggregations of existing generating units, (2) to represent retrofit and retirement options that are available to existing generating units, and (3) to represent potential (new) generating units that the model can build.

Existing Units: Theoretically, there is no predefined limit on the number of generating units that can be included in IPM. However, to keep model size and solution time within acceptable limits, EPA utilizes model plants to represent aggregations of actual individual generating units. The aggregation algorithm groups units with similar characteristics for representation by model plants with a combined capacity and weighted-average characteristics that are representative of all the units comprising the model plant. Model plants are defined to maximize the accuracy of the model's cost and emissions estimates by capturing variations in key features of those units that are critical in the EPA 2023 Reference Case and anticipated policy case runs. For EPA 2023 Reference Case, EPA employed an aggregation algorithm, which allowed over 27,000 actual existing electric generating units to be represented by nearly 4,000 model plants. Section 4.2.6 describes the aggregation procedure.

Retrofit and Retirement Options: IPM also utilizes model plants to represent the retrofit and retirement options that are available to existing generating units. EPA 2023 Reference Case provides existing model plants with a wide range of options for retrofitting with emission control equipment as well as with an option to retire. (See Chapter 5 for a detailed discussion of the options that are included.) Model plants that represent potential (new) generation resources are not given the option to take on a retrofit or to retire.

The options available to each model plant are pre-defined at the model set-up. The retrofit and retirement options are themselves represented in IPM by model plants, which, if actuated during a model run, take on all or a portion of the capacity initially assigned to a model plant, which represents existing generating units.[7] In setting up IPM, parent-child-grandchild relationships are pre-defined between each existing model plant (parent) and the specific retrofit and retirement model plants (children and grandchildren) that may replace the parent model plant during the course of a model run. The child and grandchild model plants are inactive unless the model finds it economical to engage one of the options provided, e.g., retrofit with particular emission controls or retire.

Theoretically, there are no limits on the number of successive retrofit and retirement options that can be associated with each existing model plant. However, model size and computational considerations dictate that the number of successive retrofits is limited. In EPA 2023 Reference Case, a maximum of

[7] IPM has a linear programming structure whose decision variables can assume any value within the specified bounds subject to the constraints. Therefore, IPM can generate solutions where model plants retrofit or retire a portion of the model plants capacity. IPM's standard model plant outputs explicitly present these partial investment decisions.

three stages of retrofit options are provided. For example, an existing model plant may retrofit with an activated carbon injection (ACI) for mercury control in one model run year (stage 1), with a selective catalytic reduction (SCR) for NO_x control in the same or subsequent run year (stage 2), and with carbon capture and sequestration (CCS) for CO_2 control in the same or subsequent run year (stage 3). However, if it exercises this succession of retrofit options, no further retrofit or retirement options are possible beyond the third stage.

Potential (New) Units: IPM also uses model plants to represent new generation capacity that may be built during a model run. All the model plants representing new capacity are pre-defined at set-up. They are differentiated by type of technology, regional location, and years available. When it is economically advantageous to do so (or otherwise required by reserve margin constraints to maintain electric reliability), IPM builds one or more of these predefined model plants by raising its generation capacity from zero during a model run. In determining whether it is economically advantageous to build new plants, IPM considers cost differentials between technologies, expected technology cost improvements (by differentiating costs based on a plant's vintage, i.e., build year), and regional variations in capital costs that are expected to occur over time.

Parsing and post-processing: Since EPA 2023 Reference Case results are presented at the model plant level, EPA has developed a post-processor, a parsing tool, designed to translate results at the model plant level into generating unit-specific results. The parsing tool produces unit-specific emissions, fuel use, emission control retrofit, and capacity projections based on model plant results. Another post-processing activity involves deriving inputs for air quality modeling from IPM outputs. This entails using emission factors to derive the levels of pollutants needed in EPA's air quality models from emissions and other parameters generated by IPM. It also involves using decision rules to assign point source locators to these emissions. (See Figure 1-1 for a graphical representation of the relationship of the post-processing tools to the overall IPM structure.)

2.3.2 Model Run Years

Another important structural feature of IPM is the use of model run years to represent the full planning horizon being modeled. Although IPM can represent an individual year in an analysis time horizon, mapping each year in the planning horizon into a representative model run year enables IPM to perform multiple year analyses while keeping the model size manageable. IPM considers the costs in all years in the planning horizon while reporting results only for model run years. (See Section 2.3.3 below for further details.)

The analysis time horizon for EPA 2023 Reference Case extends from 2028 through 2059. The seven years designated as model run years and the mapping of calendar years to the model run years is shown in Table 2-1.

Table 2-1 Model Run Year and Year Mapping in the EPA 2023 Reference Case

Run Year	Years Represented
2028	2028-2029
2030	2030-2031
2035	2032-2037
2040	2038-2041
2045	2042-2047
2050	2048-2052
2055	2053-2059

Often, models like IPM include a final model run year that is not used in the analysis of results. This technique reduces the likelihood that modeling results in the last represented year will be skewed due to the modeling artifact of having to specify an endpoint in the planning horizon. In reality, economic decision-making will continue to take information into account from years beyond the model's time horizon. This should be considered when assessing model projections from the last output year.

2.3.3 Cost Accounting

As noted, IPM is a dynamic linear programming model that solves for the least cost investment and electricity dispatch strategy for meeting electricity demand subject to resource availability and other operating and environmental constraints. The cost components that IPM considers in deriving an optimal solution include the costs of investing in new capacity options, the cost of installing and operating pollution control technology, fuel costs, and the operation and maintenance costs associated with unit operations. Several cost accounting assumptions are built into IPM's objective function that ensures a technically sound and unbiased treatment of the cost of all investment options offered in the model. These features include:

- All costs in IPM's single multi-year objective function are discounted to a base year. Since the model solves for all run years simultaneously, discounting to a common base year ensures that IPM properly captures complex inter-temporal cost relationships.

- Capital costs in IPM's objective function are represented as the net present value of a levelized stream of annual capital outlays, not as a one-time total investment cost. The payment period used in calculating the levelized annual outlays never extends beyond the model's planning horizon: it is either the book life of the investment or the years remaining in the planning horizon, whichever is shorter. This approach avoids presenting artificially higher capital costs for investment decisions taken closer to the model's time horizon boundary simply because some of that cost would typically be serviced in years beyond the model's view. This treatment of capital costs ensures both realism and consistency in accounting for the full cost of each of the investment options in the model.

- The cost components informing IPM's objective function represent the composite cost over all years in the planning horizon rather than just the cost in the individual model run years. The approach permits the model to capture more accurately the escalation of the cost components over time.

2.3.4 Modeling Wholesale Electricity Markets

IPM is also designed to simulate electricity production activity in a manner that would minimize production costs, as is the intended outcome in wholesale electricity markets. For this purpose, although not designed to capture retail distribution costs, the model captures transmission costs and losses between IPM model regions. However, the model implicitly includes distribution losses since net energy for load,[8] rather than delivered sales,[9] is used to represent electricity demand in the model. Further, the production costs calculated by IPM are the wholesale production costs. In reporting costs, the model does not include embedded costs, such as carrying charges of existing units, which may ultimately be part of the retail cost incurred by end-use consumers.

2.3.5 Load Duration Curves (LDCs)

IPM uses LDCs to provide realism to the dispatching of electric generating units. Unlike a chronological electric load curve, which is simply an hourly record of electricity demand, the LDCs are created by rearranging the hourly chronological electric load data from the highest to lowest (MW) value. To aggregate such load detail into a format enabling this scale of power sector modeling, EPA 2023 Reference Case uses a 24-step piecewise linear representation of the LDC.

IPM can include any number of user-defined seasons. A season can consist of a single month or several months. EPA 2023 Reference Case contains four seasons: summer (May through September), winter

---

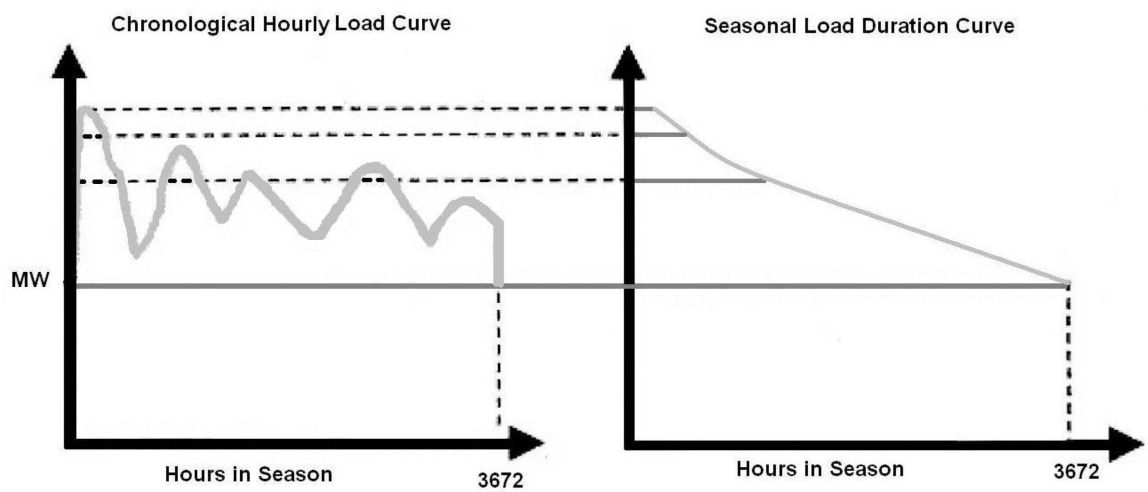
[8] Net energy for load is the electrical energy requirements of an electrical system, defined as system net generation, plus energy received from others, less energy delivered to others through interchange. It includes distribution losses.

[9] Delivered sales is the electrical energy delivered under a sales agreement. It does not include distribution losses.

(December through February), spring (March and April), and a fall season (October, November). The summer season corresponds to the ozone season for modeling seasonal NO_x policies. The remaining seven months are split into a three-month winter season, two-month spring season, and a two-month fall season to better capture winter peak and seasonality in the wind and solar hourly generation profiles. Separate summer, winter, spring, and fall season LDCs are created for each of IPM's model regions. Figure 2-1 below presents side-by-side graphs of a hypothetical chronological hourly load curve and a corresponding load duration curve for a summer season.

The use of seasonal LDCs rather than annual LDCs allows IPM to capture seasonal differences in the level and patterns of customer demand for electricity. For example, in most regions, air conditioner cycling only impacts customer demand patterns during the summer season. The use of seasonal LDCs also allows IPM to capture seasonal variations in the generation resources available to respond to the customer demand depicted in an LDC. For example, power exchanges between utility systems may be seasonal in nature. Some air regulations affecting power plants are also seasonal in nature. This can impact the type of generation resources that are dispatched during a particular season. Further, because of maintenance scheduling for individual generating units, the capacity and utilization for these supply resources also vary between seasons.

Figure 2-1 Hypothetical Chronological Hourly Load Curve and Seasonal Load Duration Curve for Summer Season



In EPA 2023 Reference Case, regional forecasts of peak and total electricity demand from AEO 2023 and hourly load curves from FERC Form 714 and ISO/RTOs[10] are used to derive seasonal load duration curves for each IPM run year in each IPM region. The results of this process are individualized seasonal LDCs that capture the unique hourly electricity demand profile of each region. The LDCs change over time to reflect projected changes in load factors because of future variations in electricity consumption patterns.[11]

Within IPM, LDCs are represented by a discrete number of load segments, or generation blocks, as illustrated in Figure 2-2 for a six-load segment LDC. EPA 2023 Reference Case uses 24 load segments in its seasonal LDCs.

Figure 2-2 illustrates and the following text describes the 24-segment LDCs. Length of time and system demand are the two parameters, which define each segment of the load duration curve. The load segment represents the amount of time (along the x-axis) and the capacity that the electric dispatch mix

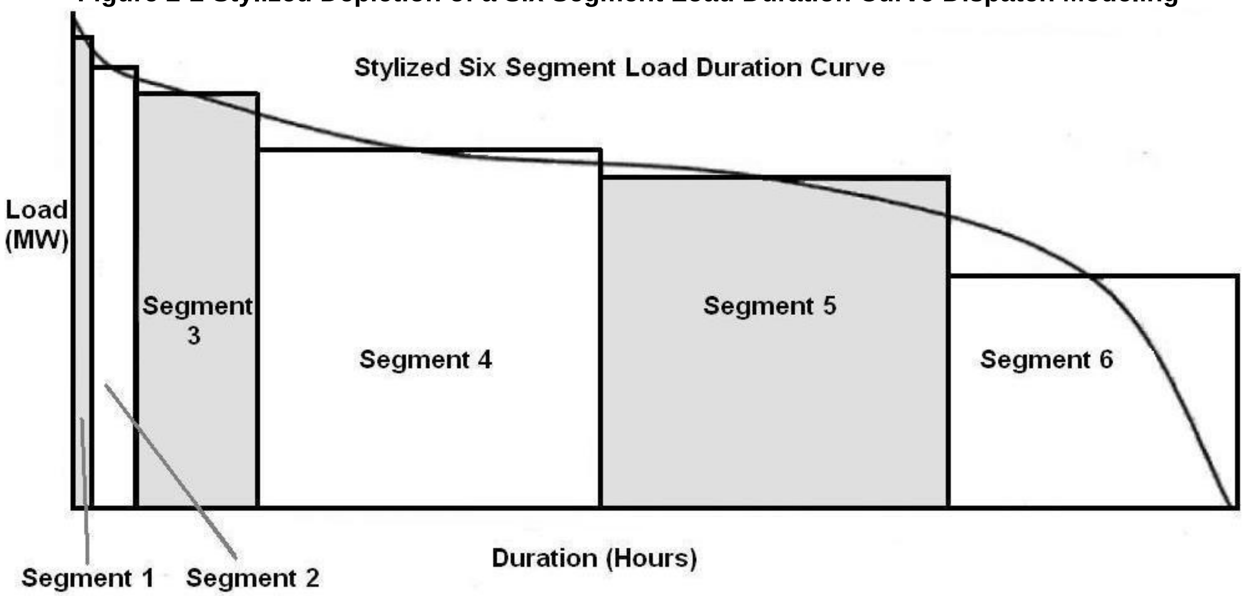
[10] The 2018 load curves are used for all IPM model regions. For further details, see Section 3.2.4.

[11] For further details regarding the source of the load factors used in EPA 2023 Reference Case, see Section 3.2.3.

must be producing (represented along the y-axis) to meet system load. The hours in the LDC are initially clustered into six groups. Group 1 incorporates 1% of all hours in the season with the highest load. Groups 2 to 6 have 4%, 10%, 30%, 30%, and 25% of the hours with progressively lower levels of demand. Each of these 6 groups of hours are further separated into four time of day categories to result in a possible maximum of 24 load segments. This approach better accounts for the impact of solar generation during periods of high demand. The four time-of-day categories are 8PM – 6AM, 6AM – 9AM, 9AM – 5PM, and 5PM – 8PM. Plants are dispatched to meet load based on economic considerations and operating constraints. The most cost-effective plants are assigned to meet load in all 24 segments of the load duration curve. Section 2.3.6 discusses dispatch modeling in more detail.

Table 2-2 contains data of the 2028 seasonal LDCs in each of the 67 model regions in the lower continental U.S.

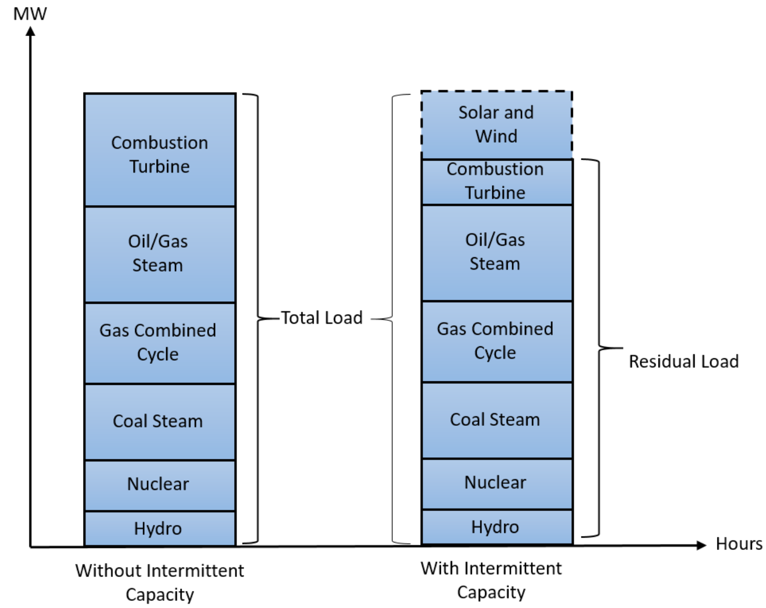
Figure 2-2 Stylized Depiction of a Six Segment Load Duration Curve Dispatch Modeling



In IPM, the dispatching of electricity is based on the variable cost of generation. In the absence of any operating constraints, units with the lowest variable cost generate first. The marginal generating unit, i.e., the generating unit that generates the last unit of electricity, sets the energy price. Physical operating constraints also influence the dispatch order. For example, IPM uses turndown constraints to prevent base load units from cycling, i.e., switching on and off. Turndown constraints often override the dispatch order that would result based purely on the variable cost of generation. Variable costs in combination with turndown constraints enable IPM to dispatch generation resources in a realistic fashion.

Figure 2-3 depicts a stylized dispatch order based on the variable cost of generation. Two hypothetical load segments are subdivided according to the type of generation resources available to respond to the load requirements represented in the segments. The generation resources with the lowest operating cost (i.e., hydro and nuclear) respond first to the demand represented in the LDC and are accordingly at the bottom of dispatch stack.” They are dispatched for the maximum possible number of hours represented in the LDC because of their low operating costs. Generation resources with the highest operating cost (i.e., peaking turbines) are at the top of the dispatch stack,” since they are dispatched last and for the minimum possible number of hours. In the load segment with a non-dispatchable generating resource (i.e., solar or wind), the conventional generation resources are dispatched to the residual load level, where residual load is defined as the difference between the total load and the load met by the non-dispatchable resource.

Figure 2-3 Stylized Dispatch Order in Illustrative Load Segments



Note: Figure 2-3 does not include all plant types modeled in EPA 2023 Reference Case. Intermittent renewable technologies such as wind and solar are considered non-dispatchable and are assigned a specific hourly generation profile.

2.3.6 Fuel Modeling

IPM can model the full range of fuels used for electric generation. The cost, supply, and (if applicable) quality of each fuel included in the model are defined during model set-up. Fuel price and supply are represented in one of two approaches: (1) through a set of supply curves (coal, natural gas, and biomass) or (2) through an exogenous price stream (fuel oil and nuclear fuel). With the first approach, the model endogenously determines the price for the fuel by balancing supply and demand. IPM uses fuel quality information (e.g., the sulfur, chlorine, or mercury content of different types of coal from different supply regions) to determine the emissions resulting from the combustion of the fuel.

EPA 2023 Reference Case includes coal, natural gas, fuel oil, nuclear fuel, biomass, hydrogen, and fossil and non-fossil waste as fuels for electric generation. Chapters 7 to 9 examine the specific assumptions for these fuels.

2.3.7 Transmission Modeling

IPM includes a detailed representation of existing transmission capabilities between model regions. The maximum transmission capabilities between regions are specified by transmission constraints. Additions to transmission lines are represented by decision variables defined for each eligible link and model run year. In IPM's objective function, the decision variables representing transmission additions are multiplied by new transmission line investment cost and capital charge rates to obtain the capital cost associated with the transmission addition. Section 3.3 describes the specific transmission assumptions.

2.3.8 Operating Reserves Modeling

Operating reserves are part of a set of services referred to as essential reliability services required to maintain the reliability and stability of the electric grid.[12] Although definitions vary by market and region, the main services required to ensure reliable grid operation in the U.S. include operating reserves, voltage support, and black start capability. Operating reserves consist of several services and products, including frequency responsive reserves, regulating reserves, contingency reserves, and ramping reserves. The grid operates across timescales ranging from milliseconds to years. Because supply and demand must always be balanced, services must be provided to ensure stability across all timescales. Energy and capacity services ensure that there is sufficient supply to meet demand over a specified period, with a reserve margin in the event of an outage of a generating unit. Operating reserves ensure that there are sufficient resources with the characteristics required to always balance supply and demand. IPM has the capability to model operating reserve services at a regional level and can account for the impact of solar and wind technologies on operating reserve requirements. Section 3.7 describes the specific operating reserve assumptions.

2.3.9 Perfect Competition and Perfect Foresight

IPM assumes perfect competition and perfect foresight. Perfect competition means that IPM models production activity in wholesale electric markets on the premise that these markets subscribe to all assumptions of a perfectly competitive market. The model does not explicitly capture any market imperfections such as market power, transaction costs, informational asymmetry, or uncertainty. However, if desired, appropriately designed sensitivity analyses or redefined model parameters can be used to gauge the impact of market imperfections on the wholesale electric markets.

Perfect foresight implies that agents precisely know the nature and timing of conditions in future years that affect the ultimate costs of decisions along the way. For example, under IPM there is complete foreknowledge of future electricity demand, fuel supplies, and other variables (including regulatory requirements) that are subject to uncertainty and limited foresight. Models like IPM frequently assume perfect foresight to establish a decision-making framework that can estimate cost-minimizing courses of action given the best-guess expectations of these future variables that can be constructed at the time the projections are made.

2.3.10 Scenario Analysis and Regulatory Modeling

IPM offers detailed and flexible modeling features that enable scenario analysis involving different outlooks of key drivers of the power sector and environmental regulations. In particular, the treatment of environmental regulations is endogenous in IPM. By providing a comprehensive representation of compliance options, IPM enables environmental decisions to be made within the model based on least cost considerations rather than exogenously imposing environmental choices on model results. For example, unlike other models that enter allowance prices as an exogenous input during model set-up, IPM obtains allowance prices as an output of the endogenous optimization process of finding the least cost compliance options in response to air regulations. (In linear programming terminology, they are the shadow prices of the respective emission constraints — a standard output from solving a linear programming problem.) IPM can capture a wide variety of regulatory program designs, including emissions trading policies, command-and-control policies, and renewable portfolio standards. Representation of emissions trading policies can include allowance banking, trading, borrowing, bonus allowance mechanisms, and progressive flow controls. Air regulations can be tailored to specific geographical regions and can be restricted to specific seasons. Many of these regulatory modeling capabilities are deployed in EPA 2023 Reference Case.

[12] Essential reliability services have also often been referred to as ancillary services.

2.4 Hardware and Programming Features

IPM produces model files in standard mathematical programming system (MPS) format. The model runs on most PC-platforms. Hardware requirements are dependent on the size of a particular model run. For example, with almost 13.1 million decision variables and 3.4 million constraints, EPA 2023 Reference Case is run on a 64-bit Windows Server 2019 Standard platform with Intel® Xeon® Gold 6240R Processor, 35.75MB Cache, 2.40 GHz (2 processor)/24Core and 512 GB of RAM. Due to the size of the EPA 2023 Reference Case, FICO Xpress Optimization Suite 8.8.0 (a 64-bit, commercial-grade solver with capability of optimizing mixed integer (MIP), linear and non-linear problems using multi-threaded parallel processing) is used.

Two data processors, a front end and the post-processing tool, support the model. The front end creates the necessary inputs that IPM uses. The post-processing tool maps IPM model-plant level outputs to individual electric generating units (a process referred to as parsing—see Section 2.3.1) and creates input files in flat file format as required by EPA's air quality models.

IPM requires an extensive set of input parameters in preparation for a model run. The input parameters are discussed in Section 2.5.1. Results from a model run are presented in a series of detailed reports, which are described in Section 2.5.2.

2.5 Model Inputs and Outputs

2.5.1 Data Parameters for Model Inputs

IPM requires input parameters that characterize the U.S. electric power system, economic outlook, fuel supply and air regulatory framework. Chapters 3-10 contain detailed discussions of the values assigned to these parameters in EPA 2023 Reference Case. The present section lists the key input parameters required by IPM:

Electric System

Existing Generation Resources

- Plant Capacity
- Heat Rate
- Fuels Used
- Emission Limits and Emission Rates for NO_x, SO_2, HCl, CO_2, and mercury
- Existing Pollution Control Equipment and Retrofit Options
- Availability
- Fixed and Variable Operation & Maintenance Costs
- Minimum Generation Requirements (Turn Down Constraints)
- Generation Profiles for Non-Dispatchable Resources

New Generation Resources

- Cost and Operating Characteristics
- Resource Limits and Generation Profiles
- Limitations on Availability

Other System Requirements

- Regional Specification
- Inter-regional Transmission Capabilities
- Reserve Margin Requirements for Reliability

- System Specific Generation Requirements

Economic Outlook

Electricity Demand

- Firm Regional Electricity Demand
- Load Curves

Financial Outlook

- Capital Charge Rates
- Discount Rate

Fuel Supply

Fuel Supply Curves for Coal, Gas, and Biomass

- Fuel Price
- Fuel Quality
- Transportation Costs for Coal, Natural Gas, and Biomass

Regulatory Outlook

Air Regulations for NO_x, SO_2, HCl, CO_2, and Mercury

- Other Air Regulations
- Non-air Regulations (affecting electric generating unit operations)

2.5.2 Model Outputs

IPM produces a variety of output reports. These range from detailed reports, which describe the results for each model plant and run year, to summary reports, which present results for regional and national aggregates. Individual topic areas can be included or excluded at the user's discretion. Standard IPM reports cover the following topics:

- Generation mix
- Capacity mix
- Capacity additions and retirements
- Capacity and energy prices
- Power production costs (capital, fixed and variable operation & maintenance costs, and fuel costs)
- Fuel consumption
- Fuel supply and demand
- Fuel prices for coal, natural gas, and biomass
- Emissions (NO_x, SO_2, HCl, CO_2, and mercury)
- Emission allowance prices

List of tables that are uploaded directly to the web:

Table 2-2 Load Curves used in EPA 2023 Reference Case

3. Power System Operation Assumptions

This chapter describes the assumptions pertaining to the North American electric power system as represented in the EPA 2023 Reference Case.

3.1 Model Regions

EPA 2023 Reference Case models the power sector in the contiguous United States, and 10 Canadian provinces (with Newfoundland and Labrador represented as two regions on the electricity network even though politically they constitute a single province[13]) as an integrated network.[14]

There are 67 IPM model regions covering the contiguous United States.[15] The IPM model regions are largely consistent with the regional configuration presented in the NERC Long-Term Reliability Assessments.[16] IPM model regions reflect the administrative structure of regional transmission organizations (RTOs) and independent system operators (ISOs). Further disaggregation allows a more accurate characterization of the operation of the United States power markets by providing the ability to represent transmission bottlenecks across RTOs and ISOs, as well as key transmission limits within them. Other items of note in the IPM regional definition include:

- The NERC assessment regions of MISO, PJM, and SPP cover the areas of the corresponding RTOs and are designed to better represent transmission limits and dispatch in each area. In IPM, model regions are designed to represent planning areas within each RTO and/or areas with internal transmission limits. Accordingly, MISO area is disaggregated into 14 IPM regions. PJM assessment area is disaggregated into 9 IPM regions, and SPP is disaggregated into 5 IPM regions.

- New York is disaggregated into 8 IPM regions, to better represent flows around New York City and Long Island, and to better represent flows across New York State from Canada and other United States regions. The NERC assessment region SERC is divided into Kentucky, TVA, AECI, the Southeast, and the Carolinas. New England is disaggregated into CT, ME, and rest of New England regions. ERCOT is also disaggregated into 3 IPM regions. IPM retains the NERC assessment areas within the overall WECC regions, and further disaggregates these areas using sub-regions from the WECC Power Supply Assessment. In total, WECC is disaggregated into 16 IPM regions.

Figure 3-1 contains a map showing the EPA 2023 Reference Case model regions.

Table 3-1 defines the abbreviated region names appearing on the map and gives a crosswalk between the IPM model regions, the NERC assessment regions, and regions used in the Energy Information Administration's (EIA's) National Energy Model System (NEMS) that is the basis for EIA's Annual Energy Outlook (AEO) reports.

---

[13] This results in a total of 11 Canadian model regions being represented in EPA 2023 Reference Case.

[14] Because United States and the Canadian power markets are being modeled in an integrated manner, IPM can model the transfer of power in between the two countries endogenously. This transfer of power is limited by the available transmission capacity in between the two countries. Hence, it is possible for the model to build capacity in one country to meet demand in the other country when economic and is operationally feasible.

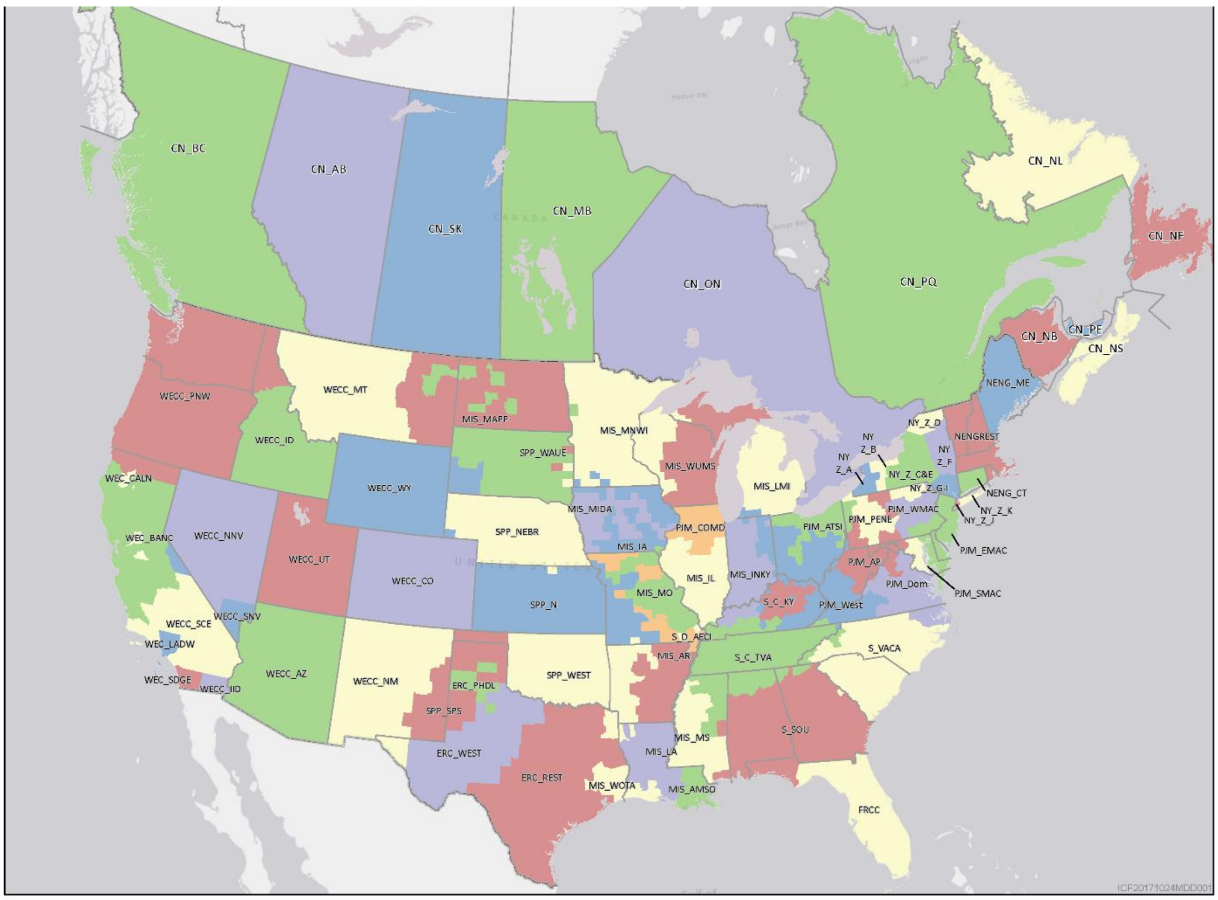
[15] The 67 U.S. IPM model regions include 64 power market regions and 3 power switching regions.

[16] IPM regions also generally conform to the boundaries of the National Energy Modeling System (NEMS) model to provide for a more accurate translation of demand projections taken from the Annual Energy Outlook (AEO).

3.2 Electric Load Modeling

Net energy for load and net internal demand are inputs to IPM that together are used to represent the grid demand for electricity. Net energy for load is the projected annual electricity grid demand, prior to accounting for intra-regional transmission and distribution losses. Net internal demand (peak demand) is the maximum hourly demand within a given year after removing interruptible demand. Table 3-2 shows the electricity demand assumptions (expressed as net energy for load) used in EPA 2023 Reference Case. It is based on the net energy for load in the AEO 2023 Reference Case.[17] Also added is the incremental demand from USEPA OTAQ's on the book rules as of end of December 2023 that are not captured in the AEO 2023 demand projections. Incremental demand was calculated by running OMEGA and MOVES models to calculate total energy consumption for all Zero Emission Vehicles (ZEVs) by EPA's OTAQ (see Attachment 3-1).

Figure 3-1 EPA 2023 Reference Case Model Regions



---

[17] The electricity demand in EPA 2023 Reference Case for the U.S. lower 48 states and the District of Columbia is obtained for each IPM model region by disaggregating the Total Net Energy for Load projected for the corresponding NEMS Electric Market Module region as reported in the Electricity and Renewable Fuel Tables 54.1-54.25 at https://www.eia.gov/outlooks/aeo/tables_ref.php.

For purposes of documentation, Table 3-2 and Table 3-3 present the net energy for load on a national- and regional-level, respectively. EPA 2023 Reference Case models net energy for load in each of the 67 U.S. IPM regions in the following steps:

- The net energy for load in each of the 25 NEMS electricity regions is taken from the AEO 2023 Reference Case.
- NERC balancing areas are assigned to both IPM regions and NEMS regions to determine the share of the NEMS net energy for load in each NEMS region that falls into each IPM region. These shares are calculated in the following steps.
  - Map the NERC Balancing Authorities/ Planning Areas in the United States to the 67 IPM regions.
  - Map the Balancing Authorities/ Planning Areas in the United States to the 25 NEMS regions.
  - Using the 2016 hourly load data from FERC Form 714, ISOs, and RTOs, calculate the proportional share of the load in the 25 NEMS regions that share geography with the 67 IPM regions.
  - Using the calculated load shares for each NEMS region that falls into each IPM region, calculate the total net energy for load for each IPM region from the NEMS regional load in the AEO 2023 Reference Case.

Table 3-1 Mapping of NERC Regions and NEMS Regions with the EPA 2023 Reference Case Model Regions

NERC Assessment Region	AEO 2021 NEMS Region	Model Region	Model Region Description
ERCOT	TRE (1)	ERC_REST	ERCOT_Rest
	TRE (1)	ERC_GWAY	ERCOT_Tenaska Gateway Generating Station
	TRE (1)	ERC_FRNT	ERCOT_Tenaska Frontier Generating Station
	TRE (1)	ERC_WEST	ERCOT_West
	TRE (1)	ERC_PHDL	ERCOT_Panhandle
FRCC	FRCC (2)	FRCC	FRCC
MAPP	MISW (3), SPPN (19)	MIS_MAPP	MISO_MT, SD, ND
MISO	MISC (4)	MIS_IL	MISO_Illinois
	MISC (4)	MIS_INKY	MISO_Indiana (including parts of Kentucky)
	MISW (3)	MIS_IA	MISO_Iowa
	MISW (3)	MIS_MIDA	MISO_Iowa-MidAmerican
	MISE (5)	MIS_LMI	MISO_Lower Michigan
	MISC (4)	MIS_MO	MISO_Missouri
	MISW (3)	MIS_WUMS	MISO_Wisconsin- Upper Michigan (WUMS)
	MISW (3)	MIS_MNWI	MISO_Minnesota and Western Wisconsin
	MISS (6)	MIS_WOTA	MISO_WOTAB (including Western)
	MISS (6)	MIS_AMSO	MISO_Amite South (including DSG)
	MISS (6)	MIS_AR	MISO_Arkansas
	MISS (6)	MIS_MS	MISO_Mississippi
	MISS (6)	MIS_LA	MISO_Louisiana
ISO-NE	ISNE (7)	NENG_CT	ISONE_Connecticut
	ISNE (7)	NENGREST	ISONE_MA, VT, NH, RI (Rest of ISO New England)
	ISNE (7)	NENG_ME	ISONE_Maine
NYISO	NYUP (9)	NY_Z_C&E	NY_Zone C&E
	NYUP (9)	NY_Z_F	NY_Zone F (Capital)
	NYUP (9)	NY_Z_G-I	NY_Zone G-I (Downstate NY)
	NYCW (8)	NY_Z_J	NY_Zone J (NYC)
	NYCW (8)	NY_Z_K	NY_Zone K (LI)
	NYUP (9)	NY_Z_A	NY_Zone A (West)

NERC Assessment Region	AEO 2021 NEMS Region	Model Region	Model Region Description
	NYUP (9)	NY_Z_B	NY_Zone B (Genesee)
	NYUP (9)	NY_Z_D	NY_Zone D (North)
PJM	PJME (10)	PJM_WMAC	PJM_Western MAAC
	PJME (10)	PJM_EMAC	PJM_EMAAC
	PJME (10)	PJM_SMAC	PJM_SWMAAC
	PJMW (11)	PJM_West	PJM West
	PJMW (11)	PJM_AP	PJM_AP
	PJMC (12)	PJM_COMD	PJM_ComEd
	PJMW (11)	PJM_ATSI	PJM_ATSI
	PJMD (13)	PJM_Dom	PJM_Dominion
	PJME (10)	PJM_PENE	PJM_PENELEC
SERC-E	SRCA (14)	S_VACA	SERC_VACAR
SERC-N	SRCE (16)	S_C_KY	SERC_Central_Kentucky
	MISC (4), SPPS (17)	S_D_AECI	SERC_Delta_AECI
	SRCE (16)	S_C_TVA	SERC_Central_TVA
SERC-SE	SRSE (15)	S_SOU	SERC_Southeastern
SPP	SPPN (19)	SPP_NEBR	SPP Nebraska
	SPPC (18)	SPP_N	SPP North- (Kansas, Missouri)
	SPPS (17)	SPP_KIAM	SPP_Kiamichi Energy Facility
	SPPS (17)	SPP_WEST	SPP West (Oklahoma, Arkansas, Louisiana)
	SPPS (17)	SPP_SPS	SPP SPS (Texas Panhandle)
	SPPN (19)	SPP_WAUE	SPP_WAUE
California/Mexico (CA/MX)	CANO (21)	WEC_CALN	WECC_Northern California (not including BANC)
	CASO (22)	WEC_LADW	WECC_LADWP
	CASO (22)	WEC_SDGE	WECC_San Diego Gas and Electric
	CASO (22)	WECC_SCE	WECC_Southern California Edison
Northwest Power Pool (NWPP)	NWPP (23)	WECC_MT	WECC_Montana
	CANO (21)	WEC_BANC	WECC_BANC
	BASN (25)	WECC_ID	WECC_Idaho
	BASN (25)	WECC_NNV	WECC_Northern Nevada
	BASN (25), SRSG (20)	WECC_SNV	WECC_Southern Nevada
	BASN (25)	WECC_UT	WECC_Utah
	NWPP (23)	WECC_PNW	WECC_Pacific Northwest
Rocky Mountain Reserve Group (RMRG)	RMRG (24)	WECC_CO	WECC_Colorado
	BASN (25), RMRG (24)	WECC_WY	WECC_Wyoming
Southwest Reserve Sharing Group (SRSG)	SRSG (20)	WECC_AZ	WECC_Arizona
	SRSG (20)	WECC_NM	WECC_New Mexico
	SRSG (20)	WECC_IID	WECC_Imperial Irrigation District (IID)
Canada		CN_AB	Canada_Alberta
		CN_BC	Canada_British Columbia
		CN_MB	Canada_Manitoba
		CN_NB	Canada_New Brunswick
		CN_NF	Canada_New Foundland
		CN_NL	Canada_Labrador
		CN_PE	Canada_Prince Edward island
		CN_NS	Canada_Nova Scotia
		CN_ON	Canada_Ontario
		CN_PQ	Canada_Quebec
		CN_SK	Canada_Saskatchewan

Table 3-2 Electric Load Assumptions in the EPA 2023 Reference Case

Year	Net Energy for Load (Billions-of kWh)
2028	4,459
2030	4,597
2035	4,939
2040	5,254
2045	5,576
2050	5,928
2055	6,274

Table 3-3 Regional Electric Load Assumptions in the EPA 2023 Reference Case

IPM Region	Net Energy for Load (Billions of kWh)						
	2028	2030	2035	2040	2045	2050	2055
ERC_FRNT	0	0	0	0	0	0	0
ERC_GWAY	0	0	0	0	0	0	0
ERC_PHDL	0	0	0	0	0	0	0
ERC_REST	399	411	438	466	494	529	563
ERC_WEST	35	35	38	40	43	46	49
FRCC	267	276	296	314	336	359	383
MIS_AMSO	37	37	40	42	44	47	50
MIS_AR	43	44	46	49	52	55	59
MIS_IA	23	23	25	26	27	28	29
MIS_IL	52	53	55	58	60	63	66
MIS_INKY	101	103	108	113	118	124	129
MIS_LA	56	57	60	64	68	72	77
MIS_LMI	106	109	117	123	128	135	140
MIS_MAPP	9	9	10	10	11	11	12
MIS_MIDA	29	29	31	32	34	35	37
MIS_MNWI	96	99	106	112	118	123	129
MIS_MO	42	43	46	48	50	53	55
MIS_MS	26	27	29	30	32	35	37
MIS_WOTA	38	39	41	43	46	49	52
MIS_WUMS	70	72	76	80	84	88	92
NENG_CT	34	35	39	41	44	47	49
NENG_ME	12	13	14	15	16	17	18
NENGREST	90	94	105	114	122	130	137
NY_Z_A	16	17	19	20	22	23	24
NY_Z_B	10	11	12	13	14	15	15
NY_Z_C&E	24	25	28	30	32	34	36
NY_Z_D	4	4	5	5	5	6	6
NY_Z_F	13	13	15	16	17	18	19
NY_Z_G-I	20	21	23	25	27	28	30
NY_Z_J	55	56	60	64	67	71	75
NY_Z_K	25	26	29	31	32	34	36
PJM_AP	51	52	56	58	61	65	68
PJM_ATSI	72	74	79	83	87	92	96
PJM_COMD	101	104	111	116	121	126	131
PJM_Dom	116	121	129	137	145	154	164
PJM_EMAC	154	161	179	193	206	219	230
PJM_PENE	18	19	20	21	22	24	25
PJM_SMAC	69	72	77	81	85	91	95
PJM_West	210	214	224	234	245	257	269
PJM_WMAC	59	60	63	66	70	75	79
S_C_KY	35	35	37	39	41	43	45
S_C_TVA	172	175	184	192	201	211	221
S_D_AECI	18	19	19	20	21	22	23
S_SOU	256	263	278	293	311	330	349

IPM Region	Net Energy for Load (Billions of kWh)						
	2028	2030	2035	2040	2045	2050	2055
S_VACA	237	244	259	274	293	312	332
SPP_KIAM	0	0	0	0	0	0	0
SPP_N	80	82	87	91	96	101	106
SPP_NEBR	32	33	35	37	39	41	42
SPP_SPS	37	37	39	42	44	47	50
SPP_WAUE	26	27	28	29	30	32	33
SPP_WEST	110	113	120	128	136	145	155
WEC_BANC	17	17	19	21	22	24	25
WEC_CALN	131	137	154	168	181	193	205
WEC_LADW	37	40	48	53	57	61	64
WEC_SDGE	24	25	28	31	33	35	37
WECC_AZ	105	109	119	128	138	149	162
WECC_CO	74	77	87	95	103	111	119
WECC_ID	26	27	29	31	34	37	40
WECC_IID	5	5	5	6	7	7	8
WECC_MT	14	14	15	16	18	19	21
WECC_NM	25	26	28	31	34	37	40
WECC_NNV	15	15	17	18	19	21	23
WECC_PNW	190	196	213	231	248	266	284
WECC_SCE	119	125	140	153	164	175	186
WECC_SNV	29	30	33	35	38	41	44
WECC_UT	41	42	46	50	54	58	63
WECC_WY	25	25	27	29	31	34	37

3.2.1 Distributed Solar Photovoltaics

Distributed solar photovoltaic (DPV) generation constitutes a significant and growing source of new electricity generation in the United States. As a result, DPV generation has become increasingly pertinent from an integrated resource planning perspective because it has the potential to significantly impact the shapes of the residual load curves that are available for the grid-connected generation sources to meet. The DPV implementation in EPA 2023 Reference Case seeks to reflect this impact on the load shape by directly representing the magnitude and timing of the electricity demand projected to be satisfied by distributed solar PV as part of the total net energy for load.

<u>Electricity Demand Assumptions:</u> Electricity demand assumptions are represented by the total net energy for load from the AEO 2023 Reference Case. To account for DPV generation, the AEO 2023 Reference Case projections of end-use solar photovoltaic generation are added to AEO 2023 Reference Case projections of net energy for load.

<u>Unit-Level Data Assumptions:</u> Non-dispatchable DPV model plants at the IPM region and state level are implemented in IPM to capture the impact of the DPV generation on the shapes of the residual load curves available for the grid-connected generation sources to meet. Their generation patterns are governed by assumed DPV generation profiles provided by NREL.

The capacity and capacity factors of DPV model plants are calculated as follows. First, the AEO 2023 Reference Case end-use solar photovoltaic generation and capacity data that are available at the NEMS region level are apportioned to IPM region level, using the methodology for mapping the electricity demand projections from NEMS regions to IPM regions. Then, the IPM region-level data are further apportioned to the state level, using state shares of regional energy sales as reported by the 2020 EIA Form 861. The data are next used to derive IPM region and state-level capacity factor data. Finally, the resulting IPM region and state-level capacity data are hardwired to the DPV model plants, while the capacity factor data are implemented by appropriately scaling the NREL's IPM region and state-level DPV hourly generation profiles. For this analysis, NREL's DPV hourly generation profiles for the highest resource class in each of the IPM region and state categories were scaled by multiplying the hourly generation values with the ratio between the AEO 2023 Reference Case capacity factor and the capacity factor underlying the NREL's hourly generation profiles.

3.2.2 Demand Elasticity

EPA 2023 Reference Case has the capability to endogenously adjust electricity demand based on changes to the price of power. However, this capability is exercised only for sensitivity analyses where different price elasticities of demand are specified for purposes of comparative analysis. The default assumption is that the electricity demand shown in Table 3-2, which was derived from EIA modeling that already considered price elasticity of demand, is static as IPM solves for least-cost electricity supply. The approach maintains a consistent expectation of future load between the EPA Platform and the corresponding EIA Annual Energy Outlook reference case (e.g., between EPA 2023 Reference Case and the AEO 2023 Reference Case).

3.2.3 Net Internal Demand (Peak Demand)

EPA 2023 Reference Case has separate regional winter, spring, summer, and fall peak demand values, as derived from each region's seasonal load duration curve (found in Table 2-2). Peak projections for the 2028-2032 period were estimated based on NERC ES&D 2022 load factors[18], and the estimated energy demand projections are shown in Table 3-3. For post 2032 years when NERC ES&D 2022 load factors were not available, the NERC ES&D 2022 load factors for 2032 were projected forward using growth factors embedded in the AEO 2023 Reference Case load factor projections.

Table 3-4 illustrates the national sum of each region's seasonal peak demand, and Table 3-26 presents each region's seasonal peak demand. Because each region's seasonal peak demand need not occur at the same time, the national peak demand is defined as non-coincidental (i.e., national peak demand is a summation of each region's peak demand at whatever point in time that region's peak occurs across the given time period).

Table 3-4 National Non-Coincidental Net Internal Demand in the EPA 2023 Reference Case

Year	Peak Demand (GW)			
	Winter	Spring	Summer	Fall
2028	720	615	808	662
2030	742	636	830	683
2035	799	691	890	739
2040	854	739	955	790
2045	915	789	1,028	845
2050	983	843	1,110	906
2055	1,038	890	1,173	956

Notes:
This data is an aggregation of the model-region-specific peak demand loads.

[18] Load factors can be calculated at the NERC assessment region level based on the NERC ES&D 2022 projections of net energy for load and net internal demand. All IPM regions that map to a particular NERC assessment region are assigned the same load factors. In instances where sub regional level load factor details could be estimated in selected ISO/RTO zones, those load factors were assigned to the associated IPM region.

3.2.4 Regional Load Shapes

EPA 2023 Reference Case uses the year 2018 as the "normal weather year"[19] for all IPM regions. The 2018 chronological hourly load data were assembled by aggregating individual utility load curves taken from Federal Energy Regulatory Commission Form 714 data and individual ISOs and RTOs.

3.3 Transmission

The contiguous United States and Canada can be represented by several power markets that are interconnected by a transmission grid. This section details the assumptions about the transfer capabilities and costs used to represent this transmission grid in the EPA 2023 Reference Case.

3.3.1 Inter-regional Transmission Capability

Table 3-27[20] shows the firm and non-firm Total Transfer Capabilities (TTCs) between model regions. TTC is a metric that represents the capability of the power system to import or export power reliably from one region to another. The purpose of TTC analysis is to identify the sub-markets created by commercially significant constraints. Firm TTCs, also called Capacity TTCs, specify the maximum power that can be transferred reliably, even after the contingency loss of a single transmission system element such as a transmission line or a transformer (a condition referred to as N-1, or "N minus one"). Firm TTCs provide a high level of reliability and are used for capacity transfers. Non-firm TTCs, also called Energy TTCs, represent the maximum power that can be transferred reliably when all facilities are under normal operation (a condition referred to as N-0, or "N minus zero"). Non-firm TTCs specify the sum of the maximum firm transfer capability between sub-regions and incremental curtailable non-firm transfer capability. Non-firm TTCs are used for energy transfers since they provide a lower level of reliability than Firm TTCs, and transactions using Non-firm TTCs can be curtailed under emergency or contingency conditions.

The amount of energy and capacity transferred on a given transmission link is modeled on a seasonal basis for all run years in the EPA 2023 Reference Case. All the modeled transmission links have the same TTCs for all seasons. The maximum values for firm and non-firm TTCs, wherever available, were obtained from public sources, such as market reports and regional transmission plans, listed below.

i) Generic Transmission Constraint Definitions posted to MIS Secure as of May 1, 2022,
ii) ISO New England, 2020 Economic Study: Draft Scope of Work and High-Level Assumptions for Production Simulations - Part II of III, June 17, 2020,
iii) ISO New England, Forward Capacity Auction 17 Transmission Transfer Capabilities & Capacity Zone Development, April 28, 2022,
iv) IESO, Annual Planning Outlook, Transfer Capabilities Across Major Interfaces and Interties, December 2021,
v) Manitoba Hydro, Transmission Interface Capability Report, May 19, 2022,
vi) New York State Reliability Council, LLC, New York Control Area Installed Capacity Requirement for the Period May 2023 to April 2024, Appendices, December 9, 2022,
vii) PJM Real Time transfer limits,
viii) PJM 2022 RTEP Base Assumptions,

[19] The term "normal weather year" refers to a representative year whose weather is closest to the long-term (e.g., 30 year) average weather. The selection of a "normal weather year" can be made, for example, by comparing the cumulative annual heating degree days (HDDs) and cooling degree days (CDDs) in a candidate year to the long-term average. For any individual day, heating degree days indicate how far the average temperature fell below 65 degrees F; cooling degree days indicate how far the temperature averaged above 65 degrees F. Cumulative annual heating and cooling degree days are the sum of all the HDDs and CDDs, respectively, in a given year.

[20] In the column headers in Table 3-27, the term "Energy TTC (MW)" is equivalent to non-firm TTCs and the term "Capacity TTC (MW)" is equivalent to firm TTCs.

ix) PJM, 2024/2025 RPM Base Residual Auction Planning Period Parameters,
x) WECC 2022 Western Assessment of Resource Adequacy Report and associated Topology Maps
xi) WECC 2016 Power Supply Assessment,
xii) AESO Information Document ATC and Transfer Path Management ID #2011-001R,
xiii) Nova Scotia Power Transmission System Operating Limits 2022,
xiv) Atlantic Energy Gateway Transmission Modeling Study Report.

Where public sources were not available, the maximum values for firm and non-firm TTCs are based on ICF's expert view. ICF analyzes the operation of the grid under normal and contingency conditions, using industry-standard methods, and calculates the transfer capabilities between regions. To calculate the transfer capabilities, ICF uses standard power flow data developed by the market operators, transmission providers, or utilities, as appropriate.

Furthermore, each transmission link between model regions shown in Table 3-27 represents a one-directional flow of power on that link. Due to the physical nature of electron flow across the grid, the maximum amount of power flow possible from region A to region B may be more or less than the maximum amount of flow of power possible from region B to region A.

3.3.2 Joint Transmission Capacity and Energy Limits

Table 3-5 shows the annual joint limits to the transmission capabilities between model regions, which are identical for the firm (capacity) and non-firm (energy) transfers. The joint limits were obtained from public sources where available or based on ICF's expert view. A joint limit represents the maximum simultaneous firm or non-firm power transfer capability of a group of interfaces. It restricts the amount of firm or non-firm transfers between one model region (or group of model regions) and a different group of model regions. For example, the New England market is connected to the New York market by four transmission links:

- NENG_CT to NY_Z_G-I: 600 MW
- NENGREST to NY_Z_F: 800 MW
- NENGREST to NY_Z_D: 0 MW
- NENG_CT to NY_Z_K: 734 MW

Without any simultaneous transfer limits, the total transfer capability from New England to New York would be 2,134 MW. However, current system conditions and reliability requirements limit the total simultaneous transfers from New England to New York to 1,730 MW, as shown in Table 3-5. IPM uses joint limits to ensure that this and similar reliability limits are not violated. Therefore, each individual link can be utilized to its limit as long as the total flow on all links does not exceed the joint limit.

Table 3-5 Annual Joint Capacity and Energy Limits to Transmission Capabilities between Model Regions in the EPA 2023 Reference Case

Region Connections	Transmission Path	Capacity TTC (MW)	Energy TTC (MW)
NY_Zone G-I (Downstate NY) & NY_Zone J (NYC) to NY_Zone K (LI)	NY_Z_G-I to NY_Z_K NY_Z_J to NY_Z_K	1,613	
NY_Zone K(LI) to NY_Zones G-I (Downstate NY) & NY_Zone J (NYC)	NY_Z_K to NY_Z_G-I NY_Z_K to NY_Z_J	135	
ISO NE to NYISO	NENG_CT to NY_Z_G-I NENGREST to NY_Z_F NENG_CT to NY_Z_K NENGREST to NY_Z_D	1,730	
NYISO to ISO NE	NY_Z_G-I to NENG_CT NY_Z_F to NENGREST NY_Z_K to NENG_CT NY_Z_D to NENGREST	1,730	
PJM West & PJM_PENELEC & PJM_AP to PJM_ATSI	PJM_West to PJM_ATSI	9,925	

Region Connections	Transmission Path	Capacity TTC (MW)	Energy TTC (MW)
	PJM_PENE to PJM_ATSI PJM_AP to PJM_ATSI		
PJM_ATSI to PJM West & PJM_PENELEC & PJM_AP	PJM_ATSI to PJM_West PJM_ATSI to PJM_PENE PJM_ATSI to PJM_AP	9,925	
PJM_West & PJM_Dominion to SERC VACAR	PJM_West to S_VACA PJM_Dom to S_VACA	2,208	3,424
SERC VACAR to PJM_West & PJM_Dominion	S_VACA to PJM_West S_VACA to PJM_Dom	2,208	3,424
MIS_MAPP & SPP_WAUE to MIS_MNWI	MIS_MAPP to MIS_MNWI SPP_WAUE to MIS_MNWI	3,000	5,000
MIS_MNWI to MIS_MAPP & SPP_WAUE	MIS_MNWI to MIS_MAPP MIS_MNWI to SPP_WAUE	3,000	5,000
SERC_Central_TVA & SERC_Central_Kentucky to PJM West	S_C_TVA to PJM_West S_C_KY to PJM_West	3,000	4,500
PJM West to SERC_Central_TVA & SERC_Central_Kentucky	PJM_West to S_C_TVA PJM_West to S_C_KY	3,000	4,500
MIS_INKY to PJM_COMD & PJM_West	MIS_INKY to PJM_COMD MIS_INKY to PJM_West	4,586	6,509
PJM_COMD & PJM_West to MIS_ INKY	PJM_COMD to MIS_INKY PJM_West to MIS_INKY	5,998	8,242
NY_Z_C&E & NY_Z_A to PJM_PENELEC	NY_Z_C&E to PJM_PENE NY_Z_A to PJM_PENE	1,050	
PJM_PENELEC to NY_Z_C&E & NY_Z_A	PJM_PENE to NY_Z_C&E PJM_PENE to NY_Z_A	1,365	
PJM_SMAC & PJM_WMAC to PJM_EMAC	PJM_SMAC to PJM_EMAC PJM_WMAC to PJM_EMAC	8,594	
PJM_AP, PJM_DOM, PJM_EMAC, PJM_WMAC to PJM_SMAC	PJM_AP to PJM_SMAC PJM_DOM to PJM_SMAC PJM_EMAC to PJM_SMAC PJM_WMAC to PJM_SMAC	7,947	
PJM_AP, PJM_ATSI & PJM_DOM to PJM_PENELEC, PJM_SMAC & PJM_WMAC	PJM_AP to PJM_PENE PJM_AP to PJM_SMAC PJM_AP to PJM_WMAC PJM_ATSI to PJM_PENE PJM_DOM to PJM_SMAC	5,965	
NY_Z_C&E, NY_Z_F & NENG_CT to NY_Z_G-I	NY_Z_C&E to NY_Z_G-I NY_Z_F to NY_Z_G-I NENG_CT to NY_Z_G-I	5,250	
NY_Z_A to NY_Z_B & PJM_PENELEC	NY_Z_A to NY_Z_B NY_Z_A to PJM_PENE	2,650	
CN_AB to CN_BC & WECC_MT	CN_AB to WECC_MT CN_AB to CN_BC	1,000	
CN_BC & WECC_MT to CN_AB	WECC_MT to CN_AB CN_BC to CN_AB	1,110	

3.3.3 Transmission Link Wheeling Charge

The transmission link wheeling charge is the cost of transferring electric power from one region to another. The EPA 2023 Reference Case has no wheeling charges within individual IPM regions and no charges between IPM regions that fall within the same RTO. The wheeling charges, expressed in 2022 mills/kWh, are shown in Table 3-27 in the column labeled "Transmission Tariff."

3.3.4 Transmission Losses

The EPA 2023 Reference Case assumes a 2.8 percent inter-regional transmission loss of energy transferred in the Western interconnection and a 2.4 percent inter-regional transmission loss of energy transferred in Eastern Interconnection and ERCOT. These factors are based on average loss factors calculated from standard power flow data developed by the transmission providers.

3.3.5 New Transmission Builds

EPA 2023 Reference Case includes new endogenous transmission build options starting in 2030.[21] An important dynamic driving this change is the increased deployment of new renewable generation capacity that is at a significant distance from the load centers driving its deployment. Consequently, the inability to deploy additional transmission capacity endogenously may be unduly limiting the economic potential of new renewable capacity. More generally, enabling transmission capacity expansion allows IPM to co-optimize generation and transmission builds and solve for the optimal mix of generation and transmission additions to meet capacity and energy needs.

For these transmission build options, representative costs were derived from NREL's Jobs and Economic Development Impact (JEDI) model. Inputs to the JEDI model included the likely voltage rating, a representative length of line between each region, and the type of terrain expected to be traversed. The approach included:

- Determination of likely voltage rating. The cost of transmission lines varies with voltage rating. Higher voltage ratings typically have higher costs per unit length. To minimize maintenance, inventory, and other costs, it is likely that a new transmission line in an area will be rated at a voltage similar to transmission lines already existing in the area. Further, it is likely that an interregional line would be rated at or close to the highest voltage rating of the area's backbone transmission system due to economies of scale. ICF reviewed the backbone transmission system in each of the model regions to determine the likely voltage rating that would be used for new transmission lines. For example, the backbone transmission system in the Northeast (New York and the New England states) is rated 345 kV. While the systems also have underlying 230 kV and lower voltage transmission lines, it is likely that new inter-regional transmission lines would be rated 345 kV. In most of the southeastern U.S. states the backbone voltage is 500 kV; therefore, we assume that a line between Florida and Southern Company, for example, would likely be rated 500 kV.

- Estimation of representative line lengths. The cost of transmission lines also varies with the length of line. The length of a particular line will depend on several factors, including the location of existing interconnecting substations, existing rights-of-way, area of need within the zone, and other factors. The length cannot be determined in advance without knowing the specific application. For this analysis EPA made a simplifying assumption that lines would be built between the geographic centers of the regions. In instances where the transmission line lengths that are calculated using the centroid approach are longer than a typical maximum for the assumed line voltage, the typical maximum[22] length was used to estimate the unit cost of the line.

- Assessment of terrain. Transmission line costs also vary with terrain. For example, a line traversing a mountainous region would have a higher capital cost than a line in a flat, rural area. Terrain classifications in the JEDI model include "Desert/Remote", "Mountainous", and "Flat With Access". The model also allows for specification of population densities, including "In Town", "Near Town", and "Rural". Terrain classifications and population densities were assigned that best represented the area that lines between the regions would likely traverse. For example, the terrain traversed by a line between New York City and Long Island was classified as Flat With

[21] New transmission options in EPA 2023 Reference Case are built simultaneously in both directions as transmission lines when built can allow bidirectional flows.

[22] The typical maximum line lengths by voltage class were estimated based on a review of projects that were under construction or complete in 2015-2018 EIA Form 411 datasets. The EIA Form 411 data was supplemented with information from the year 2016 EEI report Transmission Projects: At a Glance that describes major high voltage projects proposed by investor-owned utilities.

Access and the population density was specified as In Town, while a line between Nebraska and the Oklahoma-Missouri area was classified as Flat With Access and Rural.

Together, this information was used to determine the total cost of a new transmission line between each pair of contiguous IPM regions. ICF then calculated a unit cost in $/kW for each transmission link using estimates of the power (MW) ratings for each transmission line. The bidirectional unit costs for new transmission lines are shown in Table 3-27.

3.4 International Imports

The United States electric power system is connected with the transmission grids in Canada and Mexico and the three countries actively trade in electricity. The Canadian power market is endogenously modeled in EPA 2023 Reference Case, but Mexico is not. International electric trading between the United States and Mexico is represented by an assumption of net imports based on information from AEO 2023 Reference Case. Table 3-6 summarizes the assumptions on net imports into the United States from Mexico.

Table 3-6 International Electricity Imports (billions kWh) in the EPA 2023 Reference Case

	2028	2030	2035	2040	2045	2050	2055
Net Imports from Mexico	3.05	3.05	3.05	2.77	2.77	2.77	2.77

Note 1: Source: AEO 2023 Reference Case

Note 2: Imports & exports transactions from Canada are endogenously modeled in IPM.

3.5 Capacity, Generation, and Dispatch

While the capacity of existing units is an exogenous input into IPM, the dispatch of those units is an endogenous decision. The capacity of existing generating units included in EPA 2023 Reference Case can be found in the National Electrical Energy Data System (NEEDS), a database which provides IPM with information on all currently operating and planned-committed electric generating units. NEEDS is discussed in Chapter 4.

A unit’s generation over a time period is defined by its dispatch pattern. IPM determines the optimal economic dispatch profile given the operating and physical constraints imposed on the unit. In EPA 2023 Reference Case, unit-specific operational and physical constraints are represented through availability, capacity factor, and turndown constraints.

3.5.1 Availability

Power plant availability is the percentage of time that a generating unit is available to provide electricity to the grid. Availability takes into account both scheduled maintenance and forced outages; it is formally defined as the ratio of a unit’s available hours adjusted for the derating of capacity (due to partial outages) to the total number of hours in a year when the unit was in an active state. For most types of units in IPM, availability parameters are used to specify an upper bound on generation to meet demand. Table 3-7 summarizes the availability assumptions used in EPA 2023 Reference Case, which are based on data from NERC Generating Availability Data System (GADS) 2017-2021 and AEO 2023 Reference Case. NERC GADS summarizes the availability data by plant type and size class. Unit-level availability assignments in EPA 2023 Reference Case are made based on the unit’s plant type and size as presented in NEEDS. Table 3-33 shows the availability assumptions for all generating units in EPA 2023 Reference Case.

Table 3-7 Availability Assumptions in the EPA 2023 Reference Case

Plant Type	Annual Availability (%)
Biomass	83
Coal Steam	67 - 83
Combined Cycle	84
Combustion Turbine	86 - 93
Energy Storage	96
Fossil Waste	90
Fuel Cell	87
Geothermal	87
Hydro	75 - 82
IGCC	79 - 83
Landfill Gas	90
Municipal Solid Waste	90
Non-Fossil Waste	90
Nuclear	70 - 99
O/G Steam	62 - 85
Offshore Wind	95
Onshore Wind	95
Pumped Storage	81
Solar PV	90
Solar Thermal	90

Notes:

Ranges in unit level availability are based on varying plant sizes.

In the EPA 2023 Reference Case, separate seasonal (winter, spring, summer, and fall) availabilities are defined. For the fossil and nuclear unit types shown in Table 3-33, seasonal availabilities differ only in that no planned maintenance is assumed to be conducted during the on-peak – summer (June, July, and August) months for summer peaking regions and on-peak – winter (December, January, and February) months for winter peaking regions. Characterizing the availability of hydro, solar, and wind technologies is more complicated due to the seasonal and locational variations of the resources. The procedures used to represent seasonal variations in hydro are presented in Section 3.5.2 and of wind and solar in Section 4.4.5.

3.5.2 Capacity Factor

For non-dispatchable technologies - such as run-of-river hydro, wind, and solar - IPM uses generation profiles, not availabilities, to define the upper bound on the generation obtainable from the unit. The capacity factors that result from the implementation of generation profiles are the percentage of the maximum possible power generated by the unit. The seasonal capacity factor assumptions for hydro facilities contained in Table 3-8 were derived from EIA Form 923 data for the 2013-2022 period. A discussion of capacity factors and generation profiles for wind and solar technologies is contained in Section 4.4.5 and Table 4-18, Table 4-19, Table 4-35, Table 4-44, and Table 4-45.

Table 3-8 Seasonal Hydro Capacity Factors (%) in the EPA 2023 Reference Case

Model Region	Winter Capacity Factor	Spring Capacity Factor	Summer Capacity Factor	Fall Capacity Factor	Annual Capacity Factor
ERC_REST	13%	13%	13%	10%	12%
FRCC	65%	70%	51%	49%	58%
MIS_AR	46%	55%	56%	40%	51%
MIS_IA	41%	49%	47%	41%	45%
MIS_IL	58%	64%	62%	58%	60%
MIS_INKY	47%	37%	59%	58%	52%
MIS_LA	60%	65%	65%	58%	62%
MIS_LMI	64%	70%	58%	50%	60%
MIS_MAPP	60%	67%	69%	59%	65%
MIS_MIDA	32%	32%	31%	32%	32%
MIS_MNWI	57%	57%	61%	59%	59%

Model Region	Winter Capacity Factor	Spring Capacity Factor	Summer Capacity Factor	Fall Capacity Factor	Annual Capacity Factor
MIS_MO	47%	49%	51%	37%	47%
MIS_WOTA	31%	33%	32%	22%	31%
MIS_WUMS	64%	64%	63%	65%	64%
NENG_CT	43%	52%	33%	33%	39%
NENG_ME	58%	63%	45%	44%	51%
NENGREST	41%	49%	31%	30%	36%
NY_Z_A	75%	73%	72%	73%	73%
NY_Z_B	45%	44%	44%	44%	44%
NY_Z_C&E	51%	50%	51%	51%	51%
NY_Z_D	88%	75%	75%	75%	79%
NY_Z_F	52%	51%	50%	49%	51%
NY_Z_G-I	29%	29%	29%	29%	29%
PJM_AP	50%	54%	42%	39%	46%
PJM_ATSI	22%	21%	24%	25%	23%
PJM_COMD	43%	47%	48%	40%	45%
PJM_Dom	27%	27%	20%	18%	22%
PJM_EMAC	44%	58%	29%	25%	37%
PJM_PENE	50%	59%	44%	33%	46%
PJM_West	35%	36%	32%	29%	33%
PJM_WMAC	45%	56%	39%	34%	43%
S_C_KY	33%	31%	29%	26%	30%
S_C_TVA	55%	45%	42%	42%	46%
S_D_AECI	16%	30%	26%	9%	21%
S_SOU	32%	29%	23%	21%	26%
S_VACA	32%	30%	23%	24%	27%
SPP_N	19%	20%	20%	15%	19%
SPP_NEBR	38%	41%	41%	36%	39%
SPP_WAUE	41%	45%	45%	40%	43%
SPP_WEST	28%	33%	35%	22%	31%
WEC_BANC	17%	24%	26%	15%	21%
WEC_CALN	20%	31%	35%	18%	28%
WEC_LADW	10%	16%	17%	8%	14%
WEC_SDGE	16%	23%	27%	14%	22%
WECC_AZ	25%	29%	29%	22%	27%
WECC_CO	20%	21%	21%	9%	19%
WECC_ID	35%	46%	44%	30%	40%
WECC_IID	25%	37%	46%	24%	36%
WECC_MT	36%	45%	45%	34%	41%
WECC_NM	17%	21%	22%	15%	19%
WECC_NNV	38%	56%	56%	41%	49%
WECC_PNW	45%	46%	42%	33%	42%
WECC_SCE	19%	31%	39%	18%	29%
WECC_SNV	17%	28%	24%	18%	22%
WECC_UT	32%	39%	39%	28%	35%
WECC_WY	24%	33%	46%	23%	34%

Note: Annual capacity factor is provided for information purposes only. It is not used for modeling purposes.

Capacity factor limits are used to define the upper bound on generation obtainable from nuclear units because nuclear units will typically dispatch to their availability, and consequently, capacity factor and availability limits are equivalent. The capacity factors (and, consequently, the availabilities) of existing nuclear units in EPA 2023 Reference Case vary from region to region and over time. Further discussion of the nuclear capacity factor assumptions in EPA 2023 Reference Case is contained in Section 4.6.

In the EPA 2023 Reference Case, minimum capacity factor requirements of 10% are applied to existing coal steam units, and 2% are applied to existing oil/gas steam units and coal-to-gas retrofits in regions without capacity markets in EPA 2023 Reference Case. NYISO, ISONE, PJM, and MISO are assumed to have capacity markets. Additionally, oil/gas steam units are assigned minimum capacity factors under certain conditions. These minimum capacity factor constraints reflect stakeholder comments that if left unconstrained, IPM does not project as much operation from oil/gas steam units as has occurred historically. This dynamic is often the result of local transmission constraints, unit-specific grid reliability requirements, or other drivers that are not captured in EPA's modeling. EPA examined its modeling treatment of these units and introduced minimum capacity factor constraints to better reflect the real-world behavior of these units. The approach is designed to balance the continued operation of these units in the near-term with allowing economic forces to influence decision-making over the modeling time horizon. As a result, the minimum capacity factor limitations are relaxed over time (and are terminated even earlier if the capacity in question reaches 60 years of age). Historical operational data indicate that oil/gas steam units with high-capacity factors have maintained a high level of generation over many years. To reflect persistent operation of these units, minimum capacity factors for higher capacity factor units are phased out more slowly than those constraints for lower capacity factor units. The steps in assigning these capacity constraints are as follows:

i) Calculate an annual capacity factor for each oil/gas steam unit over a ten-year baseline (2013-2022).
ii) Identify the minimum capacity factor over this baseline period for each unit.
iii) Terminate the constraints in the earlier of (a) the run-year in which the unit reaches 60 years of age or (b) based on the assigned minimum capacity factor and the model year indicated in the following schedule:
    - For model year 2028, remove minimum constraint from units with capacity factor < 10%
    - For model year 2030, remove minimum constraint from units with capacity factor < 15%
    - No constraints beyond 2030

3.5.3 Turndown

Turndown assumptions in EPA 2023 Reference Case are used to prevent coal and oil/gas steam units from operating as peaking units, which would be inconsistent with their operational capabilities and assigned costs. The turndown constraints in EPA 2023 Reference Case require coal steam and oil/gas steam units to dispatch no less than a fixed percentage of the unit capacity in the 23 base and mid-load segments of the load duration curve in order to dispatch 100% of the unit in the peak load segments of the LDC. Oil/gas steam units are required to dispatch no less than 25% of the unit capacity in the 23 base- and mid-load segments of the LDC in order to dispatch 100% of the unit capacity in the peak load segment of the LDC. Operating under the fixed percentage of base- and mid-load segments does not preclude the unit from operating during peak hours. It merely reduces the share of peak hours in which it can operate. The unit level turndown percentages for coal units were estimated based on a review of hourly Air Markets Program Data (AMPD) data and are shown in Table 3-28.

3.6 Reserve Margins

A reserve margin is a measure of the system's generating capability above the amount required to meet the net internal demand (peak load) requirement. It is defined as the difference between total dependable capacity and annual system peak load divided by annual system peak load. The reserve margin capacity contribution for variable renewable units is described in Section 4.4.5; the reserve margin capacity contribution for other units is the capacity in the NEEDS for existing units or the capacity built by IPM for new units. In practice, each NERC region has a reserve margin requirement, or comparable reliability standard, which is designed to encourage electric suppliers in the region to build beyond their peak requirements to ensure the reliability of the electric generation system within the region.

In IPM, reserve margins represent the reliability standards in effect in each NERC region. Individual reserve margins for each NERC region are derived from reliability standards in NERC's electric reliability reports. The IPM regional reserve margins are imposed throughout the entire time horizon. EPA 2023 Reference Case reserve margin assumptions are shown in Table 3-9.

Table 3-9 Planning Reserve Margins in the EPA 2023 Reference Case

Model Region	Reserve Margin	Model Region	Reserve Margin
CN_AB	10.6% - 11.2%	NY_Z_G-I	15.0%
CN_BC	10.6% - 11.2%	NY_Z_J	15.0%
CN_MB	12.0%	NY_Z_K	15.0%
CN_NB	20.0%	PJM_AP	14.7%
CN_NF	20.0%	PJM_ATSI	14.7%
CN_NL	20.0%	PJM_COMD	14.7%
CN_NS	20.0%	PJM_Dom	14.7%
CN_ON	13.3% - 14.8%	PJM_EMAC	14.7%
CN_PE	15.0%	PJM_PENE	14.7%
CN_PQ	11.3%	PJM_SMAC	14.7%
CN_SK	15.0%	PJM_West	14.7%
ERC_FRNT	15.0%	PJM_WMAC	14.7%
ERC_GWAY	15.0%	S_C_KY	15.0%
ERC_PHDL	13.8%	S_C_TVA	15.0%
ERC_REST	13.8%	S_D_AECI	15.0%
ERC_WEST	13.8%	S_SOU	15.0%
FRCC	18.6%	S_VACA	15.0%
MIS_AR	18.6%	SPP_KIAM	15.0%
MIS_ MS	18.6%	SPP_N	16.0%
MIS_IA	18.6%	SPP_NEBR	16.0%
MIS_IL	18.6%	SPP_SPS	16.0%
MIS_INKY	18.6%	SPP_WAUE	16.0%
MIS_LA	18.6%	SPP_WEST	16.0%
MIS_LMI	16.1% - 16.9%	WEC_BANC	12.4% - 14.0%
MIS_MAPP	16.1% - 16.9%	WEC_CALN	12.4% - 14.0%
MIS_MIDA	16.1% - 16.9%	WEC_LADW	16.9% - 18.1%
MIS_MNWI	16.1% - 16.9%	WEC_SDGE	16.9% - 18.1%
MIS_MO	16.1% - 16.9%	WECC_AZ	16.9% - 18.1%
MIS_AMSO	18.6%	WECC_CO	16.9% - 18.1%
MIS_WOTA	16.1% - 16.9%	WECC_ID	16.9% - 18.1%
MIS_WUMS	16.1% - 16.9%	WECC_IID	16.9% - 18.1%
NENG_CT	16.1% - 16.9%	WECC_MT	12.4% - 14.0%
NENG_ME	16.1% - 16.9%	WECC_NM	11.2% - 12.3%
NENGREST	16.1% - 16.9%	WECC_NNV	12.4% - 14.0%
NY_Z_A	15.0%	WECC_PNW	16.9% - 18.1%
NY_Z_B	15.0%	WECC_SCE	16.9% - 18.1%
NY_Z_C&E	15.0%	WECC_SNV	12.4% - 14%
NY_Z_D	15.0%	WECC_UT	12.4% - 14%
NY_Z_F	15.0%	WECC_WY	12.4% - 14%

3.7 Operating Reserves

EPA 2023 Reference Case models operating reserve requirements in IPM to ensure that an appropriate mix of supply resources will be included that is consistent with maintaining reliability standards, especially in later years as new capacity deploys more rapidly. Operating reserves are typically deployed in order of the response speed, from fast to slow. In general, the categories of reserves include:[23]

- Frequency-Responsive Reserves. This is the fastest response. It has traditionally been provided through the automatic action of synchronous generators that react to slow down and arrest frequency deviations as a result of the inertia of the machines or their governor action (also

[23] Denholm, Paul, Yinong Sun, and Trieu Mai. 2019. An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72578. https://www.nrel.gov/docs/fy19osti/72578.pdf.

referred to as primary frequency response or PFR). As a result of the increase in renewable integration and loss of generators that provide inertial response, other products are emerging to provide frequency response on a very fast (sub-minute) timescale.

- Regulating Reserves. This is the rapid response by generators to balance supply and demand to maintain system frequency. The regulation reserve can address the random fluctuations in the load that create imbalances in supply and demand.

- Contingency Reserves. These reserves are deployed to cover the unplanned loss of power plants or transmission lines. Contingency reserves generally include spinning, non-spinning, and supplemental reserves. Spinning reserves respond quickly and are supplemented or replaced with non-spinning and supplemental reserves that are usually less costly.

- Ramping Reserves. This is used to address slower variations or events that occur over a longer period, such as variable generation forecast errors. Ramping reserves, also known as load-following or flexibility reserves, are an emerging product that is becoming more important with the increasing penetration of variable generation sources such as wind and solar.

The operating reserve products currently procured in United States electricity markets include regulating reserves, contingency reserves, and ramping reserves. FERC Order No. 842 requires that new generation resources that participate in the electricity markets provide some form of frequency-responsive reserve to support the reliability of the grid, but the Order does not mandate explicit compensation for the product. EPA's implementation of operating reserve requirements is consistent with the products offered in the electricity markets. The operating reserves modeled explicitly in EPA 2023 Reference Case are regulating reserves, contingency reserves, and ramping reserves. The plant types that can provide these reserves are listed in Table 3-12. Based on current regulations, new generation resources that are built in the EPA 2023 Reference Case are assumed to have the capability to provide frequency-responsive reserves. It is reasonable to expect that sufficient frequency-responsive reserves will be available to support grid reliability in IPM analyses, even if the requirement is not modeled explicitly.

3.7.1 Operating Reserve Requirements

Operating reserve requirements typically depend on the load and load forecast error. As variable renewable generation increase, it is likely that the operating reserve requirements will increase due to the variability of the renewable resources.[24,25] Table 3-10 shows operating reserve assumptions, which are based on the National Renewable Energy Laboratory (NREL) report, Operating Reserves in Long-term Planning Models.[26] The long-term requirements include components that depend on the penetration of wind and solar resources to address the expected increase in variability as more variable resources enter the market.

Table 3-10 Operating Reserve Requirement Assumptions by Type in the EPA 2023 Reference Case

Product	Operating Reserve Load Requirement	Operating Reserve Requirement for Wind	Operating Reserve Requirement for Solar	Operating Reserve Timescale
Spinning	3% of load	-	-	10 minutes
Regulation	1% of load	0.5% of wind capacity	0.3% of solar PV capacity	5 minutes
Flexibility	-	10% of wind capacity	4% of solar PV capacity	60 minutes

The operating reserve requirements, when modeled in IPM, have a significant impact on model size. To counter this effect, EPA made two simplifying assumptions. First, the spinning reserve, regulation, and

[24] Western Wind and Solar Integration Study (WWSIS) Phase 1, National Renewable Energy Laboratory (GE Energy), May 2010

[25] Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements, Electric Reliability Council of Texas (GE Energy), March 2008

[26] Cole, W. et al., Operating Reserves in Long-term Planning Models (NREL), June 2018

flexibility requirements are combined into a single product. Second, these constraints may be implemented only in the later years when renewable penetration and operating reserve requirements are highest; this representation of operating reserve requirements can be activated or deactivated by run year for any scenario analyzed using IPM. The operating reserve requirements in the EPA 2023 Reference Case, when modeled, are applied to the 17 regional groups summarized in Table 3-11.

Table 3-11 Operating Reserve Regions in the EPA 2023 Reference Case

Operating Reserve Region	EPA 2023 Reference Case Model Region
ERCOT	ERC_PHDL, ERC_REST, and ERC_WEST
FRCC	FRCC
ISO-NE	NENG_CT, NENGREST and NENG_ME
MISO East	MIS_WUMS, MIS_MIDA, MIS_IA, MIS_IL, MIS_LMI, MIS_INKY and MIS_MO
MISO South	MIS_MS, MIS_AR, MIS_AMSO, MIS_WOTA and MIS_LA
MISO West	MIS_MAPP and MIS_MNWI
NYISO	NY_Z_A, NY_Z_B, NY_Z_C&E, NY_Z_D, NY_Z_F, NY_Z_G-I, NY_Z_J and NY_Z_K
PJM East	PJM_PENE, PJM_EMAC, PJM_WMAC and PJM_SMAC
PJM West	PJM_West, PJM_AP, PJM_COMD, PJM_Dom and PJM_ATSI
SERC-E	S_VACA
SERC-N	S_C_TVA and S_C_KY
SERC-SE	S_SOU
SPP	SPP_WAUE, SPP_SPS, SPP_WEST, SPP_NEBR, SPP_N and S_D_AECI
WECC-CAMX	WEC_SDGE, WECC_SCE, WEC_CALN and WEC_LADW
WECC-NWPP	WECC_MT, WECC_ID, WECC_PNW, WECC_NNV, WECC_UT, WECC_SNV and WEC_BANC

3.7.2 Generation Characteristics

The ability of a generator to provide operating reserves varies with the technology type. The more flexible a unit (i.e., faster ramp rate), the higher its operating reserve capability. Table 3-12 shows the assumed operating reserve capabilities for different generation technologies and are based on the NREL's report, Operating Reserves in Long-term Planning Models. For example, gas combustion turbines and combined cycles have faster ramp rates than coal plants; therefore, gas plants can provide more operating reserves per unit capacity than coal plants. EPA also assumed that capacity meeting energy needs cannot provide operating reserves at the same time. For example, if 75% of a generator's capacity is serving the energy market, only 25% will be available to be offered into the operating reserve market. Table 3-12 summarizes the ramp rates of power plant technologies. Since EPA 2023 Reference Case is incorporating a single composite operating reserves product, the maximum operating reserve contributions are based on the 10-minute spinning reserve requirement.

Table 3-12 Operating Reserve Contribution Assumptions by Technology in the EPA 2023 Reference Case

Technology	Assumed Ramp Rate (%/minute)	Maximum Operating Reserve Contribution (%)
Combustion Turbine	8	80
Combined Cycle	5	50
Coal Steam	4	40
Geothermal	4	40
CSP with Storage	10	100
Biomass	4	40
Oil/Gas Steam	4	40
Hydro	100	100
Energy Storage	100	100

Generation resources that are not fast starting cannot provide operating reserves unless they are already operating. To provide operating reserves, the plant must also be dispatching into the energy market.

3.8 Power Plant Lifetimes

EPA 2023 Reference Case does not include any pre-specified assumptions about power plant lifetimes (i.e., the duration of service allowed) except for nuclear units. All conventional fossil units (coal, oil/gas steam, combustion turbines, and combined cycle), and biomass units can be retired during a model run if their retention is deemed uneconomic.

Nuclear Retirement: The EPA 2023 Reference Case does not assume that commercial nuclear reactors will be retired upon license expiration. EPA 2023 Reference Case incorporates life extension costs to enable these operating life extensions. (See Sections 4.2.8 and 4.6). For unit specific retirement years, see NEEDS.

3.9 Heat Rates

Heat rates, expressed in British thermal units (Btus) per kilowatt-hour (kWh), are a measure of an electric generating unit's (EGU's) efficiency. As in previous versions of NEEDS, with the exception of deploying the heat rate improvement option described below, heat rates of existing EGUs remain constant over time. This assumption reflects two offsetting factors:

i) Plant efficiencies tend to degrade over time, and
ii) Increased maintenance and component replacement costs act to maintain, or improve, an EGU's generating efficiency.

The heat rates for the model plants in EPA 2023 Reference Case are based on values from the AEO 2020 Reference Case and are informed by fuel use and net generation data reported on Form EIA-923. These values were screened and adjusted using a procedure developed by EPA (as described below) to ensure that the heat rates used in EPA 2023 Reference Case are within the engineering capabilities of the various EGU types.

The result of an earlier EPA engineering analysis, the upper and lower heat rate limits shown in Table 3-13 were applied to coal steam, oil/gas steam, combined cycle, combustion turbine, and internal combustion engines. If the reported heat rate for such a unit was below the applicable lower limit or above the upper limit, the upper or lower limit was substituted for the reported value.

Table 3-13 Lower and Upper Limits Applied to Heat Rate Data in the EPA 2023 Reference Case

Plant Type	Heat Rate (Btu/kWh)	
	Lower Limit	Upper Limit
Coal Steam	8,300	14,500
Oil/Gas Steam	8,300	14,500
Combined Cycle - Natural Gas	5,500	15,000
Combined Cycle - Oil	6,000	15,000
Combustion Turbine - Natural Gas - 80 MW and above	8,700	18,700
Combustion Turbine - Natural Gas < 80 MW	8,700	36,800
Combustion Turbine - Oil and Oil/Gas - 80 MW and above	6,000	25,000
Combustion Turbine - Oil and Oil/Gas < 80 MW	6,000	36,800
IC Engine - Natural Gas	8,700	18,000
IC Engine - Oil and Oil/Gas - 5 MW and above	8,700	20,500
IC Engine - Oil and Oil/Gas < 5 MW	8,700	42,000

3.10 Existing Legislations and Regulations Affecting Power Sector

This section describes the existing federal, regional, and state SO_2, NO_x, mercury, HCl, and CO_2 emissions regulations and legislations that are represented in EPA 2023 Reference Case. EPA 2023 Reference Case also includes three non-air federal rules affecting EGUs: Cooling Water Intakes (316(b)) Rule, Coal Combustion Residuals from Electric Utilities (CCR), and the Effluent Limitations and Guidelines Rule. The first four subsections discuss national and regional regulations. The next five subsections describe state-level environmental regulations, a variety of legal settlements, emission assumptions for potential units, renewable portfolio standards, and Canadian regulations for CO_2 and renewables.

3.10.1 Inflation Reduction Act

The Inflation Reduction Act (IRA) contains a number of tax credit provisions that affect power sector operations. The Clean Electricity Investment and Production Tax Credits (provisions 48E and 45Y of the IRA) are described in more detail in Section 4.5. The credit for Carbon Capture and Sequestration (provision 45Q) is described in Section 3.12. The impacts of the Zero-Emission Nuclear Power Production Credit (provision 45U) are reflected through modifying nuclear retirement limits, as described in Section 4.6.1. The Credit for the Production of Clean Hydrogen (provision 45V) is reflected through the inclusion of an exogenously delivered price of hydrogen fuel, see Section 9.5. The Advanced Manufacturing Production Tax Credit (45X) was reflected through adjustments to the short-term capital cost added for renewable technologies, see Section 4.4.3.

3.10.2 SO_2 Regulations

Unit-level Regulatory SO_2 Emission Rates and Coal Assignments: Before discussing the national and regional regulations affecting SO_2, it is important to note that unit-level SO_2 permit rates, including SO_2 regulations arising out of State Implementation Plan (SIP) requirements, which are not only state-specific but also county-specific, are captured at model set-up in the coal choices given to coal-fired existing units in EPA 2023 Reference Case. Since SO_2 emissions are dependent on the sulfur content of the fuel used, the SO_2 permit rates are used in IPM to define fuel capabilities.

For instance, a unit with a SO_2 permit rate of 3.0 lbs/MMBtu would be provided only with those combinations of fuel choices and SO_2 emission control options that would allow the unit to achieve an out-of-stack rate of 3.0 lbs/MMBtu or less. If the unit finds it economical, it may elect to burn a fuel that would achieve a lower SO_2 rate than its specified permit limit. In EPA 2023 Reference Case, there are six different sulfur grades of bituminous coal, four different grades of subbituminous coal, four different grades of lignite, and one sulfur grade of residual fuel oil. There are two different SO_2 scrubber options and one DSI option for coal units. Further discussion of fuel types and sulfur content is contained in Chapter 7. Further discussion of SO_2 control technologies is contained in Chapter 5.

National and Regional SO_2 Regulations: The national program affecting SO_2 emissions in EPA 2023 Reference Case is the Acid Rain Program established under Title IV of the Clean Air Act Amendments (CAAA) of 1990, which set a goal of reducing annual SO_2 emissions by 10 million tons below 1980 levels. The program, which became operational in 2000, affects all SO_2 emitting electric generating units greater than 25 MW. The program provides trading and banking of allowances over time across all affected electric generation sources.

The annual SO_2 caps over the modeling time horizon in EPA 2023 Reference Case reflect the provisions in Title IV. For allowance trading programs like the Acid Rain Program that allow banking of unused allowances over time, we usually estimate an allowance bank that is assumed to be available by the first year of the modeling horizon (which is 2028 in EPA 2023 Reference Case). However, the Acid Rain Program has demonstrated a substantial oversupply of allowances that continues to grow over time, and we anticipate projecting that the program's emission caps will not bind the model's determination of SO_2 emissions regardless of any level of initial allowance bank assumed. Therefore, EPA 2023 Reference Case does not assume any Title IV SO_2 allowance bank amount for the year of 2028 (notwithstanding that a large allowance bank will exist in that year in practice), because such an assumption would have no material impact on projections given the nonbinding nature of that program. Calculating the available 2028 allowances involved deducting allowance surrenders due to NSR settlements and state regulations from the 2028 SO_2 cap of 8.95 million tons. The surrenders totaled 977 thousand tons in allowances, leaving 7.973 million of 2021 allowances remaining. Specifics of the allowance surrender requirements under state regulations and NSR settlements can be found in Table 3-29 and Table 3-30.

EPA 2023 Reference Case also includes a representation of the Western Regional Air Partnership (WRAP) Program, a regional initiative involving New Mexico, Utah, and Wyoming directed toward addressing visibility issues in the Grand Canyon and affecting SO_2 emissions starting in 2018. The WRAP specifications for SO_2 are presented in Table 3-23.

3.10.3 NO_x Regulations

Much like SO_2 regulations, existing NO_x regulations are represented in EPA 2023 Reference Case through a combination of system level NO_x programs and generation unit-level NO_x limits. In EPA 2023 Reference Case, Good Neighbor Plan (GNP[27]) the NO_x SIP Call trading program, Cross State Air Pollution Rule (CSAPR), the CSAPR Update, and the Revised CSAPR Update Rule are represented. Table 3-23 shows the specification for the entire modeling time horizon.

By assigning unit-specific NO_x rates based on 2019 data, EPA 2023 Reference Case is implicitly representing Title IV unit-specific rate limits and Clean Air Act Reasonably Available Control Technology (RACT) requirements for controlling NO_x emissions from electric generating units in ozone non-attainment areas or in the Ozone Transport Region (OTR).[28] Unlike SO_2 emission rates, NO_x rates are calculated off historical data and reflect the fuel mix for that particular year at the unit. NEEDS represents up to four scenario NO_x rates based on historical data to capture seasonal and existing control variability. These rates are constant and do not change independently of the fuel mix assumed in the model. If the unit undertakes a post-combustion control retrofit, a coal-to-gas retrofit, a natural gas cofiring retrofit, then these rates would change in the model projections.

<u>NO_x Emission Rates</u>

Future emission projections for NO_x are a product of a unit's utilization (heat input) and emission rate (lbs/MMBtu). A unit's NO_x emission rate can vary significantly depending on the NO_x reduction requirements to which it is subject. For example, a unit may have a post-combustion control installed (i.e., SCR or SNCR), but only operate it during the time of the year in which it is subject to NO_x reduction requirements (e.g., the unit only operates its post-combustion control during the ozone season). Therefore, its ozone-season NO_x emission rate would be lower than its non-ozone-season NO_x emission rate. Because the same individual unit can have such a large variation in its emission rate, the model needs a suite of emission rate modes from which it can select the value most appropriate to the conditions in any given model scenario. The different emission rates reflect the different operational conditions a unit may experience regarding upgrades to its combustion controls and the operation of its existing post-combustion controls. Four modes of operation are developed for each unit, with each mode carrying a potentially different NO_x emission rate for that unit under those operational conditions.

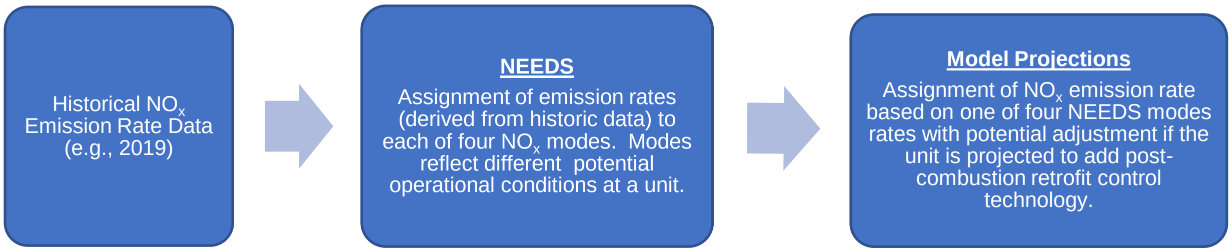
The emission rates assigned to each mode are derived from historical data (where available) and presented in NEEDS. When the model is run, IPM selects one of these four modes through a decision process depicted in Figure 3-3 below. The four modes address whether units upgrade combustion controls and/or operate *existing* post-combustion controls; the modes themselves do not address what happens to the unit's NO_x rate if it is projected to add a *new* post-combustion NO_x control. If a unit is projected to add a new post-combustion control, then after the model selects the appropriate input mode,

[27] https://www.epa.gov/Cross-State-Air-Pollution/good-neighbor-plan-2015-ozone-naaqs

[28] The OTR consists of the following states: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, District of Columbia, and northern Virginia.

it adjusts that mode's emission rate downwards to reflect the retrofit of SCR or SNCR; the adjusted rate will reflect the greater percentage removal from the mode's emission rate or an emission rate floor. The full process for determining the NO_x rate of units in EPA 2023 Reference Case model projections is summarized in Figure 3-2.

Figure 3-2 Modeling Process for Obtaining Projected NO_x Emission Rates



NO_x Emission Rates in NEEDS Database

The NO_x rates were derived, wherever possible, directly from actual monitored NO_x emission rate data reported to EPA under the Acid Rain and Cross-State Air Pollution Rule in 2019.[29] The emission rates themselves reflect the impact of applicable NO_x regulations.[30] For coal-fired units, NO_x rates were used in combination with empirical assessments of NO_x combustion control performance to prepare a set of four possible starting NO_x rates to assign to a unit, depending on the specific NO_x reduction requirements affecting that unit in a model run.

The reason for having a framework of four potential NO_x rate modes applicable to each unit in NEEDS is to enable the model to select from a range of NO_x rates possible at a unit, given its configuration of NO_x combustion controls and its assumed operation of existing post-combustion controls. There are up to four basic operating states for a given unit that significantly impacts its NO_x rate, and thus there are four NO_x rate modes.

Mode 1 and mode 2 reflect a unit's emission rates with its existing configuration of combustion and post-combustion (i.e., SCR or SNCR) controls.

- For a unit with an existing post-combustion control, mode 1 reflects the existing post-combustion control not operating and mode 2 the existing post-combustion control operating. However:
    - If a unit has operated its post-combustion control year-round during the most recent of 2019, 2017, 2016, 2015, 2014, 2011, 2009, or 2007 years then mode 1 = mode 2, which reflects that the control will likely continue to operate year-round (and thus a "not run" emission rate option is not needed as justified by historical data).
    - If a unit has not operated its post-combustion control during the most recent of 2019, 2017, 2016, 2015, 2014, 2011, 2009, or 2007 years, mode 1 will be based on this data

[29] By assigning unit-specific NO_x rates based on 2019 data, EPA 2023 Reference Case is implicitly representing Title IV unit-specific rate limits and Clean Air Act Reasonably Available Control Technology (RACT) requirements for controlling NO_x emissions from electric generating units in ozone non-attainment areas or in the Ozone Transport Region (OTR). Unlike SO_2 emission rates, NO_x emission rates are assumed not to vary with coal type but are dependent on the combustion properties of the generating unit. Under the EPA 2023 Reference Case, the NO_x emission rate of a unit can only change if the unit is retrofitted with NO_x post-combustion control equipment or if it is assumed to install state-of-the-art NO_x combustion controls. In instances where a coal steam unit converts to natural gas, the NO_x rate is assumed to reduce by 50%. When a coal unit cofires with natural gas, its NO_x rate is capped at 0.15 lbs/MMBtu.

[30] Because 2019 NO_x rates reflect CSAPR, we no longer apply any incremental CSAPR related NO_x rate adjustments exogenously for CSAPR affected units in EPA 2023 Reference Case.

and mode 2 will be calculated using the method described under Question 3 in Attachment 3-2.

    - If a unit has operated its post-combustion control seasonally in recent years (i.e., either only in the summer or winter, but not both), mode 1 will be based on historic data from when the control was not operating, and mode 2 will be based on historic data from when the SCR was operating.

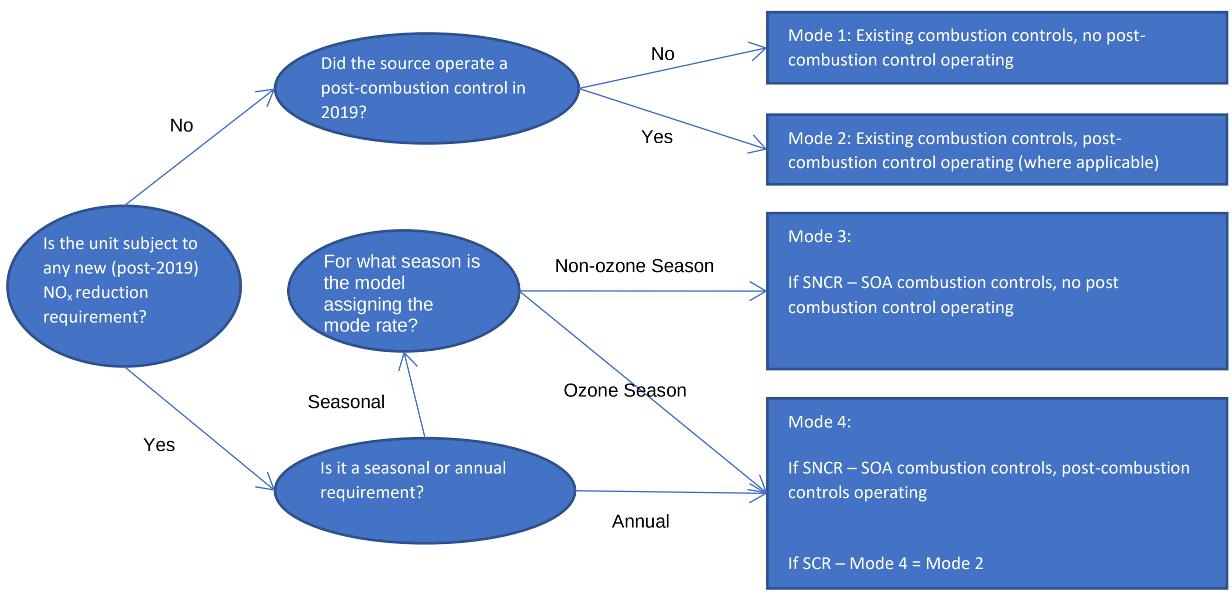
- For a unit without an existing post-combustion control, mode 1 = mode 2, which reflects the unit's historic NO_x rates from a recent year.

Mode 3 and mode 4 emission rates parallel modes 1 and 2 emission rates but are modified to reflect installation of state-of-the-art combustion controls on a unit if it does not already have them.

- For units that already have state-of-the-art combustion controls: mode 3 = mode 1 and mode 4 = mode 2.

Emission rates derived for each unit operating under each of these four modes are presented in NEEDS. Note that not every unit has a different emission rate for each mode, because certain units cannot in practice change their NO_x rates to conform to all potential operational states described above.

Figure 3-3 How One of the Four NO_x Modes Is Ultimately Selected for a Unit



State-of-the-art combustion controls (SOA combustion controls)

The definition of state-of-the-art varies depending on the unit type and configuration, indicating the incremental combustion controls that are required to achieve a state-of-the-art combustion control configuration for each unit. For instance, if a wall-fired, dry bottom boiler (highlighted below) currently has LNB but no overfire air (OFA), the state-of-the-art rate calculated for such a unit would assume a NO_x emission rate reflective of overfire air being added at the unit. As described in the attachment of this chapter, the state-of-the-art combustion controls reflected in the modes are only assigned to a unit if it is subject to a *new* (post-2019) NO_x reduction requirement (i.e., a NO_x reduction requirement that did not apply to the unit during its 2019 operation that forms the historic basis for deriving NO_x rates for units in EPA 2023 Reference Case). Existing reduction requirements as of 2019, under which units have already made combustion control decisions, would not trigger the assignment of the state-of-the-art modes that reflect additional combustion controls.

Table 3-14 State-of-the-Art Combustion Control Configurations by Boiler Type in the EPA 2023 Reference Case

Boiler Type	Existing NO_x Combustion Control	Incremental Combustion Control Necessary to Achieve State-of-the-Art
Tangential Firing	Does not Include LNC1 and LNC2	LNC3
	Includes LNC1, but not LNC2	Conversion from LNC1 TO LNC3
	Includes LNC2, but not LNC3	Conversion from LNC2 TO LNC3
	Includes LNC1 and LNC2 or LNC3	-
Wall Firing, Dry Bottom	Does not Include LNB and OFA	LNB + OFA
	Includes LNB, but not OFA	OFA
	Includes OFA, but not LNB	LNB
	Includes both LNB and OFA	-

Note:
LNB = Low NOx Burner Technology, LNC1 = Low NOx coal-and air nozzles with close-coupled overfire air, LNC2 = Low NOx Coal-and-Air Nozzles with Separated Overfire Air, LNC3 = Low NOx Coal-and-Air Nozzles with Close-Coupled and Separated Overfire Air, OFA = Overfire Air.

The emission rates for each generating unit under each mode are included in the NEEDS database, described in Chapter 4. Attachment 3-2 gives further information on the procedures employed to derive the four NO_x mode rates.

Because of the complexity of the fleet and the completeness/incompleteness of historic data, there are instances where the derivation of a unit's modeled NO_x emission rate is more detailed than the description provided above. For a more complete step-by-step description of the decision rules used to develop the NO_x rates, see Attachment 3-2.

3.10.4 Multi-Pollutant Environmental Regulations

<u>GNP</u>

On March 15, 2023, EPA finalized the Good Neighbor Plan (GNP) for the 2015 ozone National Ambient Air Quality Standards (NAAQS). Starting in 2023, 22 states will be subject to ozone season NO_x budgets consistent with Table 3-15. The programs' assurance provisions, which restrict the maximum amount of exceedance of an individual state's emissions budget each year through the use of banked or traded allowances to 21% of the state's budget, are also implemented. The starting allowance bank in 2023 is 22,319 tons, which is equal to the number of banked allowances at the start of the GNP after old CSAPR Update / RCU allowances were converted. This is equal to the sum of the states' 10.5% variability limits. In run year 2030, coal facilities greater than 100 MW lacking SCR controls and certain oil/gas steam facilities greater than 100 MW that lack existing SCR controls located in these states must meet daily emission rate limits, effectively forcing affected units to install new SCR controls, find other means of compliance, or retire. Additionally, within the GNP footprint, EPA models NO_x emissions rates at affected facilities that reflect operating and optimized existing controls.

Table 3-15 Ozone-Season NO_x Emission Caps (Tons) for Fossil Units greater than 25MW in the EPA 2023 Reference Case

State	2028	2030 onwards
Alabama	7,546	5,578
Arkansas	4,877	4,334
Illinois	5,511	4,901
Indiana	10,446	7,631
Kentucky	9,513	9,291
Louisiana	3,592	3,592
Maryland	717	717
Michigan	7,256	6,886
Minnesota	3,515	2,012
Mississippi	1,848	1,848
Missouri	8,868	8,191
Nevada	1,271	989
New Jersey	930	930
New York	4,033	4,033
Ohio	8,391	7,742
Oklahoma	4,649	4,649
Pennsylvania	8,646	5,827
Texas	27,112	26,174
Utah	3,150	3,150
Virginia	2,871	2,361
West Virginia	11,710	11,710
Wisconsin	4,123	4,123
Regional Cap	116,178	104,685

CSAPR, CSAPR Update, and RCU

EPA 2023 Reference Case includes the ozone-season NO_x limits reflecting the Cross-State Air Pollution Rule (CSAPR) Rule, CSAPR Update Rule, and the Revised CSAPR Update Rule federal regulatory measures to address transport under the 1997and 2008 National Ambient Air Quality Standards (NAAQS) for ozone. For states in which the Good Neighbor Plan is the most recently promulgated ozone-season program, then the GNP limitations replace those from these prior programs for modeling purposes (and these prior program limitations are shown for informational purposes only here).

The state budgets for Ozone Season NO_x for the CSAPR Update Rule (that were not further adjusted in the Revised CSAPR Update Rule) are shown in Table 3-16. Additionally, Georgia was modeled as a separate region, with Georgia units unable to trade allowances with units in other states and received its CSAPR Phase 2 budget and assurance level, as shown in Table 3-16. This is because Georgia, unlike the other states covered by the CSAPR Update Rule, did not significantly contribute to a downwind nonattainment or maintenance receptor for the 2008 NAAQS. Further, Georgia did not have a remanded Ozone Season NO_x budget related to a D.C. Circuit Court decision on the original Cross-State Air Pollution Rule.

The programs' assurance provisions, which restrict the maximum amount of exceedance of an individual state's emissions budget each year through the use of banked or traded allowances to 21% of the state's budget, are also implemented. This is equal to one-and-a-half times the sum of the states' 21% variability limits. For more information on CSAPR, go to https://www.epa.gov/csapr. For more information on the CSAPR Update, go to https://www.epa.gov/airmarkets/final-cross-state-air-pollution-rule-update.

Table 3-16 G1 and G2 CSAPR Update State Budgets, Variability Limits, and Assurance Levels for Ozone-Season NO_x (Tons) – 2021 through 2054

State	Budget	Variability Limit	Assurance Level
Alabama	13,211	2,774	15,985
Arkansas	9,210	1,934	11,144
Iowa	11,272	2,367	13,639
Kansas	8,027	1,686	9,713
Missouri	15,780	3,314	19,094
Mississippi	6,315	1,326	7,641
Oklahoma	11,641	2,445	14,086
Tennessee	7,736	1,625	9,361
Texas	52,301	10,983	63,284
Wisconsin	7,915	1,662	9,577
Georgia Budget, Variability Limit, and Assurance Level for Ozone-Season NO_x			
Georgia	24,041	5,049	29,090

On March 15, 2021, EPA finalized the Revised Cross-State Air Pollution Rule Update for the 2008 ozone National Ambient Air Quality Standards (NAAQS) to address the D.C. Circuit's remand of the CSAPR Update Rule. Starting in 2021, 12 of the 22 states covered in the CSAPR Update Rule will revise ozone season NO_x budgets consistent with Table 3-17. The programs' assurance provisions, which restrict the maximum amount of exceedance of an individual state's emissions budget each year through the use of banked or traded allowances to 21% of the state's budget, are also implemented. The starting allowance bank in 2023 is 22,488 tons, which is equal to the number of banked allowances at the start of the Revised CSAPR Update program after old CSAPR Update allowances were converted. This is equal to the sum of the states' 21% variability limits.

Table 3-17 Revised CSAPR Update State Budgets, Variability Limits, and Assurance Levels for Ozone-Season NO_x for G3 states (tons)

State	Budget (tons)	Variability Limit (tons)	Assurance Level (tons)
2021			
Illinois	9,102	1,911	11,013
Indiana	13,051	2,741	15,792
Kentucky	15,300	3,213	18,513
Louisiana	14,818	3,112	17,930
Maryland	1,499	315	1,814
Michigan	12,727	2,673	15,400
New Jersey	1,253	263	1,516
New York	3,416	717	4,133
Ohio	9,690	2,035	11,725
Pennsylvania	8,379	1,760	10,139
Virginia	4,516	948	5,464
West Virginia	13,334	2,800	16,134
2022			
Illinois	9,102	1,911	11,013
Indiana	12,582	2,642	15,224
Kentucky	14,051	2,951	17,002
Louisiana	14,818	3,112	17,930
Maryland	1,266	266	1,532
Michigan	12,290	2,581	14,871
New Jersey	1,253	263	1,516
New York	3,416	717	4,133
Ohio	9,773	2,052	11,825
Pennsylvania	8,373	1,758	10,131
Virginia	3,897	818	4,715

State	Budget (tons)	Variability Limit (tons)	Assurance Level (tons)
West Virginia	12,884	2,706	15,590
2023			
Illinois	8,179	1,718	9,897
Indiana	12,553	2,636	15,189
Kentucky	14,051	2,951	17,002
Louisiana	14,818	3,112	17,930
Maryland	1,266	266	1,532
Michigan	9,975	2,095	12,070
New Jersey	1,253	263	1,516
New York	3,421	718	4,139
Ohio	9,773	2,052	11,825
Pennsylvania	8,373	1,758	10,131
Virginia	3,980	836	4,816
West Virginia	12,884	2,706	15,590
2024 -2059			
Illinois	8,059	1,692	9,751
Indiana	9,564	2,008	11,572
Kentucky	14,051	2,951	17,002
Louisiana	14,818	3,112	17,930
Maryland	1,348	283	1,631
Michigan	9,786	2,055	11,841
New Jersey	1,253	263	1,516
New York	3,403	715	4,118
Ohio	9,773	2,052	11,825
Pennsylvania	8,373	1,758	10,131
Virginia	3,663	769	4,432
West Virginia	12,884	2,706	15,590

MATS

Finalized in 2011, the Mercury and Air Toxics Rule (MATS) establishes National Emissions Standards for Hazardous Air Pollutants (NESHAPS) for the “electric utility steam generating unit” source category, which includes those units that combust coal or oil for the purpose of generating electricity for sale and distribution through the electric grid to the public. EPA 2023 Reference Case applies the input-based (lbs/MMBtu) MATS control requirements for mercury and hydrogen chloride to covered units.

EPA 2023 Reference Case assumes that all active coal-fired generating units with a capacity greater than 25 MW have complied with the MATS filterable PM requirements through the operation of either electrostatic precipitator (ESP) or fabric filter (FF) particulate controls. No additional PM controls beyond those in NEEDS are modeled in EPA 2023 Reference Case.

EPA 2023 Reference Case does not model the alternative SO_2 standard offered under MATS for units to demonstrate compliance with the rule’s HCl control requirements. Coal steam units with access to lignite in the modeling are required to meet the “existing coal-fired unit low Btu virgin coal” standard. For more information on MATS, go to http://www.epa.gov/mats/.

Regional Haze

The Clean Air Act establishes a national goal for returning visibility to natural conditions through the “prevention of any future, and the remedying of any existing impairment of visibility in Class I areas [156 national parks and wilderness areas], where impairment results from manmade air pollution.” On July 1, 1999, EPA established a comprehensive visibility protection program with the issuance of the regional haze rule (64 FR 35714). The rule implements the requirements of section 169B of the CAAA and requires states to submit State Implementation Plans (SIPs) establishing goals and long-term strategies for reducing emissions of air pollutants (including SO_2 and NO_x) that cause or contribute to visibility impairment. The requirement to submit a regional haze SIP applies to all 50 states, the District of Columbia, and the Virgin Islands. Among the components of a long-term strategy is the requirement for states to establish emission limits for visibility-impairing pollutants emitted by certain source types (including EGUs) that were placed in operation between 1962 and 1977. These emission limits are to reflect Best Available Retrofit Technology (BART). States may perform individual point source BART determinations, or meet the requirements of the rule with an approved BART alternative. An alternative regional SO_2 cap for EGUs under Section 309 of the regional haze rule is available to certain western states whose emission sources affect Class 1 areas on the Colorado Plateau.

Since 2010, EPA has approved regional haze State Implementation Plans (SIPs) or, in a few cases, put in place regional haze Federal Implementation Plans for several states. The BART limits approved in these plans (as of January 2021) that will be in place for EGUs are represented in EPA 2023 Reference Case as follows.

- Source-specific NO_x or SO_2 BART emission limits, minimum SO_2 removal efficiency requirements for FGDs, limits on sulfur content in fuel oil, constraints on fuel type (e.g., natural gas only or prohibition of certain fuels such as petroleum coke), or commitments to retire units are applied to the relevant EGUs.
- EGUs in states that rely on CSAPR trading programs to satisfy BART must meet the requirements of CSAPR.
- EGUs in states that rely on state power plant rules to satisfy BART must meet the emission limits imposed by those state rules.
- For the three western states (New Mexico, Wyoming, and Utah) with approved Section 309 SIPs for SO_2 BART, emission constraints were not applied as current and projected emissions are well under the regional SO_2 cap.

Table 3-34 lists the NO_x and SO_2 limits applied to specific EGUs, and other implementations applied in IPM. For more information on the Regional Haze Rule, go to https://www.epa.gov/visibility.

On June 28, 2021, EPA filed a status update with the United States Court of Appeals for the District of Columbia Circuit noting that “the agency is convening a proceeding for reconsideration” of the August 2020 rule known as the “Texas Regional Haze BART and Interstate Visibility Transport FIP.” Any changes from the that effort will be incorporated into EPA modeling when finalized.

3.10.5 CO_2 Regulations

The Regional Greenhouse Gas Initiative (RGGI) is a CO_2 cap and trade program affecting fossil fired electric power plants 25 MW or larger in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia. Table 3-23 shows the specifications for RGGI that are implemented in EPA 2023 Reference Case. If/when other states join RGGI and finalize/implement regulations, EPA will adjust its representation accordingly.

As part of California’s Assembly Bill 32 (AB32), the Global Warming Solutions Act, a multi-sector GHG cap-and-trade program was established that establishes long-term economy-wide emission targets, starting in 2013 for electric utilities and large industrial facilities, with distributors of transportation, natural gas, and other fuels joining the capped sectors in 2015. In addition to in-state sources, the cap-and-trade program also covers the emissions associated with qualifying, out-of-state EGUs that sell power into California. Due to the inherent complexity in modeling a multi-sector cap-and-trade program where the participation of out-of-state EGUs is determined based on endogenous behavior (i.e., IPM determines whether qualifying out-of-state EGUs are projected to sell power into California), EPA has developed a simplified methodology to model California's economy-wide cap-and-trade program as follows.

- Adopt the AB32 cap-and-trade allowance price from EIA's AEO2023 Reference Case, which fully represents the non-power sectors. All qualifying fossil-fired EGUs in California are subject to this price signal, which is applied through the end of the modeled time horizon since the underlying legislation requires those emission levels to be maintained.
- Assume the marginal CO_2 emission rate for each IPM region that exports power to California to be 0.428 MT/MWh.
- For each IPM region that exports power to California, convert the $/ton CO_2 allowance price projection into a mills/kWh transmission wheeling charge using the marginal emission rate from the previous step. The additional wheeling charge for qualifying out-of-state EGUs is equal to the allowance price imposed on affected in-state EGUs. Applying the charge to the transmission link ensures that power imported into California from out-of-state EGUs must account for the cost of CO_2 emissions represented by its generation, such that the model may clear the California market in a manner consistent with AB32 policy treatment of CO_2 emissions.

Federal CO_2 standards for existing sources are not modeled, given ongoing litigation and regulatory review.[31] For new fossil fuel-fired sources, EPA 2023 Reference Case continues to include the Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Generating Units (New Source Rule).[32] Although this rule is also being reviewed,[33] the standards of performance are legally in effect until such review is completed and/or revised. In addition, state level CO_2 standards were implemented in Colorado (HB21-1266), Massachusetts (Massachusetts Senate Bill 9), North Carolina (North Carolina House Bill 951), Oregon (Oregon House Bill 2021), and Washington (Washington state SB5126).

[31] EPA Memorandum: "Status of Affordable Clean Energy Rule and Clean Power Plan," February 12, 2021. Available at https://www.epa.gov/sites/default/files/2021-02/documents/ace_letter_021121.doc_signed.pdf.

[32] 80 FR 64510

[33] 82 FR 16330

3.10.6 Non-Air Regulations Impacting EGUs

Cooling Water Intakes (316(b)) Rule

Section 316(b) of the Clean Water Act requires that National Pollutant Discharge Elimination System (NPDES) permits for facilities with cooling water intake structures ensure that the location, design, construction, and capacity of the structures reflect the best technology available to minimize harmful impacts on the environment. Under a 1995 consent decree with environmental organizations, EPA divided section 316(b) rulemaking into three phases. All new facilities except offshore oil and gas exploration facilities were addressed in Phase I in December 2001; all new offshore oil and gas exploration facilities were later addressed in June 2006 as part of Phase III. This final rule also removes a portion of the Phase I rule to comply with court rulings. Existing large electric-generating facilities were addressed in Phase II in February 2004. Existing small electric-generating and all manufacturing facilities were addressed in Phase III (June 2006). However, Phase II and the existing facility portion of Phase III were remanded to EPA for reconsideration because of legal proceedings. This final rule combines these remands into one rule and provides a holistic approach to protecting aquatic life impacted by cooling water intakes. The rule covers roughly 1,065 existing facilities that are designed to withdraw at least 2 million gallons per day of cooling water. EPA estimates that 544 power plants are affected by this rule.

The final regulation has three components for affected facilities: 1) reduce fish impingement through a technology option that meets best technology available requirements, 2) conduct site-specific studies to help determine whether additional controls are necessary to reduce entrainment, and 3) meet entrainment standards for new units at existing facilities when additional capacity is added. EPA 2023 Reference Case includes the cost of complying with this rule. The cost assumptions and analysis for 316(b) can be found in Chapter 8.7 of the Rule's Technical Development Document for the Final Section 316(b) Existing Facilities Rule at https://www.epa.gov/sites/production/files/2015-04/documents/cooling-water_phase-4_tdd_2014.pdf.

For more information on 316(b), go to https://www.epa.gov/cooling-water-intakes.

Combustion Residuals from Electric Utilities (CCR)

In December of 2014, EPA finalized national regulations to provide a comprehensive set of requirements for the safe disposal of coal combustion residuals (CCRs), commonly known as coal ash, from coal-fired power plants. The final rule is the culmination of extensive study on the effects of coal ash on the environment and public health. The rule establishes technical requirements for CCR landfills and surface impoundments under Subtitle D of the Resource Conservation and Recovery Act.

EPA 2023 Reference Case includes cost of complying with this rule's requirements by taking the estimated plant-level compliance cost identified for the CCR final rule and apportioning them into unit-level cost[34]. Three categories of unit-level cost were quantified: capital cost, fixed operating and maintenance cost (FOM), and variable operating and maintenance (VOM) cost. The method for apportioning these costs to the unit-level for inclusion in EPA Platform is discussed in the Addendum to the RIA for EPA's 2015 Coal Combustion Residuals (CCR) Final Rule. The initial plant-level cost estimates are discussed in the Rule's Regulatory Impact Analysis.

In September of 2017, EPA granted petitions to reconsider some provisions of the rule. In granting the petitions, EPA determined that it was appropriate, and in the public's interest to reconsider specific provisions of the final CCR rule based in part on the authority provided through the Water Infrastructure for Improvements to the Nation (WIIN) Act. At time of this modeling update, EPA had not committed to changing any part of the rule or agreeing with the merits of the petition – the Agency is simply granting

[34] CCR related cost adders were not applied to units with CCR-based retirement dates no later than 12/31/2028.

petitions to reconsider specific provisions. Should EPA decide to revise specific provisions of the final CCR rule, it will go through notice and comment period, and the rules corresponding model specification would be subsequently changed in future base case platforms.

On July 29, 2020, the U.S. Environmental Protection Agency (EPA) finalized several changes to the regulations for this rule to implement the court's vacatur of certain closure requirements. In response to court rulings, this final rule specified that all unlined surface impoundments are required to retrofit or close, not just those that have detected groundwater contamination above regulatory levels. The rule also changed the classification of compacted-soil lined or "clay-lined" surface impoundments from "lined" to "unlined," which means that formerly defined clay-lined surface impoundments are no longer considered lined surface impoundments and need to be retrofitted or closed. These changes, and corresponding requirements and cost, are reflected in this version of IPM using the same methodology described in the Addendum for the RIA for EPA's 2015 CCR Rule mentioned above.

For more information on CCR, go to http://www.epa.gov/coalash/coal-ash-rule.

Effluent Limitation and Guidelines (ELG)

In September 2015, the EPA finalized a rule revising the regulations for the Steam Electric Power Generating category (40 CFR Part 423).[35] The rule established federal limits on the levels of toxic metals in wastewater that can be discharged from power plants. The rule established or updated standards for wastewater streams from flue gas desulfurization, fly ash, bottom ash, flue gas mercury control, and gasification of fuels.

On October 13, 2020 – EPA published a reconsideration rule that revised the requirements for flue gas desulfurization (FGD) wastewater and bottom ash (BA) transport water; revised the voluntary incentives program for FGD wastewater; added subcategories; and established new compliance dates. These changes, and corresponding requirements and costs, are reflected in EPA 2023 Reference Case. EPA reflects this rule in this base case by apportioning the estimated total capital, and FOM costs to likely affected units based on controls and capacity. The cost adders are reflected in the model inputs and were applied starting in 2025, by which point the requirements were expected to be fully implemented.

On July 26, 2021, EPA announced it was initiating a supplemental rulemaking to strengthen certain discharge limits in the Steam Electric Power Generating category. EPA undertook a science-based review of the 2020 Steam Electric Reconsideration Rule under Executive Order 13990, finding that opportunities for improvement exist. EPA intends to issue a proposed rule for public comment in the fall of 2022. The current rule will continue to be implemented (and reflected in IPM) and any additional or updated requirements from this supplemental rulemaking will be incorporated when final.

For more information on ELG, go to https://www.epa.gov/eg/effluent-guidelines-plan.

3.10.7 State-Specific Environmental Regulations

EPA 2023 Reference Case represents enacted laws and regulations in states affecting emissions from the electricity sector. Table 3-29 summarizes the provisions of state laws and regulations that are represented in EPA 2023 Reference Case.

[35] https://www.epa.gov/eg/steam-electric-power-generating-effluent-guidelines-2015-final-rule

3.10.8 New Source Review (NSR) Settlements

New Source Review (NSR) settlements refer to legal agreements with companies resulting from the permitting process under the CAAA, which requires industry to undergo an EPA pre-construction review of proposed environmental controls either on new facilities or as modifications to existing facilities where there would result in a "significant increase" in a regulated pollutant. A summary of the units affected and how the settlements were modeled can be found in Table 3-30.

State settlements and citizen settlements are also represented in EPA 2023 Reference Case. These are summarized in Table 3-31 and Table 3-32 respectively.

3.10.9 Emission Assumptions for Potential (New) Units

There are no location-specific variations in the emission and removal rate capabilities of potential new units. In IPM, potential new units are modeled as additional capacity and generation that may come online in each model region. Across all model regions, the emission and removal rate capabilities of potential new units are the same, and they reflect applicable federal emission limitations on new sources. The specific assumptions regarding the emission and removal rates of potential new units in EPA 2023 Reference Case are presented in Table 3-24. (Note: Nuclear, wind, solar, and fuel cell technologies are not included in Table 3-24 because they do not emit any of the listed pollutants.) For additional details on the modeling of potential new units, see Chapter 4.

3.10.10 Renewable Portfolio Standards and Clean Energy Standards

Renewable Portfolio Standards (RPS) generally refer to various state-level policies that require renewable generation to meet a specified share of generation or sales. In the EPA 2023 Reference Case, the state RPS requirements are represented at a state level based on existing requirements. Table 3-18 and Table 3-19 show the state-level RPS and solar carve-out requirements.

Table 3-18 Renewable Portfolio Standards in the EPA 2023 Reference Case

State	2028	2030	2035	2040	2045	2050	2055
Arizona	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%	8.6%
California	52.0%	57.3%	70.7%	84.0%	97.3%	100.0%	100.0%
Colorado	20.9%	20.9%	20.9%	20.9%	20.9%	20.9%	20.9%
Connecticut	40.0%	44.0%	44.0%	44.0%	44.0%	44.0%	44.0%
District of Columbia	73.0%	87.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Delaware	26.5%	28.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Iowa	0.6%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%
Illinois	32.5%	40.0%	45.0%	50.0%	50.0%	50.0%	50.0%
Massachusetts	36.0%	40.0%	45.0%	50.0%	55.0%	60.0%	60.0%
Maryland	47.5%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
Maine	71.0%	80.0%	85.0%	90.0%	95.0%	100.0%	100.0%
Michigan	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%	35.0%
Minnesota	34.0%	40.0%	55.0%	55.0%	55.0%	55.0%	55.0%
Missouri	10.5%	10.5%	10.5%	10.5%	10.5%	10.5%	10.5%
North Carolina	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%	11.6%
New Hampshire	23.0%	23.0%	23.0%	23.0%	23.0%	23.0%	23.0%
New Jersey	46.5%	52.5%	52.5%	52.5%	52.5%	52.5%	52.5%
New Mexico	41.6%	45.2%	57.2%	69.2%	70.7%	72.3%	72.3%
Nevada	34.8%	41.4%	41.4%	41.4%	41.4%	41.4%	41.4%
New York	61.2%	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%
Ohio	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%	7.6%
Oregon	18.6%	23.7%	31.1%	35.5%	39.9%	39.9%	39.9%
Pennsylvania	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Rhode Island	55.5%	72.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Texas	6.5%	6.3%	6.0%	5.7%	5.4%	5.1%	5.1%
Virginia	26.1%	30.8%	44.5%	60.2%	76.0%	78.4%	78.4%
Vermont	67.0%	71.0%	75.0%	75.0%	75.0%	75.0%	75.0%

State	2028	2030	2035	2040	2045	2050	2055
Washington	12.2%	12.2%	12.2%	12.2%	12.2%	12.2%	12.2%
Wisconsin	9.6%	9.6%	9.6%	9.6%	9.6%	9.6%	9.6%

Notes:
The Renewable Portfolio Standard percentages are applied to modeled electricity sale projections.
North Carolina standards are adjusted to account for swine waste and poultry waste set-asides.

Table 3-19 State RPS Solar Carve-outs in the EPA 2023 Reference Case

State	2028	2030	2035	2040	2045	2050	2055
District of Columbia	4.50%	5.00%	7.00%	9.50%	10.00%	10.00%	10.00%
Delaware	4.25%	5.00%	10.00%	10.00%	10.00%	10.00%	10.00%
Illinois	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%
Maryland	14.50%	14.50%	14.50%	14.50%	14.50%	14.50%	14.50%
Minnesota	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%	1.50%
Missouri	0.21%	0.21%	0.21%	0.21%	0.21%	0.21%	0.21%
North Carolina	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%
New Hampshire	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%
New Jersey	3.74%	2.21%	1.10%	1.10%	1.10%	1.10%	1.10%
Oregon	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%	8.00%
Pennsylvania	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%

Clean Energy Standards require a certain percentage of electricity sales be met through zero carbon resources, such as renewables, nuclear, and hydropower. These requirements are summarized in Table 3-20. In addition, multiple U.S. states have adopted offshore wind energy policies, which are summarized in Table 3-21. Thermal generation limits are imposed in states where RPS or CES standards exceed 50% of sales to ensure that the states do not generate excess thermal power to satisfy exports. Table 3-22 summarizes the limits imposed in EPA 2023 Reference Case. These limits are not provided in affected PJM and New England states, as these states can meet their RPS requirements within PJM or ISONE.

Table 3-20 Clean Energy Standards in the EPA 2023 Reference Case

State	2028	2030	2035	2040	2045	2050	2055
California	-	-	-	-	-	100%	100%
Colorado	-	-	-	-	-	51%	51%
Connecticut	-	40%	70%	100%	100%	100%	100%
Illinois	-	-	-	-	-	100%	100%
Massachusetts	48%	60%	65%	70%	75%	80%	80%
Minnesota	-	75%	90%	100%	100%	100%	100%
Nevada	-	-	-	-	-	100%	100%
New Mexico	-	-	-	-	70%	90%	90%
New York	-	-	-	100%	100%	100%	100%
Oregon	-	-	-	100%	100%	100%	100%
Washington	-	100%	100%	100%	100%	100%	100%

Table 3-21 Offshore Wind Mandates in the EPA 2023 Reference Case

State	Bill/Act	Mandate Specifications	Implementation Year
Maryland	Senate Bill 516	400 MW, 800 MW, and 1,200 MW of offshore wind capacity by 2026, 2028 and 2030 respectively	2030
Maryland	Maryland Offshore Wind Energy Act of 2013	368 MW of offshore wind capacity (248 MW of US Wind, Inc. and 120 MW of Skipjack Offshore Energy, LLC projects)	2023
New Jersey	Executive Order No. 92	7,500 MW of offshore wind capacity by 2035	2035
Connecticut	House Bill 7156	2,000 MW of offshore wind capacity by 2030	2030

State	Bill/Act	Mandate Specifications	Implementation Year
Massachusetts	2016 Bill 4568	An Act to Promote Energy Diversity, legislation allows for the procurement of approximately 1,600MW of offshore wind	
		800MW Vineyard Wind	2024
		800MW South Coast Wind aka Mayflower Wind	2025
	Massachusetts Energy Diversity Act	4,000 MW of offshore wind capacity by 2027	2028
New York	Climate Leadership and Community Protection Act	9,000 MW of offshore wind capacity by 2035	2035
Virginia	Virginia Clean Economy Act	Development by Dominion Energy Virginia of qualified offshore wind projects having an aggregate rated capacity of not less than 5,200 megawatts by December 31, 2032 (Senate Bill 1441, legp604.exe (virginia.gov)	2035
Maine	Final Report of the Ocean Energy Task Force, 2009	Goal of 5,000 MW of offshore wind capacity by 2030	Not implemented
California		3,500 MW by 2030 and 25,000 MW by 2045	2030

Table 3-22 Fossil Generation Limits (GWh) in the EPA 2023 Reference Case

State	2028	2030	2035	2040	2045	2050	2055
California	158,266	150,564	135,237	102,949	75,365	73,943	89,090
Colorado	-	-	-	-	-	51,354	54,187
Illinois	-	-	-	91,212	94,870	11,251	11,710
New Mexico	-	-	14,248	11,682	11,995	6,309	6,747
Nevada	-	-	-	-	-	5,874	6,514
New York	69,195	58,109	63,363	14,244	15,195	15,925	16,652
Oregon	-	-	-	7,530	8,258	8,982	9,698
Virginia	-	-	-	66,893	44,218	42,019	44,149
Washington	-	10,676	11,704	12,796	14,035	15,264	16,481

3.11 Emissions Trading and Banking

Several environmental air regulations included in EPA 2023 Reference Case involve regional trading and banking of emission allowances. This includes the Regional Greenhouse Gas Initiative (RGGI) for CO_2; and the West Region Air Partnership's (WRAP) program regulating SO_2 (adopted in response to the federal Regional Haze Rule).

Table 3-23 summarizes the key parameters of these trading and banking programs as incorporated in EPA 2023 Reference Case. EPA 2023 Reference Case does not include any explicit assumptions on the allocation of emission allowances among model plants under any of the programs.

3.11.1 Intertemporal Allowance Price Calculation

Under a perfectly competitive cap-and-trade program that allows banking (with a single, fixed future cap, and full banking allowed), the allowance price always increases by the discount rate between periods if affected sources have allowances banked between those two periods. This is a standard economic result for cap-and-trade programs and is consistent with producing a least-cost solution.

EPA 2023 Reference Case uses the same discount rate assumption that governs all intertemporal economic decision-making in the model. The approach assumes that allowance trading is a standard activity engaged in by generation asset owners and that their intertemporal investment decisions as related to allowance trading will not fundamentally differ from other investment decisions. For more information on how this discount rate was calculated, see Section 10.4.

Table 3-23 Trading and Banking Rules in the EPA 2023 Reference Case

	WRAP- SO_2	RGGI - CO_2
Coverage	All fossil units > 25 MW[1]	All fossil units > 25 MW[2]
Timing	Annual	Annual
Size of Initial Bank (MTons)	The bank starting in 2018 is assumed to be zero	2028: 68,000
Total Allowances (MTons)	2018 - 2059: 89.6	2028: 94,183 2029: 90,528 2030 - 2059: 86,873

Notes:
[1] New Mexico, Utah, and Wyoming.
[2] Connecticut, Delaware, Maine, New Hampshire, New York, Vermont, Rhode Island, Massachusetts, Maryland, Virginia, and New Jersey.

Table 3-24 Emission and Removal Rate Assumptions for Potential (New) Units in the EPA 2023 Reference Case

	Controls, Removal, and Emissions Rates	Ultra-Supercritical Pulverized Coal	Ultra-Supercritical Pulverized Coal with 36% CCS	Ultra-Supercritical Pulverized Coal with 90% CCS	Advanced Combined Cycle	Advanced Combined Cycle with CCS	Advanced Combustion Turbine	Biomass	Geothermal	Landfill Gas
SO_2	**Removal / Emissions Rate**	98% with a floor of 0.06 lbs/MMBtu	98% with a floor of 0.06 lbs/MMBtu	98% with a floor of 0.06 lbs/MMBtu	None	None	None	0.08 lbs/MMBtu	None	None
NO_x	**Emission Rate**	0.05 lbs/MMBtu	0.05 lbs/MMBtu	0.05 lbs/MMBtu	0.011 lbs/MMBtu	0.011 lbs/MMBtu	0.011 lbs/MMBtu	0.02 lbs/MMBtu	None	0.09 lbs/MMBtu
Hg	**Removal / Emissions Rate**	90%	90%	90%	Natural Gas: 0.00014 lbs/MMBtu Oil: 0.48 lbs/MMBtu	Natural Gas: 0.00014 lbs/MMBtu Oil: 0.48 lbs/MMBtu	Natural Gas: 0.00014 lbs/MMBtu Oil: 0.48 lbs/MMBtu	0.57 lbs/MMBtu	3.7	None
CO_2	**Removal / Emissions Rate**	202.8 - 219.3 lbs/MMBtu	36%	90%	Natural Gas: 117.08 lbs/MMBtu Oil: 161.39 lbs/MMBtu	90%	Natural Gas: 117.08 lbs/MMBtu Oil: 161.39 lbs/MMBtu	None	None	None
HCL	**Removal / Emissions Rate**	99% with a floor of 0.001 lbs/MMBtu	99% with a floor of 0.001 lbs/MMBtu	99% with a floor of 0.001 lbs/MMBtu						

Table 3-25 Recalculated NO_x Emission Rates for SCR Equipped Units Sharing Common Stacks with Non-SCR Units in the EPA 2023 Reference Case

Plant Name	UniqueID_Final	Capacity (MW)	NOx Post-Comb Control	SCR Online Year	Mode 1 NO_x Rate (lbs/MMBtu)	Mode 2 NO_x Rate (lbs/MMBtu)	Mode 3 NO_x Rate (lbs/MMBtu)	Mode 4 NO_x Rate (lbs/MMBtu)
Ghent	1356_B_2	495			0.305	0.305	0.305	0.305
Ghent	1356_B_3	485	SCR	2004	0.075	0.075	0.075	0.075
Cooper	1384_B_1	116			0.273	0.273	0.199	0.199
Cooper	1384_B_2	225	SCR	2012	0.075	0.075	0.075	0.075
Clifty Creek	983_B_4	196	SCR	2003	0.075	0.075	0.075	0.075
Clifty Creek	983_B_5	196	SCR	2002	0.075	0.075	0.075	0.075
Clifty Creek	983_B_6	196			0.667	0.3	0.667	0.3

3.12 45Q – Credit for Carbon Dioxide Sequestration

Inflation Reduction Act of 2022, Section 45Q – which amended a Credit for Carbon Dioxide Sequestration originally passed in 2008 (hereafter referred to as the 45Q tax credit) is implemented in EPA 2023 Reference Case.

The updated 45Q tax credit offers increased monetary incentives through a tax credit for the capture and geologic storage of CO_2 that electric power plants and other industrial sources in the United States would otherwise emit. The essential features of the tax credit are as follows:

- $60 per metric ton in 2022 for CO_2 captured and injected into existing oil wells for enhanced oil recovery (EOR). The credit is adjusted for inflation post-2026.
- $85 per metric ton in 2022 for CO_2 captured and sequestrated in geologic formation (non-EOR). The credit is adjusted for inflation post-2026.
- The difference in the amounts of credit between EOR and non-EOR is designed to recognize that the EOR-captured CO_2 can be used to produce oil that may not otherwise be recovered, while the non-EOR-stored CO_2 does not bring additional revenue.
- Credits are available to plants that start construction or begin a retrofit before January 1, 2033 and are assumed to be applied for the first 12 years of operation. Due to an assumed construction lead time of 5 plus years for CCS retrofits, CCS retrofits in 2030 and 2035 run years are assumed to qualify for the tax credit.

The 45Q tax credit is implemented by applying its value through an adjustment to the step prices in the CO_2 storage cost curves. The process involves converting the credit amounts into 2022 real dollars, calculating weighted average tax credits by run year, and applying the weighted average tax credits to the individual step prices in the CO_2 storage cost curves.

List of tables and attachments that are uploaded directly to the web:

Table 3-26 Regional Net Internal Demand in EPA 2023 Reference Case

Table 3-27 Annual Transmission Capabilities of U.S. Model Regions in EPA 2023 Reference Case

Table 3-28 Turndown Assumptions for Coal Steam Units in EPA 2023 Reference Case

Table 3-29 State Power Sector Regulations included in EPA 2023 Reference Case

Table 3-30 New Source Review (NSR) Settlements in EPA 2023 Reference Case

4. Generating Resources

Existing, planned-committed, and potential are the three types of generating units modeled in EPA 2023 Reference Case. Electric generating units currently in operation are termed existing units. Units that are anticipated to be in operation in the near future, for having broken ground or secured financing, are planned-committed. Potential units refer to new generating options that IPM builds to meet industry capacity expansion projections. Existing and planned-committed units enter IPM as exogenous inputs, whereas potential units are endogenous to IPM in that the model determines the location and size of the potential units to build.

This chapter is organized as follows.

i) Section 4.1 provides background information on the National Electric Energy Data System (NEEDS), the database that serves as the repository for information on existing and planned-committed electric generating units modeled,

ii) Section 4.2 provides detailed information on existing non-nuclear generating units,

iii) Section 4.3 provides detailed information on planned-committed units,

iv) Section 4.4 provides detailed information on potential units, and

v) Section 4.6 describes assumptions pertaining to existing and potential nuclear units.

4.1 National Electric Energy Data System (NEEDS)

EPA 2023 Reference Case uses the NEEDS database as its source for data on all existing and planned-committed units. Section 4.2 discusses the sources used in developing data on existing units. The population of existing units in the NEEDS represents electric generating units that were in operation through the end of 2023. Section 4.3 discusses the sources used in developing data on planned-committed units. The population of planned-committed includes units online or scheduled to come online from 2024 through June 30, 2028.

4.2 Existing Units

The sections below describe the procedures for determining the population of existing units in NEEDS, as well as the capacity, location, and configuration information of each unit in the population.

4.2.1 Population of Existing Units

The capacity data for existing units in NEEDS was obtained from the sources reported in Table 4-1. The January 2023 EIA Form 860M is the primary data source on existing units. Table 4-2 specifies the screening rules applied to the data source to ensure data consistency and adaptability for use in EPA 2023 Reference Case.

Table 4-1 Data Sources for NEEDS

Data Source[1]	Data Source Documentation
EIA's Form EIA-860	EIA's Form EIA-860 is both a monthly and annual survey of utility and non-utility power plants at the generator level. It contains data such as summer, winter and nameplate capacity, location (state and county), operating status, prime mover, energy sources and in-service date of existing and proposed generators. NEEDS uses EIA Form 860 (January and August 2023 monthly versions, and 2021 annual release) data as primary generator data inputs. EIA's Form EIA-860 also collects data of steam boilers such as energy sources, boiler identification, location, operating status, and design information; and associated environmental equipment such as NO_x combustion and post-combustion control, FGD scrubber, mercury control and particulate collector device information. Note that boilers in plants with less than 10 MW do not report all data elements. The association between boilers and generators is also provided. Note that boilers and generators are not necessarily in a one-to-one correspondence. NEEDS uses EIA Form 860 (2021 annual release) data as one of the primary boiler data inputs.
EIA's Annual Energy Outlook (AEO)	The Energy Information Administration (EIA) Annual Energy Outlook presents annually updated projections of energy supply, demand and prices covering a 20-25 year time horizon. The projections are based on results from EIA's National Energy Modeling System (NEMS). Information from AEO 2023 Reference Case such as capacity for nuclear units was used in NEEDS.
EPA's Emission Tracking System	The Emission Tracking System (ETS) database is updated quarterly. It contains boiler-level information such as primary fuel, heat input, SO_2, NO_x, Mercury, and HCL controls, and SO_2 and NO_x emissions. NEEDS uses annual and seasonal ETS (2019) data as one of the primary data inputs for NO_x rate development and ETS (2022) data for environmental equipment assignment.
Utility and Regional EPA Office Comments	Comments from utilities and regional EPA offices, and EPA research regarding the population in NEEDS as of Summer 2023 (e.g., retirements and new units) as well as unit characteristics were incorporated in NEEDS.

Note:

[1] Shown in Table 4-1 are the primary issue dates of the indicated data sources used. Other vintages of these data sources were also used in instances where data were not available for the indicated issued date, or where there were methodological reasons for using other vintages of the data.

Table 4-2 Rules Used in Populating NEEDS

Scope	Rule
Capacity	Excluded units that had reported summer capacity, winter capacity, and nameplate capacity of zero or blank.
Status	Excluded units that were out of service for three consecutive years (i.e., generators or boilers with status codes "OS[36]" or "OA[37]" in the latest three reporting years) and units that were no longer in service and not expected to be returned to service (i.e., generators or boilers with status codes of "RE[38]"). Status of boiler(s) and associated generator(s) were considered for determining operation status.
Planned or Committed Units	For plant types other than wind, solar and energy storage, included planned units that had broken ground and were expected to be online by June 30, 2028.

[36] OS - Out of service and was not used for some or all of the reporting period and is NOT expected to be returned to service in the next calendar year.

[37] OA - Out of service and was not used for some or all of the reporting period but is expected to be returned to service in the next calendar year.

[38] RE - Retired and no longer in service and not expected to be returned to service.

Scope	Rule
	For wind, solar and energy storage units, included planned units that had broken ground, had received, had pending regulatory approvals or had planned for installation and were expected to be online by June 30, 2028[39].
Firm/Non-firm Electric Sales	Excluded non-utility onsite generators that did not produce electricity for sale to the grid on a net basis.

The NEEDS includes steam units at the boiler level and non-steam units at the generator level (nuclear units are also at the generator level). A unit in NEEDS, therefore, refers to a boiler in the case of a steam unit and a generator in the case of a non-steam unit.

Table 4-3 provides a summary of the population and capacity of the existing units included in NEEDS through 2023. The final population of existing units is supplemented based on information from other sources. These include comments from utilities, submissions to EPA's Emission Tracking System, Annual Energy Outlook, and other research.

EPA 2023 Reference Case removes units from the NEEDS inventory based on public announcements of future closures. The removal of such units pre-empts IPM from making any further decisions regarding the operational status or configuration of the units. These units are removed from the NEEDS inventory only if a high degree of certainty could be assigned to future implementation of the announced action and are identified from reviewing several data sources, including:

i) Reviewing unit retirement list from EIA Electric Generator Capacity data (EIA Form 860M), January 2023

ii) PJM Future Deactivation Requests and PJM Generator Deactivations, May 2023 (updated frequently)

iii) Units that have committed specifically to retire before June 30, 2028, under federal or state enforcement actions or regulatory requirements

iv) Research by EPA and ICF staff as of Summer 2023

Research includes:

- Reviewing utility company Integrated Resource Plan (IRP), Sustainably, Climate and ESG Reports, along with company news releases, to capture retirement or repowering data on the owned fleet.
- Reviewing investor news released by the company that outlines the closure or repowering of owned fleet
- Referencing EIA Electric Power Monthly Report Table 6.6 Planned U.S. Electric Generation Unit Retirements.
- Reviewing outside news articles that capture closure or repowering of individual Electricity Generating Units (EGU), or reports released from utility companies.

Units required to retire pursuant to enforcement actions or state rules on July 1, 2028, or later are retained in NEEDS. Such July 1, 2028- or later retirements are captured as constraints on those units in IPM modeling, and the units are retired in future year projections per the terms of the related requirements.

[39] Also included one solar PV unit at Alira plant with a capacity of 222.8 megawatt that has pending regulatory approval and is scheduled to come online in 2030, one solar PV unit at Aiya Solar Project plant with a capacity of 100 megawatt that has planned for installation and is scheduled to come online in 2029, as well as one offshore wind unit at Ocean Wind II plant with a capacity of 1,148 megawatt that is planned for installation and is scheduled to come online in 2029.

The “Capacity Dropped” and the “Retired Through 2028” worksheets in NEEDS list all units that are removed from the NEEDS inventory.

Table 4-3 Summary Population (through 2023) of Existing Units in NEEDS

Plant Type	Number of Units	Capacity (MW)
Biomass	144	3,123
Coal Steam	360	154,170
Combined Cycle	1,889	288,182
Combustion Turbine	6,285	148,865
Energy Storage	646	19,656
Fossil Waste	54	1,071
Fuel Cell	207	354
Geothermal	164	2,609
Hydro	3,766	79,541
IGCC	5	815
Landfill Gas	1,425	1,659
Municipal Solid Waste	147	1,913
Non-Fossil Waste	197	2,094
Nuclear	91	93,570
O/G Steam	393	63,581
Offshore Wind	3	171
Onshore Wind	1,510	149,351
Pumped Storage	151	22,907
Solar PV	6,267	102,177
Solar Thermal	12	1,480
Tires	1	26
US Total	23,717	1,137,316

4.2.2 Capacity

The unit capacity data implemented in NEEDS reflects net summer dependable capacity.[40] Table 4-4 summarizes the hierarchy of data sources used in compiling capacity data. In other words, capacity values are taken from a particular source only if the sources listed above it do not provide adequate data for the unit in question.

Table 4-4 Hierarchy of Data Sources for Capacity in NEEDS

Sources Presented in Hierarchy
Net Summer Capacity from Comments / ICF Research
AEO 2023 Nuclear Capacity in 2028
January 2023 EIA Form 860 monthly Net Summer Capacity
2021 EIA Form 860 Net Summer Capacity

Notes:
Presented in a hierarchical order that applies.
If the capacity of a unit is zero MW, the unit is excluded from the NEEDS population.

As noted earlier, NEEDS includes boiler-level data for steam units and generator-level data for non-steam units. Capacity data in EIA Form 860 are generator-specific, not boiler-specific. Therefore, it was necessary to develop an algorithm for parsing generator-level capacity to the boiler level for steam-producing units.

The capacity-parsing algorithm used for steam units in NEEDS considered boiler-generator mapping. Fossil steam electric units have boilers attached to generators that produce electricity. There are

[40] As used here, net summer dependable capacity is the net capability of a generating unit in megawatts (MW) for daily planning and operation purposes during the summer peak season, after accounting for station or auxiliary services.

generally four types of links between boilers and generators: one boiler to one generator, one boiler to many generators, many boilers to one generator, and many boilers to many generators.

The capacity-parsing algorithm used for steam units in NEEDS utilizes steam flow data with the boiler-generator mapping. Under EIA Form 860, steam units report the maximum steam flow from the boiler to the generator. There is, however, no further data on the steam flow of each boiler-generator link. Instead, EIA Form 860 contains only the maximum steam flow for each boiler. Table 4-5 summarizes the algorithm used for parsing capacity with data on maximum steam flow and boiler-generator mapping. In Table 4-5, MF_{Bi} refers to the maximum steam flow of boiler *i* and MW_{Gj} refers to the capacity of generator *j*. The algorithm uses the available data to derive the capacity of a boiler, referred to as MW_{Bj} in Table 4-5.

Table 4-5 Capacity-Parsing Algorithm for Steam Units in NEEDS

	Type of Boiler-Generator Links			
For Boiler B1 to BN linked to Generators G1 to GN	One-to-One	One-to-Many	Many-to-One	Many-to-Many
	$MW_{Bi} = MW_{Gj}$	$MW_{Bi} = \Sigma j MW_{Gj}$	$MW_{Bi} = (MF_{Bi} / \Sigma i MF_{Bi}) * MW_{Gj}$	$MW_{Bi} = (MF_{Bi} / \Sigma i MF_{Bi}) * \Sigma j MW_{Gj}$

Notes:
MF_{Bi} = maximum steam flow of boiler *i*
MW_{Gj} = electric generation capacity of generator *j*

Since EPA 2023 Reference Case uses net energy for load as demand, NEEDS includes only generators that sell most of their power to the electric grid. The approach is intended to be broadly consistent with the generating capacity used in the AEO projections where demand is net energy for load. The generators that should be in NEEDS by this qualification are determined from the 2021 EIA Form 923 non-utility source and disposition data set.

4.2.3 Plant Location

The physical location of each unit in NEEDS is represented by the unit's model region, state, and county data.

<u>State and County</u>

NEEDS uses the state and county data from the January 2023 EIA Form 860M.

<u>Model Region</u>

For each unit, the associated model region was derived based on NERC assessment regions reported in EIA Form 860 and ISO/RTO reports. For units with no NERC assessment region data, state, and county data were used to derive associated model regions. Table 3-1 in Chapter 3 provides a summary of the mapping between NERC assessment regions and EPA 2023 Reference Case model regions.

4.2.4 Online Year

EPA 2023 Reference Case uses online year to capture when a unit entered service. NEEDS includes online years for all units in the population. Online years for boilers were from the 2021 EIA Form 860, and online years for generators were derived primarily from reported in-service dates in the January 2023 EIA Form 860M.

EPA 2023 Reference Case includes constraints to set the retirement year for generating units that are firmly committed to retiring after June 30, 2028, based on state or federal regulations, enforcement actions, and announcements.

Economic retirement options are also provided to allow the model the option to retire a unit if it finds it economical to do so. In IPM, a retired unit ceases to incur fixed O&M and variable O&M costs. The unit, however, continues to make annualized capital cost payments on any previously incurred capital cost for model-installed retrofits projected before retirement.

4.2.5 Unit Configuration

Unit configuration refers to the physical specification of a unit's design. Unit configuration in EPA 2023 Reference Case drives model plant aggregation and modeling of pollution control options and mercury emission modification factors. NEEDS contains for each unit, data on the firing and bottom type, as well as existing and committed emission controls the unit has. Table 4-6 shows the hierarchy of data sources used in determining a unit configuration. The sources listed below are also supplemented by recent ICF and EPA research to ensure the unit configuration data in NEEDS is the most comprehensive and up-to-date possible.

Table 4-6 Data Sources for Unit Configuration in NEEDS

Unit Component	Primary Data Source	Secondary Data Source	Tertiary Data Source	Other Sources	Default
Firing Type	EPA's Emission Tracking System (ETS) – 2022	2021 EIA 860	--	--	--
Bottom Type	EPA's Emission Tracking System (ETS) – 2022	2021 EIA 860	--	--	Dry
SO_2 Pollution Control	EPA's Emission Tracking System (ETS) – 2022	2018 EIA 860	NSR Settlement or Comments	--	No Control
NO_x Pollution Control	EPA's Emission Tracking System (ETS) – 2022	2018 EIA 860	NSR Settlement or Comments	--	No Control
Particulate Matter Control	EPA's Emission Tracking System (ETS) – 2022	2021 EIA 860	NSR Settlement or Comments	--	--
Mercury Control	EPA's Emission Tracking System (ETS) – 2022	2018 EIA 860	NSR Settlement or Comments	--	--
HCL Control	EPA's Emission Tracking System (ETS) – 2022	2018 EIA 860	NSR Settlement or Comments	--	--

4.2.6 Model Plant Aggregation

While EPA 2023 Reference Case using IPM is comprehensive in representing all the units contained in NEEDS, an aggregation scheme is used to combine existing units with similar characteristics into model plants. The aggregation scheme serves to reduce the size of the model, making the model manageable while capturing the essential characteristics of the generating units. The aggregation scheme is designed so that each model plant represents only generating units from a single model region and state. The design makes it possible to obtain state-level results directly from IPM outputs. In addition, the aggregation scheme supports the modeling of plant-level emission limits on fossil generation.

The aggregation scheme encompasses different categories including location, size, technology, heat rate, fuel choices, unit configuration, SO_2 emission rates, and environmental regulations among others. Units are aggregated together only if they match on all the different categories specified for the aggregation. The 11 major categories used for the aggregation scheme in EPA 2023 Reference Case are the following.

i) Facility (ORIS) for all fossil units except combustion turbine units smaller than or equal to 25 MW in the United States
ii) Model Region
iii) State

iv) Unit Technology Type
v) Unit Configuration
vi) Cogen
vii) Fuel Category
viii) Fuel Demand Region
ix) Applicable Environmental Regulations
x) Heat Rates for coal steam and Oil/Gas steam units
xi) Size

Table 4-7 shows the number of actual units by generation technology type and the related number of aggregated model plants in the EPA 2023 Reference Case. For each plant type, the table shows the number of generating units and the number of model plants representing the generating units.[41]

Table 4-7 Aggregation Profile of Model Plants as Provided at Set up of the EPA 2023 Reference Case

Existing and Planned/Committed Units		
Plant Type	**Number of Units**	**Number of IPM Model Plants**
Biomass	296	108
Coal Steam	375	290
Combined Cycle	2,013	866
Combustion Turbine	6,589	1,193
Distributed Solar PV	130	130
Energy Storage	667	70
Fossil Waste	60	25
Fuel Cell	207	23
Geothermal	164	13
Hydro	5,461	213
IGCC	5	2
IMPORT	1	1
Landfill Gas	1,449	92
Municipal Solid Waste	148	52
Non-Fossil Waste	228	86
Nuclear	104	104
O/G Steam	481	296
Offshore Wind	16	7
Onshore Wind	1,950	87
Pumped Storage	158	28
Solar PV	6,798	110
Solar Thermal	13	6
Tires	1	1
Total	**27,314**	**3,803**
New Units		

[41] (1) The “Number of IPM Model Plants” shown for many of the “Plant Types” in the “Retrofits” block in Table 4-7 exceeds the “Number of IPM Model Plants” shown for “Plant Type” “Coal Steam” in the block labeled “Existing and Planned - Committed Units”, because a particular retrofit “Plant Type” can include multiple technology options and multiple timing options (e.g., Technology A in Stage 1 + Technology B in Stage 2 + Technology C in Stage 3, the reverse timing, or multiple technologies simultaneously in Stage 1).

(2) Since only a subset of coal plants is eligible for certain retrofits, many of the “Plant Types” in the “Retrofits” block that represent only a single retrofit technology (e.g., “Retrofit Coal with SNCR”) have a “Number of IPM Model Plants” that is a smaller than the “Number of IPM Model Plants” shown for “Plant Type” “Coal Steam”.

(3) The total number of model plants representing different types of new units often exceeds the 67 U.S. model regions and varies from technology to technology for several reasons. First, some technologies have multiple vintages (i.e., different cost and/or performance parameters depending on which run year in which the unit is created), which must be represented by separate model plants in each IPM region. Second, some technologies are not available in particular regions (e.g., geothermal is geographically restricted to certain regions).

Plant Type	Number of Units	Number of IPM Model Plants
New Battery Storage	--	524
New Biomass	--	134
New Combined Cycle	--	82
New Combined Cycle with CCS	--	128
New Combined Cycle with CCS Retrofit	--	142
New Combined Cycle with CF Limit	--	71
New Combined Cycle with HRI Retrofit	--	71
New Combined Cycle with Hydrogen Retrofit	--	71
New Combined Cycle with Hydrogen Retrofit Undone	--	71
New Combustion Turbine	--	94
New Combustion Turbine with HRI Retrofit	--	83
New Combustion Turbine with Hydrogen Retrofit	--	166
New Combustion Turbine with Hydrogen Retrofit Undone	--	166
New Fuel Cell	--	75
New Geothermal	--	61
New Hydro	--	153
New Landfill Gas	--	379
New Nuclear	--	66
New Offshore Wind	--	388
New Onshore Wind	--	2,058
New Small Modular Reactor	--	66
New Solar PV	--	2,110
New Solar Thermal	--	248
New Ultrasupercritical Coal with 30% CCS	--	128
New Ultrasupercritical Coal with 90% CCS	--	128
New Ultrasupercritical Coal without CCS	--	5
Total	--	**7,668**

Retrofits

Plant Type	Number of Units	Number of IPM Model Plants
Retrofit Coal with ACI	--	98
Retrofit Coal with ACI + C2G	--	69
Retrofit Coal with ACI + C2G + SCR	--	16
Retrofit Coal with ACI + CCS	--	74
Retrofit Coal with ACI + DRET	--	98
Retrofit Coal with ACI + DSI	--	2
Retrofit Coal with ACI + DSI + C2G	--	2
Retrofit Coal with ACI + DSI + C2G + SCR	--	2
Retrofit Coal with ACI + DSI + DRET	--	2
Retrofit Coal with ACI + DSI + GPM	--	2
Retrofit Coal with ACI + DSI + GPM + C2G	--	2
Retrofit Coal with ACI + DSI + GPM + C2G + SCR	--	2
Retrofit Coal with ACI + DSI + GPM + DRET	--	2
Retrofit Coal with ACI + DSI + GPM + NGC	--	2
Retrofit Coal with ACI + DSI + GPM + SCR	--	2
Retrofit Coal with ACI + DSI + GPM + SCR + DRET	--	2
Retrofit Coal with ACI + DSI + GPM + SCR + NGC	--	2
Retrofit Coal with ACI + DSI + GPM + Scrubber + SCR + CCS	--	4
Retrofit Coal with ACI + DSI + GPM + SNCR	--	2
Retrofit Coal with ACI + DSI + GPM + SNCR + DRET	--	2
Retrofit Coal with ACI + DSI + GPM + SNCR + NGC	--	2
Retrofit Coal with ACI + DSI + NGC	--	2
Retrofit Coal with ACI + DSI + SCR	--	2
Retrofit Coal with ACI + DSI + SCR + DRET	--	2
Retrofit Coal with ACI + DSI + SCR + NGC	--	2
Retrofit Coal with ACI + DSI + Scrubber + SCR + CCS	--	4
Retrofit Coal with ACI + DSI + SNCR	--	2
Retrofit Coal with ACI + DSI + SNCR + DRET	--	2
Retrofit Coal with ACI + DSI + SNCR + NGC	--	2

Retrofit Coal with ACI + GPM	--	81
Retrofit Coal with ACI + GPM + C2G	--	54
Retrofit Coal with ACI + GPM + C2G + SCR	--	14
Retrofit Coal with ACI + GPM + CCS	--	61
Retrofit Coal with ACI + GPM + DRET	--	81
Retrofit Coal with ACI + GPM + NGC	--	81
Retrofit Coal with ACI + GPM + SCR	--	14
Retrofit Coal with ACI + GPM + SCR + CCS	--	6
Retrofit Coal with ACI + GPM + SCR + DRET	--	14
Retrofit Coal with ACI + GPM + SCR + NGC	--	14
Retrofit Coal with ACI + GPM + Scrubber + SCR + CCS	--	4
Retrofit Coal with ACI + GPM + SNCR	--	21
Retrofit Coal with ACI + GPM + SNCR + DRET	--	21
Retrofit Coal with ACI + GPM + SNCR + NGC	--	21
Retrofit Coal with ACI + NGC	--	98
Retrofit Coal with ACI + SCR	--	16
Retrofit Coal with ACI + SCR + CCS	--	8
Retrofit Coal with ACI + SCR + DRET	--	16
Retrofit Coal with ACI + SCR + NGC	--	16
Retrofit Coal with ACI + Scrubber + SCR + CCS	--	4
Retrofit Coal with ACI + SNCR	--	22
Retrofit Coal with ACI + SNCR + DRET	--	22
Retrofit Coal with ACI + SNCR + NGC	--	22
Retrofit Coal with C2G	--	239
Retrofit Coal with C2G + SCR	--	98
Retrofit Coal with CCS	--	190
Retrofit Coal with DCCS	--	163
Retrofit Coal with DCCS + CCS	--	95
Retrofit Coal with DCCS + SCR + CCS	--	41
Retrofit Coal with DCCS + Scrubber + CCS	--	8
Retrofit Coal with DCCS + Scrubber + SCR + CCS	--	19
Retrofit Coal with DCCS + SNCR + CCS	--	2
Retrofit Coal with DRET	--	278
Retrofit Coal with DSI	--	34
Retrofit Coal with DSI + C2G	--	33
Retrofit Coal with DSI + C2G + SCR	--	24
Retrofit Coal with DSI + DRET	--	33
Retrofit Coal with DSI + GPM	--	9
Retrofit Coal with DSI + GPM + C2G	--	9
Retrofit Coal with DSI + GPM + C2G + SCR	--	6
Retrofit Coal with DSI + GPM + DRET	--	9
Retrofit Coal with DSI + GPM + NGC	--	9
Retrofit Coal with DSI + GPM + SCR	--	6
Retrofit Coal with DSI + GPM + SCR + DRET	--	6
Retrofit Coal with DSI + GPM + SCR + NGC	--	6
Retrofit Coal with DSI + GPM + Scrubber + CCS	--	6
Retrofit Coal with DSI + GPM + Scrubber + SCR + CCS	--	11
Retrofit Coal with DSI + GPM + SNCR	--	6
Retrofit Coal with DSI + GPM + SNCR + DRET	--	6
Retrofit Coal with DSI + GPM + SNCR + NGC	--	6
Retrofit Coal with DSI + NGC	--	33
Retrofit Coal with DSI + SCR	--	24
Retrofit Coal with DSI + SCR + DRET	--	24
Retrofit Coal with DSI + SCR + NGC	--	24
Retrofit Coal with DSI + Scrubber + CCS	--	12
Retrofit Coal with DSI + Scrubber + SCR + CCS	--	40
Retrofit Coal with DSI + SNCR	--	26
Retrofit Coal with DSI + SNCR + DRET	--	26
Retrofit Coal with DSI + SNCR + NGC	--	26
Retrofit Coal with GPM	--	278
Retrofit Coal with GPM + C2G	--	238
Retrofit Coal with GPM + C2G + SCR	--	97

Retrofit Coal with GPM + CCS	--	186
Retrofit Coal with GPM + DRET	--	277
Retrofit Coal with GPM + NGC	--	277
Retrofit Coal with GPM + SCR	--	97
Retrofit Coal with GPM + SCR + CCS	--	80
Retrofit Coal with GPM + SCR + DRET	--	97
Retrofit Coal with GPM + SCR + NGC	--	97
Retrofit Coal with GPM + Scrubber + CCS	--	16
Retrofit Coal with GPM + Scrubber + SCR + CCS	--	52
Retrofit Coal with GPM + SNCR	--	92
Retrofit Coal with GPM + SNCR + CCS	--	6
Retrofit Coal with GPM + SNCR + DRET	--	92
Retrofit Coal with GPM + SNCR + NGC	--	92
Retrofit Coal with NGC	--	278
Retrofit Coal with SCR	--	98
Retrofit Coal with SCR + C2G	--	98
Retrofit Coal with SCR + CCS	--	80
Retrofit Coal with SCR + DRET	--	98
Retrofit Coal with SCR + NGC	--	98
Retrofit Coal with SCR + Scrubber + CCS	--	52
Retrofit Coal with Scrubber + CCS	--	16
Retrofit Coal with SNCR	--	93
Retrofit Coal with SNCR + C2G	--	79
Retrofit Coal with SNCR + CCS	--	6
Retrofit Coal with SNCR + DRET	--	93
Retrofit Coal with SNCR + NGC	--	93
Retrofit Combined Cycle with CCS	--	1476
Retrofit Combined Cycle with CF Limit	--	741
Retrofit Combined Cycle with HRI	--	672
Retrofit Combined Cycle with Hydrogen	--	741
Retrofit Combined Cycle with Hydrogen Retrofit Undone	--	741
Retrofit Combustion Turbine with HRI	--	769
Total	--	**11,101**
Retirements		
Plant Type	**Number of Units**	**Number of IPM Model Plants**
Biomass Retirement	--	108
Coal Steam Retirement	--	5,006
Existing Combined Cycle Retirement	--	5,237
Existing Combustion Turbine Retirement	--	1,962
Fossil Other Retirement	--	25
Fuel Cell Retirement	--	23
Geothermal Retirement	--	13
Hydro Retirement	--	105
IGCC Retirement	--	2
Landfill Gas Retirement	--	92
New Combined Cycle Retirement	--	426
New Combustion Turbine Retirement	--	332
Non Fossil Other Retirement	--	139
Nuclear Retirement	--	104
Oil/Gas Steam Retirement	--	1,378
Total	--	**14,952**
Grand Total (Existing and Planned/Committed + New + Retrofits + Early Retirements): 37,524		

4.2.7 Cost and Performance Characteristics of Existing Units[42]

In EPA 2023 Reference Case, the cost and performance characteristics of an existing unit are determined by the unit's heat rates, emission rates, variable operation, and maintenance cost (VOM), and fixed operation and maintenance costs (FOM). For existing units, only the cost of maintaining (FOM) and running (VOM) the unit are modeled because capital costs and all related carrying capital charges are sunk, and hence, economically irrelevant for projecting least-cost investment and operational decisions going forward. The section below discusses the cost and performance assumptions for existing units used in the EPA 2023 Reference Case.

Variable Operating and Maintenance Cost (VOM)

VOM represents the non-fuel variable cost associated with producing electricity. If the generating unit contains pollution control equipment, VOM includes the cost of operating the control equipment. Table 4-8 below summarizes VOM assumptions used in EPA 2023 Reference Case. The following further discusses the components of VOM costs and the VOM modeling methodology.

Variable O&M Approach: EPA 2023 Reference Case uses a modeling construct termed as Segmental VOM for combined cycle units to capture the variability in operation and maintenance costs that are treated as a function of the unit's dispatch pattern. All other technologies are assigned static VOM assumptions.

The VOM for combustion turbines are differentiated by the turbine technology. The VOM for combined cycles and combustion turbine units includes the costs of both major maintenance and consumables while for coal steam and oil/gas steam units includes only the cost of consumables. The VOM cost of various emission control technologies is also incorporated.

Major maintenance: Major maintenance costs are those required to maintain a unit at its delivered performance specifications and whose terms are usually dictated through its long-term service agreement (LTSA). The three main areas of maintenance for gas turbines include combustion inspection, hot gas path inspection, and major inspections. All these costs are driven by the hours of operation and the number of starts that are incurred within that time period of operation. In a cycling or mid-merit type mode of operation, there are many starts, accelerating the approach of an inspection. As more starts are incurred compared to the generation produced, the cost per generation increases. For base load operation there are fewer starts spread over more generations, lowering the cost per generation. While this nomenclature is for gas-turbine based systems, steam turbine-based systems have a parallel construct.

Consumables: The model captures consumable costs, as purely a function of output and does not vary across the segmented time period. In other words, the consumables cost component is held constant over both peak and off-peak segments. Consumables include chemicals, lube oils, make-up water, wastewater disposal, reagents, and purchased electricity.

Data Sources for Gas-Turbine Based Prime Movers:

ICF has engaged its deep expertise in operation & maintenance costs for these types of prime movers to develop generic variable O&M costs as a function of technology. As mentioned above, the variable O&M for gas-turbine based systems tracks LTSA costs, start-up, and consumables.

[42] All units excluding nuclear units.

Data Sources for Stand-Alone Steam Turbine Based Prime Movers:

The value levels of non-fuel variable O&M data for stand-alone steam turbine plants are based on ICF expertise. The VOM cost adders of various emission control technologies are based on cost functions described in Chapter 5.

Table 4-8 VOM Assumptions in the EPA 2023 Reference Case

Capacity Type	SO_2 Control	NO_x Control	Hg Control	Variable O&M (2022$/mills/kWh)
Biomass	--	--	--	8.05
Coal Steam	No SO_2 Control	No NO_x Control	No Hg Control	1.72
			ACI	1.93 - 2.17
		SCR	ACI	2.94 - 3.85
		SNCR	ACI	2.68
	Dry FGD	No NO_x Control	No Hg Control	6.02
			ACI	2.84 - 6.93
		SCR	No Hg Control	4.21
			ACI	3.63 - 9.28
		SNCR	No Hg Control	6.56 - 8.04
			ACI	3.84 - 6.51
	Wet FGD	No NO_x Control	No Hg Control	2.90 - 6.86
			ACI	2.88 - 4.68
		SCR	No Hg Control	3.83 - 9.47
			ACI	3.71 - 9.48
		SNCR	No Hg Control	3.10 - 8.79
			ACI	3.63 - 14.75
	DSI	No NO_x Control	No Hg Control	6.39 - 6.43
			ACI	6.20 - 10.16
		SCR	ACI	8.09 - 12.51
		SNCR	ACI	6.92 - 11.65
Combined Cycle	No SO_2 Control	No NO_x Control	No Hg Control	4.55
		SCR		4.62 - 5.28
Combustion Turbine	No SO_2 Control	No NO_x Control	No Hg Control	5.22 - 7.38
		SCR		5.34 - 7.51
		SNCR		5.34 - 7.51
Fuel Cell	--	--	--	0.67
Geothermal	--	--	--	1.58
Hydro	--	--	--	1.89
IGCC	--	--	--	4.87
Landfill Gas / Municipal Solid Waste	--	--	--	6.97
Oil/gas Steam	No SO_2 Control	No NO_x Control	No Hg Control	1.00
		SCR	No Hg Control	1.12 - 1.68
		SNCR	No Hg Control	1 - 1.76
Pumped Storage	--	--	--	0.01
Solar	--	--	--	0.00
Wind	--	--	--	0.00

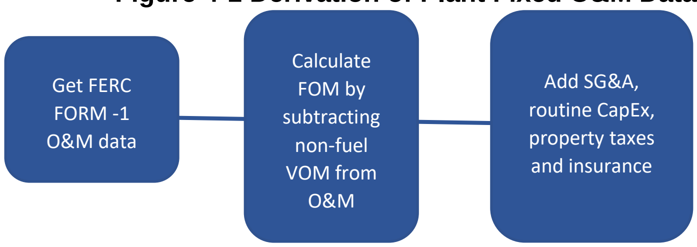
Fixed Operation and Maintenance Cost (FOM)

FOM represents the annual fixed cost of maintaining a unit. FOM costs are incurred independent of generation levels and signify the fixed cost of operating and maintaining the unit's availability to provide generation. Table 4-9 summarizes the FOM assumptions.[43] Note that FOM varies by the age of the unit, and the total FOM cost incurred by a unit depends on its capacity size. The values appearing in the table include the cost of maintaining any associated pollution control equipment. The values in Table 4-9 are based on FERC (Federal Energy Regulatory Commission) Form 1 data maintained by SNL and ICF research. The following further discusses the procedure for developing the FOM costs.

Stand Alone – Steam Turbines Based Prime Movers

O&M cost data for existing coal and oil/gas steam units were developed starting with FERC Form 1 data sets from the years 2011 to 2016. The FERC Form-1 database does not explicitly report separate fixed and variable O&M expenses. In deriving Fixed O&M costs, generic variable O&M costs are assigned to each individual power plant. Next, the assumed variable O&M cost is subtracted from the total O&M reported by FERC Form-1 to calculate a starting point for fixed O&M. Thereafter, other cost items which are not reported by FERC Form-1 are added to the raw FOM starting point. These unreported cost items are selling, general, and administrative expenses (SG&A), property taxes, insurance, and routine capital expenditures. A detailed description of the fixed O&M derivation methodology is provided below.

Figure 4-1 Derivation of Plant Fixed O&M Data



i) Assign generic VOM cost to each unit in FERC Form 1 based on the control configuration. Subtract this VOM from the total O&M cost from FERC Form 1 to calculate raw FOM cost. The FOM cost of operating the existing controls is estimated based on cost functions in Chapter 5. and deducted from the raw FOM cost. Aggregate this unit level raw FOM cost data into age-based categories. The weighted average raw FOM costs for uncontrolled units by age group is the output of this step and is used as the starting point for subsequent steps.

ii) An owner/operator fee for SG&A services in the range of 20-30% is added to raw fixed O&M figures in step 1.

iii) Property tax and insurance cost estimates in $/kW-year are also added. These figures vary by plant type.

iv) A generic percentage value to cover routine capex is added to raw fixed O&M figures in step 1. The percentage varies by prime mover and is based on a review of FERC Form 1 data

v) Finally, generic FOM cost adders for various emission control technologies are estimated using cost functions described in Chapter 5. Based on the emission control configuration of each unit in NEEDS, the appropriate emission control cost adder is added to the FOM cost of an uncontrolled unit from step iv.

[43] Cogen units whose primary purpose is to provide process heat are called as bottoming cycle units and are identified based on Form EIA 860. Such units are provided a FOM of zero in EPA 2023 Reference Case. This is to acknowledge the fact that the economics of such a unit cannot be comprehensively modeled in a power sector focused model.

The fixed O&M derivation approach relies on top-down calculation of fixed costs based on FERC Form-1 data and ICF's own non-fuel variable O&M, SG&A, routine capital expenditures, property tax, and insurance.

Gas-Turbine Based Prime Movers

Similar to the stand-alone steam turbine based prime movers, the fixed O&M for gas-turbine based systems tracks labor, routine maintenance, property taxes, insurance, owner/operator SG&A, and routine capital expenditures. These generic fixed O&M costs as a function of technology are based on ICF's expertise in fixed O&M costs for these types of prime movers.

Table 4-9 FOM Assumptions in the EPA 2023 Reference Case

Plant Type	SO_2 Control	NO_x Control	Hg Control	Age of Unit	FOM (2022$ /kW-Yr)
Biomass	--	--	--	All Years	169.3
Coal Steam	No SO_2 Control	No NO_x Control	No Hg Control	0 to 40 Years	34.1
				40 to 50 Years	39.0
				Greater than 50 Years	50.1
			ACI	0 to 40 Years	36.1
				40 to 50 Years	39.1 - 39.5
				Greater than 50 Years	50.2 - 51.4
		SCR	ACI	40 to 50 Years	40.0 - 40.1
				Greater than 50 Years	51.2 - 52.5
		SNCR	ACI	40 to 50 Years	39.3
	Dry FGD	No NO_x Control	No Hg Control	0 to 40 Years	46.2
			ACI	0 to 40 Years	44.0 - 57.6
				40 to 50 Years	45.8 - 62.1
				Greater than 50 Years	70.7
		SCR	No Hg Control	Greater than 50 Years	67.5
			ACI	0 to 40 Years	41.5 - 60.5
				40 to 50 Years	47.2 - 48.8
				Greater than 50 Years	59.5 - 65.7
		SNCR	No Hg Control	0 to 40 Years	46.1 - 56.7
			ACI	0 to 40 Years	45.6 - 56.9
				40 to 50 Years	46.6 - 48.4
				Greater than 50 Years	59.0
	Wet FGD	No NO_x Control	No Hg Control	0 to 40 Years	46.0
				40 to 50 Years	49.7 - 50.1
				Greater than 50 Years	61.1 - 70.1
			ACI	0 to 40 Years	45.0 - 45.7
				40 to 50 Years	48.4 - 66.7
				Greater than 50 Years	59.6 - 81.7
		SCR	No Hg Control	0 to 40 Years	43.9 - 46.6
				40 to 50 Years	47.5 - 56.5
				Greater than 50 Years	58.5 - 82.1
			ACI	0 to 40 Years	43.3 - 56.9
				40 to 50 Years	48.8 - 52.4
				Greater than 50 Years	60.0 - 67.1
		SNCR	No Hg Control	0 to 40 Years	45.7 - 45.8
				40 to 50 Years	68.3
				Greater than 50 Years	63.2 - 82.0
			ACI	40 to 50 Years	47.9 - 60.3
				Greater than 50 Years	60.6 - 69.0
	DSI	No NO_x Control	No Hg Control	Greater than 50 Years	52.7
			ACI	40 to 50 Years	39.7 - 40.3
				Greater than 50 Years	55.9 - 65.0

Plant Type	SO_2 Control	NO_x Control	Hg Control	Age of Unit	FOM (2022$ /kW-Yr)
		SCR	ACI	0 to 40 Years	35.3
				40 to 50 Years	40.2 - 41.3
				Greater than 50 Years	53.0
		SNCR	ACI	40 to 50 Years	40.2
				Greater than 50 Years	51.5 - 58.9
Combined Cycle	No SO_2 Control	No NO_x Control	No Hg Control	-	34.2
		SCR	No Hg Control	-	34.4 - 37.6
Combustion Turbine	No SO_2 Control	No NO_x Control	No Hg Control	-	22.3
		SCR	No Hg Control	-	22.8 - 27.2
		SNCR	No Hg Control	-	22.3
Fuel Cell	--	--	--	All Years	34.8
Geothermal	--	--	--	All Years	112.5
Hydro	--	--	--	All Years	18.2
Integrated Gasification Combined Cycle	No SO_2 Control	No NO_x Control	--	All Years	123.1
Landfill Gas / Municipal Solid Waste	--	--	--	All Years	211.6
Oil/gas Steam	No SO_2 Control	No NO_x Control	No Hg Control	0 to 40 Years	20.4
				40 to 50 Years	31.0
				Greater than 50 Years	40.3
		SCR	No Hg Control	0 to 40 Years	21.3 - 24.3
				40 to 50 Years	34.7 - 34.7
				Greater than 50 Years	40.7 - 43.2
		SNCR	No Hg Control	0 to 40 Years	20.4 - 22.3
				40 to 50 Years	31.1
				Greater than 50 Years	40.5 - 41.4
Pumped Storage	--	--	--	All Years	20.7
Solar Photovoltaics	--	--	--	All Years	18.7
Solar Thermal	--	--	--	All Years	91.9
Wind	--	--	--	All Years	30.0

Heat Rates

Heat Rates describe the efficiency of the unit expressed as BTUs per kWh. The treatment of heat rates is discussed in Section 3.9.

Lifetimes

Unit lifetime assumptions are detailed in Sections 3.8 and 4.2.8.

SO_2 Rates

Section 3.10.1 contains a detailed discussion of SO_2 rates for existing units.

NO_x Rates

Section 3.10.3 contains a detailed discussion of NO_x rates for existing units.

Mercury Emission Modification Factors (EMF)

Mercury EMF refers to the ratio of mercury emissions (mercury outlet) to the mercury content of the fuel (mercury inlet). Section 5.7.2 contains a detailed discussion of the EMF assumptions in EPA 2023 Reference Case.

Cogeneration Units

For cogeneration units, the dispatch decisions in IPM are only based on the benefits obtained from the electric portion of a cogeneration unit. In IPM, a cogeneration unit uses a net heat rate, which is calculated by dividing the heat content of fuel consumed for power generation by electricity generated from this fuel. To capture the total emissions from the cogeneration unit, a multiplier is applied to the power-only emissions. The multiplier is calculated as a ratio between the total heat rate and the net heat rate, where the total heat rate is calculated by dividing the heat content of fuel consumed for power and steam generation by electricity generated from this fuel.

Coal Switching

Recognizing that boiler modifications and fuel handling enhancements may be required for unrestricted switching from bituminous to subbituminous coal, and vice versa, the following procedure applies in EPA 2023 Reference Case to coal units that have the option to burn both bituminous and subbituminous coals.

(i) An examination of the EIA Form 923 coal delivery data for the period 2010-2019 is conducted for each unit to determine the unit's historical maximum share of bituminous coal and that of subbituminous coal. For example, if in at least one year during the period 2010-2019 a unit burned 90% or less subbituminous coal, its historical maximum share of subbituminous coal is set at 90%.

(ii) The following rules then apply.

Blending Subbituminous Coal:

If a unit's historical maximum share of subbituminous coal is greater than 90%, the unit incurs no fuel switching cost adder to increase its subbituminous coal burn. The unit is assumed to have already made the fuel handling and boiler investments needed to burn up to 100% subbituminous coal. It would therefore face no additional cost. In addition, the unit's heat rate is assumed to reflect the impact of burning the corresponding proportion of subbituminous coal.

If a unit's historical maximum share of subbituminous coal is less than 90%, the unit incurs a heat rate penalty of 5% and a fuel switching cost adder. The heat rate penalty reflects the impact of the higher moisture content subbituminous coal on the unit's heat rate. The cost adder is designed to cover boiler modifications, or alternative power purchases in lieu of capacity deratings that would otherwise be associated with burning subbituminous coal with its lower heating value relative to bituminous coal. The cost adder is determined as follows:

- If the unit's historical maximum share of subbituminous coal is less than 20%, the unit can burn up to 20% subbituminous coal at no cost adder. Burning beyond 20% subbituminous coal, the unit incurs a cost adder of 324 (2022$ per kW).

- If the unit's historical maximum share of subbituminous coal is greater than 20% but less than 90%, the unit can burn up to its historical maximum share of subbituminous coal at no cost adder. Burning beyond its historical maximum share of subbituminous coal, the unit incurs a cost adder calculated by the following equation:

$$\text{Fuel Switching Cost Adder (2022\$ per kW)} =$$
$$324 \times \left\{\frac{(100 - \text{Historical Maximum Share of Subbituminous})}{(100 - 20)}\right\}$$

Blending Bituminous Coal:

If a unit's historical maximum share of bituminous coal is greater than 90%, the unit incurs no fuel switching cost adder.

If a unit's historical maximum share of bituminous coal is less than 90%, the unit incurs a fuel switching cost adder determined as follows:

- If the unit's historical maximum share of bituminous coal is less than 20%, the unit can burn up to 20% bituminous coal at no cost adder. Burning beyond 20% bituminous coal, the unit incurs a cost adder of 65 (2022$ per kW).
- If the unit's historical maximum share of bituminous coal is greater than 20% but less than 90%, the unit can burn up to its historical maximum share of bituminous coal at no cost adder. Burning beyond its historical maximum share of bituminous coal, the unit incurs a cost adder calculated by the following equation:

$$\text{Fuel Switching Cost Adder (2022\$ per kW)} =$$
$$65 \times \left\{\frac{(100 - \text{Historical Maximum Share of Bituminous})}{(100 - 20)}\right\}$$

4.2.8 Life Extension Costs for Existing Units

The modeling time horizon in EPA 2023 Reference Case extends to 2059 and covers almost 30 years. This time horizon requires consideration of investments, beyond routine maintenance, necessary to extend the life of existing units. The life extension costs for different unit types are summarized in Table 4-10 below. Each unit has the option to retire or incorporate the life extension costs. These costs were based on a review of 2007-2016 FERC Form 1 data maintained by SNL regarding reported annual capital expenditures made by older units. The life extension costs were added once the unit reached its assumed lifespan. Life extension costs for nuclear units are discussed in Section 4.6.1.

Table 4-10 Life Extension Cost Assumptions Used in the EPA 2023 Reference Case

Plant Type	Lifespan without Life Extension Expenditures	Life Extension Cost (2022$/kW)	Capital Cost of New Unit (2022$/kW)	Life Extension Cost as Proportion of New Unit Capital Cost (%)
Biomass	40	276	4,201	6.6
Coal Steam	40	221	3,789	5.84
Combined Cycle	30	90	989	9.06
Combustion Turbine	30	260	717	36.3
IC Engine	30	252	1,914	13.2
Oil/Gas Steam	40	190	3,450	5.5
IGCC	40	281	3,789	7.4

Notes:
Life extension expenditures double the lifespan of the unit.

4.3 Planned-Committed Units

EPA 2023 Reference Case includes all planned-committed units that are likely to come online because ground has been broken, financing obtained, or other demonstrable factors indicate a high probability that the unit will be built before June 30, 2028.

In addition, wind, solar, and energy storage units that had received, had pending regulatory approvals, or were flagged as planned for installation per the August 2023 version of EIA Form 860 monthly and were expected to be online by June 30, 2028, were also included.

4.3.1 Population and Model Plant Aggregation

Table 4-11 summarizes the extent of the inventory of planned-committed units represented by unit types and generating capacity. Table 4-34 gives a breakdown of planned-committed units by IPM region, plant type, and capacity.

Table 4-11 Summary of Planned-Committed Units in NEEDS

Type	Capacity (MW)	Year Range Described
Renewables/Non-conventional		
Biomass	20	2025 - 2025
Energy Storage	23,778	2024 - 2028
Hydro	13	2024 - 2024
Non-Fossil Waste	42	2024 - 2024
Offshore Wind	6,014	2024 - 2029
Onshore Wind	18,550	2024 - 2028
Solar PV	67,109	2024 - 2030
Subtotal	115,527	
Fossil/Conventional		
Combined Cycle	6,287	2024 - 2026
Combustion Turbine	2,722	2024 - 2027
Subtotal	9,009	
Grand Total	124,535	

Note:
Any unit in NEEDS that has an online year of 2024 or later was considered a Planned/Committed Unit.

4.3.2 Capacity

The capacity data of planned-committed units in NEEDS was obtained from the August 2023 version of EIA Form 860 monthly.

4.3.3 State and Model Region

State location data for the planned-committed units in NEEDS came from the August 2023 version of EIA Form 860 monthly. The state-county information was then used to assign planned-committed units to their respective model regions.

4.3.4 Online and Retirement Year

As noted above, planned-committed units included in NEEDS are only those likely to come online before June 30, 2028, as 2028 is the first analysis year in the EPA 2023 Reference Case. All planned-committed units were assigned an online year and given a default retirement year of 9999.

4.4 Potential Units

The EPA 2023 Reference Case includes options for developing a variety of potential units that may be built at a future date in response to electricity demand and the constraints represented in the model. Defined by region, technology, and the year available, potential units with an initial capacity of zero MW are inputs into IPM. When the model is run, the capacity of certain potential units is raised from zero to meet demand and other system and operating constraints. This results in the model's projection of new capacity.

In Table 4-7, the block labeled "New Units" provides the type and number of potential units available in EPA 2023 Reference Case. The following sections describe the cost and performance assumptions for the potential units represented in the EPA 2023 Reference Case.

4.4.1 Methodology for Deriving the Cost and Performance Characteristics of Conventional Potential Units

The cost and performance characteristics of conventional potential units in EPA 2023 Reference Case are derived primarily from assumptions used in the Annual Energy Outlook (AEO) 2023 published by the U.S. Department of Energy's Energy Information Administration.

4.4.2 Cost and Performance for Potential Conventional Units

Table 4-12 shows the cost and performance assumptions for potential conventional units. The cost and performance assumptions are based on the size (i.e., net electrical generating capacity in MW) indicated in the table. However, the total new capacity that is added in each model run for these technologies is not restricted to these capacity levels.

The table includes several components of cost. The total installed cost of developing and building a new unit is captured through capital cost. It includes expenditures on pollution control equipment that new units are assumed to be installed to satisfy air regulatory requirements. The capital costs shown are typically referred to as overnight capital costs. They include engineering, procurement, construction, startup, and owner's costs (for such items as land, cooling infrastructure, administration and associated buildings, site works, switchyards, project management, and licenses). The capital costs of new units are increased to account for the cost of maintaining and expanding the transmission network. This cost based on AEO 2023 is equal to 116 2022\$/kW outside of WECC and NY regions and 174 2022\$/kW within these regions. The capital costs do not include interest during construction (IDC). IDC is added to the capital costs during the set-up of an IPM run. The calculation of IDC is based on the construction profile of the build option and the discount rate. Details on the discount rate used in the EPA 2023 Reference Case are provided in Chapter 10 of this documentation.

Table 4-12 also shows fixed operating and maintenance (FOM) and variable operating and maintenance (VOM) components of cost. FOM is the annual cost of maintaining a generating unit. It represents expenses incurred regardless of the extent that the unit is run. It is expressed in units of \$ per kW per year. VOM represents the non-fuel variable costs incurred in running an electric generating unit. It is proportional to the electrical energy produced and is expressed in units of \$ per MWh.

In addition to the three components of cost, Table 4-12 indicates the first run year available, lead time, vintage periods, heat rate, and availability for each type of unit. Lead time represents the construction time needed for a unit to come online. Vintage periods are used to capture the cost and performance improvements resulting from technological advancement and learning-by-doing. Mature technologies and technologies whose first year available are not at the start of the modeling time horizon may have only one vintage period, whereas newer technologies may have several vintage periods. Heat rate indicates the efficiency of the unit and is expressed in units of energy consumed (Btus) per unit of electricity generated (kWh). Availability indicates the percentage of time that a generating unit is available to provide electricity to the grid once it is online. Availability considers estimates of the time consumed by planned maintenance and forced outages. The emission characteristics of the potential units can be found in Table 3-24.

4.4.3 Short-Term Capital Cost Adder

In addition to the capital costs shown in Table 4-12 and Table 4-15, EPA 2023 Reference Case includes a short-term capital cost adder that takes effect if the new capacity deployed in a specific model run year exceeds certain upper bounds. This adder reflects the added cost incurred due to short-term competition for scarce labor and materials. Table 4-13 shows the cost adders for each type of potential unit for model run years through 2035. The adder is not imposed after 2035, assuming markets for labor and materials have sufficient time to respond to changes in demand.

The column labeled “Step 1” in Table 4-13 indicates the total capacity of a particular plant type that can be built in a given model run year without incurring a cost adder. However, if the Step 1 upper bound is exceeded, then either the Step 2 or Step 3 cost adder is incurred by the entire capacity deployed, where the level of the cost adder depends upon the total new capacity added in that run year. For example, the Step 1 upper bound in 2030 for landfill gas potential units is 355 MW. If no more than this total new landfill gas capacity is built in 2030, only the capital cost shown in Table 4-15 is incurred. If the model builds between 355 and 617 MW, the Step 2 cost adder of $745/kW applies to the entire capacity deployed. If the total new landfill gas capacity exceeds the Step 2 upper bound of 617 MW, the Step 3 capacity adder of $2,367/kW is incurred by the entire capacity deployed in that run year. The short-term capital cost adders shown in Table 4-13 were based on AEO assumptions. The short-term capital cost adder step widths for renewable technologies are increased by 21%, 29%, and 50% in 2028, 2030, and 2035 run years respectively to reflect the impact of IRA’s Advanced Manufacturing Production Tax Credit (45X). The scalars are linearly interpolated in between 2023 (no increase) and 2035 (50% increase).

4.4.4 Regional Cost Adjustment

The capital costs reported in Table 4-12 are generic. Before implemented, the capital cost values are converted to region-specific costs by applying regional cost adjustment factors that capture regional differences in labor, material, and construction costs and ambient conditions. These factors are calculated by multiplying the regional cost and ambient condition multipliers. The regional cost multipliers are based on county level estimates developed by the Energy Institute at the University of Texas at Austin.[44] The ambient condition multipliers are from AEO 2017. Table 4-14 summarizes the regional cost adjustment factors at the IPM region and technology level. The factors are applied to both conventional technologies shown in Table 4-12 and renewable and nonconventional technologies shown in Table 4-15. However, they are not applied to hydro and geothermal technologies as site-specific costs are used for these two technologies.

[44] New U.S. Power Costs: by County, with Environmental Externalities, University of Texas at Austin, Energy Institute. July 2016

Table 4-12 Performance and Unit Cost Assumptions for Potential (New) Capacity from Conventional Technologies in the EPA 2023 Reference Case

	Combined Cycle - Single Shaft	Combined Cycle - Multi Shaft	Combined Cycle with 90% CCS	Combustion Turbine - Industrial Frame	Combustion Turbine - Aeroderivative	Advanced Nuclear	Small Modular Reactor	Ultra-supercritical Coal without CCS
Size (MW)	418	1083	377	237	105	2156	600	650
First Year Available	2028	2028	2030	2028	2028	2030	2030	2028
Lead Time (Years)	3	3	3	2	2	6	6	4
Availability	87%	87%	87%	92%	92%	90%	95%	85%
Vintage #1 (2028)								
Heat Rate (Btu/kWh)	6,431	6,370	7,124	9,905	9,124	10,447	10,447	8,638
Capital (2022$/kW)	1,118	989	2,605	717	1,182	6,426	7,019	3,789
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	7.88	18.35	136.91	106.92	45.68
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	5.29	2.67	3.38	5.06
Vintage #2 (2030)								
Heat Rate (Btu/kWh)	6,431	6,370	7,124	9,905	9,124	10,447	10,447	8,638
Capital (2022$/kW)	1,096	969	2,539	697	1,148	6,304	6,886	3,717
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	7.88	18.35	136.91	106.92	45.68
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	5.29	2.67	3.38	5.06
Vintage #3 (2035)								
Heat Rate (Btu/kWh)	6,431	6,370	7,124	9,905	9,124	10,447	10,447	8,638
Capital (2022$/kW)	1,054	932	2,396	665	1,096	5,999	6,554	3,538
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	7.88	18.35	136.91	106.92	45.68
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	5.29	2.67	3.38	5.06
Vintage #4 (2040)								
Heat Rate (Btu/kWh)	6,431	6,370	7,124	9,905	9,124	10,447	10,447	8,638
Capital (2022$/kW)	1,012	895	2,252	635	1,047	5,683	6,210	3,353
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	7.88	18.35	136.91	106.92	45.68
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	5.29	2.67	3.38	5.06
Vintage #5 (2045)								
Heat Rate (Btu/kWh)	6,431	6,370	7,124	9,905	9,124	10,447	10,447	8,638
Capital (2022$/kW)	968	856	2,105	604	995	5,356	5,853	3,160
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	7.88	18.35	136.91	106.92	45.68
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	5.29	2.67	3.38	5.06
Vintage #6 (2050 - 2055)								
Heat Rate (Btu/kWh)	6,431	6,370	7,124	9,905	9,124	10,447	10,447	8,638
Capital (2022$/kW)	922	816	1,958	572	942	5,026	5,494	2,966
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	7.88	18.35	136.91	106.92	45.68
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	5.29	2.67	3.38	5.06

Notes:

[a] Capital cost represents overnight capital cost.

[b] IPM regions in urban areas (NENGREST, NY_Z_J, NY_Z_K, PJM_SMAC, PJM_COMD, WEC_LADW, WEC_SDGE, and WEC_BANC) are assigned "Combined Cycle - Single Shaft" and "Combustion Turbine - Aeroderivative" technologies. All other regions are assigned "Combined Cycle - Multi Shaft" and "Combustion Turbine - Industrial Frame" technologies.

[c] The ultra-supercritical coal plant without CCS is not compliant with 80 FR 64510.

Table 4-13 Short-Term Capital Cost Adders for New Power Plants in the EPA 2023 Reference Case (2022$)

Plant Type		2028			2030			2035		
		Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Biomass	Upper Bound (MW)	3,220	5,614	No limit	1,296	2,254	No limit	3,240	5,634	No limit
	Adder ($/kW)	-	1,347	4,277	-	1,887	5,994	-	1,796	5,704
Coal Steam - UPC + UPC36 + UPC90	Upper Bound (MW)	8,784	15,276	No limit	3,513	6,110	No limit	8,784	15,276	No limit
	Adder ($/kW)	-	2,793	8,872	-	2,732	8,679	-	2,581	8,199
Combined Cycle + Combustion Turbine	Upper Bound (MW)	109,085	190,861	No limit	44,255	76,965	No limit	110,637	192,413	No limit
	Adder ($/kW)	-	318	1,011	-	306	971	-	292	926
Fuel Cell	Upper Bound (MW)	2,875	5,000	No limit	1,150	2,000	No limit	2,875	5,000	No limit
	Adder ($/kW)	-	2,503	7,952	-	2,402	7,631	-	2,152	6,837
Geothermal	Upper Bound (MW)	643	1,119	No limit	287	498	No limit	833	1,449	No limit
	Adder ($/kW)	-	3,148	10,000	-	3,113	9,887	-	3,113	9,887
Landfill Gas	Upper Bound (MW)	887	1,542	No limit	355	617	No limit	887	1,542	No limit
	Adder ($/kW)	-	448	1,424	-	745	2,367	-	694	2,204
Nuclear	Upper Bound (MW)	7,471	12,993	No limit	3,329	5,790	No limit	9,677	16,830	No limit
	Adder ($/kW)	-	2,309	6,716	-	2,266	6,589	-	2,156	6,270
Solar Thermal	Upper Bound (MW)	5,416	9,419	No limit	2,413	4,197	No limit	7,016	12,201	No limit
	Adder ($/kW)	-	1,657	5,264	-	1,454	4,617	-	1,402	4,452
Solar PV	Upper Bound (MW)	41,328	107,753	No limit	40,045	69,644	No limit	116,411	202,454	No limit
	Adder ($/kW)	-	299	949	-	258	819	-	179	567
Onshore Wind	Upper Bound (MW)	83,292	154,447	No limit	42,897	74,604	No limit	124,701	216,872	No limit
	Adder ($/kW)	-	306	973	-	244	775	-	210	667
Hydro	Upper Bound (MW)	1,695	3,770	No limit	1,251	2,176	No limit	3,637	6,326	No limit
	Adder ($/kW)	-	669	2,126	-	669	2,126	-	669	2,126

Table 4-14 Regional Cost Adjustment Factors for Conventional and Renewable Generating Technologies in the EPA 2023 Reference Case

Model Region	Regional Multiplier															
	Combined Cycle	Combined Cycle with 90% CCS	Combustion Turbine	Hydro	Nuclear	Biomass	Geothermal	Landfill Gas	Offshore Wind	Onshore Wind	Solar PV/Battery Storage	Solar Thermal	Fuel Cell	Ultra-supercritical Coal without CCS	Ultra-supercritical Coal with 36% CCS	Ultra-supercritical Coal with 90% CCS
ERC_PHDL	1.006	1.006	1.042	1.000	0.979	0.922	1.000	0.920	1.002	1.002	0.961	0.916	0.937	1.005	1.005	0.992
ERC_REST	0.977	0.977	1.027	1.000	0.969	0.922	1.000	0.920	0.968	0.968	0.935	0.889	0.937	0.981	0.981	0.969
ERC_WEST	0.999	0.999	1.038	1.000	0.976	0.922	1.000	0.920	0.989	0.989	0.952	0.909	0.937	0.997	0.997	0.985
FRCC	0.983	0.983	1.033	1.000	0.976	0.948	1.000	0.949	0.961	0.961	0.936	0.899	0.960	1.001	1.001	0.991
MIS_AMSO	0.955	0.955	1.015	1.000	0.963	0.930	1.000	0.933	0.949	0.949	0.917	0.865	0.946	0.958	0.958	0.947
MIS_AR	0.977	0.977	1.022	1.000	0.977	0.930	1.000	0.933	0.977	0.977	0.950	0.914	0.946	0.995	0.995	0.987
MIS_MS	0.958	0.958	1.013	1.000	0.968	0.930	1.000	0.933	0.958	0.958	0.929	0.884	0.946	0.972	0.972	0.962
MIS_IA	1.001	1.001	1.017	1.000	0.999	0.968	1.000	0.968	1.041	1.041	1.011	0.993	0.975	1.013	1.013	1.008
MIS_IL	1.000	1.000	1.016	1.000	0.999	1.017	1.000	1.019	1.014	1.014	0.999	0.990	1.017	1.021	1.021	1.020
MIS_INKY	0.987	0.987	1.007	1.000	0.998	1.010	1.000	0.994	1.003	1.003	0.987	0.972	0.997	1.009	1.009	1.008
MIS_LA	0.958	0.958	1.013	1.000	0.967	0.930	1.000	0.933	0.957	0.957	0.926	0.879	0.946	0.968	0.968	0.956
MIS_LMI	1.009	1.009	1.015	1.000	1.016	0.995	1.000	0.997	1.024	1.024	1.007	1.002	0.999	1.025	1.025	1.022
MIS_MAPP	0.970	0.970	1.003	1.000	0.986	0.968	1.000	0.968	1.035	1.035	0.985	0.945	0.975	0.976	0.976	0.967
MIS_MIDA	0.996	0.996	1.015	1.000	0.997	0.968	1.000	0.968	1.040	1.040	1.007	0.984	0.975	1.007	1.007	1.000
MIS_MNWI	1.006	1.006	1.020	1.000	1.000	0.968	1.000	0.968	1.050	1.050	1.021	1.008	0.975	1.015	1.015	1.010
MIS_MO	0.995	0.995	1.015	1.000	0.995	1.017	1.000	1.019	1.016	1.016	0.996	0.981	1.017	1.013	1.013	1.009

Model Region	Regional Multiplier															
	Combined Cycle	Combined Cycle with 90% CCS	Combustion Turbine	Hydro	Nuclear	Biomass	Geothermal	Landfill Gas	Offshore Wind	Onshore Wind	Solar PV/Battery Storage	Solar Thermal	Fuel Cell	Ultra-supercritical Coal without CCS	Ultra-supercritical Coal with 36% CCS	Ultra-supercritical Coal with 90% CCS
MIS_WOTA	0.956	0.956	1.010	1.000	0.966	0.930	1.000	0.933	0.956	0.956	0.923	0.875	0.946	0.964	0.964	0.952
MIS_WUMS	1.028	1.028	1.032	1.000	1.013	1.010	1.000	0.994	1.045	1.045	1.029	1.029	0.997	1.046	1.046	1.044
NENG_CT	1.181	1.181	1.146	1.000	1.068	1.030	1.000	1.009	1.081	1.081	1.076	1.103	1.009	1.112	1.112	1.116
NENG_ME	1.064	1.064	1.074	1.000	1.042	1.030	1.000	1.009	1.065	1.065	1.017	0.993	1.009	1.048	1.048	1.047
NENGREST	1.115	1.115	1.105	1.000	1.053	1.030	1.000	1.009	1.068	1.068	1.038	1.034	1.009	1.075	1.075	1.075
NY_Z_A	1.061	1.061	1.072	1.000	1.039	1.034	1.000	0.999	1.021	1.021	1.000	0.988	0.995	1.050	1.050	1.046
NY_Z_B	1.076	1.076	1.081	1.000	1.043	1.034	1.000	0.999	1.027	1.027	1.004	0.992	0.995	1.058	1.058	1.054
NY_Z_C&E	1.110	1.110	1.111	1.000	1.056	1.034	1.000	0.999	1.038	1.038	1.015	1.005	0.995	1.080	1.080	1.078
NY_Z_D	1.076	1.076	1.092	1.000	1.045	1.034	1.000	0.999	1.043	1.043	1.008	0.986	0.995	1.056	1.056	1.053
NY_Z_F	1.129	1.129	1.122	1.000	1.055	1.034	1.000	0.999	1.060	1.060	1.039	1.040	0.995	1.085	1.085	1.085
NY_Z_G-I	1.195	1.195	1.161	1.000	1.068	1.034	1.000	0.999	1.079	1.079	1.085	1.130	0.995	1.119	1.119	1.122
NY_Z_J	1.257	1.257	1.205	1.000	1.074	1.227	1.000	1.260	1.093	1.093	1.123	1.216	1.212	1.157	1.157	1.162
NY_Z_K	1.241	1.241	1.196	1.000	1.073	1.227	1.000	1.260	1.092	1.092	1.104	1.163	1.212	1.153	1.153	1.158
PJM_AP	1.073	1.073	1.088	1.000	1.034	1.010	1.000	0.994	1.008	1.008	0.982	0.961	0.997	1.072	1.072	1.069
PJM_ATSI	1.031	1.031	1.046	1.000	1.018	1.010	1.000	0.994	1.007	1.007	0.988	0.974	0.997	1.043	1.043	1.039
PJM_COMD	1.022	1.022	1.026	1.000	1.009	1.010	1.000	0.994	1.040	1.040	1.033	1.042	0.997	1.039	1.039	1.039
PJM_Dom	1.144	1.144	1.153	1.000	1.046	0.913	1.000	0.911	1.018	1.018	0.988	0.964	0.932	1.130	1.130	1.127
PJM_EMAC	1.209	1.209	1.179	1.000	1.073	1.065	1.000	1.033	1.066	1.066	1.063	1.090	1.027	1.144	1.144	1.148
PJM_PENE	1.097	1.097	1.105	1.000	1.047	1.065	1.000	1.033	1.024	1.024	1.002	0.988	1.027	1.083	1.083	1.081
PJM_SMAC	1.155	1.155	1.144	1.000	1.063	1.065	1.000	1.033	1.036	1.036	1.008	0.990	1.027	1.118	1.118	1.118
PJM_West	0.991	0.991	1.019	1.000	1.004	1.010	1.000	0.994	0.989	0.989	0.965	0.939	0.997	1.012	1.012	1.008
PJM_WMAC	1.151	1.151	1.144	1.000	1.060	1.065	1.000	1.033	1.043	1.043	1.024	1.018	1.027	1.113	1.113	1.113
S_C_KY	0.981	0.981	1.015	1.000	0.990	0.934	1.000	0.933	0.979	0.979	0.953	0.919	0.948	1.006	1.006	1.004
S_C_TVA	0.957	0.957	1.003	1.000	0.979	0.934	1.000	0.933	0.968	0.968	0.939	0.899	0.948	0.981	0.981	0.975
S_D_AECI	0.989	0.989	1.014	1.000	0.992	1.017	1.000	1.019	1.013	1.013	0.990	0.971	1.017	1.005	1.005	0.999
S_SOU	0.963	0.963	1.020	1.000	0.969	0.925	1.000	0.925	0.953	0.953	0.922	0.873	0.942	0.982	0.982	0.972
S_VACA	1.015	1.015	1.059	1.000	1.003	0.913	1.000	0.911	0.975	0.975	0.940	0.896	0.932	1.033	1.033	1.025
SPP_N	1.000	1.000	1.032	1.000	0.986	0.973	1.000	0.975	1.016	1.016	0.980	0.948	0.979	1.009	1.009	0.998
SPP_NEBR	0.976	0.976	1.009	1.000	0.988	0.968	1.000	0.968	1.029	1.029	0.984	0.945	0.975	0.982	0.982	0.971
SPP_SPS	0.992	0.992	1.028	1.000	0.980	0.956	1.000	0.952	1.005	1.005	0.963	0.920	0.962	0.991	0.991	0.979
SPP_WAUE	0.974	0.974	1.006	1.000	0.987	0.968	1.000	0.968	1.034	1.034	0.986	0.947	0.975	0.979	0.979	0.970
SPP_WEST	0.978	0.978	1.020	1.000	0.978	0.956	1.000	0.952	0.991	0.991	0.957	0.918	0.962	0.989	0.989	0.978
WEC_BANC	1.232	1.232	1.173	1.000	1.072	1.076	1.000	1.055	1.124	1.124	1.098	1.112	1.045	1.208	1.208	1.203
WEC_CALN	1.230	1.230	1.172	1.000	1.071	1.076	1.000	1.055	1.123	1.123	1.096	1.109	1.045	1.207	1.207	1.201
WEC_LADW	1.183	1.183	1.141	1.000	1.055	1.076	1.000	1.055	1.104	1.104	1.074	1.076	1.045	1.167	1.167	1.151
WEC_SDGE	1.154	1.154	1.120	1.000	1.046	1.076	1.000	1.055	1.084	1.084	1.054	1.049	1.045	1.141	1.141	1.123
WECC_AZ	1.187	1.187	1.190	1.000	1.011	1.000	1.000	0.982	1.035	1.035	0.998	0.970	0.986	1.181	1.181	1.166
WECC_CO	1.157	1.157	1.194	1.000	0.988	0.936	1.000	0.947	1.027	1.027	0.976	0.932	0.958	1.156	1.156	1.142
WECC_ID	1.045	1.045	1.070	1.000	1.004	1.002	1.000	0.982	1.048	1.048	1.000	0.965	0.989	1.066	1.066	1.058
WECC_IID	1.262	1.262	1.236	1.000	1.036	1.000	1.000	0.982	1.069	1.069	1.038	1.028	0.986	1.252	1.252	1.233
WECC_MT	1.021	1.021	1.054	1.000	0.992	1.002	1.000	0.982	1.039	1.039	0.990	0.953	0.989	1.037	1.037	1.030
WECC_NM	1.131	1.131	1.161	1.000	0.990	1.000	1.000	0.982	1.018	1.018	0.977	0.938	0.986	1.129	1.129	1.115
WECC_NNV	1.157	1.157	1.137	1.000	1.040	1.002	1.000	0.982	1.087	1.087	1.053	1.045	0.989	1.157	1.157	1.147
WECC_PNW	1.123	1.123	1.109	1.000	1.035	1.002	1.000	0.982	1.074	1.074	1.042	1.032	0.989	1.145	1.145	1.144
WECC_SCE	1.180	1.180	1.139	1.000	1.054	1.076	1.000	1.055	1.100	1.100	1.070	1.071	1.045	1.163	1.163	1.144
WECC_SNV	1.230	1.230	1.220	1.000	1.030	1.000	1.000	0.982	1.071	1.071	1.044	1.042	0.986	1.237	1.237	1.219
WECC_UT	1.050	1.050	1.075	1.000	1.002	1.002	1.000	0.982	1.043	1.043	0.997	0.962	0.989	1.063	1.063	1.051
WECC_WY	1.016	1.016	1.055	1.000	0.987	1.002	1.000	0.982	1.031	1.031	0.976	0.927	0.989	1.024	1.024	1.012

Table 4-15 Performance and Unit Cost Assumptions for Potential (New) Renewable and Non-Conventional Technologies in the EPA 2023 Reference Case

	Geothermal	Biomass	Landfill Gas LGHI	Fuel Cells	Solar Photovoltaic	Solar Thermal	Onshore Wind	Offshore Wind	Battery Storage (4 Hours)	Battery Storage (10 hours)
Size (MW)	50	50	36	10	100	115	200	1000	60	60
First Year Available	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028
Lead Time (Years)	4	4	3	3	1	3	3	3	1	1
Availability	80% - 90%	83%	90%	87%	90%	90%	95%	95%	96.4%	96.4%
Generation Capability	Economic Dispatch	Economic Dispatch	Economic Dispatch	Economic Dispatch	Generation Profile	Economic Dispatch	Generation Profile	Generation Profile	Economic Dispatch	Economic Dispatch
	Vintage #1 (2028-2055)	**Vintage #1 (2028)**								
Heat Rate (Btu/kWh)	30,000	13,500	8,513	6,469	0	0	0	0	0	0
Capital (2022$/kW)	3,662 - 48,811	4,201	1,707	5,571	1,065	5,594	1,206	1,979	960	2,077
Fixed O&M (2022$/kW/yr)	114 - 1,208	141.50	21.82	34.65	19.08	59.54	29.66	96.04	34.59	74.82
Variable O&M (2022$/MWh)	0.00	5.44	6.73	0.66	0.00	3.37	0.00	0.00	0.00	0.00
Vintage #2 (2030)										
Heat Rate (Btu/kWh)		13,500	8,513	6,469	0	0	0	0	0	0
Capital (2022$/kW)		4,121	1,659	5,346	1,005	5,107	1,159	1,923	891	1,902
Fixed O&M (2022$/kW/yr)		141.50	21.82	34.65	18.37	55.43	28.88	92.95	32.11	68.52
Variable O&M (2022$/MWh)		5.44	6.73	0.66	0.00	3.21	0.00	0.00	0.00	0.00
Vintage #3 (2035)										
Heat Rate (Btu/kWh)		13,500	8,513	6,469	0	0	0	0	0	0
Capital (2022$/kW)		3,921	1,544	4,790	856	4,925	1,102	1,818	823	1,741
Fixed O&M (2022$/kW/yr)		141.50	21.82	34.65	16.60	55.43	27.89	86.93	29.64	62.74
Variable O&M (2022$/MWh)		5.44	6.73	0.66	0.00	3.21	0.00	0.00	0.00	0.00
Vintage #4 (2040)										
Heat Rate (Btu/kWh)		13,500	8,513	6,469	0	0	0	0	0	0
Capital (2022$/kW)		3,715	1,449	4,236	788	4,743	1,044	1,742	754	1,581
Fixed O&M (2022$/kW/yr)		141.50	21.82	34.65	15.88	55.43	26.90	82.40	27.16	56.97
Variable O&M (2022$/MWh)		5.44	6.73	0.66	0.00	3.21	0.00	0.00	0.00	0.00
Vintage #5 (2045)										
Heat Rate (Btu/kWh)		13,500	8,513	6,469	0	0	0	0	0	0
Capital (2022$/kW)		3,500	1,361	3,686	721	4,560	987	1,683	685	1,422
Fixed O&M (2022$/kW/yr)		141.50	21.82	34.65	15.16	55.43	25.91	78.76	24.68	51.23
Variable O&M (2022$/MWh)		5.44	6.73	0.66	0.00	3.21	0.00	0.00	0.00	0.00
Vintage #6 (2050-2055)										
Heat Rate (Btu/kWh)		13,500	8,513	6,469	0	0	0	0	0	0
Capital (2022$/kW)		3,284	1,268	3,150	653	4,378	930	1,634	617	1,263
Fixed O&M (2022$/kW/yr)		141.50	21.82	34.65	14.44	55.43	24.92	75.72	22.21	45.51
Variable O&M (2022$/MWh)		5.44	6.73	0.66	0.00	3.21	0.00	0.00	0.00	0.00

Note: The capital costs for the landfill gas units at low, and very low methane producing sites are assumed to be 26% and 94% higher than the capital costs for the landfill gas units at high methane producing sites.
The capital costs for solar PV units in 2028 are from the ATB 2023 advanced case, and the capital costs starting in 2035 are from the ATB 2023 moderate case. The capital costs in 2030 are linearly interpolated.
The capital costs and FOM of energy storage units are based on the AEO 2023 estimate for 2023 and are adjusted in future years based on the trend underlying the ATB 2023 moderate case assumptions

4.4.5 Cost and Performance for Potential Renewable Generating and Non-Conventional Technologies

Table 4-15 summarizes the cost and performance assumptions in EPA 2023 Reference Case for potential renewable and non-conventional technology generating units. The parameters shown in the table are based on AEO 2023 for biomass, landfill gas, and fuel cells. For battery storage, onshore wind, offshore wind, solar PV, and solar thermal technologies, the parameters shown are based on the National Renewable Energy Laboratory's (NREL's) 2023 Annual Technology Baseline (ATB) moderate case. The geothermal assumptions are based on ATB 2019. The size (MW) shown in Table 4-15 represents the capacity on which unit cost estimates were developed and does not indicate the total potential capacity that the model can build for a given technology. Due to the distinctive nature of generation from renewable resources, some of the values shown are averages or ranges that are discussed in further detail in the following subsections. The short-term capital cost adder in Table 4-13 and the regional cost adjustment factors in Table 4-14 apply equally to the renewable and non-conventional generation technologies as to the conventional generation technologies.

<u>Wind Generation</u>

EPA 2023 Reference Case includes onshore wind, offshore-fixed, and offshore-floating wind generation technologies. The following sections describe key aspects of the representation of wind generation: wind quality and resource potential, distance to transmission, generation profiles, reserve margin contribution, and capital cost calculation.

<u>Wind Quality and Resource Potential</u>: The NREL resource base for onshore wind is represented by ten wind speed class categories (Class 1 - Class 10). EPA 2023 Reference Case only models the categories Class 1 - Class 9. The NREL resource base for offshore wind is represented by fixed (Class 1 - Class 7), and floating (Class 8 - Class 14) categories. EPA 2023 Reference Case models the categories Class 1 - - Class 6 and Class 8 - Class 12. Table 4-36, Table 4-16, and Table 4-17 present the onshore, offshore fixed, and offshore floating wind resource assumptions. The resource class field in the tables further subdivides the wind speed class categories based on wind speed.

Table 4-16 Offshore Fixed Regional Potential Wind Capacity (MW) by Wind Class, Resource Class, and Cost Class in the EPA 2023 Reference Case

IPM Region	State	Wind Class	Resource Class	Cost Class					
				1	2	3	4	5	6
ERC_REST	TX	Class 5	6	2,976	693				
		Class 6	5	2,622	3,245	3,035	3,052	3,004	4,243
FRCC	FL	Class 6	5	2,900	3,091	2,636	3,362	2,810	9,172
MIS_AMSO	LA	Class 6	5	885	909	858	900	920	12,957
MIS_LA	LA	Class 6	5	31					
MIS_LMI	MI	Class 2	7	154					
MIS_WOTA	LA	Class 6	5	871	922	903	903	875	36,861
	TX	Class 6	5	519	1,038	1,038	781	1,049	15,042
MIS_WUMS	MI	Class 3	7	237					
	WI	Class 4	6	0					
NENG_ME	ME	Class 1	8	12					
NENGREST	MA	Class 1	8	1,418	2,118	4,236	2,118	2,118	8,708
	RI	Class 1	8	14					
NY_Z_K	NY	Class 1	8	165					
		Class 2	7	685	212				
PJM_ATSI	OH	Class 3	7	1,560	1,606	1,491			
PJM_Dom	NC	Class 2	7	2,597	2,545	841			
	VA	Class 2	7	2,390	1,022				
		Class 4	6	2					
PJM_EMAC	DE	Class 1	8	2,894					
		Class 2	7	2,987	274				

IPM Region	State	Wind Class	Resource Class	Cost Class 1	2	3	4	5	6
	MD	Class 2	7	2,423					
	NJ	Class 1	8	2,945	3,010	3,004	2,922		
		Class 2	7	2,968	2,475				
	VA	Class 2	7	2,983	3,014	14			
S_SOU	AL	Class 6	5	2,950	3,040	983			
	FL	Class 6	5	29					
	GA	Class 6	5	2,980	3,020	357			
	MS	Class 6	5	2,435					
S_VACA	NC	Class 3	7	2,971	2,393				
		Class 5	6	2,767	2,645	3,586	2,307		
	SC	Class 5	6	2,647	2,885	3,299	2,978	3,162	20,234
		Class 6	5	2,957	2,996				

Note: Resource potential depleted to account for the NEEDS capacity built in 2021 - 2028 by IPM Region & State.

Table 4-17 Offshore Floating Regional Potential Wind Capacity (MW) by Wind Class, Resource Class, and Cost Class in the EPA 2023 Reference Case

IPM Region	State	Wind Class	Resource Class	Cost Class 1	2	3	4	5	6
MIS_LMI	MI	Class 12	7	2,154					
MIS_WUMS	MI	Class 12	7	113					
NENG_ME	ME	Class 8	8		330	330	330	330	85,755
		Class 11	7		397	397	397		6,940
NENGREST	MA	Class 8	8	2,176	2,888	1,444	3,882	2,528	370,283
		Class 11	7	1,450					
	RI	Class 8	8	376					
NY_Z_J	NY	Class 11	7						8,509
NY_Z_K	NY	Class 9	8	608	696	796	694	663	74,310
		Class 11	7	397	794	794	789	588	
PJM_Dom	NC	Class 12	7	2,509	2,681	2,595	1,782	2,515	4,918
	VA	Class 12	7	1,986					
PJM_EMAC	DE	Class 10	8	2,978	992				
		Class 11	7	496					
	MD	Class 10	8	397					
		Class 11	7	2,846	2,846	2,846	2,846	2,846	27,846
	NJ	Class 10	8	2,717	3,194	2,577	3,376	3,022	33,803
		Class 11	7	2,942	3,031	1,539	3,839	1,919	34,612
	VA	Class 12	7	2,978	2,796	3,200	2,600		
S_VACA	NC	Class 12	7	397	3,176	3,176	3,176	3,176	321,572
WEC_CALN	CA	Class 8	8	2,222	3,640		3,640	3,640	360,347
		Class 12	7	2,984	2,800	3,210	2,762	3,177	513,613
WECC_PNW	CA	Class 8	8	2,780	3,197	2,774	1,646		
	OR	Class 8	8	2,754	3,175	3,064	2,908	2,383	43,714
		Class 12	7						345,408
	WA	Class 12	7	2,646	2,646	2,646	2,646	2,646	74,215
WECC_SCE	CA	Class 12	7	1,312	3,772	3,772		3,772	72,915

Note: Resource potential depleted to account for the NEEDS capacity built in 2021 - 2028 by IPM Region & State.

Generation Profiles: Unlike other generation technologies, which dispatch on an economic basis subject to their availability constraint, wind, and solar technologies dispatch only when the wind blows and the sun shines. To represent intermittent renewable generating sources such as wind and solar, EPA 2023 Reference Case uses hourly generation profiles. All wind and solar photovoltaic units are provided with hourly generation profiles. The profiles are customized for each resource class within an IPM region and state combination.

The generation profile indicates the amount of generation (kWh) per MW of available capacity. The wind generation profiles were prepared with data from NREL. Table 4-37 shows the generation profiles for onshore and offshore wind units in all model region, state, and class combinations for vintage 2028. Improvements in onshore wind capacity factors over time are modeled through two vintages (2028 and 2030) of potential wind units.

To obtain the seasonal generation for the units in a particular resource class in a specific region, the installed capacity is multiplied by the number of hours in the season and the seasonal capacity factor. Capacity factor is the average “kWh of generation per MW” from the applicable generation profile. The annual capacity factors for wind generation that are used in EPA 2023 Reference Case were obtained from NREL and are shown in Table 4-35, Table 4-18, and Table 4-19.

Table 4-18 Offshore Fixed Average Capacity Factor by Wind Class and Resource Class in the EPA 2023 Reference Case

IPM Region	State	Wind Class	Resource Class	Capacity Factor (%)
				Vintage #1 (2028-2059)
ERC_REST	TX	Class 5	6	50%
		Class 6	5	45%
FRCC	FL	Class 6	5	40%
MIS_AMSO	LA	Class 6	5	39%
MIS_LA	LA	Class 6	5	41%
MIS_LMI	MI	Class 2	7	53%
MIS_WOTA	LA	Class 6	5	42%
	TX	Class 6	5	44%
MIS_WUMS	MI	Class 3	7	54%
	WI	Class 4	6	53%
NENG_ME	ME	Class 1	8	55%
NENGREST	MA	Class 1	8	54%
	RI	Class 1	8	51%
NY_Z_K	NY	Class 1	8	51%
		Class 2	7	53%
PJM_ATSI	OH	Class 3	7	52%
PJM_Dom	NC	Class 2	7	50%
	VA	Class 2	7	50%
		Class 4	6	51%
PJM_EMAC	DE	Class 1	8	50%
		Class 2	7	53%
	MD	Class 2	7	52%
	NJ	Class 1	8	51%
		Class 2	7	53%
	VA	Class 2	7	50%
S_SOU	AL	Class 6	5	39%
	FL	Class 6	5	38%
	GA	Class 6	5	45%
	MS	Class 6	5	39%
S_VACA	NC	Class 3	7	51%
		Class 5	6	50%
	SC	Class 5	6	48%
		Class 6	5	45%

Table 4-19 Offshore Floating Average Capacity Factor by Wind Class and Resource Class in the EPA 2023 Reference Case

IPM Region	State	Wind Class	Resource Class	Capacity Factor (%)
				Vintage #1 (2028-2059)
MIS_LMI	MI	Class 12	7	52%
MIS_WUMS	MI	Class 12	7	50%
NENG_ME	ME	Class 8	8	57%
		Class 11	7	53%
NENGREST	MA	Class 8	8	55%
		Class 11	7	55%
	RI	Class 8	8	56%
NY_Z_J	NY	Class 11	7	55%
NY_Z_K	NY	Class 9	8	56%
		Class 11	7	55%
PJM_Dom	NC	Class 12	7	50%
	VA	Class 12	7	49%
PJM_EMAC	DE	Class 10	8	54%
		Class 11	7	55%
	MD	Class 10	8	54%
		Class 11	7	54%
	NJ	Class 10	8	55%
		Class 11	7	55%
	VA	Class 12	7	50%
S_VACA	NC	Class 12	7	50%
WEC_CALN	CA	Class 8	8	60%
		Class 12	7	54%
WECC_PNW	CA	Class 8	8	51%
	OR	Class 8	8	55%
		Class 12	7	50%
	WA	Class 12	7	48%
WECC_SCE	CA	Class 12	7	53%

<u>Reserve Margin Contribution (also referred to as capacity credit):</u> EPA 2023 Reference Case uses reserve margins, discussed in detail in Section 3.6, to model reliability. Each region has a reserve margin requirement which is used to determine the total capacity needed to reliably meet peak demand. The ability of a unit to assist a region in meeting its reliability requirements is modeled through the unit's contribution to the reserve margin. If the unit has a 100 percent contribution towards the reserve margin, then the entire capacity of the unit is counted towards meeting the region's reserve margin requirement. However, if any unit has less than a 100 percent contribution towards the reserve margin, then only the designated share of the unit's capacity counts towards the reserve margin requirement.

All units except those that depend on intermittent resources have 100% contributions toward the reserve margin. Intermittent resources such as wind and solar have limited (less than 100 percent) contributions toward reserve margin requirements.

Capacity credit assumptions for onshore wind, offshore wind, and solar PV units are estimated as the function of penetration of solar and wind. A two-step approach is developed to estimate the capacity credit at a unit level. In the first step, the method estimates the sequence of solar and wind units to be built in each ISO/NERC assessment region. Table 3-11 provides the mapping between the ISO/NERC assessment region and the IPM region. To do so, each solar and wind unit in an ISO/NERC assessment region is sorted from cheapest to most expensive in terms of cost and potential revenue generation. Unit-level capital costs, FOM costs, capital charge rate, and average energy price in each IPM region are used. In the second step, capacity credit is estimated for each unit in the sequence as the ratio between the MW of peak reduced and the capacity of the unit. Unit-level hourly generation profiles and ISO/NERC assessment region-level hourly load curves are used. The approach allows the EPA 2023 Reference

Case to endogenously account for the decline of capacity credit for intermittent resources with their rising penetration.

Table 4-20, Table 4-21, and Table 4-22 present the reserve margin contributions apportioned to new wind units in the EPA 2023 Reference Case.

Table 4-20 Onshore Reserve Margin Contribution by Wind Class in the EPA 2023 Reference Case

Wind Class	Vintage #1 (2028)	Vintage #2 (2030-2059)
Class 1	0% - 70%	0% - 75%
Class 2	15%	16%
Class 3	0% - 82%	0% - 88%
Class 4	0% - 78%	0% - 84%
Class 5	0% - 55%	0% - 59%
Class 6	0% - 83%	0% - 90%
Class 7	0% - 83%	0% - 90%
Class 8	0% - 62%	0% - 67%
Class 9	0% - 93%	0% - 100%

Table 4-21 Offshore Fixed Reserve Margin Contribution by Wind Class in the EPA 2023 Reference Case

Wind Class	Vintage #1 (2028-2059)
Class 1	0.3% - 89%
Class 2	0.1% - 94%
Class 3	0% - 20%
Class 4	7.4% - 21%
Class 5	1.5% - 40%
Class 6	0% - 70%

Table 4-22 Offshore Floating Reserve Margin Contribution by Wind Class in the EPA 2023 Reference Case

Wind Class	Vintage #1 (2028-2059)
Class 8	0% - 93.8%
Class 9	1.9% - 78.5%
Class 10	1.6% - 3.1%
Class 11	0% - 34.4%
Class 12	0% - 36.1%

Capital cost calculation: Capital costs for wind units include spur-line transmission costs. The resources for wind and solar are highly sensitive to location. These spur-line costs represent the cost of needed spur lines and are based on an estimated distance to transmission infrastructure. NREL develops these supply curves based on a geographic-information-system analysis, which estimates the resource accessibility costs in terms of supply curves based on the expected cost of linking renewable resource sites to the high-voltage, long-distance transmission network. For IPM modeling purposes, the NREL spur line cost curves are aggregated into a piecewise step curve for each resource class within each model region and state combination. The sizes of the initial steps are based on the model region load, while the last step holds the residual resource. The wind class and resource class level spur line cost curves for each model region and state combination are aggregated into a six-step cost curve for onshore wind and offshore wind units. To obtain the capital cost for a particular new wind model plant, the capital cost adder applicable to the new plant by resource and cost class shown in Table 4-23, Table 4-24, and Table 4-38, is added to the base capital cost shown in Table 4-15.

Table 4-23 Capital Cost Adder (2022$/kW) for New Offshore Fixed Wind Plants in the EPA 2023 Reference Case

IPM Region	State	Wind Class	Resource Class	Cost Class					
				1	2	3	4	5	6
ERC_REST	TX	Class 5	6	140	1,040				
		Class 6	5	31	31	35	46	54	110
FRCC	FL	Class 6	5	22	23	30	35	54	149
MIS_AMSO	LA	Class 6	5	47	56	133	199	207	406
MIS_LA	LA	Class 6	5	5,143					
MIS_LMI	MI	Class 2	7	5,431					
MIS_WOTA	LA	Class 6	5	70	95	114	120	127	354
	TX	Class 6	5	28	28	28	29	31	108
MIS_WUMS	MI	Class 3	7	11,000					
	WI	Class 4	6	133,304					
NENG_ME	ME	Class 1	8	6,139					
NENGREST	MA	Class 1	8	15	178	178	178	178	476
	RI	Class 1	8	14,035					
NY_Z_K	NY	Class 1	8	278					
		Class 2	7	4	207				
PJM_ATSI	OH	Class 3	7	296	458	1,683			
PJM_Dom	NC	Class 2	7	44	148	420			
	VA	Class 2	7	67	400				
		Class 4	6	17,645					
PJM_EMAC	DE	Class 1	8	71					
		Class 2	7	49	438				
	MD	Class 2	7	204					
	NJ	Class 1	8	35	89	124	211		
		Class 2	7	4	225				
	VA	Class 2	7	325	244,697	4,032,984			
S_SOU	AL	Class 6	5	117	246	720			
	FL	Class 6	5	1,241					
	GA	Class 6	5	58	135	691			
	MS	Class 6	5	235					
S_VACA	NC	Class 3	7	76	528				
		Class 5	6	9	67	74	232		
	SC	Class 5	6	6	12	17	20	22	103
		Class 6	5	21	148				

Table 4-24 Capital Cost Adder (2022$/kW) for New Offshore Floating Wind Plants in the EPA 2023 Reference Case

IPM Region	State	Wind Class	Resource Class	Cost Class					
				1	2	3	4	5	6
MIS_LMI	MI	Class 12	7	873					
MIS_WUMS	MI	Class 12	7	5,044					
NENG_ME	ME	Class 8	8		67	67	67	67	669
		Class 11	7		67	67	67		251
NENGREST	MA	Class 8	8	9	11	11	12	66	383
		Class 11	7	133					
	RI	Class 8	8	1,264					
NY_Z_J	NY	Class 11	7						133
NY_Z_K	NY	Class 9	8	3	3	6	13	49	251
		Class 11	7	104	104	104	105	105	
PJM_Dom	NC	Class 12	7	51	73	111	233	266	320
	VA	Class 12	7	101					
PJM_EMAC	DE	Class 10	8	55	104				
		Class 11	7	189					

IPM Region	State	Wind Class	Resource Class	Cost Class					
				1	2	3	4	5	6
	MD	Class 10	8	58					
		Class 11	7	78	78	78	78	78	198
	NJ	Class 10	8	21	45	77	80	85	142
		Class 11	7	57	61	73	78	78	122
	VA	Class 12	7	78	253	526	174,958		
S_VACA	NC	Class 12	7	67	70	70	70	70	245
WEC_CALN	CA	Class 8	8	9	79		79	79	429
		Class 12	7	4	30	42	59	76	361
WECC_PNW	CA	Class 8	8	287	311	724	1,389		
	OR	Class 8	8	38	41	47	72	74	173
		Class 12	7						68
	WA	Class 12	7	51	51	51	51	51	271
WECC_SCE	CA	Class 12	7	63	92	92		92	596

As an illustrative example, Table 4-25 shows the calculations that would be performed to derive the potential electric generation, reserve margin contribution, and cost of potential (new) onshore capacity in wind class 7, resource class 5, and cost class 1 in the WECC_CO model region in run year 2028.

Table 4-25 Example Calculations of Wind Generation, Reserve Margin Contribution, and Capital Cost for Onshore Wind in WECC_CO for Wind Class 7, Resource Class 5, and Cost Class 1.

<u>Required Data</u>

Table 4-36	Potential wind capacity (*C*) =	1,876 MW
Table 4-37	Winter average generation (G_W) per available MW =	277 kWh/MW
Table 4-37	Spring average generation (G_{SP}) per available MW =	397 kWh/MW
Table 4-37	Summer average generation (G_{SM}) per available MW =	363 kWh/MW
Table 4-37	Fall average generation (G_F) per available MW =	262 kWh/MW
	Hours in Winter (H_W) season (December - February) =	2,160 hours
	Hours in Spring (H_{SP}) season (March - April) =	1,464 hours
	Hours in Summer (H_{SM}) season (May - September) =	3,672 hours
	Hours in Summer (H_F) season (October - November) =	1,464 hours
Table 4-20	Reserve Margin Contribution (*RM*) WECC_CO, Wind Class 7, Resource Class 5 =	3.64 percent
Table 4-15	Capital Cost (Cap_{2028}) in vintage range for year 2028 =	$1,206/kW
Table 4-38	Capital Cost Adder ($CCA_{ON,C1}$) for onshore cost class 1 =	$37/kW
Table 4-14	Regional Factor (RF)	1.027

<u>Calculations</u>

$$\begin{aligned}\text{Generation Potential} &= \mathrm{C} \times \mathrm{G_W} \times \mathrm{H_W} + \mathrm{C} \times \mathrm{G_{SP}} \times \mathrm{H_{SP}} + \mathrm{C} \times \mathrm{G_{SM}} \times \mathrm{H_{SM}} + \mathrm{C} \times \mathrm{G_F} \times \mathrm{H_F} \\ &= 1{,}876\ \mathrm{MW} \times 277\mathrm{kWh/MW} \times 2{,}160\ \text{hours} \ + \\ &\quad 1{,}876\ \mathrm{MW} \times 397\mathrm{kWh/MW} \times 1{,}464\ \text{hours} \ + \\ &\quad 1{,}876\ \mathrm{MW} \times 363\mathrm{kWh/MW} \times 3{,}672\ \text{hours} \ + \\ &\quad 1{,}876\ \mathrm{MW} \times 262\mathrm{kWh/MW} \times 1{,}464\ \text{hours} \\ &= 5{,}431\ \mathrm{GWh}\end{aligned}$$

$$\begin{aligned}\text{Reserve Margin Contribution} &= \mathrm{RM} \times \mathrm{C} \\ &= 3.64\% \times 1{,}876\ \mathrm{MW} \\ &= 68\ \mathrm{MW}\end{aligned}$$

$$\begin{aligned}\text{Capital Cost} &= (\mathrm{Cap_{2028}} \times \mathrm{RF} + \mathrm{CCA_{ON,C1}}) \times \mathrm{C} \\ &= (\$1{,}207/\mathrm{kW} \times 1.027 + \$33/\mathrm{kW}) \times 1{,}876\mathrm{MW} \\ &= \$2{,}394{,}152\end{aligned}$$

Solar Generation

EPA 2023 Reference Case includes solar photovoltaics and solar thermal generation technologies. The following sections describe four key aspects of the representation of solar generation: solar resource potential, generation profiles, reserve margin contribution, and capital cost calculation.

Solar Resource Potential: The resource potential estimates for solar photovoltaics and solar thermal technologies were developed by NREL by model region, state, and resource class. The NREL resource base for solar photovoltaics is represented by ten resource classes. In EPA 2023 Reference Case, the top ten resource classes are primarily modeled for solar photovoltaics. The NREL resource base for solar thermal is represented by twelve resource classes. In EPA 2023 Reference Case, the top eight resource classes are modeled for solar thermal. The solar thermal technology has a ten-hour thermal energy storage (TES) and is considered a dispatchable resource for modeling purposes. These are summarized in Table 4-39 and Table 4-40.

Generation Profiles: Table 4-41 shows the generation profiles for solar photovoltaics units in all model region, state, and resource combinations. The capacity factors for solar generation that are used in EPA 2023 Reference Case were obtained from NREL and are shown in Table 4-44 and Table 4-45.

Reserve margin contribution (also referred to as capacity credit): The reserve margin contribution section for wind units summarizes the approach followed for calculating the reserve margin contribution for solar photovoltaics units. Table 4-26 presents the reserve margin contributions apportioned to new solar photovoltaics units in the EPA 2023 Reference Case. The solar thermal units are assumed to have 10-hour TES and are assigned 100% reserve margin contribution.

Table 4-26 Solar Photovoltaic Reserve Margin Contribution by PV Class in the EPA 2023 Reference Case

PV Class	Vintage #1 (2028-2059)
Class 1	0%
Class 2	0% - 100%
Class 3	0% - 65%
Class 4	0% - 100%
Class 5	0% - 64%
Class 6	0% - 49%
Class 7	0% - 61%
Class 8	0% - 100%
Class 9	0% - 3%
Class 10	0% - 37%

Capital Costs: Similar to wind units, capital costs for solar units include transmission spur line cost adders. The resource class level spur line cost curves for each model region and state combination are aggregated into a seven-step cost curve. Table 4-42 and Table 4-43 illustrate the capital cost adder by resource and cost class for new solar units.

Geothermal Generation

Geothermal Resource Potential: Twelve model regions in EPA 2023 Reference Case have geothermal potential. The potential resource in each of these regions is shown in Table 4-27 and is based on NREL ATB 2019. GEO-Hydro Flash[45], GEO-Hydro Binary, GEO-NF EGS Flash, and GEO-NF EGS Binary are the included technologies.

[45] In dual flash systems, high temperature water (above 400□F) is sprayed into a tank held at a much lower pressure than the fluid. This causes some of the fluid to "flash," i.e., rapidly vaporize to steam. The steam is used to drive a turbine, which, in turn, drives a generator. In the binary cycle technology, moderate temperature water (less than

Table 4-27 Regional Assumptions on Potential Geothermal Capacity in the EPA 2023 Reference Case

IPM Model Region	Capacity (MW)
WEC_CALN	498
WECC_AZ	26
WECC_CO	21
WECC_ID	237
WECC_IID	2,832
WECC_MT	29
WECC_NM	22
WECC_NNV	1,421
WECC_PNW	633
WECC_SCE	496
WECC_UT	208
WECC_WY	39
Grand Total	**6,461**

Cost Calculation: EPA 2023 Reference Case does not contain a single capital cost, but multiple geographically dependent capital costs for geothermal generation. The assumptions for geothermal were developed using NREL 2019 ATB cost and performance estimates for 152 sites. Both dual flash and binary cycle technologies were represented. The 152 sites were aggregated into 61 different options based on geographic location and cost and performance characteristics of geothermal sites in each of the 12 eligible IPM regions where geothermal generation opportunities exist. Table 4-28 shows the potential geothermal capacity and cost characteristics for applicable model regions.

Table 4-28 Potential Geothermal Capacity and Cost Characteristics by Model Region in the EPA 2023 Reference Case

Region	Net Capacity (MW)	Capital Cost (2022$/kW)	FOM (2022$/kW-yr)
WEC_CALN	6	17,886	556
	8	24,471	674
	11	15,277	436
	29	4,823	139
	29	6,978	225
	82	28,516	695
	333	12,724	242
WECC_AZ	26	23,588	654
WECC_CO	8	24,495	675
	12	17,206	486
WECC_ID	10	20,301	567
	14	25,697	694
	28	22,479	628
	28	48,811	1,208
	44	14,444	408
	112	10,836	301
WECC_IID	74	3,766	129
	85	30,678	744
	91	6,572	214
	137	5,210	166
	257	12,856	236
	2,188	4,764	114
WECC_MT	7	24,912	683

400°F) vaporizes a secondary, working fluid, which drives a turbine and generator. Due to its use of more plentiful, lower temperature geothermal fluids, these systems tend to be most cost effective and are expected to be the most prevalent future geothermal technology.

Region	Net Capacity (MW)	Capital Cost (2022$/kW)	FOM (2022$/kW-yr)
	22	20,139	563
WECC_NM	9	24,399	672
	13	16,944	437
WECC_NNV	45	17,932	491
	50	7,107	215
	66	8,541	248
	67	22,005	607
	77	15,293	444
	92	30,716	769
	93	4,342	145
	103	3,662	116
	138	10,601	318
	148	4,631	155
	264	26,571	667
	279	5,240	172
WECC_PNW	6	22,875	658
	12	9,042	285
	15	18,915	555
	15	24,695	678
	17	21,053	606
	19	18,230	505
	23	14,863	419
	23	19,139	537
	41	6,092	199
	48	11,107	331
	57	13,981	390
	101	7,565	232
	124	3,704	123
	132	8,610	261
WECC_SCE	25	27,424	712
	27	18,382	517
	155	12,468	226
	289	3,662	114
WECC_UT	1	35,564	589
	2	25,456	606
	86	3,662	126
	120	21,854	532
WECC_WY	39	15,974	450

Landfill Gas Electricity Generation

Landfill Gas Resource Potential: Estimates of potential electric capacity from landfill gas are based on the AEO 2019 inventory. EPA 2023 Reference Case represents the “high”, “low”, and “very low” categories of potential landfill gas units. The categories refer to the amount and rate of methane production from the existing landfill site. Table 4-46 summarizes the potential electric capacity of landfill gas.

There are several things to note about Table 4-46. The AEO 2019 NEMS region-level estimates of the potential electric capacity from new landfill gas units are disaggregated to IPM regions based on electricity demand. The limits listed in Table 4-46 apply to the IPM regions indicated in column 1. In EPA 2023 Reference Case, the new landfill gas electric capacity in the corresponding IPM regions shown in column 1 cannot exceed the limits shown in columns 3-5. As noted, the capacity limits for three categories of potential landfill gas units are distinguished in the table based on the rate of methane production at three categories of landfill sites: LGHI = high rate of landfill gas production, LGLo = low rate of landfill gas production, and LGLVo = very low rate of landfill gas production. The values shown in Table 4-46 represent an upper bound on the amount of new landfill capacity that can be added in each of the indicated model regions and states for each of the three landfill categories. The cost and performance assumptions for adding new capacity in each of the three landfill categories are presented in Table 4-15.

Small Hydro

EPA 2023 Reference Case models resource potential from non-powered dams (NPDs) and new stream development (NSDs) categories of new small hydro. While NPDs are existing dams that do not currently have hydropower, NSDs are greenfield hydropower developments along previously undeveloped waterways. Table 4-29 and Table 4-30 summarize the assumptions for NPDs and NSDs.

Table 4-29 Potential Non-Powered Dam in the EPA 2023 Reference Case

IPM Region	State	Capacity (MW)	Capacity Factor (%) - Winter	Capacity Factor (%) - Spring	Capacity Factor (%) - Summer	Capacity Factor (%) - Fall	Capital Cost (2022$/kW)	FOM (2022$/kW)
ERC_REST	TX	338	55.1%	68.4%	48.7%	46.6%	2,485	17.35
ERC_WEST	TX	27	45.0%	64.8%	49.4%	41.3%	2,480	54.51
FRCC	FL	126	56.6%	53.0%	66.6%	67.8%	2,645	27.19
MIS_AMSO	LA	158	66.8%	76.3%	43.5%	45.9%	1,863	24.53
MIS_AR	AR	786	61.3%	81.2%	53.9%	46.1%	1,845	11.84
MIS_IA	IA	383	49.4%	90.3%	75.5%	52.4%	1,988	16.40
MIS_IL	IL	630	55.1%	90.5%	72.7%	53.2%	1,752	13.09
MIS_INKY	IN	65	68.4%	79.6%	52.2%	51.5%	3,174	36.66
	KY	536	75.2%	85.0%	46.1%	52.2%	1,481	14.09
MIS_LA	LA	643	66.7%	76.2%	43.3%	45.7%	1,823	12.97
MIS_LMI	MI	24	75.4%	90.5%	60.8%	62.4%	4,402	57.37
MIS_MAPP	MT	17	42.5%	76.4%	80.2%	46.7%	2,515	62.88
	ND	15	32.2%	81.0%	67.1%	38.7%	2,968	71.83
MIS_MIDA	IA	150	49.4%	90.3%	75.5%	52.3%	1,994	25.05
MIS_MNWI	MI	0.02	68.6%	90.8%	72.0%	65.0%	5,822	145.56
	MN	123	54.0%	86.7%	74.8%	56.8%	2,594	27.46
	WI	94	52.1%	92.0%	76.7%	57.0%	2,175	30.94
MIS_MO	IA	4	49.1%	90.1%	75.3%	51.7%	2,106	52.65
	MO	159	52.7%	90.0%	74.8%	52.7%	1,648	24.47
MIS_MS	MS	102	73.4%	72.1%	45.1%	54.1%	2,271	29.86
MIS_WOTA	LA	23	66.8%	76.3%	43.5%	45.9%	2,011	50.28
	TX	123	60.4%	73.7%	46.1%	44.7%	1,699	27.43
MIS_WUMS	MI	4	71.1%	90.7%	67.8%	64.0%	4,998	124.96
	WI	111	53.7%	92.8%	77.2%	58.0%	2,102	28.71
NENG_CT	CT	59	74.3%	89.9%	54.7%	60.1%	3,418	38.41
NENG_ME	ME	15	66.7%	87.4%	61.6%	60.1%	5,706	70.84
NENGREST	MA	53	74.2%	89.3%	51.1%	57.7%	5,278	40.13
	NH	56	70.2%	91.1%	58.3%	59.9%	3,548	39.34
	RI	11	76.3%	87.9%	48.7%	56.7%	5,153	81.81
	VT	13	69.5%	91.8%	56.3%	57.5%	3,655	76.09
NY_Z_A	NY	12	74.2%	87.4%	50.6%	58.0%	2,684	67.11
NY_Z_B	NY	8	74.2%	87.4%	50.6%	58.0%	2,759	68.97
NY_Z_C&E	NY	66	74.2%	87.4%	50.6%	58.0%	2,867	36.37
NY_Z_D	NY	49	74.2%	87.4%	50.6%	58.0%	2,839	41.66
NY_Z_F	NY	78	74.2%	87.4%	50.6%	58.0%	2,887	33.67
NY_Z_G-I	NY	28	74.2%	87.4%	50.6%	58.0%	2,650	53.51
PJM_AP	MD	13	70.2%	85.5%	49.5%	51.4%	3,132	76.36
	PA	236	78.3%	86.3%	47.7%	56.5%	2,311	20.42
	VA	3	68.9%	83.7%	50.1%	54.0%	4,048	101.21
	WV	138	73.7%	84.7%	48.1%	51.5%	2,244	26.03
PJM_ATSI	OH	64	70.2%	83.9%	52.0%	50.7%	3,162	36.86

IPM Region	State	Capacity (MW)	Capacity Factor (%) - Winter	Capacity Factor (%) - Spring	Capacity Factor (%) - Summer	Capacity Factor (%) - Fall	Capital Cost (2022$/kW)	FOM (2022$/kW)
	PA	43	77.9%	85.9%	48.2%	56.9%	2,146	44.25
PJM_COMD	IL	198	57.5%	90.0%	71.9%	55.2%	2,115	22.14
PJM_Dom	NC	2	68.6%	74.3%	49.4%	57.1%	2,416	60.41
	VA	13	68.9%	83.8%	50.1%	53.9%	3,424	75.64
PJM_EMAC	DE	1	71.3%	85.4%	56.7%	57.9%	5,422	135.56
	MD	13	72.8%	85.0%	58.5%	60.7%	2,781	69.52
	NJ	17	75.7%	84.5%	56.3%	62.8%	4,998	66.71
	PA	9	74.9%	83.7%	50.7%	58.9%	2,884	72.11
PJM_PENE	PA	316	77.7%	85.9%	48.2%	56.9%	2,360	17.91
PJM_SMAC	DC	1	72.8%	85.0%	58.5%	60.7%	3,458	86.46
	MD	15	72.5%	85.0%	57.9%	60.2%	3,602	71.46
PJM_West	IN	8	69.6%	77.6%	53.4%	54.0%	2,960	74.00
	KY	375	74.8%	84.6%	46.5%	52.0%	1,690	16.57
	OH	170	70.2%	85.0%	51.1%	49.1%	2,959	23.70
	VA	8	69.2%	84.6%	49.4%	51.8%	2,881	72.01
	WV	37	70.5%	85.7%	46.1%	48.3%	2,524	47.47
PJM_WMAC	PA	49	74.9%	84.2%	50.1%	58.3%	3,085	41.83
S_C_KY	KY	134	70.4%	80.6%	40.0%	46.4%	2,550	26.38
S_C_TVA	AL	118	74.5%	75.5%	41.3%	50.0%	1,896	27.94
	GA	30	75.8%	78.3%	61.9%	64.3%	2,055	51.38
	KY	1,022	76.6%	85.7%	48.3%	53.8%	1,351	10.52
	MS	94	75.3%	76.5%	43.4%	51.5%	2,273	31.06
	NC	2	72.7%	79.0%	57.4%	61.0%	4,247	106.18
	TN	12	75.4%	77.1%	48.4%	55.2%	2,705	67.63
	VA	1	69.2%	84.6%	49.3%	51.7%	2,875	71.88
S_D_AECI	MO	92	53.5%	90.9%	73.1%	52.8%	1,853	31.35
S_SOU	AL	723	74.5%	76.1%	43.8%	51.3%	1,542	12.30
	FL	11	72.5%	78.4%	64.4%	62.9%	2,688	67.19
	GA	51	75.8%	78.3%	61.9%	64.3%	2,226	40.90
	MS	12	74.1%	73.6%	44.5%	53.3%	2,298	57.45
S_VACA	GA	0.09	75.8%	78.3%	61.9%	64.3%	2,537	63.43
	NC	91	68.9%	74.6%	50.0%	57.3%	2,735	31.47
	SC	43	75.5%	77.8%	62.4%	65.9%	3,463	44.06
SPP_N	KS	36	40.3%	67.6%	58.5%	38.1%	2,603	47.96
	MO	10	63.9%	80.8%	50.5%	47.0%	2,888	72.21
SPP_NEBR	KS	3	40.3%	67.6%	58.5%	38.1%	2,803	70.08
SPP_SPS	NM	26	40.6%	71.0%	75.7%	52.9%	2,766	55.29
SPP_WEST	AR	343	61.3%	81.2%	53.8%	46.1%	1,774	17.24
	LA	24	66.8%	76.3%	43.5%	45.9%	1,881	47.02
	MO	0.40	53.5%	74.7%	48.4%	39.9%	3,272	81.80
	OK	312	48.5%	75.7%	54.6%	39.9%	2,116	17.99
	TX	20	59.7%	64.1%	35.0%	38.9%	2,533	62.86
WEC_BANC	CA	0.09	62.6%	84.4%	61.6%	53.6%	4,020	100.50
WEC_CALN	CA	111	62.7%	84.4%	61.6%	53.7%	2,985	28.77
WEC_LADW	CA	27	55.6%	85.9%	77.5%	58.5%	2,322	54.15
WECC_AZ	AZ	58	67.3%	81.6%	72.8%	65.9%	2,529	38.59
WECC_CO	CO	146	47.5%	76.7%	80.4%	54.3%	2,167	25.38
WECC_ID	ID	6	65.8%	81.8%	72.1%	66.3%	4,126	103.15
WECC_IID	CA	0.38	55.6%	85.9%	77.5%	58.5%	1,990	49.74
WECC_MT	MT	54	52.8%	76.1%	79.5%	56.7%	3,299	39.83
WECC_NM	NM	63	37.8%	84.7%	82.1%	49.8%	2,735	37.29
	TX	15	36.6%	86.2%	83.0%	48.1%	2,846	70.24
WECC_NNV	NV	12	50.0%	82.5%	69.2%	48.7%	4,673	79.40
WECC_PNW	CA	4	74.8%	88.5%	68.5%	65.2%	3,779	94.47
	ID	1	47.5%	80.1%	74.2%	48.5%	3,477	86.93
	OR	87	79.1%	82.8%	56.1%	61.5%	2,979	32.16
	WA	70	83.9%	83.6%	61.4%	61.7%	2,871	35.39

IPM Region	State	Capacity (MW)	Capacity Factor (%) - Winter	Capacity Factor (%) - Spring	Capacity Factor (%) - Summer	Capacity Factor (%) - Fall	Capital Cost (2022$/kW)	FOM (2022$/kW)
WECC_SCE	CA	34	55.6%	85.9%	77.4%	58.4%	2,226	49.37
WECC_SNV	NV	2	88.1%	83.2%	81.7%	86.2%	4,086	102.15
WECC_UT	UT	29	55.5%	79.1%	78.4%	59.3%	2,697	53.14
WECC_WY	WY	36	43.8%	83.6%	76.2%	45.9%	2,447	47.90

Table 4-30 Potential New Stream Development in the EPA 2023 Reference Case

IPM Region	State	Capacity (MW)	Capacity Factor (%) - Winter	Capacity Factor (%) - Spring	Capacity Factor (%) - Summer	Capacity Factor (%) - Fall	Capital Cost (2022$/kW)	FOM (2022$/kW)
MIS_MO	MO	639	51.7%	86.9%	75.2%	51.1%	4,039	13.02
NENG_ME	ME	406	65.4%	86.6%	62.7%	59.9%	6,698	15.97
NENGREST	MA	13	75.3%	89.9%	53.6%	59.6%	6,343	76.43
	NH	117	71.1%	91.4%	59.9%	61.0%	5,636	28.05
	VT	58	69.9%	91.4%	57.4%	58.5%	6,608	38.59
PJM_AP	PA	7	74.6%	85.8%	48.3%	56.4%	5,224	97.89
PJM_EMAC	NJ	27	75.7%	85.3%	56.6%	63.0%	5,631	54.24
	PA	30	74.8%	85.8%	48.3%	56.5%	5,224	52.20
PJM_PENE	PA	239	74.8%	85.8%	48.3%	56.5%	4,731	20.32
PJM_SMAC	MD	79	69.8%	85.6%	50.6%	53.9%	5,664	33.56
PJM_WMAC	PA	622	74.8%	85.9%	48.2%	56.4%	4,599	13.17
S_VACA	SC	51	76.0%	78.7%	61.5%	65.8%	6,372	40.85
SPP_N	MO	350	49.7%	86.9%	79.6%	53.0%	3,993	17.09
WECC_NNV	NV	13	47.5%	83.8%	71.7%	47.8%	7,620	74.87
WECC_PNW	OR	48	51.3%	87.4%	86.5%	57.2%	5,190	42.18
	WA	394	64.8%	88.0%	72.3%	54.1%	4,512	16.21

Energy Storage

Energy storage is the capture of energy produced at one time for use at a later time. Presently, the most common energy storage technologies are pumped storage and lithium-ion battery storage. EPA 2023 Reference Case includes both existing and new battery storage by IPM region and state. While EPA 2023 Reference Case models existing pumped storage, it does not model new pumped storage options.

The cost and performance assumptions for new 4-hour and 10-hour battery storage units in EPA 2023 Reference Case are based on NREL ATB 2023 and are summarized in Table 4-15. Energy storage options in EPA 2023 Reference Case are assigned capacity credits that are a function of penetration. Using a heuristic approach, a capacity credit curve is independently calculated for both 4-hour and 10-hour battery storage options at an IPM model region level. It estimates how much storage is needed to reduce net peak demand at different levels of storage penetration. For each model region, 300 storage power capacities (sized from 0 to 30% of the annual peak in 0.1% increments) are simulated. The amount of stored energy required to reduce the episodic peak demand by the storage power capacity is determined for each storage power capacity. The capacity credit is calculated as the ratio between the storage duration (4/10 hours) and the episode length with the most storage requirement. Hourly load curves adjusted for hourly generation from existing solar and wind units are used for the analysis. Four steps of storage options are provided in each IPM region. The first step is assigned 100% capacity credit for 4-hour storage options, and the second step 100% capacity credit for 10-hour storage options. The sum of step widths for the first and second steps equals the step width of the 100% capacity credit step of 10-hour energy storage options. The other two steps are assigned lower than 100% capacity credits based on the capacity credit curve for 10-hour storage options. Table 4-31 summarizes these assumptions.

Table 4-31 Bounds and Reserve Margin Contribution for Potential (New) Battery Storage in the EPA 2023 Reference Case

IPM Region	Bound (MW)				Reserve Margin Contribution (%)			
	Step 1	Step 2	Step 3	Step 4	Step 1	Step 2	Step 3	Step 4
ERC_PHDL	0	1,748	418	NA	100%	100%	0%	0%
ERC_REST	0	17,643	2,826	NA	100%	100%	0%	0%
ERC_WEST	0	1,748	418	NA	100%	100%	0%	0%
FRCC	9,139	14,190	1,483	NA	100%	100%	0%	0%
MIS_AMSO	301	572	768	NA	100%	100%	0%	0%
MIS_AR	482	727	1,870	NA	100%	100%	21%	0%
MIS_IA	419	789	270	NA	100%	100%	0%	0%
MIS_IL	1,775	2,130	87	NA	100%	100%	0%	0%
MIS_INKY	1,449	3,190	193	NA	100%	100%	0%	0%
MIS_LA	698	721	1,601	NA	100%	100%	0%	0%
MIS_LMI	2,778	3,188	2,755	NA	100%	100%	0%	0%
MIS_MAPP	229	337	102	NA	100%	100%	0%	0%
MIS_MIDA	961	562	513	NA	100%	100%	0%	0%
MIS_MNWI	3,544	3,107	378	NA	100%	100%	0%	0%
MIS_MO	658	1,860	254	NA	100%	100%	0%	0%
MIS_MS	494	638	781	NA	100%	100%	0%	0%
MIS_WOTA	383	443	815	NA	100%	100%	0%	0%
MIS_WUMS	1,331	1,546	1,532	NA	100%	100%	0%	0%
NENG_CT	1,661	1,595	1,557	NA	100%	100%	0%	0%
NENG_ME	330	568	145	NA	100%	100%	0%	0%
NENGREST	4,475	2,826	512	NA	100%	100%	0%	0%
NY_Z_A	711	655	52	NA	100%	100%	0%	0%
NY_Z_B	798	308	188	NA	100%	100%	0%	0%
NY_Z_C&E	1,197	1,295	0	NA	100%	100%	0%	0%
NY_Z_D	37	116	28	NA	100%	100%	0%	0%
NY_Z_F	723	425	178	NA	100%	100%	0%	0%
NY_Z_G-I	393	624	817	NA	100%	100%	0%	0%
NY_Z_J	72	2,503	1,229	NA	100%	100%	0%	0%
NY_Z_K	907	750	211	NA	100%	100%	0%	0%
PJM_AP	735	1,013	438	NA	100%	100%	0%	0%
PJM_ATSI	1,729	2,137	1,519	NA	100%	100%	0%	0%
PJM_COMD	2,168	4,290	2,214	NA	100%	100%	0%	0%
PJM_Dom	668	1,086	3,531	NA	100%	100%	37%	0%
PJM_EMAC	5,176	4,780	3,714	NA	100%	100%	0%	0%
PJM_PENE	380	525	214	NA	100%	100%	0%	0%
PJM_SMAC	1,347	2,013	1,038	NA	100%	100%	0%	0%
PJM_West	4,185	746	3,192	NA	100%	100%	0%	0%
PJM_WMAC	738	1,541	229	NA	100%	100%	0%	0%
S_C_KY	513	1,444	609	NA	100%	100%	0%	0%
S_C_TVA	1,646	1,308	3,780	NA	100%	100%	17%	0%
S_D_AECI	623	385	189	NA	100%	100%	0%	0%
S_SOU	5,430	3,196	8,523	NA	100%	100%	9%	0%
S_VACA	5,503	3,259	4,997	NA	100%	100%	0%	0%
SPP_N	870	4,316	783	NA	100%	100%	0%	0%
SPP_NEBR	456	1,569	263	NA	100%	100%	0%	0%
SPP_SPS	100	1,350	465	NA	100%	100%	0%	0%
SPP_WAUE	378	251	180	NA	100%	100%	0%	0%
SPP_WEST	508	5,762	952	NA	100%	100%	0%	0%
WEC_BANC	968	519	152	NA	100%	100%	0%	0%
WEC_CALN	10,263	3,993	5,216	NA	100%	100%	0%	0%
WEC_LADW	2,768	3,126	418	NA	100%	100%	0%	0%
WEC_SDGE	1,052	1,144	198	NA	100%	100%	0%	0%
WECC_AZ	5,784	3,206	1,109	NA	100%	100%	0%	0%
WECC_CO	2,236	3,750	577	NA	100%	100%	0%	0%
WECC_ID	1,224	794	171	NA	100%	100%	0%	0%
WECC_IID	0	593	0	NA	100%	100%	0%	0%
WECC_MT	324	251	279	NA	100%	100%	0%	0%

IPM Region	Bound (MW)				Reserve Margin Contribution (%)			
	Step 1	Step 2	Step 3	Step 4	Step 1	Step 2	Step 3	Step 4
WECC_NM	1,301	1,553	1,106	NA	100%	100%	0%	0%
WECC_NNV	706	1,056	269	NA	100%	100%	0%	0%
WECC_PNW	3,393	4,613	1,411	NA	100%	100%	0%	0%
WECC_SCE	7,759	5,768	2,725	NA	100%	100%	0%	0%
WECC_SNV	119	1,416	2,022	NA	100%	100%	0%	0%
WECC_UT	2,145	847	517	NA	100%	100%	0%	0%
WECC_WY	1,186	367	189	NA	100%	100%	0%	0%
CN_AB	964	964	1,151	NA	100%	100%	0%	0%
CN_BC	952	1,073	2,040	NA	100%	100%	11%	0%
CN_MB	341	218	494	NA	100%	100%	7%	0%
CN_NB	182	90	145	NA	100%	100%	0%	0%
CN_NF	81	88	96	NA	100%	100%	0%	0%
CN_NL	184	137	173	NA	100%	100%	0%	0%
CN_NS	227	339	36	NA	100%	100%	0%	0%
CN_ON	1,266	4,558	2,880	NA	100%	100%	0%	0%
CN_PE	58	71	21	NA	100%	100%	0%	0%
CN_PQ	5,687	776	2,585	NA	100%	100%	0%	0%
CN_SK	224	178	238	NA	100%	100%	0%	0%

Multiple U.S. states have instituted standalone targets and mandates for energy storage procurement. Table 4-33 summarizes the state-specific energy storage mandates in EPA 2023 Reference Case. Under Assembly Bill No. 2514 and Assembly Bill No. 2868, the California Public Utilities Commission (CPUC) established energy storage targets for the state's three investor-owned utilities (IOUs), namely, Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas & Electric. The California state mandates are therefore modeled at the utility level.

4.5 Inflation Reduction Act Impacts on New Units

The tax credits for new renewable technology investments provided under the Inflation Reduction Act of 2022 are implemented in EPA 2023 Reference Case as a reduction to capital costs. A production tax credit (PTC) of 1.5 cents/kWh in 1992 dollars or an investment tax credit (ITC) of 30 percent are applied to renewable technologies, The 1.5 cents PTC and 30 percent ITC is the rate for units that meet the wage and apprenticeship requirements. While a 10% energy community tax credit is provided to all new energy storage technologies, the 10% energy community tax credit is prorated based on the share of the total IPM regional land area that qualifies as an energy community for solar and wind units. Table 4-32 summarizes the PTC/ITC Energy Community Tax Credit increment allocated to each IPM region.

The tax credits are applied to investments made in the run years during the 2028-2055 period when the power sector CO_2 emissions do not reduce by 75% below the 2022 level of 1,539 million metric tonnes.

Table 4-32 Energy Community Tax Credit Increment for Solar and Wind Units

IPM Region	PTC/ITC increment (%)	IPM Region	PTC/ITC increment (%)
ERC_PHDL	10	PJM_Dom	2.5
ERC_REST	5	PJM_EMAC	2.5
ERC_WEST	10	PJM_PENE	10
FRCC	2.5	PJM_SMAC	2.5
MIS_AMSO	7.5	PJM_West	5
MIS_AR	0	PJM_WMAC	7.5
MIS_D_MS	0	S_C_KY	5
MIS_IA	2.5	S_C_TVA	2.5
MIS_IL	7.5	S_D_AECI	2.5
MIS_INKY	5	S_SOU	2.5
MIS_LA	5	S_VACA	2.5
MIS_LMI	2.5	SPP_N	2.5
MIS_MAPP	2.5	SPP_NEBR	0
MIS_MIDA	2.5	SPP_SPS	10
MIS_MNWI	2.5	SPP_WAUE	2.5
MIS_MO	2.5	SPP_WEST	2.5
MIS_WOTA	7.5	WEC_BANC	0
MIS_WUMS	2.5	WEC_CALN	0
NENG_CT	0	WEC_LADW	0
NENG_ME	0	WEC_SDGE	0
NENGREST	0	WECC_AZ	5
NY_Z_A	2.5	WECC_CO	7.5
NY_Z_B	2.5	WECC_ID	0
NY_Z_C&E	2.5	WECC_IID	0
NY_Z_D	0	WECC_MT	2.5
NY_Z_F	0	WECC_NM	7.5
NY_Z_G-I	0	WECC_NNV	2.5
NY_Z_J	0	WECC_PNW	2.5
NY_Z_K	2.5	WECC_SCE	5
PJM_AP	7.5	WECC_SNV	7.5
PJM_ATSI	5	WECC_UT	5
PJM_COMD	2.5	WECC_WY	5

Table 4-33 Energy Storage Mandates in the EPA 2023 Reference Case

State/Region	Bill	Mandate Type	Mandate Specifications	Implementation Status
California	Assembly Bill No. 2514	Target in MW	Energy storage target of 1,325 megawatts for Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas & Electric by 2020, with installations required no later than the end of 2024.	2025
			LADWP adopted a resolution setting its 2021 energy storage target at 178 MW.	
Maryland	House Bill 910.	Target in MW	3,000 MW energy storage target for 2033, with interim targets of 750 MW in 2027 and 1500 MW in 2030.	2033
New York	New York State Energy Storage Target	Target in MW	1,500 Megawatts by 2025 and up to 3,000 megawatts by 2030.	2025
New Jersey	Assembly Bill No. 3723	Target in MW	600 megawatts of energy storage by 2021 and 2,000 megawatts of energy storage by 2030.	2021
Oregon	House Bill 2193	Target in MWh per electric company	An electric company shall procure one or more qualifying energy storage systems that have the capacity to store at least five megawatt hours of energy on or before January 1, 2020.	2020
Massachusetts	Chapter 188	Target in MWh	200 Megawatt hour (MWh) energy storage target for electric distribution companies to procure viable and cost-effective energy storage systems to be achieved by January 1, 2020.	2020
	House Bill 4857	Target in MWh	Goal of 1,000 MWh of energy storage by the end of 2025.	2025
Virginia	Virginia Clean Economy Act	Target in MW	Requires, by 2035, American Electric Power and Dominion Energy Virginia to construct or acquire 400 and 2,700 megawatts of energy storage capacity, respectively	2035
Connecticut		Target in MW	300 MW by 2025, 650 MW by 2028, and 1,000 MW by 2031	2025
Minnesota		Target in MW	400 MW by 2030	2030
Nevada	Order No. 44671	Target in MW	1,000 MW by 2030	2030

4.6 Nuclear Units

4.6.1 Existing Nuclear Units

Population, Plant Location, and Unit Configuration: To provide maximum granularity in forecasting the behavior of existing nuclear units, all 91 nuclear units in EPA 2023 Reference Case are represented by separate model plants. All units are listed in Table 4-47. The population characteristics, plant location, and unit configuration data in the NEEDS were obtained primarily from EIA Form 860 and AEO 2023.

Capacity: Nuclear units are baseload power plants with high fixed (capital and fixed O&M) costs and relatively low variable (fuel and variable O&M) costs. Due to their low variable costs, nuclear units are typically projected to dispatch up to their assumed availability (the maximum extent possible). Consequently, a nuclear unit's capacity factor is equivalent to its availability. Thus, EPA 2023 Reference Case uses capacity factor assumptions to define the upper bound on generation from nuclear units. Nuclear capacity factor assumptions in EPA 2023 Reference Case are based on an Annual Energy Outlook projection algorithm. The nuclear capacity factor projection algorithm is described below:

- For each reactor, the capacity factor over time depends on the reactor's age.
- Capacity factors increase initially due to learning and decrease in the later years due to aging.
- For individual reactors, vintage classifications (older and newer) are used.
- For the older vintage (starting before 1982) nuclear power plants, the performance peaks at 25 years:
  - Before 25 years: Performance increases by 0.5 percentage points per year;
  - 25- years: Performance remains flat; and
- For the newer vintage (starting in or after 1982) nuclear power plants, the performance peaks at 30 years:
  - Before 30 years: Performance increases by 0.7 percentage points per year;
  - 30- years: Performance remains flat; and
- A maximum capacity factor of 90 percent is assumed unless a capacity factor above 90 percent was observed for the unit.

Cost and Performance: Unlike non-nuclear existing conventional units discussed in Section 4.2.7, emission rates are not needed for nuclear units since there are no SO_2, NO_x, CO_2, or mercury emissions from nuclear units.

As with other generating resources, EPA 2023 Reference Case uses heat rate, variable O&M costs, and fixed O&M costs from AEO 2023 to characterize the cost of operating existing nuclear units. The data are shown in Table 4-47.

As nuclear units have aged, some units have been retired from service or are planning to retire over the modeled time horizon. For a list of operational nuclear units, see the NEEDS database In EPA 2023 Reference Case.

Zero Emission Credit (ZEC) Programs: New York and Illinois passed legislation in 2017 to provide support to selected existing nuclear units that could be at risk of early closure due to declining profitability.

The New York Clean Energy Standard for a 12-year period creates ZECs that are currently applicable for Fitzpatrick, Ginna, and Nine Mile Point nuclear power plants. The New York load-serving entities (LSEs) are responsible for purchasing ZECs equal to their share of the statewide load, providing an additional revenue stream to the nuclear power plants holding the ZECs. Similar to the New York program, the

Illinois Future Energy Jobs Bill creates a ZEC program covering a 10-year term for Clinton and Quad Cities nuclear power plants.

EPA 2023 Reference Case implicitly models the effect of ZECs by disabling the retirement options for Fitzpatrick, Ginna, Nine Mile Point nuclear power plants in the 2028 run years.

New Jersey has established a ZEC program. As a result, Salem Harbor 1 & 2 and Hope Creek nuclear units are eligible to receive payments during the year of implementation plus the three following years and may be considered for additional three-year renewal periods thereafter.

Ohio passed House Bill 6 which includes a provision to collect $150 million per year through 2027 into a Nuclear Generation Fund to be distributed to qualifying nuclear-generating units located in Ohio at a rate of $9 per MWh credit. Due to the ongoing uncertainty of this provision, the EPA 2023 Reference Case does not model the impact of this provision on the Perry and Davis Besse nuclear plants.

<u>Nuclear Retirement Limits:</u> In EPA 2023 Reference Case, endogenous retirements of nuclear units are not allowed. Nuclear units are retired per a predetermined retirement schedule. Single-unit plants owned by regulated and nonregulated entities and multiple-unit plants owned by nonregulated entities are assumed to have a lifetime of 60 years. In addition, multiple-unit plants owned by regulated entities are assumed to have a lifetime of 80 years.

<u>Life-Extension Costs:</u> EPA 2023 Reference Case imposes lifetime extension costs for nuclear units. Attachment 4-1 summarizes the approach to estimating unit-level life extension costs for existing nuclear units. Unlike other plant types, life-extension costs for nuclear units are calculated as a function of age and are applied starting in the 2028 run year. The life-extension costs are calculated as 17 + 1.25 multiplied by the age of the unit before 50 years of age. After the age of 50 years, the life-extension costs are assumed to be 70 $/kW-yr.

To reflect the improvements made through the life extension investments, the FOM costs are reduced by 25 $/kW-yr starting age of 51 years.

4.6.2 Potential Nuclear Units

The cost and performance assumptions for nuclear potential units that the model has the option to build are shown in Table 4-12. The cost assumptions are from AEO 2023.

<u>List of tables that are uploaded directly to the web:</u>

Table 4-34 Planned-Committed Units by Model Region in NEEDS for EPA 2023 Reference Case

Table 4-35 Onshore Average Capacity Factor by Wind Class, Resource Class, and Vintage in EPA 2023 Reference Case

Table 4-36 Onshore Regional Potential Wind Capacity (MW) by Wind Class, Resource Class, and Cost Class in EPA 2023 Reference Case

Table 4-37 Wind Generation Profiles in EPA 2023 Reference Case (kWh of Generation per MW of Capacity)

Table 4-38 Capital Cost Adder (2022$/kW) for New Onshore Wind Plants by Resource and Cost Class in EPA 2023 Reference Case

Table 4-39 Solar Photovoltaic Regional Potential Capacity (MW) by Resource and Cost Class in EPA 2023 Reference Case

5. Emission Control Technologies

This chapter describes the emission control technology assumptions implemented in the EPA 2023 Reference Case. EPA uses retrofit emission control cost models developed for EPA by the engineering firm Sargent & Lundy. EPA 2023 Reference Case includes assumptions regarding control options for sulfur dioxide (SO_2), nitrogen oxides (NO_x), mercury (Hg), carbon dioxide (CO_2), and hydrogen chloride (HCl). The options are listed in Table 5-1. They are available in EPA 2023 Reference Case for meeting existing and potential federal, regional, and state emission limits. Besides the options shown in Table 5-1 and described in this chapter, EPA 2023 Reference Case offers other compliance options for meeting emission limits. These include switching fuel, adjusting the level of dispatch, and retiring.

Table 5-1 Retrofit Emission Control Options in the EPA 2023 Reference Case

SO_2 Control Technology Options	NO_x Control Technology Options	Mercury Control Technology Options	CO_2 Control Technology Options	HCl Control Technology Options
Limestone Forced Oxidation (LSFO) Scrubber	Selective Catalytic Reduction (SCR) System	Activated Carbon Injection (ACI) System	CO_2 Capture and Sequestration	Limestone Forced Oxidation (LSFO) Scrubber
Lime Spray Dryer (LSD) Scrubber	Selective Non-Catalytic Reduction (SNCR) System	SO_2 and NO_x Control Technology Removal Co-benefits	Coal-to-Gas	Lime Spray Dryer (LSD) Scrubber
Dry Sorbent Injection (DSI)			Natural Gas Co-firing	Dry Sorbent Injection (DSI)

Attachments 5-1 through 5-11 contain detailed reports and example calculation worksheets for the Sargent & Lundy retrofit emission control cost models used by the EPA.

5.1 Sulfur Dioxide Control Technologies - Scrubbers

Two commercially available Flue Gas Desulfurization (FGD) scrubber technology options for removing the SO_2 produced by coal-fired power plants are offered in EPA 2023 Reference Case: Limestone Forced Oxidation (LSFO) — a wet FGD technology and Lime Spray Dryer (LSD) — a semi-dry FGD technology which employs a spray dryer absorber (SDA). In wet FGD systems, the polluted gas stream is brought into contact with a liquid alkaline sorbent (typically limestone) by forcing it through a pool of the liquid slurry or by spraying it with the liquid. In dry FGD systems, the polluted gas stream is brought into contact with the alkaline sorbent in a semi-dry state through the use of a spray dryer. The removal efficiency for SDA drops steadily for coals whose SO_2 content exceeds 3 lbs SO_2/MMBtu, the technology is therefore provided to only plants which have the option to burn coals with sulfur content no greater than 3 lbs SO_2/MMBtu. Hence, when a unit retrofits with an LSD SO_2 scrubber, it loses the option of burning certain high sulfur content coals (see Table 5-2).

The LSFO and LSD SO_2 emission control technologies are available to existing unscrubbed units. They are also available to existing scrubbed units with reported removal efficiencies of less than 50%. Such units are considered to have an injection technology and are classified as unscrubbed for modeling purposes in the NEEDS database. The scrubber retrofit costs for these units are the same as those for regular unscrubbed units retrofitting with a scrubber.

Default SO_2 removal rates for wet and dry FGD were based on data reported in EIA 860 (2018). These default removal rates were the average of all SO_2 removal rates for a dry or wet FGD as reported in EIA 860 (2018) for the FGD installation year.

The following adjustment is made to reduce the incidence of implausibly high outlier removal rates. Units for which reported EIA Form 860 (2018) SO_2 removal rates are higher than the average of the upper quartile of SO_2 removal rates across all scrubbed units are assigned the upper quartile average. The adjustment is not made, however, if a unit's reported removal rate was recently confirmed by utility comments. Furthermore, one upper quartile removal rate is calculated across all installation years and replaces any reported removal rate that exceeds it, no matter the installation year.

Existing units not reporting FGD removal rates in EIA Form 860 (2018) are assigned the default SO_2 removal rate for a dry or wet FGD for that installation year.

As shown in Table 5-2, for FGD retrofits installed by the model, the assumed SO_2 removal rates will be 98% for wet FGD and 95% for dry FGD.

The procedures used to derive the cost of each scrubber type are discussed in detail in the following sections.

Table 5-2 Retrofit SO_2 Emission Control Performance Assumptions in the EPA 2023 Reference Case

Performance Assumptions	Limestone Forced Oxidation (LSFO)	Lime Spray Dryer (LSD)
Percent Removal*	98% with a floor of 0.06 lbs/MMBtu	95% with a floor of 0.08 lbs/MMBtu
Capacity Penalty	Calculated based on characteristics of the unit: See Table 5-3	Calculated based on characteristics of the unit: See Table 5-3
Heat Rate Penalty		
Cost (2022$)		
Applicability	Units ≥ 25 MW	Units ≥ 25 MW
Sulfur Content Applicability		Coals ≤ 3 lbs SO_2/MMBtu
Applicable Coal Types	BA, BB, BD, BE, BG, BH, SA, SB, SD, SE, LD, LE, LG, LH, PK, and WC	BA, BB, BD, BE, SA, SB, SD, SE, LD, and LE

* If the SO_2 permit rate of the unit is lower than the floor rate, the SO_2 permit rate is used as the floor rate.

Potential (new) coal-fired units built by IPM are also assumed to be constructed with a wet scrubber achieving a removal efficiency of 98%. Further, the costs of potential new coal units include the cost of scrubbers.

5.1.1 Methodology for Obtaining SO_2 Controls Costs

Sargent & Lundy's performance/cost models for wet and dry SO_2 scrubbers are implemented in EPA 2023 Reference Case to develop the capital, fixed O&M (FOM), and variable O&M (VOM) components of cost. For details of Sargent & Lundy Wet FGD and SDA FGD cost models, see Attachment 5-1 and Attachment 5-2.

Capacity and Heat Rate Penalties: In IPM the amount of electrical power required to operate a retrofit emission control device is represented through a reduction in the amount of electricity available for sale to the grid. For example, if 1.6% of a unit's electrical generation is needed to operate a scrubber, the unit's capacity is reduced by 1.6%. The reduction in the unit's capacity is called the capacity penalty. At the same time, to capture the total fuel used in generation both for sale to the grid and for internal load (i.e., for operating the control device), the unit's heat rate is scaled up such that a comparable reduction (1.6% in the example) in the new higher heat rate yields the original heat rate.[46] The factor used to scale up the original heat rate is called the heat rate penalty. It is a modeling procedure only and does not represent an increase in the unit's actual heat rate (i.e., a decrease in the unit's generation efficiency).[47] In EPA

[46] Mathematically, the relationship of the heat rate and capacity penalties (both expressed as positive percentage values) can be represented as follows:

$$\text{Heat Rate Penalty} = \left(\frac{1}{\left(1 - \frac{\text{Capacity Penalty}}{100}\right)} - 1 \right) \times 100$$

[47] The NEEDS heat rate is an unmodified, original heat rate to which this retrofit-based heat rate penalty procedure is applied. The procedure is limited to units at which IPM adds a retrofit in the model.

2023 Reference Case, specific LSFO and LSD heat rate and capacity penalties are calculated for each installation based on equations from the Sargent & Lundy models that consider the rank of coal burned, its uncontrolled SO_2 rate, and the heat rate of the model plant.

Table 5-3 presents the LSFO and LSD capital, fixed O&M, and variable O&M costs, as well as capacity and heat rate penalties for representative capacities and heat rates.

5.1.2 SO_2 Controls for Units with Capacities from 25 MW to 100 MW (25 MW ≤ capacity < 100 MW)

In EPA 2023 Reference Case, coal units with capacities between 25 MW and 100 MW are offered the same SO_2 control options as larger units. However, for modeling purposes, the costs of controls for these units are assumed to be equivalent to that of 50 MW for Dry FGD and 100 MW for Wet FGD. These assumptions are based on several considerations. First, to achieve economies of scale, several units within this size range are likely to be ducted to share a single common control, so the minimum capacity cost equivalency assumption, though generic, would be technically plausible. Second, single units within this size range that are not grouped to achieve economies of scale are likely to switch to a lower sulfur coal, repower or convert to natural gas firing, use dry sorbent injection, and/or reduce operating hours.

Illustrative scrubber costs for 25-100 MW coal units with a range of heat rates can be found by referring to the LSFO 100 MW and LSD 100MW “Capital Costs ($/kW)” and “Fixed O&M” columns in Table 5-3. The Variable O&M cost component, which applies to units regardless of size, can be found in the fifth column in this table.

Table 5-3 Illustrative Scrubber Costs (2022$) for Representative Capacities and Heat Rates in the EPA 2023 Reference Case

Scrubber Type	Heat Rate (Btu/kWh)	Capacity Penalty (%)	Heat Rate Penalty (%)	Variable O&M (mills/kWh)	Capacity (MW)									
					100		300		500		700		1000	
					Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)
LSFO Minimum Cutoff: ≥ 100 MW	9,000	-1.60	1.63	2.66	1075	29.7	781	14.2	673	10.6	610	9.8	550	8.1
Maximum Cutoff: None	10,000	-1.78	1.82	2.94	1,125	30.3	817	14.6	705	10.9	639	10.1	576	8.3
Assuming 3 lb/MMBtu SO_2 Content Bituminous Coal	11,000	-1.96	2.00	3.22	1,173	30.8	852	14.9	735	11.2	667	10.3	601	8.6
LSD Minimum Cutoff: ≥ 100 MW	9,000	-1.18	1.20	3.16	908	21.7	664	10.9	575	8.3	516	7.0	516	6.5
Maximum Cutoff: None	10,000	-1.32	1.33	3.52	950	22.1	696	11.2	602	8.6	540	7.3	540	6.7
Assuming 2 lb/MMBtu SO_2 Content Bituminous Coal	11,000	-1.45	1.47	3.88	991	22.6	726	11.5	628	8.9	563	7.5	563	6.9

Note 1: The above cost estimates assume a boiler burning 3 lb/MMBtu SO_2 Content Bituminous Coal for LSFO and 2 lb/MMBtu SO_2 Content Bituminous Coal for LSD.

Note 2: The Variable O&M costs in this table do not include the cost of additional auxiliary power (VOMP) component in the Sargent & Lundy cost models. For modeling purposes, IPM reflects the auxiliary power consumption through capacity penalty.

5.2 Nitrogen Oxides Control Technology

There are two main categories of NO_x reduction technologies: combustion and post-combustion controls. Combustion controls reduce NO_x emissions during the combustion process by regulating flame characteristics such as temperature and fuel-air mixing. Post-combustion controls operate downstream of the combustion process and remove NO_x emissions from the flue gas. All the technologies included in EPA 2023 Reference Case are commercially available and currently in use in numerous power plants.

5.2.1 Combustion Controls

EPA 2023 Reference Case does not model combustion control upgrades as a retrofit option. The decision was based on two considerations: the relatively low cost of combustion controls compared with that of post-combustion NO_x controls and the possible impact on model size. EPA identified units in NEEDS that have not employed state-of-the-art combustion controls. EPA then estimated the NO_x rates for such units based on an analysis of historical rates of units with state-of-the-art NO_x combustion controls. Emission rates provided by state-of-the-art combustion controls are presented in Attachment 3-2.

5.2.2 Post-combustion NO_x Controls

EPA 2023 Reference Case provides two post-combustion retrofit NO_x control technologies for existing coal units: Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR). Oil/gas steam units, on the other hand, are provided with only SCR retrofits. NO_x reduction in a SCR system takes place by injecting ammonia (NH_3) vapor into the flue gas stream, where the NO_x is reduced to nitrogen (N_2) and water (H_2O) abetted by passing over a catalyst bed typically containing titanium, vanadium oxides, molybdenum, and/or tungsten. As its name implies, SNCR operates without a catalyst. In an SNCR system, a nitrogenous reducing agent (reagent), typically urea or ammonia, is injected into and mixed with hot flue gas, where it reacts with the NO_x in the gas stream, reducing it to nitrogen gas and water vapor. Due to the presence of a catalyst, SCR can achieve greater NO_x reductions than SNCR. However, SCR costs are higher than SNCR costs.

Table 5-4 summarizes the performance and applicability assumptions for each post-combustion NO_x control technology and provides a cross-reference to information on cost assumptions.

Table 5-4 Retrofit NO_x Emission Control Performance Assumptions in the EPA 2023 Reference Case

Control Performance Assumptions	Selective Catalytic Reduction (SCR)		Selective Non-Catalytic Reduction (SNCR)
Unit Type	Coal	Oil/Gas	Coal
Output Rate	0.05 lb/MMBtu	0.03 lb/MMBtu	--
Percent Removal	--	--	Pulverized Coal: 25% (25-200 MW), 20% (200-400 MW), 15% (>400 MW) Fluidized Bed: 50%
Rate Floor	--	--	Pulverized Coal: 0.1 lb/MMBtu Fluidized Bed: 0.08 lb/MMBtu
Size Applicability	Units ≥ 25 MW	Units ≥ 25 MW	Units ≥ 25 MW
Costs (2022$)	See Table 5-5	See Table 5-6	See Table 5-5

5.2.3 Methodology for Obtaining SCR and SNCR Costs for Coal Steam Units

Sargent & Lundy SCR and SNCR cost models are implemented to develop the capital, fixed O&M, and variable O&M costs. For details of Sargent & Lundy SCR and SNCR cost models, see Attachment 5-3, Attachment 5-4, Attachment 5-5, and Attachment 5-6.

In the Sargent & Lundy's cost models for SNCR, the NO_x removal efficiency varies by unit size and burner type as summarized in Table 5-4. Additionally, the capital, fixed, and variable operating and maintenance costs of SNCR on circulating fluidized bed (CFB) units are distinguished from the corresponding costs for other boiler types (e.g., cyclone and wall fired). -An air heater modification cost applies for plants that burn bituminous coal whose SO_2 content is 3 lbs/MMBtu or greater.

Table 5-5 presents the SCR and SNCR capital, fixed O&M, and variable O&M costs as well as capacity and heat rate penalties for coal steam units of representative capacities and heat rates.

Table 5-5 Illustrative Post Combustion NOx Control Costs (2022$) for Coal Plants for Representative Sizes and Heat Rates under the Assumptions in the EPA 2023 Reference Case

Control Type	Heat Rate (Btu/kWh)	Capacity Penalty (%)	Heat Rate Penalty (%)	Variable O&M (mills/kWh)	Capacity (MW)									
					100		300		500		700		1000	
					Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)
SCR Minimum Cutoff: ≥ 100 MW Maximum Cutoff: None Assuming Bituminous Coal	9,000	-0.54	0.54	1.51	482	2.38	394	1.06	365	0.90	349	0.83	333	0.77
NO_x rate: 0.5 lb/MMBtu	10,000	-0.56	0.56	1.63	524	2.52	431	1.13	400	0.98	382	0.90	366	0.84
SO_2 rate: 2.0 lb/MMBtu	11,000	-0.58	0.59	1.75	565	2.67	467	1.21	434	1.05	415	0.97	398	0.90
SNCR - Tangential, 25% Removal Efficiency Minimum Cutoff: ≥ 25 MW Maximum Cutoff: 200 MW Assuming Bituminous Coal	9,000	-0.05	0.05	1.25	77	0.69	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NO_x rate: 0.5 lb/MMBtu	10,000			1.38	79	0.70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SO_2 rate: 2.0 lb/MMBtu	11,000			1.53	81	0.72	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SNCR - Tangential, 20% Removal Efficiency Minimum Cutoff: ≥ 200 MW Maximum Cutoff: 400 MW Assuming Bituminous Coal	9,000	-0.05	0.05	1.00	N/A	N/A	41	0.36	N/A	N/A	N/A	N/A	N/A	N/A
NO_x rate: 0.5 lb/MMBtu	10,000			1.10	N/A	N/A	42	0.37	N/A	N/A	N/A	N/A	N/A	N/A
SO_2 rate: 2.0 lb/MMBtu	11,000			1.21	N/A	N/A	43	0.38	N/A	N/A	N/A	N/A	N/A	N/A
SNCR - Tangential, 15% Removal Efficiency Minimum Cutoff: ≥ 400 MW Maximum Cutoff: None Assuming Bituminous Coal	9,000	-0.05	0.05	0.75	N/A	N/A	N/A	N/A	30	0.27	25	0.22	20	0.18
NO_x rate: 0.5 lb/MMBtu	10,000			0.83	N/A	N/A	N/A	N/A	31	0.27	25	0.23	21	0.19
SO_2 rate: 2.0 lb/MMBtu	11,000			0.91	N/A	N/A	N/A	N/A	31	0.28	26	0.23	21	0.19
SNCR - Fluidized Bed Minimum Cutoff: ≥ 25 MW Maximum Cutoff: None Assuming Bituminous Coal	9,000	-0.05	0.05	1.25	58	0.51	31	0.28	24	0.21	19	0.17	16	0.14
NO_x rate: 0.5 lb/MMBtu	10,000			1.38	59	0.53	32	0.28	24	0.21	20	0.18	16	0.15
SO_2 rate: 2.0 lb/MMBtu	11,000			1.53	60	0.54	33	0.29	25	0.22	20	0.18	17	0.15

Note 1: Assumes Bituminous Coal, NO_x rate: 0.5 lb/MMBtu, and SO_2 rate: 2.0 lb/MMBtu.

Note 2: The Variable O&M costs in this table do not include the cost of additional auxiliary power (VOMP) component in the Sargent & Lundy cost models. For modeling purposes, IPM reflects the auxiliary power consumption through capacity penalty.

Note 3: Heat rate penalty includes the effect of capacity penalty.

5.2.4 Methodology for Obtaining SCR Costs for Oil/Gas Steam Units

The cost calculations for SCR described in section 5.2.3 apply to coal units. Table 5-6 presents the SCR capital, fixed O&M, and variable O&M costs as well as capacity and heat rate penalties for oil/gas steam units of representative capacities and heat rates.

Table 5-6 Post-Combustion NOx Controls Costs (2022$) for Oil/Gas Steam for Representative Sizes and Heat Rates under the Assumptions in the EPA 2023 Reference Case

Control Type	Heat Rate (Btu/kWh)	Capacity Penalty (%)	Heat Rate Penalty (%)	Variable O&M (mills/kWh)	Capacity (MW)									
					100		300		500		700		1000	
					Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)
SCR Minimum Cutoff: ≥ 100 MW Maximum Cutoff: None Assuming Natural Gas	9,000	-0.27	0.27	1.15	208	1.42	156	0.56	140	0.43	132	0.38	124	0.33
NO_x rate: 0.5 lb/MMBtu	10,000	-0.28	0.28	1.27	224	1.47	169	0.59	153	0.46	144	0.40	136	0.35
SO_2 rate: 2.0 lb/MMBtu	11,000	-0.29	0.29	1.39	240	1.53	183	0.61	165	0.48	156	0.43	147	0.38

Notes:

The SCR retrofit option in the table above is provided to only coal steam units that have retrofitted with a Coal-to-Gas option.

5.3 Biomass Co-firing

Biomass co-firing is provided as an option for those coal-fired units in EPA 2023 Reference Case that per EIA Form 923 had co-fired biomass during the 2018-2022 period. Table 5-7 lists the units provided with the co-firing option and the limit on the share of the biomass co-firing. The remaining coal power plants are not provided with this choice as logistics and boiler engineering considerations place limits on the extent of biomass that can be fired. The logistical considerations arise primarily because biomass is only economic to transport a limited distance from where it is grown due to its relatively low energy density. In addition, the extent of storage that can be devoted at a power plant to such a fuel is another limiting factor. Boiler efficiency and other engineering considerations, largely driven by the relatively higher moisture content and lower heat content of biomass compared to fossil fuel, also plays a role in limiting the potential adoption of co-firing.

Table 5-7 Coal Units with Biomass Co-firing Option in the EPA 2023 Reference Case

Plant Name	Unit ID	Biomass Co-Firing Share Limit (%)[48]
Virginia City Hybrid Energy Center	1	16.26%
Northampton Generating Company LP	BLR1	0.61%
Pixelle Specialty Solutions LLC - Spring Grove Facility	5PB036	32.94%
Manitowoc	9	16.55%
Schiller	4	0.25%
Schiller	6	0.19%

5.4 Mercury Control Technologies

For any power plant, mercury emissions depend on the mercury content of the fuel used, the combustion and physical characteristics of the unit, and the emission control technologies deployed. In the absence of activated carbon injection (ACI), mercury emission reductions below the mercury content of the fuel are strictly due to characteristics of the combustion process and incidental removal resulting from other pollution control technologies, e.g., the SO_2, NO_x, and particulate matter controls. The following discussion is divided into three parts. Sections 5.4.1 and 5.4.2 explain the two factors that determine mercury emissions that result from unit configurations lacking ACI. Section 5.4.1 discusses how the mercury content of a fuel is modeled. Section 5.4.2 looks at the procedure to capture the mercury reductions resulting from different unit and (non-mercury) control configurations. Section 5.4.3 explains the mercury emission control options that are available. Each section indicates the data sources and methodology used.

5.4.1 Mercury Content of Fuels

Coal

Assumptions pertaining to the mercury content of coal (and the majority of emission modification factors discussed below in Section 5.4.2) are derived from EPA's "Information Collection Request for Electric Utility Steam Generating Unit Mercury Emissions Information Collection Effort" (ICR).[49] A two-year effort initiated in 1998 and completed in 2000, the ICR had three main components: (1) identifying all coal-fired units owned and operated by publicly-owned utility companies, federal power agencies, rural electric cooperatives, and investor-owned utility generating companies, (2) obtaining "accurate information on the

[48] In EPA 2023 Reference Case, the limit on biomass co-firing is expressed as the percentage of the facility (ORIS code) level fuel input that is produced from biomass.

[49] Data from the ICR can be found at http://www.epa.gov/ttn/atw/combust/utiltox/mercury.html. In 2009, EPA collected some additional information regarding mercury through the Collection Effort for New and Existing Coal- and Oil-Fired Electricity Utility Steam Generating Units (EPA ICR No.2362.01 (OMB Control Number 2060-0631), however the information collected was not similarly comprehensive and was thus not used to update mercury assumptions in EPA 2023 Reference Case.

amount of mercury contained in the as-fired coal used by each electric utility steam generating unit with a capacity greater than 25 megawatts electric [MWe]), as well as accurate information on the total amount of coal burned by each such unit," and (3) obtaining data by coal sampling and stack testing at selected units to characterize mercury reductions from representative unit configurations.

The ICR resulted in more than 40,000 data points indicating the coal type, sulfur content, mercury content, and other characteristics of coal burned at coal-fired utility units greater than 25 MW. To make this data usable, these data points were first grouped by IPM coal types and IPM coal supply regions. IPM coal types divide bituminous, subbituminous, and lignite coal into different grades based on sulfur content.

<u>Oil, natural gas, and waste fuels</u>

Assumptions pertaining to the mercury content for oil, gas, and waste fuels are based on data derived from previous EPA analyses of mercury emissions from power plants.[50] Table 5-8 provides a summary of the assumptions on the mercury content for oil, gas, and waste fuels.

Table 5-8 Mercury Concentration Assumptions for Non-Coal Fuels in the EPA 2023 Reference Case

Fuel Type	Mercury Concentration (lbs/TBtu)
Oil	0.48
Natural Gas	0.00 [a]
Petroleum Coke	2.66
Biomass	0.57
Municipal Solid Waste	71.85
Geothermal Resource	2.97 - 3.7

Note:

[a] The values appearing in this table are rounded to two decimal places. The zero-value shown for natural gas is based on an EPA study that found a mercury content of 0.000138 lbs/TBtu. Values for geothermal resources represent a range.

5.4.2 Mercury Emission Modification Factors

Emission Modification Factors (EMFs) represent the mercury reductions attributable to the specific burner type and configuration of SO_2, NO_x, and particulate matter control devices at an electric generating unit. An EMF is the ratio of outlet mercury concentration to inlet mercury concentration, and depends on the unit's burner type, particulate control device, post-combustion NO_x control and SO_2 scrubber control. In other words, the mercury reduction achieved (relative to the inlet) during combustion and flue-gas treatment process is (1-EMF), such that the lower the EMF, the greater the mercury reduction. If the EMF is 0.25, then 25% of the inlet mercury concentration is emitted as outlet mercury concentration, and therefore the unit has achieved a 75% reduction in mercury that would otherwise be emitted without the properties influencing the EMF. The EMF varies by the type of coal (i.e., bituminous, subbituminous, and lignite) used during the combustion process.

Deriving EMFs involves obtaining mercury inlet data by coal sampling and mercury emission data by stack testing at a representative set of coal units. As noted, EPA's EMFs were initially based on 1999 mercury ICR emission test data. More recent testing conducted by the EPA, DOE, and industry participants[51] has provided a better understanding of mercury emissions from electric generating units and mercury capture in pollution control devices. Overall, the 1999 ICR data revealed higher levels of mercury capture for bituminous coal-fired plants than for subbituminous and lignite coal-fired plants, and

[50] Analysis of Emission Reduction Options for the Electric Power Industry, Office of Air and Radiation, U.S. EPA, March 1999.

[51] For a detailed summary of emissions test data see Control of Emissions from Coal-Fired Electric Utility Boilers: An Update, EPA/Office of Research and Development, February 2005. The report can be found at https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=219113.

significant capture of ionic Hg in wet-FGD scrubbers. Additional mercury testing indicates that for bituminous coals, SCR systems can convert elemental Hg into ionic Hg and thus allow easier capture in a downstream wet-FGD scrubber. This understanding of mercury capture with SCRs is incorporated in EPA 2023 Reference Case mercury EMFs for unit configurations with SCR and wet scrubbers.

Table 5-9 provides a summary of EMFs used in EPA 2023 Reference Case. Table 5-10 provides definitions of acronyms for existing controls that appear in Table 5-9. Table 5-11 provides a key to the burner type designations appearing in Table 5-9.

Table 5-9 Mercury Emission Modification Factors Used in the EPA 2023 Reference Case

Burner Type	Particulate Control	Post-combustion Control - NO_x	Post-combustion Control - SO_2	Bituminous EMF	Subbituminous EMF*	Lignite EMF
FBC	Cold Side ESP	No SCR	None	0.65	0.1	0.62
FBC	Cold Side ESP	No SCR	Dry FGD	0.64	0.1	1
FBC	Cold Side ESP + FF	No SCR	None	0.05	0.1	0.43
FBC	Cold Side ESP + FF	No SCR	Dry FGD	0.05	0.1	1
FBC	Fabric Filter	No SCR	None	0.05	0.1	0.43
FBC	Fabric Filter	No SCR	Dry FGD	0.05	0.1	0.43
FBC	Hot Side ESP + FGC	No SCR	None	1	0.1	1
FBC	Hot Side ESP + FGC	No SCR	Dry FGD	0.6	0.1	1
FBC	No Control	No SCR	None	1	0.1	1
Non FBC	Cold Side ESP	SCR	None	0.64	0.1	1
Non FBC	Cold Side ESP	SCR	Wet FGD	0.1	0.1	0.56
Non FBC	Cold Side ESP	SCR	Dry FGD	0.64	0.1	1
Non FBC	Cold Side ESP	No SCR	None	0.64	0.1	1
Non FBC	Cold Side ESP	No SCR	Wet FGD	0.05	0.1	0.56
Non FBC	Cold Side ESP	No SCR	Dry FGD	0.64	0.1	1
Non FBC	Cold Side ESP + FF	SCR	None	0.2	0.1	1
Non FBC	Cold Side ESP + FF	SCR	Wet FGD	0.1	0.1	0.56
Non FBC	Cold Side ESP + FF	SCR	Dry FGD	0.05	0.1	1
Non FBC	Cold Side ESP + FF	No SCR	None	0.2	0.1	1
Non FBC	Cold Side ESP + FF	No SCR	Wet FGD	0.05	0.1	0.56
Non FBC	Cold Side ESP + FF	No SCR	Dry FGD	0.05	0.1	1
Non FBC	Cold Side ESP + FGC	SCR	None	0.64	0.1	1
Non FBC	Cold Side ESP + FGC	SCR	Wet FGD	0.1	0.1	0.56
Non FBC	Cold Side ESP + FGC	SCR	Dry FGD	0.64	0.1	1
Non FBC	Cold Side ESP + FGC	No SCR	None	0.64	0.1	1
Non FBC	Cold Side ESP + FGC	No SCR	Wet FGD	0.05	0.1	0.56
Non FBC	Cold Side ESP + FGC	No SCR	Dry FGD	0.64	0.1	1
Non FBC	Cold Side ESP + FGC + FF	SCR	None	0.2	0.1	1
Non FBC	Cold Side ESP + FGC + FF	SCR	Wet FGD	0.1	0.1	0.56
Non FBC	Cold Side ESP + FGC + FF	SCR	Dry FGD	0.05	0.1	1
Non FBC	Cold Side ESP + FGC + FF	No SCR	None	0.2	0.1	1
Non FBC	Cold Side ESP + FGC + FF	No SCR	Wet FGD	0.05	0.1	0.56
Non FBC	Cold Side ESP + FGC + FF	No SCR	Dry FGD	0.05	0.1	1
Non FBC	Fabric Filter	SCR	None	0.11	0.1	1
Non FBC	Fabric Filter	SCR	Wet FGD	0.1	0.1	0.56
Non FBC	Fabric Filter	SCR	Dry FGD	0.05	0.1	1
Non FBC	Fabric Filter	No SCR	None	0.11	0.1	1
Non FBC	Fabric Filter	No SCR	Wet FGD	0.1	0.1	0.56
Non FBC	Fabric Filter	No SCR	Dry FGD	0.05	0.1	1
Non FBC	Hot Side ESP	SCR	None	0.9	0.1	1
Non FBC	Hot Side ESP	SCR	Wet FGD	0.1	0.1	1
Non FBC	Hot Side ESP	SCR	Dry FGD	0.6	0.1	1
Non FBC	Hot Side ESP	No SCR	None	0.9	0.1	1
Non FBC	Hot Side ESP	No SCR	Wet FGD	0.05	0.1	1

Burner Type	Particulate Control	Post-combustion Control - NO_x	Post-combustion Control - SO_2	Bituminous EMF	Subbituminous EMF*	Lignite EMF
Non FBC	Hot Side ESP	No SCR	Dry FGD	0.6	0.1	1
Non FBC	Hot Side ESP + FF	SCR	None	0.11	0.1	1
Non FBC	Hot Side ESP + FF	SCR	Wet FGD	0.1	0.1	0.56
Non FBC	Hot Side ESP + FF	SCR	Dry FGD	0.05	0.1	1
Non FBC	Hot Side ESP + FF	No SCR	None	0.11	0.1	1
Non FBC	Hot Side ESP + FF	No SCR	Wet FGD	0.03	0.1	0.56
Non FBC	Hot Side ESP + FF	No SCR	Dry FGD	0.05	0.1	1
Non FBC	Hot Side ESP + FGC	SCR	None	0.9	0.1	1
Non FBC	Hot Side ESP + FGC	SCR	Wet FGD	0.1	0.1	1
Non FBC	Hot Side ESP + FGC	SCR	Dry FGD	0.6	0.1	1
Non FBC	Hot Side ESP + FGC	No SCR	None	0.9	0.1	1
Non FBC	Hot Side ESP + FGC	No SCR	Wet FGD	0.05	0.1	1
Non FBC	Hot Side ESP + FGC	No SCR	Dry FGD	0.6	0.1	1
Non FBC	Hot Side ESP + FGC + FF	SCR	Dry FGD	0.05	0.1	1
Non FBC	Hot Side ESP + FGC + FF	No SCR	None	0.11	0.1	1
Non FBC	Hot Side ESP + FGC + FF	No SCR	Dry FGD	0.05	0.1	1
Non FBC	No Control	SCR	None	1	0.1	1
Non FBC	No Control	SCR	Wet FGD	0.1	0.1	1
Non FBC	No Control	SCR	Dry FGD	0.6	0.1	1
Non FBC	No Control	No SCR	None	1	0.1	1
Non FBC	No Control	No SCR	Wet FGD	0.58	0.1	1
Non FBC	No Control	No SCR	Dry FGD	0.6	0.1	1
Non FBC	PM Scrubber	SCR	None	0.9	0.1	1
Non FBC	PM Scrubber	SCR	Wet FGD	0.1	0.1	1

Note: 2017 annual emissions data suggests that, with subbituminous coal, many configurations are now achieving at least 90% removal of mercury. This table was updated from previous versions to reflect this recent observation. For 2017 emissions data, see: https://ampd.epa.gov.

Table 5-10 Definition of Acronyms for Existing Controls

Acronym	Description
ESP	Electrostatic Precipitator - Cold Side
HESP	Electrostatic Precipitator - Hot Side
ESP/O	Electrostatic Precipitator - Other
FF	Fabric Filter
FGD	Flue Gas Desulfurization - Wet
DS	Flue Gas Desulfurization - Dry
SCR	Selective Catalytic Reduction
PMSCRUB	Particulate Matter Scrubber

Table 5-11 Key to Burner Type Designations in Table 5-9

"PC" refers to conventional pulverized coal boilers. Typical configurations include wall-fired and tangentially fired boilers (also called T-fired boilers). In wall-fired boilers the burner's coal and air nozzles are mounted on a single wall or opposing walls. In tangentially fired boilers the burner's coal and air nozzles are mounted in each corner of the boiler.
"Cyclone" refers to cyclone boilers where air and crushed coal are injected tangentially into the boiler through a "cyclone burner" and "cyclone barrel" which create a swirling motion allowing smaller coal particles to be burned in suspension and larger coal particles to be captured on the cyclone barrel wall where they are burned in molten slag.
"Stoker" refers to stoker boilers where lump coal is fed continuously onto a moving grate or chain, which moves the coal into the combustion zone in which air is drawn through the grate and ignition takes place. The carbon gradually burns off, leaving ash which drops off at the end into a receptacle, from which it is removed for disposal.
"FBC" refers to "fluidized bed combustion" where solid fuels are suspended on upward-blowing jets of air, resulting in a turbulent mixing of gas and solids and a tumbling action which provides especially effective chemical reactions and heat transfer during the combustion process.
"Other" refers to miscellaneous burner types including cell burners and arch, roof, and vertically-fired burner configurations.

5.4.3 Mercury Control Capabilities

EPA 2023 Reference Case offers two options for mercury pollution control: (1) combinations of SO_2, NO_x, and particulate controls which deliver mercury reductions as a co-benefit; and (2) Activated Carbon Injection (ACI), a retrofit option specifically designed for mercury control. The options are discussed below.

Mercury Control through SO_2 and NO_x Retrofits

Units that install SO_2, NO_x, and particulate controls reduce mercury emissions as a byproduct of these retrofits. Section 5.4.2 described how EMFs are used to capture mercury emissions depending on the rank of coal burned, the generating unit's combustion characteristics, and the specific configuration of SO_2, NO_x, and particulate controls (i.e., hot and cold-side electrostatic precipitators (ESPs), fabric filters (also called "baghouses"), and particulate matter (PM) scrubbers).

Activated Carbon Injection (ACI)

The technology used for mercury control in EPA 2023 Reference Case is Activated Carbon Injection (ACI) downstream of the combustion process in coal-fired units. Sargent & Lundy's updated cost and performance assumptions for ACI are used (and are described further below).

Three alternative ACI options are represented as capable of providing 90% mercury removal for all possible configurations of boiler, emission controls, and coal types used in the U.S. electric power sector. The three ACI options differ based on whether they are used in conjunction with an electrostatic precipitator (ESP) or a fabric filter (also called a baghouse). The three ACI options are:

- ACI with Existing ESP
- ACI with Existing Baghouse
- ACI with an Additional Baghouse (also referred to as Toxecon)

In the third option listed above, the additional baghouse is installed downstream of the preexisting particulate matter device, and the activated carbon is injected after the existing controls. This configuration allows the fly ash to be removed before it is contaminated by mercury.

For modeling purposes, EPA assumes that all three configurations use brominated ACI, where a small amount of bromine is chemically bonded to the powdered carbon, which is injected into the flue gas stream. EPA recognizes that amended silicates and possibly other non-carbon, non-brominated substances are in development and may become available as alternatives to brominated carbon as a mercury sorbent.

The applicable ACI option depends on the coal type burned, its SO_2 content, the boiler, and particulate control type, and, in some instances, consideration of whether an SO_2 scrubber (FGD) system and SCR NO_x post-combustion control are present. Table 5-12 shows the ACI assignment scheme used to achieve 90% mercury removal. EPA 2023 Reference Case does not explicitly model ACI retrofit options.

Table 5-12 Assignment Scheme for Mercury Emissions Control Using Activated Carbon Injection in the EPA 2023 Reference Case

Air pollution controls				Bituminous Coal			Subbituminous Coal			Lignite Coal		
Burner Type	**Particulate Control Type**	**SCR System**	**FGD System**	**ACI Required?**	**Toxecon Required?**	**Sorbent Inj Rate (lb/million acfm)**	**ACI Required?**	**Toxecon Required?**	**Sorbent Inj Rate (lb/million acfm)**	**ACI Required?**	**Toxecon Required?**	**Sorbent Inj Rate (lb/million acfm)**
FBC	Cold Side ESP + Fabric Filter without FGC	--	--	Yes	No	2	Yes	No	2	Yes	No	2
FBC	Cold Side ESP without FGC	--	--	Yes	No	5	Yes	No	5	Yes	No	5
FBC	Fabric Filter	--	Dry FGD	No	No	0	Yes	No	2	Yes	No	2
FBC	Fabric Filter	--	--	Yes	No	2	Yes	No	2	Yes	No	2
FBC	Hot Side ESP with FGC	--	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Cold Side ESP + Fabric Filter with FGC	--	Dry FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter with FGC	--	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter with FGC	--	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter with FGC	SCR	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter with FGC	SCR	Dry FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter with FGC	SCR	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter without FGC	--	Dry FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter without FGC	--	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter without FGC	--	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter without FGC	SCR	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter without FGC	SCR	Dry FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP + Fabric Filter without FGC	SCR	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Cold Side ESP with FGC	--	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Cold Side ESP with FGC	--	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Cold Side ESP with FGC	--	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Cold Side ESP with FGC	SCR	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Cold Side ESP with FGC	SCR	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Cold Side ESP with FGC	SCR	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Cold Side ESP without FGC	--	--	Yes	No	5	Yes	No	5	Yes	No	5
Non-FBC	Cold Side ESP without FGC	--	Wet FGD	Yes	No	5	Yes	No	5	Yes	No	5
Non-FBC	Cold Side ESP without FGC	SCR	--	Yes	No	5	Yes	No	5	Yes	No	5
Non-FBC	Cold Side ESP without FGC	SCR	Dry FGD	Yes	No	5	Yes	No	5	Yes	No	5
Non-FBC	Cold Side ESP without FGC	SCR	Wet FGD	Yes	No	5	Yes	No	5	Yes	No	5
Non-FBC	Fabric Filter	--	Dry FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Fabric Filter	--	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Fabric Filter	--	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Fabric Filter	SCR	Dry FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Fabric Filter	SCR	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Fabric Filter	SCR	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter with FGC	--	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter with FGC	--	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter with FGC	--	Dry FGD	No	No	0	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter with FGC	SCR	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter with FGC	SCR	Dry FGD	No	No	0	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter with FGC	SCR	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter without FGC	--	Dry FGD	No	No	0	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter without FGC	--	--	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter without FGC	--	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter without FGC	SCR	Dry FGD	No	No	0	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP + Fabric Filter without FGC	SCR	--	Yes	No	2	Yes	No	2	Yes	No	2

Air pollution controls				Bituminous Coal			Subbituminous Coal			Lignite Coal		
Burner Type	**Particulate Control Type**	**SCR System**	**FGD System**	**ACI Required?**	**Toxecon Required?**	**Sorbent Inj Rate (lb/million acfm)**	**ACI Required?**	**Toxecon Required?**	**Sorbent Inj Rate (lb/million acfm)**	**ACI Required?**	**Toxecon Required?**	**Sorbent Inj Rate (lb/million acfm)**
Non-FBC	Hot Side ESP + Fabric Filter without FGC	SCR	Wet FGD	Yes	No	2	Yes	No	2	Yes	No	2
Non-FBC	Hot Side ESP with FGC	--	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP with FGC	--	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP with FGC	--	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP with FGC	SCR	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP with FGC	SCR	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP with FGC	SCR	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP without FGC	--	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP without FGC	--	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP without FGC	--	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP without FGC	SCR	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP without FGC	SCR	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	Hot Side ESP without FGC	SCR	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	No Control	--	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	No Control	--	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	No Control	--	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	No Control	SCR	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	No Control	SCR	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	No Control	SCR	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	PM Scrubber	--	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	PM Scrubber	--	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	PM Scrubber	--	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	PM Scrubber	SCR	Dry FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	PM Scrubber	SCR	--	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2
Non-FBC	PM Scrubber	SCR	Wet FGD	Yes	Yes	2	Yes	Yes	2	Yes	Yes	2

Note: In the table above "Toxecon" refers to the option described as "ACI System with an Additional Baghouse" and "ACI + Full Baghouse with a Sorbent Injection (Inj) Rate of 2 lbs/million acfm" elsewhere in this chapter.

5.4.4 Methodology for Obtaining ACI Control Costs

The ACI model developed by Sargent & Lundy in 2017 assumes that the carbon feed rate dictates the size of the equipment and resulting costs. The feed rate, in turn, is a function of the required removal (in this case 90%) and the type of particulate control device. The model assumes a carbon feed rate of 5 pounds of carbon injected for every 1,000,000 actual cubic feet per minute (acfm) of flue gas would provide the stipulated 90% mercury removal rate for units shown in Table 5-13 as qualifying for ACI systems with existing ESP. For generating units with fabric filters, a lower injection rate of 2 pounds per million acfm is required. Alternative sets of costs were developed for each of the three ACI options: ACI systems for units with existing ESPs, ACI for units with existing fabric filters (baghouses), and the combined cost of ACI plus an additional baghouse for units that either have no existing particulate control or that require ACI plus a baghouse in addition to their existing particulate control. There are various reasons that a combined ACI plus additional baghouse would be required. These include situations where the existing ESP cannot handle the additional particulate load associated with the ACI or where SO_3 injection is currently in use to condition the flue gas for the ESP. Another cause for combined ACI and baghouse is the use of PRB coal, whose combustion produces mostly elemental mercury, not ionic mercury, due to this coal's low chlorine content.

For the combined ACI and fabric filter option, a full-size baghouse with an air-to-cloth (A/C) ratio of 4.0 is assumed, as opposed to a polishing baghouse with a 6.0 A/C ratio.[52]

Table 5-13 presents the capital, fixed O&M, and variable O&M costs as well as the capacity and heat rate penalties for the three ACI options represented in EPA 2023 Reference Case. For each ACI option, values are shown for an illustrative set of generating units with a representative range of capacities and heat rates. For details of Sargent & Lundy ACI cost model, see Attachment 5-8.

5.5 Hydrogen Chloride (HCl) Control Technologies

The following subsections describe how HCl emissions from coal are represented, the emission control technologies available for HCl removal, and the cost and performance characteristics of these technologies in EPA 2023 Reference Case.

5.5.1 Chlorine Content of Fuels

HCl emissions from the power sector result from the chlorine content of the coal that is combusted by electric generating units. Data on the chlorine content of coals had been collected as part of EPA's 1999 "Information Collection Request for Electric Utility Steam Generating Unit Mercury Emissions Information Collection Effort" (ICR 1999) described above in section 5.4.1. This data is incorporated into the model to provide the capability for EPA 2023 Reference Case to project HCl emissions. The procedures used for this are presented below.

Western subbituminous coal (such as that mined in the Powder River Basin) and lignite coal contain natural alkalinity in the form of non-glassy calcium oxide (CaO) and other alkaline and alkaline earth oxides. This fly ash (classified as 'Class C' fly ash) has a natural pH of 9 and higher, and the natural alkalinity can effectively neutralize much of the HCl in the flue gas stream prior to the primary control device.

[52] The air-to-cloth (A/C) ratio is the volumetric flow, (typically expressed in Actual Cubic Feet per Minute, ACFM) of flue gas entering the baghouse divided by the areas (typically in square feet) of fabric filter cloth in the baghouse. The lower the A/C ratio, e.g., A/C = 4.0 compared to A/C = 6.0, the greater area of the cloth required and the higher the cost for a given volumetric flow.

Table 5-13 Illustrative Activated Carbon Injection (ACI) Costs (2022$) for Representative Sizes and Heat Rates under the Assumptions in the EPA 2023 Reference Case

Control Type	Heat Rate (Btu/kWh)	Capacity Penalty (%)	Heat Rate Penalty (%)	Variable O&M cost (mills/kWh)	Capacity (MW)									
					100		300		500		700		1000	
					Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)
ACI System with an Existing ESP ACI with a Sorbent Injection Rate of 5 lbs/million acfm assuming Bituminous Coal	9,000	-0.02	0.02	2.67	48.23	0.39	18.96	0.15	12.29	0.10	9.23	0.08	6.82	0.06
	10,000	-0.02	0.02	2.97	49.02	0.40	19.27	0.16	12.48	0.10	9.38	0.08	6.92	0.06
	11,000	-0.02	0.02	3.26	49.72	0.40	19.54	0.16	12.66	0.10	9.51	0.08	7.02	0.06
ACI System with an Existing Baghouse ACI with a Sorbent Injection Rate of 2 lbs/million acfm Assuming Bituminous Coal	9,000	-0.02	0.02	1.91	42.04	0.34	16.54	0.14	10.70	0.09	8.04	0.07	5.93	0.05
	10,000	-0.02	0.02	2.13	42.72	0.34	16.78	0.14	10.87	0.09	8.17	0.07	6.04	0.05
	11,000	-0.02	0.02	2.34	43.34	0.35	17.03	0.14	11.03	0.09	8.29	0.07	6.12	0.05
ACI System with an Additional Baghouse ACI + Full Baghouse with a Sorbent Injection Rate of 2 lbs/million acfm Assuming Bituminous Coal	9,000	-0.62	0.62	0.57	355.54	1.25	268.23	0.94	238.47	0.84	221.39	0.77	205.06	0.71
	10,000	-0.62	0.62	0.63	383.66	1.34	290.72	1.02	258.80	0.91	240.43	0.84	222.83	0.78
	11,000	-0.62	0.62	0.70	411.23	1.44	312.79	1.10	278.75	0.97	259.10	0.91	240.24	0.84

Note 1: The above cost estimates assume bituminous coal consumption.

Note 2: The Variable O&M costs in this table do not include the cost of additional auxiliary power (VOMP) component in the Sargent & Lundy cost models. For modeling purposes, IPM reflects the auxiliary power consumption through capacity penalty.

Eastern bituminous coals, by contrast, tend to produce fly ash with lower natural alkalinity. Though bituminous fly ash (classified as 'Class F' fly ash) may contain calcium, it tends to be present in a glassy matrix and unavailable for acid-base neutralization reactions.

To assess the extent of expected natural neutralization, resulting in large part from the alkalinity of the fly ash, the 2010 ICR[53] data was examined. According to that data, units burning some of the subbituminous coals without operating acid gas control technology emitted substantially lower HCl than would otherwise be expected if the emissions were based solely on the chlorine content of those coals. Comparing the assumed chlorine content of the subbituminous coals modeled in EPA 2023 Reference Case with the estimated values based on responses to the 2010 ICR supports the EPA 2023 Reference Case assumption that combustion of subbituminous and lignite coals results in a 95% reduction in HCl emissions relative to the assumed chlorine content of the coal.

5.5.2 HCl Removal Rate Assumptions for Existing and Potential Units

SO_2 emission controls on existing and new (potential) units provide the HCl reductions indicated in Table 5-14. New supercritical pulverized coal units (column 3) that the model builds include FGD (wet or dry), which is assumed to provide a 99% removal rate for HCl. For existing conventional pulverized coal units with pre-existing FGD (column 5), the HCl removal rate is assumed to be 5% higher than the reported SO_2 removal rate up to a maximum of 99% removal. In addition, for fluidized bed combustion units (column 4) with no FGD and no fabric filter, the HCl removal rate is assumed to be the same as the SO_2 removal rate up to a maximum of 95%. FBCs with fabric filters are assumed to have an HCl removal rate of 95%.

Table 5-14 HCl Removal Rate Assumptions for Potential (New) and Existing Units in the EPA 2023 Reference Case

		Potential (New)	**Existing Units with FGD**	
Gas	Controls ==>	Ultra-Supercritical Pulverized Coal with 30%/90% CCS	Fluidized Bed Combustion (FBC)	Conventional Pulverized Coal (CPC) with Wet or Dry FGD
HCl	Removal Rate	99%	**Without fabric filter:** Same as reported SO_2 removal rate up to a maximum of 95% ––– **With fabric filter: 95%**	Reported SO_2 removal rate + 5% up to a maximum of 99%

5.5.3 HCl Retrofit Emission Control Options

The retrofit options for HCl emission control are discussed in detail in the following sub-sections and summarized in Table 5-15.

<u>Wet and Dry FGD</u>

In addition to providing SO_2 reductions, wet scrubbers (Limestone Forced Oxidation, LSFO) and dry scrubbers (Lime Spray Dryer, LSD) reduce HCl as well. For both LSFO and LSD the HCl removal rate is assumed to be 99% with a floor of 0.001 lbs/MMBtu. This is summarized in columns 2-5 of Table 5-15.

[53] Collection Effort for New and Existing Coal- and Oil-Fired Electricity Utility Steam Generating Units (EPA ICR No.2362.01 (OMB Control Number 2060-0631)

Table 5-15 Retrofit HCl and SO_2 Emission Control Performance Assumptions in the EPA 2023 Reference Case

Performance Assumptions	Limestone Forced Oxidation (LSFO)		Lime Spray Dryer (LSD)		Dry Sorbent Injection (DSI)	
	SO_2	HCl	SO_2	HCl	SO_2	HCl
Percent Removal	98% with a floor of 0.06 lbs/MMBtu	99% with a floor of 0.001 lbs/MMBtu	95% with a floor of 0.08 lbs/MMBtu	99% with a floor of 0.001 lbs/MMBtu	50%	98% with a floor of 0.001 lbs/MMBtu
Capacity Penalty	Calculated based on characteristics of the unit: See Table 5-3		Calculated based on characteristics of the unit: See Table 5-3		Calculated based on characteristics of the unit: See Table 5-16	
Heat Rate Penalty						
Cost (2022$)						
Applicability	Units ≥ 100 MW		Units ≥ 100 MW		Units ≥ 25 MW	
Sulfur Content Applicability			Coals ≤ 3 lbs of SO_2/MMBtu		Coals ≤ 2.0 lbs of SO_2/MMBtu	
Applicable Coal Types	BA, BB, BD, BE, BG, BH, SA, SB, SD, SE, LD, LE, LG, LH, PK and WC		BA, BB, BD, BE, SA, SB, SD, SE, LD, and LE		BA, BB, BD, SA, SB, SD, and LD	

Dry Sorbent Injection

EPA 2023 Reference Case includes dry sorbent injection (DSI) as a retrofit option for achieving (in combination with a particulate control device) both SO_2 and HCl removal. In DSI for HCl reduction, a dry sorbent is injected into the flue gas duct, where it reacts with the HCl and SO_2 in the flue gas to form compounds that are then captured in a downstream fabric filter or electrostatic precipitator (ESP) and disposed of as waste. A sorbent is a material that takes up another substance by either adsorption on its surface or absorption internally or in solution. A sorbent may also chemically react with another substance. The sorbent assumed in the cost and performance characterization discussed in this section is Trona (sodium sesquicarbonate), a sodium-rich material with major underground deposits found in Sweetwater County, Wyoming. Trona is typically delivered with an average particle size of 30 µm diameter but can be reduced to about 15 µm through onsite in-line milling to increase its surface area and capture capability. While the Sargent & Lundy description of the DSI technology includes references to the hydrated lime option, only the Trona option is implemented in EPA 2023 Reference Case.

Removal rate assumptions: The removal rate assumptions for DSI are summarized in Table 5-15. The assumptions shown in the last two columns of Table 5-15 were derived from assessments by EPA engineering staff in consultation with Sargent & Lundy. As indicated in this table, the assumed SO_2 removal rate for DSI + fabric filter is 50%. The retrofit DSI option on an existing unit with existing ESP is always provided in combination with a fabric filter (Toxecon configuration).

Methodology for Obtaining DSI Control Costs: The cost and performance model for DSI was updated by Sargent & Lundy. The model is used to derive the cost of DSI retrofits with two alternatives, associated particulate control devices, i.e., ESP and fabric filter. The cost model notes that the cost drivers of DSI are quite different from those of wet or dry FGD. Whereas plant size and coal sulfur rates are key underlying determinants of FGD cost, sorbent feed rate and fly ash waste handling are the main drivers of the capital cost of DSI, with plant size and coal sulfur rates playing a secondary role.

Furthermore, the DSI sorbent feed rate and variable O&M costs are based on assumptions that a fabric filter and in-line Trona milling are used, and that the SO_2 removal rate is 50%. The corresponding HCl removal effect is estimated to be 98% for units with fabric filter.

The cost of fly ash waste handling, which is the other key contributor to DSI cost, is a function of the type of particulate capture device and the flue gas SO_2.

Total waste production involves the production of both reacted and unreacted sorbent and fly ash. Sorbent waste is a function of the sorbent feed rate with an adjustment for excess sorbent feed. The use of sodium-based DSI may make the fly ash unsalable, which would mean that any fly ash produced must be landfilled along with the reacted and unreacted sorbent waste. Typical ash contents for each fuel are used to calculate the total fly ash production rate. The fly ash production is added to the sorbent waste to account for the total waste stream for the variable O&M analysis.

For purposes of modeling, the total variable O&M includes the first two component costs noted in the previous paragraph, i.e., the costs for sorbent usage and the costs associated with waste production and disposal.

Table 5-16 presents the capital, fixed O&M, and variable O&M costs, as well as the capacity and heat rate penalties of a DSI retrofit for an illustrative and representative set of generating units with the indicated capacities and heat rates. For details of the Sargent & Lundy DSI cost model, see Attachment 5-7.

5.6 Fabric Filter (Baghouse) Cost Development

Fabric filters are not endogenously modeled as a separate retrofit option. In EPA 2023 Reference Case, an existing or new fabric filter particulate control device is a pre-condition for installing a DSI retrofit, and the cost of these retrofits at plants without an existing fabric filter includes the cost of installing a new fabric filter. This cost was added to the DSI costs discussed in section 5.5. The costs associated with a new fabric filter retrofit are derived from the cost and performance updated by Sargent & Lundy. Similarly, dry scrubber retrofit costs also include the cost of a fabric filter.

The engineering cost analysis is based on a pulse-jet fabric filter which collects particulate matter on a fabric bag and uses air pulses to dislodge the particulate from the bag surface and collect it in hoppers for removal via an ash handling system to a silo. This is a mature technology that has been operating commercially for more than 25 years. “Baghouse” and “fabric filters” are used interchangeably to refer to such installations.

Capital Cost: The major driver of fabric filter capital cost is the air-to-cloth (A/C) ratio. The A/C ratio is defined as the volumetric flow (typically expressed in Actual Cubic Feet per Minute, ACFM) of flue gas entering the baghouse divided by the areas (typically in square feet) of fabric filter cloth in the baghouse. The lower the A/C ratio, e.g., A/C = 4.0 compared to A/C = 6.0, the greater the area of the cloth required and the higher the cost for a given volumetric flow. An A/C ratio of 4.0 is used in the EPA 2023 Reference Case, and it is assumed that the existing ESP remains in place and active.

Table 5-17 presents the capital, fixed O&M, and variable O&M costs for fabric filters as represented in EPA 2023 Reference Case for an illustrative set of generating units with a representative range of capacities and heat rates. See Attachments 5-9a and 5-9b for details of the Sargent & Lundy fabric filter PM control cost model.

Table 5-16 Illustrative Dry Sorbent Injection (DSI) Costs (2022$) for Representative Sizes and Heat Rates in the EPA 2023 Reference Case

Control Type	Heat Rate (Btu/kWh)	SO_2 Rate (lb/ MMBtu)	Capacity Penalty (%)	Heat Rate Penalty (%)	Variable O&M (mills/kWh)	Capacity (MW)									
						100		300		500		700		1000	
						Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)
DSI	9,000	2.0	-0.94	0.95	12.08	166.0	3.93	83.8	1.54	61.0	1.01	58.8	0.84	58.8	0.73
Assuming Bituminous	10,000	2.0	-1.05	1.06	13.43	173.0	3.99	87.3	1.57	65.5	1.05	65.5	0.90	65.5	0.79
Coal	11,000	2.0	-1.15	1.17	14.79	179.5	4.04	90.6	1.59	72.1	1.10	72.1	0.95	72.1	0.84

Note 1: A SO_2 removal efficiency of 50% is assumed in the above calculations.

Note: The Variable O&M costs in this table do not include the cost of additional auxiliary power (VOMP) component in the Sargent & Lundy cost models. For modeling purposes, IPM reflects the auxiliary power consumption through capacity penalty.

Table 5-17 Illustrative Particulate Controls Costs (2022$) for Representative Sizes and Heat Rates in the EPA 2023 Reference Case

Coal Type	Heat Rate (Btu/kWh)	Capacity Penalty (%)	Heat Rate Penalty (%)	Variable O&M (mills/kWh)	Capacity (MW)									
					100		300		500		700		1000	
					Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)
	9,000			2.43	305.09	1.07	247.6	0.9	224.73	0.79	210.81	0.74	197.00	0.69
Bituminous	10,000	-0.60	0.60	2.70	332.32	1.16	269.7	0.9	244.75	0.86	229.59	0.80	214.55	0.75
	11,000			2.97	358.97	1.26	291.3	1.0	264.39	0.92	248.02	0.87	231.77	0.81

Note: The Variable O&M costs in this table do not include the cost of additional auxiliary power (VOMP) component in the Sargent & Lundy cost models. For modeling purposes, IPM reflects the auxiliary power consumption through capacity penalty.

5.7 Coal-to-Gas Conversions[54]

In EPA 2023 Reference Case, existing coal plants are given the option to burn natural gas by investing in a coal-to-gas retrofit. There are two components of cost in this option: boiler modification costs and the cost of extending natural gas lateral pipeline spurs from the boiler to a natural gas main pipeline. These two components of cost and their associated performance implications are discussed in the following sections.

5.7.1 Boiler Modifications for Coal-To-Gas Conversions

Enabling natural gas firing in a coal boiler typically involves the installation of new gas burners and modifications to the ducting, wind box (i.e., the chamber surrounding a burner through which pressurized air is supplied for fuel combustion), and possibly to the heating surfaces used to transfer energy from the exiting hot flue gas to steam (referred to as the convection pass). It may also involve modification of environmental equipment. Engineering studies are performed to assess operating characteristics like furnace heat absorption and exit gas temperature; material changes affecting piping and components like superheaters, reheaters, economizers, and recirculating fans; and operational changes to soot blowers, spray flows, air heaters, and emission controls.

The following table summarizes the cost and performance assumptions for coal-to-gas boiler modifications as incorporated in EPA 2023 Reference Case. The values in the table were developed by EPA's engineering staff based on technical papers[55] and discussions with industry engineers familiar with such projects. They were designed to be broadly applicable across the existing coal fleet (with the exceptions noted in the table). Coal-to-gas retrofit options in EPA 2023 Reference Case force a permanent change in fuel type from coal to natural gas. Coal, therefore, can no longer be fired.

Table 5-18 Cost and Performance Assumptions for Coal-to-Gas Retrofits in the EPA 2023 Reference Case

Factor	Description	Notes
Applicability:	Existing pulverized coal (PC) fired and cyclone boiler units of a size greater than 25 MW:	Not applicable for fluidized bed combustion (FBC) and stoker boilers.
Capacity Penalty:	None	The furnace of a boiler designed to burn coal is oversized for natural gas, and coal boilers include equipment, such as coal mills, that are not needed for gas. As a result, burning gas should have no impact on net power output.
Heat Rate Penalty:	5%	When gas is combusted instead of coal, the stack temperature is lower and the moisture loss to stack is higher. This reduces efficiency, which is reflected in an increase in the heat rate.
Incremental Capital Cost:	PC units: (2022$)/kW = 484.74*(75/MW)^0.35 Cyclone units: (2022$)/kW = 346.24*(75/MW)^0.35	The cost function covers new gas burners and piping, windbox modifications, air heater upgrades, gas recirculating fans, and control system modifications. <u>Example for 50 MW PC unit:</u> $/kW = 484.74*(75/50)^0.35 = 558.65
Incremental Fixed O&M:	-33% FOM cost of the existing coal unit	Due to reduced needs for operators, maintenance materials, and maintenance staff when natural gas combusted, FOM costs decrease by 33%.

[54] As discussed here coal-to-gas conversion refers to the modification of an existing boiler to allow it to fire natural gas. It does not refer to the addition of a gas turbine to an existing boiler cycle, the replacement of a coal boiler with a new natural gas combined cycle plant, or to the gasification of coal for use in a natural gas combustion turbine.

[55] For an example see Babcock and Wilcox's White Paper MS-14 "Natural Gas Conversions of Exiting Coal-Fired Boilers" 2010 (https://slidex.tips/download/natural-gas-conversions-of-existing-coal-fired-boilers).

Factor	Description	Notes
Incremental Variable O&M:	-25% VOM cost of the existing coal unit	Due to reduced waste disposal and miscellaneous other costs, VOM costs decrease by 25%.
Fuel Cost:	Natural Gas	To obtain natural gas the unit incurs the cost of extending lateral pipeline spurs from the boiler to the local transmission mainline. See Section 5.7.2.
NO_x emission rate:	50% of existing coal unit NO_x emission rate, with a floor of 0.05 lbs/MMBtu	The 0.05 lbs/MMBtu floor is the same as the NO_x rate floor for new retrofit SCR on units burning subbituminous coal.
SO_2 emissions:	Zero	

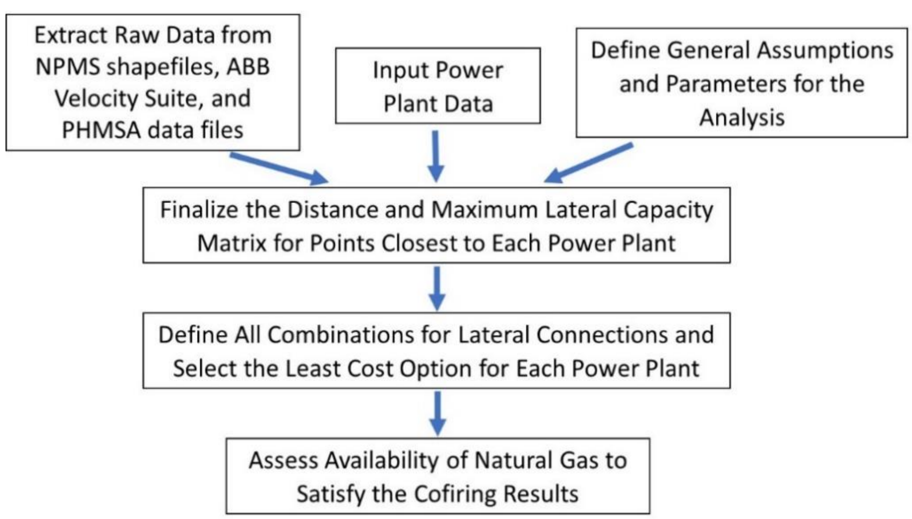
5.7.2 Natural Gas Pipeline Requirements for Coal-To-Gas Conversions

For every individual coal facility in the U.S., the distance and associated cost of constructing pipeline laterals from each facility to the interstate natural gas pipeline system was determined. Table 5-22 shows the pipeline costing results for each qualifying existing coal-fired unit in EPA 2023 Reference Case.

The lateral costs represent the minimum cost to connect coal power plants to the closest pipelines so that the plants can use natural gas. The estimated costs include both the cost for the lateral based on its mileage and size and the compression needed to support the movement of incremental gas needed for cofiring. They do not, however, include costs for mainline transport beyond those represented by the gas basis in EPA 2023 Reference Case. Thus, it is implicit that all gas needed to fire the plants would be purchased on a spot basis, and mainline expansion will not be needed to support the transport of incremental gas associated with cofiring beyond the amounts included in the EPA Base Case. This assumption will hold so long as the gas needed to support coal-to-gas conversion is not overly concentrated at specific locations during specific times of the year on gas pipeline systems in those areas are being highly utilized.

The process for estimating the lateral costs is shown in Figure 5-1 below. A general description of the process follows.

Figure 5-1 Process for Lateral Cost Estimation



First, the raw data for pipelines is extracted from *National Pipeline Mapping System (NPMS)* shapefiles that contain maps of pipelines throughout the United States, published by the *U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA)*. The NPMS shapefiles contain thousands of data points that are used to digitally map over 300 pipelines across the U.S. The NPMS shapefiles *are preprocessed along with ABB Velocity Suite data provided by Hitachi Energy and* *with data from the PHMSA Natural and Other Gas Transmission and Gathering Pipeline Systems Annual Report Part H* database to provide pipeline distance and diameter information. This initial step of the process extracts the necessary raw data from the three different data sets, including the pipeline ID, location, and diameter of the closest 50 points to each power plant.

The second step defines the necessary data for each power plant considered in the analysis. The most relevant data includes the location, size, and heat rate of the power plant, the amount of gas needed by the plant for converting to natural gas, and the lateral cost factor on a dollar-per-inch-mile basis.

The third step defines lateral assumptions for each plant. Broad assumptions have been made as well as direct assumptions for the configuration of laterals for each power plant included in the analysis. They include assumptions for the maximum distance that can be considered for each lateral connection and the potential offtake from each pipeline point.

Using the raw data, power plant information, and the general assumptions from steps 1, 2, and 3, the fourth step in the process finalizes the distances to and pipeline capacity of the pipelines closest to each power plant. This step of the process defines values for the matrix of mileage and lateral capacity for up to 20 laterals for each plant that are subsequently applied in the optimization analysis.

Step five sets up the matrix for all lateral options. The analysis assumes that up to two laterals may be applied for each power plant, and the capacity and costs for the lateral combinations for each power plant are defined. The matrix of lateral combinations considers both the distance and size of each lateral. Diameters from 4” to 32” in 2” increments are considered in the size matrix, yielding a total of up to 43,050 combinations of laterals that could serve each plant. This matrix includes 300 single lateral options, i.e., 15 different lateral diameters for each of the 20 potential pipeline connections, plus 42,750 2-lateral options that work through all combinations of lateral diameter and pipeline connections, applying two different laterals to serve each plant.

After the lateral option matrix has been fully populated, the option from the 43,050 combinations that satisfy a power plant’s natural gas need at the lowest cost is selected.

5.8 Natural Gas Co-firing

To accommodate the prospect of converting a coal-fired power plant to co-fire both coal and natural gas, EPA makes natural gas co-firing available as a retrofit option in the EPA 2023 Reference Case. The resulting cost and performance of the conversion depend on several factors. These comprise the existing natural gas system infrastructure, required burner level modifications, combustion system configuration, and boiler performance impact. Further, several variables associated with an existing coal plant affect the expected performance impacts and required modifications due to co-firing natural gas. These include the type of coal that is currently being burned, the type of ignition/warm-up fuel that is currently being used, the OEM and type of boiler, the boiler capacity, the existence of any backend emissions equipment, and the type and number of coal burners.

The following table summarizes the cost and performance assumption of the natural gas co-firing retrofit option as incorporated in the EPA 2023 Reference Case. EPA developed the values in the table based on Sargent & Lundy’s Natural Gas Co-firing Methodology, which is provided in Attachment 5-11.

Table 5-19 Cost and Performance Assumptions for Natural Gas Co-firing Retrofits in the EPA 2023 Reference Case

Factor	Description
Applicability:	Coal steam > 25 MW
Capacity Penalty:	None
Heat Rate Penalty:	1%

Factor	Description
Incremental Capital Cost (2022$):	$55.8
Incremental Fixed O&M:	None
Incremental Variable O&M:	None
Fuel Cost:	Natural Gas
NO_x Emission:	Adjust all NO_x rate modes to the lower of 0.15 lb/MMBtu or the current rate.
Other emissions:	All other emissions consistent with the reduction of coal.

5.9 Retrofit Assignments

In IPM, model plants that represent existing generating units have the option of maintaining their current system configuration, retrofitting with pollution controls, or retiring. The decision to retrofit or retire is endogenous to IPM and based on the least cost approach to meeting demand subject to modeled system and operational constraints. IPM is capable of modeling retrofits and retirements at each applicable model unit at three different points in time, referred to as three stages. At each stage, a retrofit set may consist of a single retrofit (e.g., LSFO Scrubber) or pre-specified combinations of retrofits (e.g., ACI + LSFO Scrubber + SCR). In EPA 2023 Reference Case, first-stage retrofit options are provided to existing coal-steam and oil/gas steam plants. These plants, along with others such as combined cycle, combustion turbines, biomass, and nuclear plants, are also given retirement as an option in stage one. Third-stage retrofit options are offered to coal-steam plants only.

Table 5-20 presents the first stage retrofit options available by plant type. Table 5-21 presents the second and third stage retrofit options available to coal-steam plants. The cost of multiple retrofits on the same model plant, whether installed in one or multiple stages, is additive. In EPA 2023 Reference Case, projections of pollution control equipment capacity and retirements are limited to the pre-specified combinations listed in Table 5-20 and Table 5-21.

Table 5-20 First Stage Retrofit Assignment Scheme in the EPA 2023 Reference Case

Plant Type	Retrofit Option 1st Stage	Criteria
Coal Steam		
	Coal Retirement	All coal steam boilers.
	LSFO	Standalone LSFO retrofits are not provided.
	LSD	Standalone LSD retrofits are not provided.
	SCR	All non-FBC coal steam boilers that are 100 MW or larger and do not possess an existing SCR control option.
	SNCR – FBC Boilers	All non-FBC coal steam boilers that are 25 MW or larger and do not have an existing post-combustion NO_x control option
	SNCR – Non-FBC Boilers	All coal FBC units that are 25 MW or larger and smaller than 100 MW and do not have an existing post-combustion NO_x control option.
	ACI (with and without Toxecon)	All coal steam boilers that are larger than 25 MW and do not have an ACI. The actual ACI technology type will be based on the boiler's fuel and technology configuration.
	DSI	All non-FBC coal steam boilers without DSI or FGD, 25 MW or larger, with Fabric Filter, and burning less than 2 lbs/MMBtu SO_2 coal.
	DSI + Fabric Filter	All non-FBC coal steam boilers without DSI or FGD, 25 MW or larger, without Fabric Filter, with CESP or HESP, and burning less than 2 lbs/MMBtu SO_2 coal.
	CCS	All non-FBC scrubbed coal steam boilers with SCR and all FBC boilers that are 100 MW or larger.
	CCS + LSFO	All non-FBC unscrubbed coal steam boilers with SCR that are 100 MW or larger.
	NGC	All coal steam boilers that are 25 MW or larger.

Plant Type	Retrofit Option 1st Stage	Criteria
	C2G	All cyclone and pulverized coal steam boilers that are 25 MW or larger.
	C2G + SCR	Individual technology restrictions are applied.
	ACI + DSI	
	ACI + DSI + Fabric Filter	
	SCR + DRET	
	SCR + C2G	
	SCR + CCS	
	SCR + CCS + LSFO	
	SCR + NGC	
	SNCR + DRET	
	SNCR + C2G	
	SNCR + CCS	
	SNCR + CCS + LSFO	
	SNCR + NGC	
Integrated Gasification Combined Cycle		
	IGCC Retirement	All integrated gasification combined cycle units
Combined Cycle		
	CC Retirement	All combined cycle units
	CO_2 Capture and Storage	All combined cycle sets 100 MW or larger.
Combustion Turbine		
	CT Retirement	All combustion turbine units
Nuclear		
	Nuclear Retirement	All nuclear power units
Oil and Gas Steam		
	Oil/Gas Retirement	All oil/gas steam boilers

Table 5-21 Second and Third Stage Retrofit Assignment Schemes in the EPA 2023 Reference Case

Plant Type	Retrofit Option 1st Stage	Retrofit Option 2nd Stage	Retrofit Option 3rd Stage
Coal Steam			
	NO_x Control Option (SCR, SNCR)	Coal-to-Gas	Oil/Gas Retirement
		CO_2 Control Option	Coal Retirement
		Natural Gas Cofiring	Coal Retirement
		Coal Retirement	None
	Hg Control Option (ACI)	NO_x Control Option	Coal Retirement
		Coal-to-Gas	Oil/Gas Retirement
		Coal-to-Gas + NO_x Control Option	Oil/Gas Retirement
		CO_2 Control Option	Coal Retirement
		Natural Gas Cofiring	Coal Retirement
		Coal Retirement	None
		NO_x Control Option + CO_2 Control Option	Coal Retirement
		NO_x Control Option + Natural Gas Cofiring	Coal Retirement
	HCl Control Option (DSI/DSI+FF)	NO_x Control Option	Coal Retirement
		Coal-to-Gas	Oil/Gas Retirement
		Coal-to-Gas + NO_x Control Option	Oil/Gas Retirement
		CO_2 Control Option	Coal Retirement
		Natural Gas Cofiring	Coal Retirement
		Coal Retirement	None
		NO_x Control Option (SCR only) + CO_2 Control Option	Coal Retirement

Plant Type	Retrofit Option 1st Stage	Retrofit Option 2nd Stage	Retrofit Option 3rd Stage
		NO_x Control Option + Natural Gas Cofiring	Coal Retirement
	CO_2 Control Option (CCS)	Coal Retirement	None
	Coal-to-Gas (C2G)	NO_x Control Option	Oil/Gas Retirement
		Oil/Gas Retirement	None
	Natural Gas Cofiring (NGC)	Coal Retirement	None
	Coal Retirement (RET)	None	None
	Hg Control Option[3] + HCl Control ACI+DSE or ACI+DSF	NO_x Control Option	Coal Retirement
		Coal-to-Gas	Oil/Gas Retirement
		Coal-to-Gas + NO_x Control Option	Oil/Gas Retirement
		CO_2 Control Option	Coal Retirement
		Natural Gas Cofiring	Coal Retirement
		Coal Retirement	None
		NO_x Control Option + CO_2 Control Option	Coal Retirement
		NO_x Control Option + Natural Gas Cofiring	Coal Retirement
Combined Cycle			
	CC Retirement	None	None
	CO_2 Capture and Storage	CC Retirement	None
Oil and Gas Steam			
	Oil/Gas Retirement	None	None
Combustion Turbine			
	CT Retirement	None	None
IGCC			
	IGCC Retirement	None	None
Nuclear			
	Nuclear Retirement	None	None
Biomass, Geothermal, Hydro, Landfill Gas, Fuel Cell, Non-Fossil Other, Fossil Other			
	Retirement	None	None

List of tables and attachments that are directly uploaded to the web:

6. CO_2 Capture, Storage, and Transport

6.1 CO_2 Capture

The EPA 2023 Reference Case allows for the building of potential (new) Ultra-Supercritical Coal (USC) and Natural Gas Combined Cycle (NGCC) Electric Generating Units (EGUs) with Carbon Capture and Storage (CCS) technology.[56] CCS is also available as a retrofit option to existing coal-fired and NGCC EGUs.

6.1.1 CO_2 Capture for Potential EGUs

Potential USC EGUs are provided with two CCS options, namely, a 36-percent carbon dioxide (CO_2) capture efficiency option and a 90-percent CO_2 capture efficiency option. Potential NGCC EGUs, on the other hand, are provided with only the 90-percent CO_2 capture efficiency option. The CCS cost and performance assumptions provided in Table 6-1 are based on the Annual Energy Outlook 2023 (AEO 2023).

Table 6-1 Cost and Performance Assumptions for Potential USC and NGCC with and without Carbon Capture in the EPA 2023 Reference Case

	Combined Cycle - Single Shaft	Combined Cycle - Multi Shaft	Combined Cycle with 90% CCS	Ultra-supercritical Coal without CCS	Ultra-supercritical Coal with 36% CCS	Ultra-supercritical Coal with 90% CCS
Size (MW)	418	1083	377	650	650	650
First Year Available	2028	2028	2030	2028	2030	2030
Lead Time (Years)	3	3	3	4	4	4
Availability	87%	87%	87%	85%	85%	85%
Vintage #1 (2028)						
Heat Rate (Btu/kWh)	6,431	6,370		8,638		
Capital (2022$/kW)	1,118	989		3,789		
Fixed O&M (2022$/kW/yr)	15.87	13.73		45.68		
Variable O&M (2022$/MWh)	2.87	2.10		5.06		
Vintage #2 (2030)						
Heat Rate (Btu/kWh)	6,431	6,370	7,124	8,638	9,751	12,507
Capital (2022$/kW)	1,096	969	2,539	3,717	4,624	5,979
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	45.68	61.11	67.02
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	7.97	12.35
Vintage #3 (2035)						
Heat Rate (Btu/kWh)	6,431	6,370	7,124	8,638	9,751	12,507
Capital (2022$/kW)	1,054	932	2,396	3,538	4,385	5,648
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	45.68	61.11	67.02
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	7.97	12.35
Vintage #4 (2040)						
Heat Rate (Btu/kWh)	6,431	6,370	7,124	8,638	9,751	12,507
Capital (2022$/kW)	1,012	895	2,252	3,353	4,138	5,309
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	45.68	61.11	67.02
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	7.97	12.35
Vintage #5 (2045)						
Heat Rate (Btu/kWh)	6,431	6,370	7,124	8,638	9,751	12,507
Capital (2022$/kW)	968	856	2,105	3,160	3,884	4,960
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	45.68	61.11	67.02
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	7.97	12.35
Vintage #6 (2050-2055)						
Heat Rate (Btu/kWh)	6,431	6,370	7,124	8,638	9,751	12,507
Capital (2022$/kW)	922	816	1,958	2,966	3,628	4,612
Fixed O&M (2022$/kW/yr)	15.87	13.73	31.06	45.68	61.11	67.02
Variable O&M (2022$/MWh)	2.87	2.10	6.57	5.06	7.97	12.35

[56] The term carbon capture refers to removing CO_2 from the flue gases emitted by fossil fuel-fired EGUs.

6.1.2 CO_2 Capture for Existing EGUs with CCS Retrofit

As noted, EPA 2023 Reference Case offers the option of adding CCS to existing coal-fired and NGCC EGUs as a retrofit option starting in 2030. The option comes with a CO_2 capture efficiency of 90 percent. As in the case of potential EGUs with CCS, the CO_2 capture assumptions for CCS retrofit represent an amine-based, post-combustion CO_2 capture system.

The cost and performance assumptions provided in Table 6-2 are based on the Sargent & Lundy[57] cost algorithm (Attachment 6-1 summarizes the study)[58]. One issue that must be addressed when installing an amine-based, post-combustion CO_2 capture system is that sulfur oxides (e.g., sulfur dioxide (SO_2) and sulfur trioxide (SO_3)) in the EGU flue gas can degrade the amine-based solvent that absorbs the CO_2. Since the amine will preferentially absorb SO_2 before CO_2, it will be necessary to treat the EGU flue gas to lower the sulfur oxide concentration to 10 parts per million by volume or less. Meeting this constraint will require installing a supplemental Wet Flue Gas Desulfurization (FGD) technology or retrofitting an existing FGD. In EPA 2023 Reference Case, non FBC coal units without FGD or SCR controls are required to install FGD and SCR controls before retrofitting with CCS retrofits. However, existing FGDs are not retrofitted in the EPA 2023 Reference Case.

Table 6-2 Performance and Unit Cost (2022$) Assumptions for Carbon Capture in the EPA 2023 Reference Case

Technology	Capacity (MW)	Heat Rate (Btu/kWh)	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Variable O&M (mills/kWh)[2]	Capacity Penalty (%)	Heat Rate Penalty (%)
Coal Steam (Assuming Bituminous Coal)	400	9,000	2,160	31.47	4.87	27.61	38.14
		10,000	2,506	35.30	5.66	30.68	44.25
		11,000	2,884	39.49	6.51	33.75	50.94
	700	9,000	2,160	27.00	4.87	27.62	38.15
		10,000	2,506	30.63	5.66	30.69	44.27
		11,000	2,884	34.60	6.51	33.76	50.95
	1,000	9,000	2,160	25.21	4.87	27.62	38.16
		10,000	2,506	28.76	5.66	30.68	44.26
		11,000	2,884	32.64	6.51	33.75	50.94
Combined Cycle (Assuming Natural Gas)	100	7,000	1,176	47.13	1.90	15.23	17.97
		8,000	1,380	50.05	2.23	17.40	21.07
		9,000	1,594	53.13	2.58	19.58	24.35
	300	7,000	1,176	23.35	1.90	15.23	17.97
		8,000	1,380	25.64	2.23	17.40	21.07
		9,000	1,594	28.06	2.58	19.58	24.35
	500	7,000	1,177	18.59	1.90	15.24	17.99
		8,000	1,380	20.76	2.23	17.40	21.07
		9,000	1,595	23.05	2.58	19.60	24.37

[1]Incremental costs are applied to the derated (i.e., after retrofit) capacity.
[2]The CO_2 Transportation, Storage, and Monitoring portion of the variable O&M has been removed from Sargent & Lundy cost method and modeled separately.

[57] Sargent & Lundy. "*IPM Model – Updates to Cost and Performance for APC Technologies – CO_2 Reduction Retrofit Cost Development Methodology.*" Project 13527-002; March 2023.

[58] The capital cost of the CCS retrofit options on coal steam units is assumed to reduce by 5% starting in 2030 and by 10% starting in 2040. Similarly, the capital cost of the CCS retrofit options on combined cycle units is assumed to reduce by 5%, 7%,10%, and 15% starting in 2028, 2030, 2035, and 2040 respectively. These reductions are expected due to lessons learned and experience gained from demonstrations based on 45Q incentivized projects and movement toward competitive bidding projects with multiple executed projects for each supplier.

The capacity-derating penalty and associated heat rate penalty are an output of the Sargent & Lundy model. (See Section 5.1.1 for further details.)

6.1.3 Coal-Fired Units Installing CCS Retrofit by 2030

Table 6-3 shows the existing coal-fired units allowed to install CCS retrofit by 2030 as these units are in the process of, or have completed Front-End Engineering Design (FEED) studies. All other coal steam and combined cycle units can install CCS retrofits starting in 2035.

Table 6-3 Existing Coal-Fired Units that can Install CCS Retrofit by 2030 in the EPA 2023 Reference Case

Unit Name	Plant Type	State Name
Four Corners	Coal Steam	New Mexico
Four Corners	Coal Steam	New Mexico
Gerald Gentleman	Coal Steam	Nebraska
Dry Fork Station	Coal Steam	Wyoming
Milton R Young	Coal Steam	North Dakota
Milton R Young	Coal Steam	North Dakota
Brame Energy Center	Coal Steam	Louisiana
Brame Energy Center	Coal Steam	Louisiana
Dallman	Coal Steam	Illinois
Prairie State Generating Station	Coal Steam	Illinois

6.2 CO_2 Storage

This section describes the cost of geologic storage of carbon dioxide as updated in 2023 using the GeoCAT 2.0 model and applied in the EPA 2023 Reference Case.[59] This update includes the quantity (in metric tons of capacity) and cost (in dollars per metric ton of CO_2) of potential geologic storage of carbon dioxide by location (generally defined as that portion of a geologic basin contained within one state) and by geologic storage type. There are three storage types that are estimated:

- Saline reservoirs (a.k.a. saline aquifers),
- Enhanced oil recovery, and
- Abandoned oil and gas fields.

The storage costs are calculated as the levelized[60] real-dollar costs for hypothetical storage projects of each type that might be developed inside of 10km by 10km grid "cells" located within each basin/state storage region. The portion of the gross cell area that can be developed is estimated based on:

- Population density (a higher population density reduces available area),
- Wilderness status, and
- A general availability factor that accounts for considerations such as geologic suitability, land accessibility, permitting difficulties, etc.

The geologic characteristics for each cell assumed for modeling come from several sources, including:

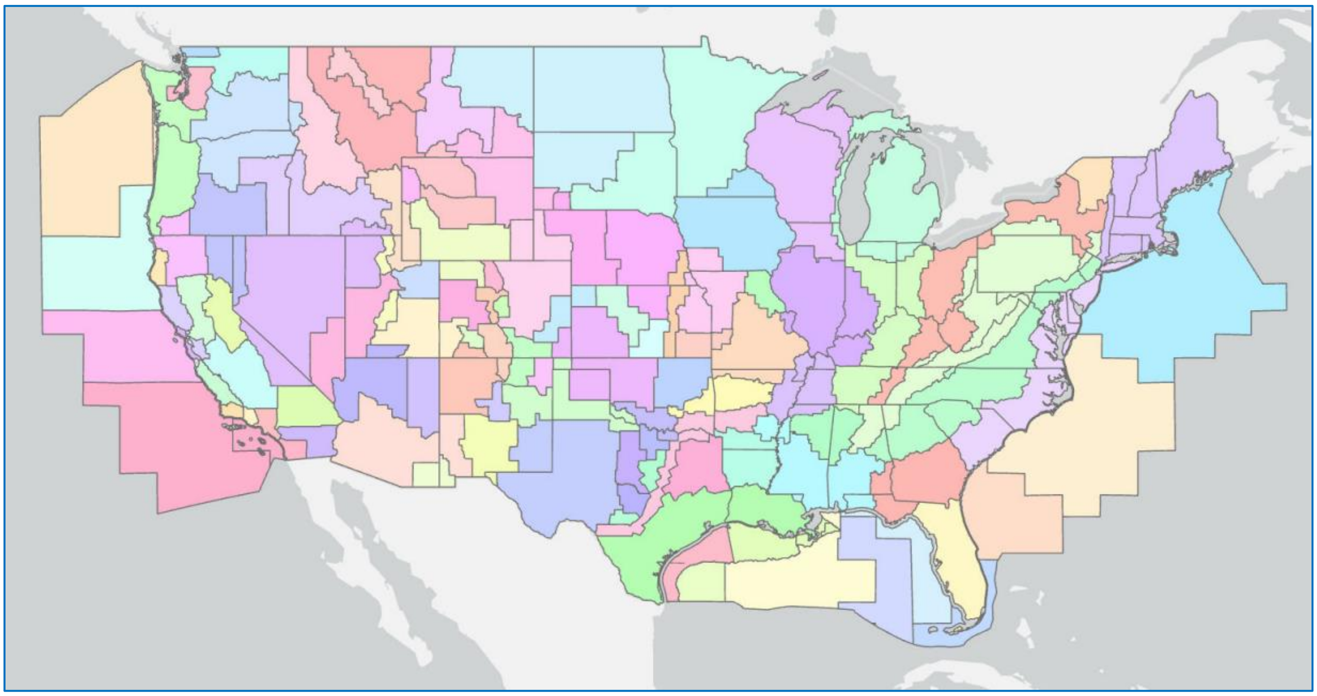
[59] A discussion of the original GeoCAT model and its application for EPA can be found in U.S. Environmental Protection Agency, Office of Water, "Geologic CO_2 Sequestration Technology and Cost Analysis, Technical Support Document" (EPA 816-B-08-009) June 2008, https://www.epa.gov/sites/production/files/2015-07/documents/support_uic_co2_technologyandcostanalysis.pdf and Harry Vidas, Robert Hugman and Christa Clapp, "Analysis of Geologic Sequestration Costs for the United States and Implications for Climate Change Mitigation," Science Digest, Energy Procedia, Volume 1, Issue 1, February 2009, Pages 4281-4288. Available online at https://www.sciencedirect.com/science/article/pii/S1876610209008832.

[60] The levelized real-dollar cost is the constant real $/unit revenue required by the provider of the geologic storage services to recover all capital and operating costs and exactly earn his target rate of return on his investment.

- Saline reservoir information from NATCARB[61] (saline reservoir depth, pressure, temperature, porosity, estimated potential storage capacity, etc.),
- Studies conducted by NETL to characterize the geology and estimate the economics of specific storage locations (saline reservoir depth, pressure, temperature, potential storage capacity, etc.),
- Studies conducted by the US Geologic Survey (regional temperature gradients, regional EOR potential, and storage capacity),
- Commercial oil and gas well databases (historical oil and gas well locations, reservoir depths, cumulative production, current reserves, regional formation tops, etc.).[62]

The outputs of the model are sequestration cost curves that indicate how much potential storage capacity is available at different CO_2 price points within each basin/state storage region. The various basins/states that were modeled as "storage regions" are shown in Figure 6-1. Note that not every storage type is available in each region and that regions with zero or near-zero capacity were not put into the EPA 2023 Reference Case when their estimated potential storage capacity was below three million metric tons (about the capacity needed for a 100 MW gas-fired power plant over 20 years).

Figure 6-1: Storage Regions in GeoCAT 2.0



Note: Regional boundaries are based on the American Association of Petroleum Geologists (AAPG) basin definitions, Department of Interior offshore leasing areas and state borders. Not every type of storage reservoir can be found in each storage region.

6.2.1 Unit Costs for Geologic Storage

The storage cost calculated for each type of storage for each cell is largely a function of the geologic characteristics of that cell and assumptions used in the costing algorithms for individual components of geologic sequestration of CO_2. The largest economic drivers are the costs of well operation, injection and monitoring well construction costs, and the costs of site monitoring. Depending on the nature of each cost

[61] NATCARB Saline spatial database, National Energy Technology Laboratory's Energy Data eXchange: NATCARB - Submissions - EDX (doe.gov)

[62] Historical oil and gas well data came from the Enverus Foundations databases: Enverus Foundations | Analyst-Curated Datasets | Enverus

element, "unit costs" are specified as dollars per storage site, dollars per square mile, dollars per foot as a function of well depth, dollars per labor hour, or other kinds of specifications or algorithms. The unit costs are then multiplied by the number of units required for a project. For example, the drilling of injection wells could be modelled as:

$230/foot injection well drilling and completion (D&C) construction cost
x 6,000 feet (measured drilling depth) per well
x 4 injection wells per project
= $5.52 million capital expenditures for injection well D&C per project.

6.2.2 Levelized Costs for Geologic Storage

The individual capital cost and operating cost components are combined into a pro forma project cash flow model for each 10km-by-10km cell. For example, the pro forma calculations for saline reservoirs would typically cover a four-year site characterization and construction period, a 30-year injection period, and a 50-year post-closure monitoring period. Each pro forma project has specifications for the volume of CO_2 injected, depth of injection, number of injection and monitoring wells, and other factors. Based on the timing of expenses and financial assumptions, these costs are translated in the model into levelized real dollars per metric ton of CO_2 injected using standard discounted cash flow techniques.[63] For EOR projects, the value of incremental crude oil recovery is subtracted from the gross storage costs to obtain the net costs – which can be negative in cases where the value of incremental oil exceeds the gross storage costs.

Note that the levelized cost shown here does not include the effect of federal tax credits under Section 45Q. Under the Inflation Reduction Act (IRA), the tax credit was raised to $60/metric ton for carbon dioxide used in enhanced oil recovery or other industrial operations and to $85/metric for permanently stored CO_2 such as in saline aquifers or abandoned oil and gas fields. The CCUS credit is available for CCUS projects beginning construction before January 1, 2033, and is to be applied to CO_2 quantities stored in the first 12 years of a project's operation. While not included in the storage cost curves presented here, the value of any applicable tax credit is accounted for in the EPA 2023 Reference Case.

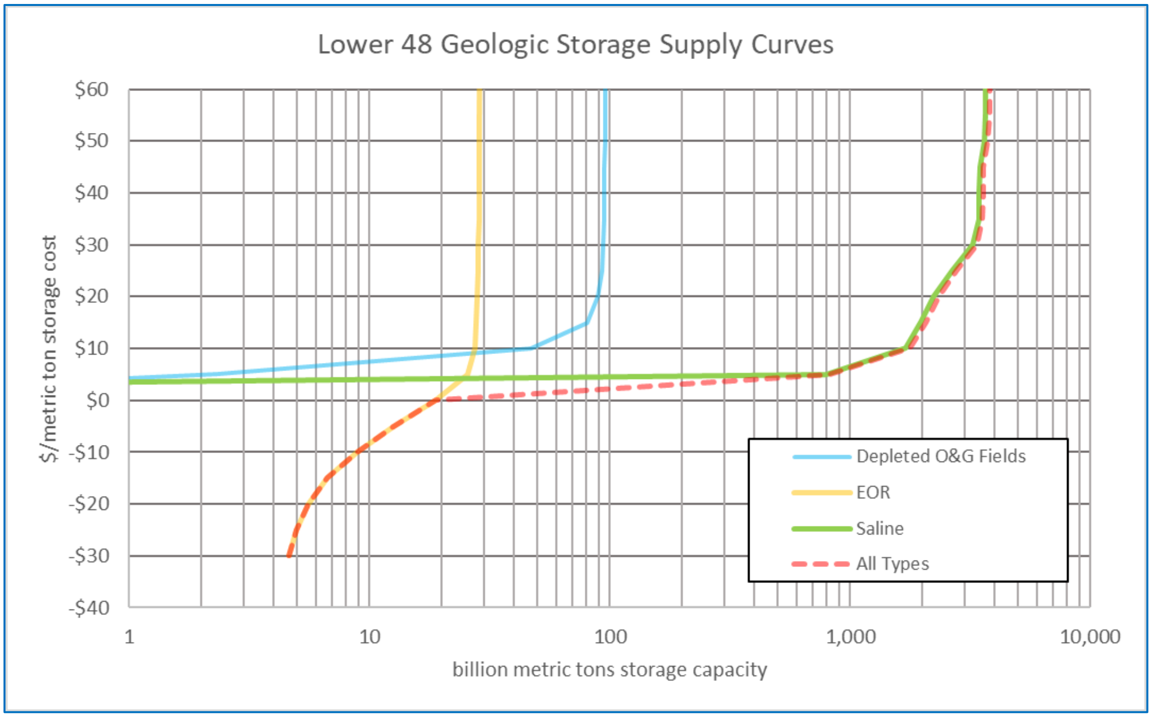
6.2.3 Aggregated Storage Cost Curves

For purposes of modeling within the EPA 2023 Reference Case, separate cost curves are created for each basin/state storage region in cost increments or steps of $5/metric ton. These curves are constructed by sorting each element (that is, the storage quantity and levelized cost for each individual cell/reservoir type) from lowest to highest costs and then aggregating all the elements into a single curve for each storage region.

For the Lower 48 as a whole, the geologic storage cost curves that result from this analysis are shown in Figure 6-2. Note that the x-axis is in units for billion metric tons of potential storage capacity and is shown on a logarithmic scale due to the wide range of capacities among the three storage types.

[63] In mathematical terms, the levelized cost produces a net present value of cash inflows (discounted at the operator's weighted average cost of capital) that exactly equals the net present value of cash outflows (also discounted at the operator's weighted average cost of capital).

Figure 6-2: Lower 48 Geologic Storage Supply Cost Curves



Note: These are levelized costs for geologic storage of carbon dioxide computed using GeoCAT 2.0. They do not include capture or transportation costs, and they also exclude the effects of 45Q tax credits.

The aggregated Lower 48 curves are constructed like the regional storage cost supply curves by sorting each element (that is, a reservoir type within each cell) starting from the least expensive to the most expensive and then accumulating the potential storage capacity at higher and higher costs. The aggregated Lower 48 curve for saline aquifers alone is shown as a green line, the curve for EOR alone is shown as an orange line, and the curve for abandoned oil and gas fields alone is shown as a blue line. The aggregation of all three types is shown as a dashed red line. The total modeled potential geologic storage capacity is 3,813 billion metric tons for the Lower 48. This is about 752 times the annual US carbon dioxide emission for all fossil fuel combustion (estimated in EPA's 2021 National GHG Inventory to be 5.067 billion metric tons).

6.3 CO_2 Transport

The EPA 2023 Reference Case includes the cost of transporting carbon dioxide by pipeline from a power plant to the geologic storage site. These pipeline transportation costs are represented by a matrix (in dollars per metric ton) between "sources" (that is, either center points of IPM regions for "new" power plants or individual existing power plant locations) and "sinks" (the center points of basin/state storage regions). These transport costs are a function of transport distance measured in miles and are based on the assumption that each source/sink pair is served by its own pipeline. The costs of pipeline transportation are based on standard engineering calculations for what diameter of pipeline is needed to transport a given volume of CO_2 and recent capital costs for pipelines in terms of dollars per inch-mile of pipeline. The tariff rate is calculated using standard discounted cash flow techniques given these capital costs plus some assumptions about the cost of capital (that is, interest on debt, return on equity, and the debt-to-equity ratio) and operating and maintenance costs for the CO_2 pipelines. The source-to-sink transportation cost matrix is created by multiplying the travel distances (calculated with geospatial geometry using latitude-longitude center points of the regions) by the relevant dollar-per-ton-mile transportation cost factors. To limit the size of the cost matrix, only the transportation links with a distance of less than 750 miles are modeled in the EPA 2023 Reference Case.

List of tables that are uploaded directly to the web:

Table 6-4 CO_2 Storage Cost Curves in EPA 2023 Reference Case

Table 6-5 CO_2 Transportation Matrix in EPA 2023 Reference Case

Attachment 6-1 CO_2 Reduction Retrofit Cost Development Methodology

7. Coal

The next three chapters cover the representation and underlying assumptions for fuels in EPA 2023 Reference Case. Chapter 7 focuses on coal, Chapter 8 on natural gas, and Chapter 9 on other fuels (fuel oil, biomass, nuclear fuel, and waste fuels).

This chapter presents four main topics. The first topic discusses how the coal market is represented. Included are discussions of coal supply and demand regions, coal quality characteristics, and the assignment of coal to power plants.

The second topic concerns coal supply curves which were developed using a bottom-up, mine-based approach. The approach depicts the coal choices and associated prices that power plants face over the modeling time horizon. Included are discussions of the methods and data used to quantify the economically recoverable coal reserves, characterize their cost, and build the 71 coal supply curves implemented in EPA 2023 Reference Case. Also, step-by-step illustrative examples of the approach are provided.

The third topic covers coal transportation. Included are discussions of the transport network, the methodology used to assign costs to the links in the network, and the geographic, infrastructure, and regulatory considerations that come into play in developing specific rail, barge, and truck transport rates.

Finally, issues concerning competition among sources of coal supply and demand are addressed. Competition on the supply side includes imported coal that arrives from non-U.S. or non-Canadian basins. Competition on the demand side includes demand for international thermal exports, as well as domestic industrial, residential, and commercial demand for thermal coal. These assumptions are discussed in Section 7.4.

The assumptions for the coal supply curves and coal transportation were finalized in January 2021, and were developed through a collaborative process with EPA supported by the following independent team of coal experts (with key areas of responsibility noted in parenthesis): ICF (IPM model integration and team coordination), Wood Mackenzie (coal supply curve development), and Hellerworx (coal transportation cost development).

7.1 Coal Market Representation

Coal supply, coal demand, coal quality, and the assignment of specific types of coals to individual coal-fired generating units are the four key components of the endogenous coal market modeling framework in EPA 2023 Reference Case. The modeling representation attempts to reflect the actual options available to each existing coal-fired power plant while aggregating data sufficiently to keep the model size and solution time within acceptable limits.

Each coal-fired power plant modeled is reflected as its own coal demand region. The demand regions are defined to reflect the coal transportation options, including rail, barge, truck, and conveyor belt, that are available to the plant. These demand regions are interconnected by a transportation network to at least one of the 34 geographically dispersed coal supply regions. The model's supply-demand region links reflect actual on-the-ground transportation pathways. Each coal supply region can supply, and each coal demand region can demand at least one grade of coal. Based on historical and engineering data (as described in Section 7.1.5), each coal-fired power plant is also assigned several coal grades, which it may use if available within its demand region.

The endogenous demand for coal is generated by coal-fired power plants interacting with a set of exogenous supply curves (see Table 7-26 for coal supply curve data) for each coal grade in each supply region. The curves show the supply of coal (by coal supply region and coal grade) that is available to meet the demand at a given price. The supply and demand for each coal grade is linked to and affected by the supply and demand for every other coal grade across supply and demand regions. The transportation network, which is also called the coal transportation matrix, in Table 7-25 provides the delivery cost to move coal from a free-on-board point of sale in the coal basin to the end-use power plant. The transportation cost combined with the free-on-board supply cost reflects the delivered cost a plant considers when making its coal selection. IPM derives the equilibrium coal consumption and prices that result when the entire electric system is operating at the least cost while meeting emission constraints and other operating requirements over the modeling time horizon.

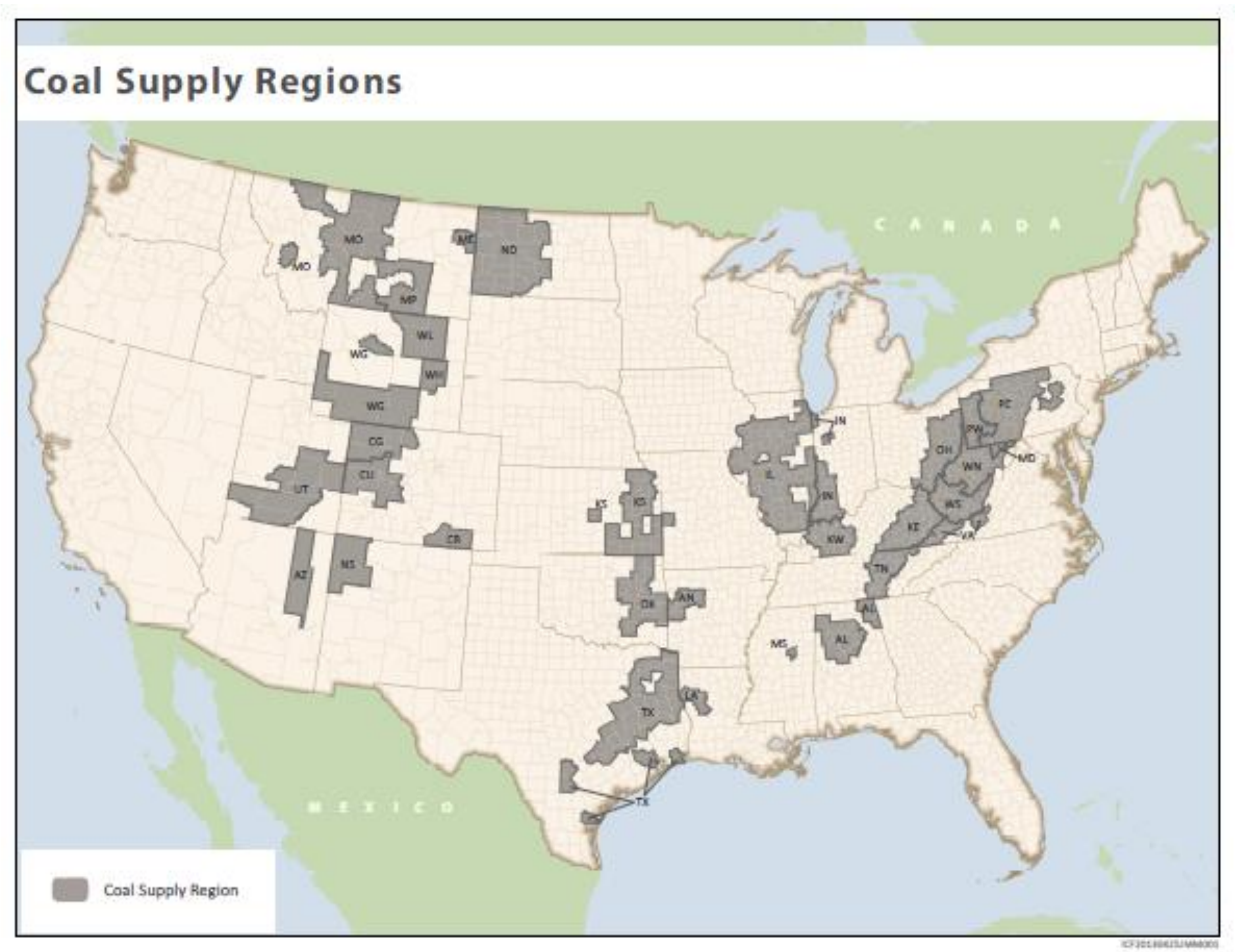
7.1.1 Coal Supply Regions

There are 34 coal supply regions, each representing geographic aggregations of coal-mining areas that supply one or more coal grades. Coal supply regions may differ from one another in the types and quality of coal they can supply. Table 7-1 lists the coal supply regions included in EPA 2023 Reference Case. Figure 7-1 provides a map showing the location of the coal supply regions listed in Table 7-1 and the broader supply basins commonly used when referring to U.S. coal reserves.

Table 7-1 Coal Supply Regions in EPA 2023 Reference Case

Region	State	Supply Region
Central Appalachia	Kentucky, East	KE
Central Appalachia	Tennessee	TN
Central Appalachia	Virginia	VA
Central Appalachia	West Virginia, South	WS
Dakota Lignite	Montana, East	ME
Dakota Lignite	North Dakota	ND
East Interior	Indiana	IN
East Interior	Kentucky, West	KW
East Interior	Illinois	IL
Gulf Lignite	Texas	TX
Gulf Lignite	Louisiana	LA
Gulf Lignite	Mississippi	MS
Northern Appalachia	Maryland	MD
Northern Appalachia	Ohio	OH
Northern Appalachia	Pennsylvania, Central	PC
Northern Appalachia	Pennsylvania, West	PW
Northern Appalachia	West Virginia, North	WN
Rocky Mountains	Utah	UT
Rocky Mountains	Colorado, Green River	CG
Rocky Mountains	Colorado, Raton	CR
Rocky Mountains	Colorado, Uinta	CU
Southern Appalachia	Alabama	AL
Southwest	Arizona	AZ
Southwest	New Mexico, San Juan	NS
West Interior	Oklahoma	OK
Western Montana	Montana, Bull Mountains	MT
Western Montana	Montana, Powder River	MP
Western Wyoming	Wyoming, Green River	WG
Wyoming Northern PRB	Wyoming, Powder River Basin (8800)	WH
Wyoming Southern PRB	Wyoming, Powder River Basin (8400)	WL
Alaska	Alaska	AK
Alberta	Alberta	AB
British Columbia	British Columbia	BC
Saskatchewan	Saskatchewan	SK

Figure 7-1 Map of the Coal Supply Regions in the EPA 2023 Reference Case



7.1.2 Coal Demand Regions

Coal demand regions are designed to reflect coal transportation options available to power plants. Each existing coal-fired power plant is reflected as its own individual demand region. The transportation infrastructure (i.e., rail, barge, truck, or conveyor belt), proximity to mine (i.e., mine mouth or not mine mouth), and transportation competitiveness levels (i.e., non-competitive, low-cost competitive, or high-cost competitive) are developed specific to each plant (demand region).

IPM determines the amount and type of new generation capacity to add within each of the 67 U.S. IPM model regions. The model regions reflect the administrative, operational, and transmission geographic structure of the U.S. electricity grid. Since new plants could be located at various locations within a region, a generic transportation cost for different coal types is developed for these new plants. The methodology for deriving that cost is described in Section 7.3.

7.1.3 Coal Quality Characteristics

Coal varies by heat content, SO_2 content, HCl content, and mercury content, among other characteristics. A two-letter coal grade nomenclature is used to capture differences in the sulfur and heat content of coal. The first letter indicates the coal rank (i.e., bituminous, subbituminous, or lignite) with their associated heat content ranges (as shown in Table 7-2). The second letter indicates their sulfur grade, (i.e., the SO_2 ranges associated with a given type of coal). The sulfur grades and associated SO_2 ranges are shown in Table 7-3.

Table 7-2 Coal Rank Heat Content Ranges

Coal Type	Heat Content (Btu/lb)	Classification
Bituminous	>10,260 – 13,000	B
Subbituminous	> 7,500 – 10,260	S
Lignite	less than 7,500	L

Table 7-3 Coal Grade SO_2 Content Ranges

SO_2 Grade	SO_2 Content Range (lbs/MMBtu)
A	0.00 – 0.80
B	0.81 – 1.20
D	1.21 – 1.66
E	1.67 – 3.34
G	3.35 – 5.00
H	> 5.00

The EPA 2023 Reference Case assumptions on the heat, HCl, mercury, SO_2, and ash contents of coal are derived from EPA's Information Collection Request for Electric Utility Steam Generating Unit Mercury Emissions Information Collection Effort (ICR).[64]

A two-year effort initiated in 1998 and completed in 2000, the ICR had three main components: (1) identifying all coal-fired units owned and operated by publicly-owned utility companies, federal power agencies, rural electric cooperatives, and investor-owned utility generating companies, (2) obtaining "accurate information on the amount of mercury contained in the as-fired coal used by each electric utility steam generating unit with a capacity greater than 25 megawatts electric, as well as accurate information on the total amount of coal burned by each such unit,", and (3) obtaining data by coal sampling and stack testing at selected units to characterize mercury reductions from representative unit configurations. Data regarding the coal's SO_2, chlorine, and ash contents was obtained along with mercury content. The ICR captured the origin of the coal burned and thus provided a pathway for linking emission properties to coal basins.

The 1998-2000 ICR resulted in more than 40,000 data points indicating the coal type, sulfur content, mercury content, ash content, chlorine content, and other characteristics of coal burned at coal-fired utility boilers greater than 25 MW.

Annual fuel characteristic and delivery data reported on EIA Form 923 also provide data points on coal heat content, sulfur content, and geographic origin, which are used to check against characteristics initially identified through the ICR.

7.1.4 Coal Emission Factors

To make the data usable in EPA 2023 Reference Case, the ICR data points were first grouped by IPM coal grades and IPM coal supply regions. Using the grouped ICR data, the average heat, SO_2, mercury, HCl, and ash contents were calculated for each coal grade and supply region combination. In instances where no data was available for a particular coal grade in a specific supply region, the national average SO_2 and mercury values for the coal grade were used. The coal characteristics of Canadian coal supply regions are based on the coal characteristics of the adjacent U.S. coal supply regions. The resulting values are shown in Table 7-4. The CO_2 values were derived from data in the Energy Information Administration's Annual Energy Outlook 2016.

[64] Data from the ICR can be found at http://www.epa.gov/ttn/atw/combust/utiltox/mercury.html

Table 7-4 Coal Quality Characteristics by Supply Region and Coal Grade in the EPA 2023 Reference Case

Coal Supply Region	Coal Grade	SO_2 Content (lbs/MMBtu)	Mercury Content (lbs/TBtu)	Ash Content (lbs/MMBtu)	HCl Content (lbs/MMBtu)	CO_2 Content (lbs/MMBtu)	Cluster Number
AB	SA	0.59	5.29	5.47	0.009	215.5	1
	SB	0.94	6.06	6.94	0.013	215.5	4
	SD	1.43	5.35	11.60	0.008	215.5	1
AK	SA	0.59	5.29	5.47	0.009	216.1	1
AL	BB	1.09	4.18	9.76	0.012	204.7	4
	BD	1.35	7.28	10.83	0.029	204.7	1
	BE	2.68	12.58	10.70	0.028	204.7	1
AZ	BB	1.05	5.27	7.86	0.067	207.1	2
BC	BD	1.40	6.98	8.34	0.096	216.1	3
CG	BB	0.90	4.09	8.42	0.021	209.6	4
	SB	0.93	2.03	7.06	0.007	212.8	1
CR	BB	1.05	5.27	7.86	0.067	209.6	2
CU	BB	0.86	4.01	7.83	0.009	209.6	4
IL	BE	2.25	6.52	6.61	0.214	203.1	2
	BG	4.56	6.53	8.09	0.113	203.1	3
	BH	5.58	5.43	9.06	0.103	203.1	1
IN	BE	2.31	5.21	7.97	0.036	203.1	3
	BG	4.27	7.20	8.22	0.028	203.1	3
	BH	6.15	7.11	8.63	0.019	203.1	3
KE	BB	1.04	4.79	6.41	0.112	206.4	5
	BD	1.44	5.97	7.45	0.087	206.4	2
	BE	2.12	7.93	7.71	0.076	206.4	4
KW	BG	4.46	6.90	8.01	0.097	203.1	3
	BH	5.73	8.16	10.21	0.053	203.1	3
LA	LE	2.49	7.32	17.15	0.014	212.6	1
MD	BE	2.78	15.62	11.70	0.072	204.7	5
	BG	3.58	16.64	16.60	0.018	204.7	5
ME	LE	1.83	11.33	11.69	0.019	219.3	2
MP	SA	0.62	4.24	3.98	0.007	215.5	1
	SD	1.49	4.53	10.13	0.006	215.5	1
MS	LE	2.76	12.44	21.51	0.018	216.5	3
MT	BB	1.05	5.27	7.86	0.067	215.5	2
ND	LE	2.27	8.30	12.85	0.014	219.3	1
NS	SB	0.89	4.60	14.51	0.014	209.2	2
	SD	1.55	7.54	23.09	0.007	209.2	2
	SE	1.90	8.65	23.97	0.008	209.2	1
OH	BE	3.08	18.70	7.08	0.075	204.7	6
	BG	3.99	18.54	8.00	0.071	204.7	5
	BH	6.43	13.93	9.13	0.058	204.7	4
OK	BG	4.65	26.07	13.54	0.051	202.8	4
PC	BE	2.57	17.95	9.23	0.096	204.7	6
	BG	3.79	21.54	9.59	0.092	204.7	2
	BH	6.29	34.71	13.89	0.148	204.7	5
PW	BE	2.51	8.35	5.37	0.090	204.7	4
	BG	3.69	8.56	6.48	0.059	204.7	1
	BH	7.78	16.46	11.56	0.046	204.7	2
SK	LD	1.51	7.53	11.57	0.014	219.3	1

Coal Supply Region	Coal Grade	SO_2 Content (lbs/MMBtu)	Mercury Content (lbs/TBtu)	Ash Content (lbs/MMBtu)	HCl Content (lbs/MMBtu)	CO_2 Content (lbs/MMBtu)	Cluster Number
	LE	2.76	12.44	21.51	0.018	219.3	3
TN	BB	1.14	3.78	10.35	0.083	206.4	3
	BE	2.13	8.43	6.47	0.043	206.4	4
TX	LE	3.00	14.65	25.65	0.020	212.6	4
	LG	3.91	14.88	25.51	0.036	212.6	1
	LH	5.67	30.23	23.95	0.011	212.6	1
UT	BA	0.67	4.37	7.39	0.015	209.6	1
	BB	0.94	3.93	8.58	0.016	209.6	4
	BD	1.37	4.38	10.50	0.026	209.6	3
	BE	2.34	9.22	7.41	0.095	209.6	4
VA	BB	1.05	4.61	6.97	0.054	206.4	5
	BD	1.44	5.67	7.97	0.028	206.4	2
	BE	2.09	8.40	8.05	0.028	206.4	4
WG	BB	1.13	1.82	5.58	0.005	214.3	3
	SB	1.06	4.22	8.72	0.009	214.3	3
	SD	1.33	4.33	10.02	0.008	214.3	1
WH	SA	0.52	5.61	5.51	0.010	214.3	2
WL	SA	0.71	5.61	7.09	0.010	214.3	3
	SB	0.93	6.44	7.92	0.012	214.3	4
WN	BE	2.55	10.28	7.89	0.092	204.7	7
	BH	6.09	8.82	9.62	0.045	204.7	3
WS	BB	1.09	5.75	9.15	0.091	206.4	1
	BD	1.32	8.09	9.25	0.098	206.4	4
	BE	1.94	8.83	9.89	0.102	206.4	4

Next, a clustering algorithm was used to further aggregate the data for model size management purposes. Using the SAS statistical software package, the clustering analysis was performed on the SO_2, mercury, and HCl content data shown in Table 7-4. Clustering analysis places objects into groups or clusters such that data in a given cluster tend to be similar to each other and dissimilar to data in other clusters. The clustering analysis involved two steps. First, the number of clusters of SO_2, mercury, and HCl contents for each coal grade was determined based on the range in SO_2, mercury, and HCl contents across all coal supply regions. Each coal grade used one to seven clusters. The number of clusters for each coal grade was limited to keep the model size and run time within acceptable limits. Second, for each coal grade, the clustering procedure was applied to all the regional SO_2, mercury, and HCl contents shown in Table 7-4. Using the SAS cluster procedure, each of the constituent regional contents was assigned to a cluster, and the cluster average SO_2, mercury, and HCl contents were estimated. The resulting contents are shown in Table 7-5 through Table 7-9.

Table 7-5 Coal Clustering by Coal Grade – SO_2 Emission Factors (lbs/MMBtu)

Coal Type by Sulfur Grade	SO_2 Emission Factors (lbs/MMBtu)																				
	Cluster #1			Cluster #2			Cluster #3			Cluster #4			Cluster # 5			Cluster # 6			Cluster # 7		
	Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range	
		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High
Low Sulfur Bituminous (BA)	0.67	0.67	0.67	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Bituminous (BB)	1.10	1.09	1.10	1.05	1.05	1.05	1.14	1.13	1.14	0.95	0.86	1.09	1.04	1.04	1.05	--	--	--	--	--	--
Low Medium Sulfur Bituminous (BD)	1.35	1.35	1.35	1.44	1.44	1.44	--	--	--	1.39	1.37	1.40	1.32	1.32	1.32	--	--	--	--	--	--
Medium Sulfur Bituminous (BE)	2.68	2.68	2.68	2.25	2.25	2.25	2.31	2.31	2.31	2.19	1.94	2.51	2.78	2.78	2.78	2.82	2.57	3.08	2.55	2.55	2.55
High Sulfur Bituminous (BG)	3.69	3.69	3.69	3.79	3.79	3.79	4.43	4.27	4.56	--	--	--	--	--	--	4.65	4.65	4.65	3.78	3.58	3.99
High Sulfur Bituminous (BH)	5.58	5.58	5.58	7.78	7.78	7.78	5.99	5.73	6.15	6.43	6.43	6.43	6.29	6.29	6.29	--	--	--	--	--	--
Low Sulfur Subbituminous (SA)	0.60	0.59	0.62	0.52	0.52	0.52	0.71	0.71	0.71	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Subbituminous (SB)	0.93	0.93	0.93	--	--	--	0.89	0.89	0.89	1.06	1.06	1.06	0.94	0.93	0.94	--	--	--	--	--	--
Low Medium Sulfur Subbituminous (SD)	1.42	1.33	1.49	1.55	1.55	1.55	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Subbituminous (SE)	1.90	1.90	1.90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Medium Sulfur Lignite (LD)	1.51	1.51	1.51	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Lignite (LE)	2.38	2.27	2.49	1.83	1.83	1.83	2.76	2.76	2.76	3.00	3.00	3.00	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LG)	3.91	3.91	3.91	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LH)	5.67	5.67	5.67	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7-6 Coal Clustering by Coal Grade – Mercury Emission Factors (lbs/TBtu)

Coal Type by Sulfur Grade	Mercury Emission Factors (lbs/TBtu)																				
	Cluster #1			Cluster #2			Cluster #3			Cluster #4			Cluster # 5			Cluster # 6			Cluster # 7		
	Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range	
		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High
Low Sulfur Bituminous (BA)	4.37	4.37	4.37	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Bituminous (BB)	6.74	5.75	7.74	5.27	5.27	5.27	2.80	1.82	3.78	4.05	3.93	4.18	4.70	4.61	4.79	--	--	--	--	--	--
Low Medium Sulfur Bituminous (BD)	7.28	7.28	7.28	5.82	5.67	5.97	--	--	--	5.68	4.38	6.98	8.09	8.09	8.09	--	--	--	--	--	--
Medium Sulfur Bituminous (BE)	12.58	12.58	12.58	6.52	6.52	6.52	5.21	5.21	5.21	8.53	7.93	9.22	15.62	15.62	15.62	18.33	17.95	18.70	10.28	10.28	10.28
High Sulfur Bituminous (BG)	8.56	8.56	8.56	21.54	21.54	21.54	6.88	6.53	7.20	--	--	--	--	--	--	26.07	26.07	26.07	17.59	16.64	18.54
High Sulfur Bituminous (BH)	5.43	5.43	5.43	16.46	16.46	16.46	8.03	7.11	8.82	13.93	13.93	13.93	34.71	34.71	34.71	--	--	--	--	--	--
Low Sulfur Subbituminous (SA)	4.94	4.24	5.29	5.61	5.61	5.61	5.61	5.61	5.61	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Subbituminous (SB)	2.03	2.03	2.03	--	--	--	4.60	4.60	4.60	4.22	4.22	4.22	6.25	6.06	6.44	--	--	--	--	--	--
Low Medium Sulfur Subbituminous (SD)	4.74	4.33	5.35	7.54	7.54	7.54	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Subbituminous (SE)	8.65	8.65	8.65	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Medium Sulfur Lignite (LD)	7.53	7.53	7.53	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Lignite (LE)	7.81	7.32	8.30	11.33	11.33	11.33	12.44	12.44	12.44	14.65	14.65	14.65	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LG)	14.88	14.88	14.88	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LH)	30.23	30.23	30.23	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7-7 Coal Clustering by Coal Grade – Ash Emission Factors (lbs/MMBtu)

Coal Type by Sulfur Grade	Ash Emission Factors (lbs/MMBtu)																				
	Cluster #1			Cluster #2			Cluster #3			Cluster #4			Cluster # 5			Cluster # 6			Cluster # 7		
	Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range	
		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High
Low Sulfur Bituminous (BA)	7.39	7.39	7.39	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Bituminous (BB)	6.98	4.81	9.15	7.86	7.86	7.86	7.97	5.58	10.35	8.65	7.83	9.76	6.69	6.41	6.97	--	--	--	--	--	--
Low Medium Sulfur Bituminous (BD)	10.83	10.83	10.83	7.71	7.45	7.97	--	--	--	9.42	8.34	10.50	9.25	9.25	9.25	--	--	--	--	--	--
Medium Sulfur Bituminous (BE)	10.70	10.70	10.70	6.61	6.61	6.61	7.97	7.97	7.97	7.48	5.37	9.89	11.70	11.70	11.70	8.16	7.08	9.23	7.89	7.89	7.89
High Sulfur Bituminous (BG)	6.48	6.48	6.48	9.59	9.59	9.59	8.10	8.01	8.22	--	--	--	--	--	--	13.54	13.54	13.54	12.30	8.00	16.60
High Sulfur Bituminous (BH)	9.06	9.06	9.06	11.56	11.56	11.56	9.49	8.63	10.21	9.13	9.13	9.13	13.89	13.89	13.89	--	--	--	--	--	--
Low Sulfur Subbituminous (SA)	4.97	3.98	5.47	5.51	5.51	5.51	7.09	7.09	7.09	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Subbituminous (SB)	7.06	7.06	7.06	--	--	--	14.51	14.51	14.51	8.72	8.72	8.72	7.43	6.94	7.92	--	--	--	--	--	--
Low Medium Sulfur Subbituminous (SD)	10.58	10.02	11.60	23.09	23.09	23.09	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Subbituminous (SE)	23.97	23.97	23.97	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Medium Sulfur Lignite (LD)	11.57	11.57	11.57	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Lignite (LE)	15.00	12.85	17.15	11.69	11.69	11.69	21.51	21.51	21.51	25.65	25.65	25.65	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LG)	25.51	25.51	25.51	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LH)	23.95	23.95	23.95	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7-8 Coal Clustering by Coal Grade – HCl Emission Factors (lbs/MMBtu)

Coal Type by Sulfur Grade	HCl Emission Factors (lbs/MMBtu)																				
	Cluster #1			Cluster #2			Cluster #3			Cluster #4			Cluster # 5			Cluster # 6			Cluster # 7		
	Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range	
		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High
Low Sulfur Bituminous (BA)	0.015	0.015	0.015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Bituminous (BB)	0.054	0.018	0.091	0.067	0.067	0.067	0.044	0.005	0.083	0.015	0.009	0.021	0.083	0.054	0.112	--	--	--	--	--	--
Low Medium Sulfur Bituminous (BD)	0.029	0.029	0.029	0.057	0.028	0.087	--	--	--	0.061	0.026	0.096	0.098	0.098	0.098	--	--	--	--	--	--
Medium Sulfur Bituminous (BE)	0.028	0.028	0.028	0.214	0.214	0.214	0.036	0.036	0.036	0.072	0.028	0.102	0.072	0.072	0.072	0.085	0.075	0.096	0.092	0.092	0.092
High Sulfur Bituminous (BG)	0.059	0.059	0.059	0.092	0.092	0.092	0.079	0.028	0.113	--	--	--	--	--	--	0.051	0.051	0.051	0.045	0.018	0.071
High Sulfur Bituminous (BH)	0.103	0.103	0.103	0.046	0.046	0.046	0.039	0.019	0.053	0.058	0.058	0.058	0.148	0.148	0.148	--	--	--	--	--	--
Low Sulfur Subbituminous (SA)	0.008	0.007	0.009	0.010	0.010	0.010	0.010	0.010	0.010	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Subbituminous (SB)	0.007	0.007	0.007	--	--	--	0.014	0.014	0.014	0.009	0.009	0.009	0.013	0.012	0.013	--	--	--	--	--	--
Low Medium Sulfur Subbituminous (SD)	0.007	0.006	0.008	0.007	0.007	0.007	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Subbituminous (SE)	0.008	0.008	0.008	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Medium Sulfur Lignite (LD)	0.014	0.014	0.014	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Lignite (LE)	0.014	0.014	0.014	0.019	0.019	0.019	0.018	0.018	0.018	0.020	0.020	0.020	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LG)	0.036	0.036	0.036	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LH)	0.011	0.011	0.011	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 7-9 Coal Clustering by Coal Grade – CO_2 Emission Factors (lbs/MMBtu)

Coal Type by Sulfur Grade	CO_2 Emission Factors (lbs/MMBtu)																				
	Cluster #1			Cluster #2			Cluster #3			Cluster #4			Cluster # 5			Cluster # 6			Cluster # 7		
	Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range		Cluster Value	Data Range	
		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High		Low	High
Low Sulfur Bituminous (BA)	209.6	209.6	209.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Bituminous (BB)	206.8	206.4	207.1	210.7	207.1	215.5	210.4	206.4	214.3	208.4	204.7	209.6	206.4	206.4	206.4	--	--	--	--	--	--
Low Medium Sulfur Bituminous (BD)	204.7	204.7	204.7	206.4	206.4	206.4	--	--	--	212.9	209.6	216.1	206.4	206.4	206.4	--	--	--	--	--	--
Medium Sulfur Bituminous (BE)	204.7	204.7	204.7	203.1	203.1	203.1	203.1	203.1	203.1	206.7	204.7	209.6	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7
High Sulfur Bituminous (BG)	204.7	204.7	204.7	204.7	204.7	204.7	203.1	203.1	203.1	--	--	--	--	--	--	202.8	202.8	202.8	204.7	204.7	204.7
High Sulfur Bituminous (BH)	203.1	203.1	203.1	204.7	204.7	204.7	203.6	203.1	204.7	204.7	204.7	204.7	204.7	204.7	204.7	--	--	--	--	--	--
Low Sulfur Subbituminous (SA)	215.7	215.5	216.1	214.3	214.3	214.3	214.3	214.3	214.3	--	--	--	--	--	--	--	--	--	--	--	--
Low Sulfur Subbituminous (SB)	212.8	212.8	212.8	--	--	--	209.2	209.2	209.2	214.3	214.3	214.3	214.9	214.3	215.5	--	--	--	--	--	--
Low Medium Sulfur Subbituminous (SD)	215.1	214.3	215.5	209.2	209.2	209.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Subbituminous (SE)	209.2	209.2	209.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Low Medium Sulfur Lignite (LD)	219.3	219.3	219.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Medium Sulfur Lignite (LE)	216.0	212.6	219.3	219.3	219.3	219.3	217.9	216.5	219.3	212.6	212.6	212.6	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LG)	212.6	212.6	212.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
High Sulfur Lignite (LH)	212.6	212.6	212.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

7.1.5 Coal Grade Assignments

The grades of coal that may be used by specific generating units were determined by an expert assessment of the ranks of coal that a unit had used in the past, the removal efficiency of the installed FGD, and the SO_2 permit rate of the unit. Examples of the coal grade assignments made for individual plants in EPA 2023 Reference Case are shown in Table 7-10. Not all the coal grades allowed to a plant by the coal grade assignment are necessarily available in the plant's assigned coal demand region (due to transportation limitations). IPM endogenously selects the coal consumed by a plant by considering both the constraint of the plant's coal grade assignment and the constraint of the coals available within a plant's coal demand region.

Table 7-10 Example of Coal Assignments Made in the EPA 2023 Reference Case

Plant Name	Unit	Permit Rate (lbs/MMBtu)	Scrubber?	Fuels Allowed
Mt Storm	3	0.15	Yes	BA, BB, BD
Mitchell	1	1.2	Yes	BA, BB, BD, BE, BG, BH
Scherer	1	1.2	Yes	SA, SB, SD, SE
Limestone	LIM1	0.6	Yes	LD, LE, LG, LH, SA, SB, SD, SE
San Miguel	SM-1	1.2	Yes	LD, LE, LG, LH

7.2 Coal Supply Curves

7.2.1 Nature of Supply Curves Developed for EPA 2023 Reference Case

In keeping with IPM's data-driven bottom-up modeling framework, a bottom-up approach (relying heavily on detailed economic and resource geology data and assessments) was used to prepare the thermal coal supply curves for EPA 2023 Reference Case.[65] EPA utilized Wood Mackenzie to develop the curves based on their extensive experience in preparing mine-by-mine estimates of cash operating costs for operating mines in the U.S., their access to both public and proprietary data sources, and their active updating of the data through research and interviews.

In order to establish consistent nomenclature, Wood Mackenzie first mapped its internal list of coal regions and qualities to EPA's 34 coal supply regions (described above in section 7.1.1) and the 14 coal rank/grade combinations (described above in section 7.1.3). The combined code list is shown in Table 7-11 below, with the IPM coal supply regions appearing in the rows and the coal grades in the columns. Wood Mackenzie then created supply curves for each region and coal-grade combination (indicated by the "x" in Table 7-11) for forecast years 2023, 2025, 2028, 2030, 2035, 2040, 2045, and 2050.

Table 7-11 Basin-Level Groupings Used in Preparing the EPA 2023 Reference Case Coal Supply Curves

			Bituminous						Lignite				Subbituminous			
Coal Supply Region	Geo Region	Geo. Sub-Region	BA	BB	BD	BE	BG	BH	LD	LE	LG	LH	SA	SB	SD	SE
AB	Canada	Alberta, Canada											x	x	x	
AK	Alaska	Alaska											x			
AL	Appalachia	Southern Appalachia		x	x	x										
AZ	West	Southwest		x												

[65] These coal supply curves are initialized for the start year of 2023. Since the first run year in the EPA 2023 Base Case is 2028, the resource base underlying the coal supply curves is depleted for the expected coal produced during the 2023-2027 period. The depletion amount is calculated as five times the coal consumed by the power sector in 2022 per the 2022 EIA Form 923.

			Bituminous						Lignite				Subbituminous			
Coal Supply Region	Geo Region	Geo. Sub-Region	BA	BB	BD	BE	BG	BH	LD	LE	LG	LH	SA	SB	SD	SE
BC	Canada	British Columbia			x											
CG	West	Rocky Mountain		x										x		
CR	West	Rocky Mountain		x												
CU	West	Rocky Mountain		x												
IL	Interior	East Interior (Illinois Basin)				x	x	x								
IN	Interior	East Interior (Illinois Basin)				x	x	x								
KE	Appalachia	Central Appalachia		x	x	x										
KW	Interior	East Interior (Illinois Basin)					x	x								
LA	Interior	Gulf Lignite								x						
MD	Appalachia	Northern Appalachia				x	x									
ME	West	Dakota Lignite								x						
MP	West	Powder River Basin											x		x	
MS	Gulf	Gulf Lignite Coast								x						
MT	West	Western Montana		x												
ND	West	Dakota Lignite								x						
NS	West	Southwest												x	x	x
OH	Appalachia	Northern Appalachia				x	x	x								
OK	West	West Interior					x									
PC	Appalachia	Northern Appalachia				x	x	x								
PW	Appalachia	Northern Appalachia				x	x	x								
SK	Canada	Saskatchewan							x	x						
TN	Appalachia	Central Appalachia		x		x										
TX	Interior	Gulf Lignite								x	x	x				
UT	West	Rocky Mountain	x	x	x	x										
VA	Appalachia	Central Appalachia		x	x	x										
WG	West	Western Wyoming		x										x	x	
WH	West	Powder River Basin											x			
WL	West	Powder River Basin											x	x		
WN	Appalachia	Northern Appalachia				x		x								
WS	Appalachia	Central Appalachia		x	x	x										

7.2.2 Cost Components in the Supply Curves

Costs are represented as total cash costs, which is a combination of a mine's operating cash costs plus royalty & levies. These costs are estimated on a Free on Board (FOB) basis at the point of sale. Capital costs (either expansionary or sustaining) are not included in the cash cost estimate for existing mines. For projects, the expansionary capital is spread across the mine life and included in the costs. The total cash cost is the best metric for the supply curves as coal prices tend to be ultimately determined by the incremental cost of production (i.e., total cash cost).

Operating cash cost

These are the direct operating cash costs and include, where appropriate, mining, coal preparation, product transport, and overheads. No capital cost component or depreciation & amortization charge is included for operating mines. Expansionary capital is included for new greenfield projects. Operating cash costs consist of the following elements:

Mining costs - Mining costs are the direct cost of mining coal and associated waste material for surface and underground operations. It includes any other mine site costs, such as ongoing rehabilitation / reclamation, security, community development costs. It also includes the cost of transporting raw coal from the mining location to the raw coal stockpile at the coal preparation plant.

Coal preparation - The cost of coal preparation includes raw coal stockpile reclaim, crushing and screening, washing and marketable coal product stockpiling (if applicable).

Transport - This covers all transport costs of product coal to point of sale. Transport routes with multiple modes (e.g., truck and rail) are shown as total cost per marketable ton for all stages of the transport route. Loading charges are included in this cost if relevant.

Overheads - This is any non-production related general and administration overheads that are essential to the production and sale of a mine's coal product. Examples would be mine site staff not related to mining, essential corporate management or a sales and marketing charge.

It is important to note that although the formula for calculating mine costs is consistent across regions, some tax rates and fees vary by state and mine type. In general, there are two mine types: underground (deep) or surface mines. Underground mining is categorized as being either a longwall (LW) or a continuous room-and-pillar mine (CM). Geologic conditions and characteristics of the coal seams determine which method will be used. Surface mines are typically categorized by the type of mining equipment used in their operation such as draglines (DL), or truck & shovels (TS). These distinctions are important because the equipment used by the mine affects productivity measures and ultimately mine costs. Further information on operating cost methodology and assumptions can be found in Attachment 7-1.

Royalties and Levies

These include, where appropriate, coal royalties, mine safety levies, health levies, industry research levies and other production taxes. These taxes, fees and levies vary on a regional basis.

7.2.3 Procedures Employed in Determining Mining Costs

The total cash costs of mines have been estimated in current year terms using public domain information including; geological reports, reported statistics on production, labor and input costs, and company reports. The estimates have been validated by reference to information gained by visits to operations, and discussions with industry participants.

Because the estimates are based only on public information and analysis, and do not represent private knowledge of an operation's actual costs, there may be deviations from actual costs. In instances where confidential information is held by Wood Mackenzie, it has not been used to produce the published estimates. Several methods are employed for cost estimation depending on the availability of information and the diversity of mining operations. When possible, Wood Mackenzie analysts developed detailed lists of mine-related costs. Costs such as employee wages & benefits, diesel fuel, spare parts, roof bolts, and explosives among a host of others are summed to form a mine's operating cash costs.

Where information is incomplete, cost items are grouped into categories that can be compared with industry averages by mine type and location. These averages can be adjusted up or down based on new information or added assumptions. The adjustments take the form of cost multipliers or parameter values. Specific cost multipliers are developed with the aid of industry experts and proprietary formulas. This method is at times used to convert materials and supplies, on-site trucking costs and mine and division overhead categories into unit removal costs by equipment type. To check the accuracy of these cost estimates, cash flow analysis of publicly traded companies is used. Mine cash-costs are extracted from corporate cash flows and compared with the initial estimates. Adjustments for discrepancies are made on a case-by-case basis.

Many of the cost assumptions associated with labor and productivity were taken from the Mine Safety Health Administration (MSHA) database. All active mines report information specific to production levels, number of employees and employee hours worked. Wood Mackenzie supplements the basic MSHA data with information obtained from mine personnel interviews and industry contacts. Phone conversations and conferences with industry professionals provide additional non-reported information such as work schedules, equipment types, percentages of washed coal, and trucking distances from the mine to wash-plants and load-out terminals.

For each active or proposed mine, Wood Mackenzie reports the estimated cost to take coal from the mine to a logical point-of-sale. The logical point-of-sale may be a truck or railcar load-out or even a barge facility. This is done to produce a consistent cost comparison between mines. Any transport costs beyond the point-of-sale terminal are not part of this analysis and are not reflected in the supply curves themselves.

7.2.4 Procedure Used in Determining Mine Productivity

Projected production and stripping ratios are the key determinants of surface mine productivity. Wood Mackenzie assumes mining costs increase as stripping ratios increase. The stripping ratio is the quantity of overburden removed relative to the quantity of coal recovered. Assuming that reserves are developed where they are easiest to mine and deliver to market, general theory suggests that as the easy reserves are depleted, greater amounts of overburden must be handled for the same amount of coal production; thus causing a decrease in mining productivity. However, some productivity loss may be offset by technological improvements in labor saving equipment.

In order to calculate the amount of employee hours, and therefore the labor cost, of future production Wood Mackenzie uses a multi-step process. First, employee hours associated with coal production for each mine are obtained from MSHA. Total production is then divided by these hours to calculate productivity, measured in short tons per employee hour. Future production levels are divided by this productivity measurement to obtain future employee hours needed to produce that volume of coal. From there, the total staffing level can be determined, and the associated cost calculated.

A similar approach is used for underground mines. First, as background, the specific factors affecting productivity at such mines are identified. For example, underground mines do not have stripping ratios. Productivity estimates for these mines largely depend on the type of mining technique used (which is a function of the region's geology). For instance, longwall-mines can produce a high volume of low-cost coal but geologic constraints like small reserve blocks and the occurrence of faulting tends to limit this technique to certain regions. In addition to geologic constraints, there are variables that can impact underground-mine productivity that are often difficult to quantify and forecast.

7.2.5 Procedure to Determine Total Recoverable Reserves by Region and Type

Before mine operators are allowed to mine coal, they must request various permits, conduct environmental impact studies (EIS) and, in many cases, notify corporate shareholders. In each of these instances, mine operators are asked to estimate annual production and total recoverable reserves. Wood

Mackenzie uses the mine operators' statements as the starting point for production and reserves forecasts. If no other material is available, interviews with company personnel will provide an estimate.

Region and coal type determinations for unlisted reserves are based on public information reported for similarly located mines. Classifying reserves this way means considering not only a mine's geographic location but also its geologic conditions such as depth and type of overburden and the specific identity of the coal seam(s) being mined. For areas where public information is not available or is incomplete, Wood Mackenzie engineers and geologists estimate reserve amounts based on land surveys and reports of coal depth and seam thickness provided by the U.S. Geologic Service (USGS). This information is then used to extrapolate reserve estimates from known coal sources to unknown sources. Coal quality determinations for unknown reserves are assigned in much the same way.

Once a mine becomes active, actual production numbers reported in corporate SEC filings and MSHA reports are subtracted from the total reserve number to arrive at current reserve amounts. Wood Mackenzie consistently updates the reserves database when announcements of new or amended reserves are made public. As a final check, the Wood Mackenzie supply estimates are balanced against the Demonstrated Reserve Base (DRB)[66] estimates to ensure that they do not exceed the DRB estimates.

7.2.6 New Mine Assumptions

New mines have been included based on information that Wood Mackenzie maintains on each supply region. They include announced projects, coal lease applications and unassigned reserves reported by mining companies. Where additional reserves are known to exist, additional incremental steps have been added and designated with the letter "N" in the "Step Name" field of the supply curves. These incremental steps were added based on characteristics of the specific region, typical mine size, and cost trends. They do not necessarily imply a specific mine or mine type.

Wood Mackenzie has also identified technical coal reserves that may be commercial in the longer-term, but would most likely not be developed until after the completion of mine development already underway or announced. These reserves are often the "last step" in a coal supply curve due to the more difficult geologic conditions and have been designated using the above methodology.

In addition to new mines, Wood Mackenzie also identifies extension mines. These are denoted with the letter "A", "B", "C" or "D" at the end of an existing mine step name (e.g., E2A). These mine steps reflect the extension of a particular mine operating through a new lease covering tracts not previously recoverable under the existing mine operation. These mine expansions, like new mines, include the capital expansionary component in their cost of production.

7.2.7 Other Notable Procedures

<u>Currency Assumptions</u>

For consistency with the cost basis used in EPA 2023 Reference Case, costs are converted to real 2019$.

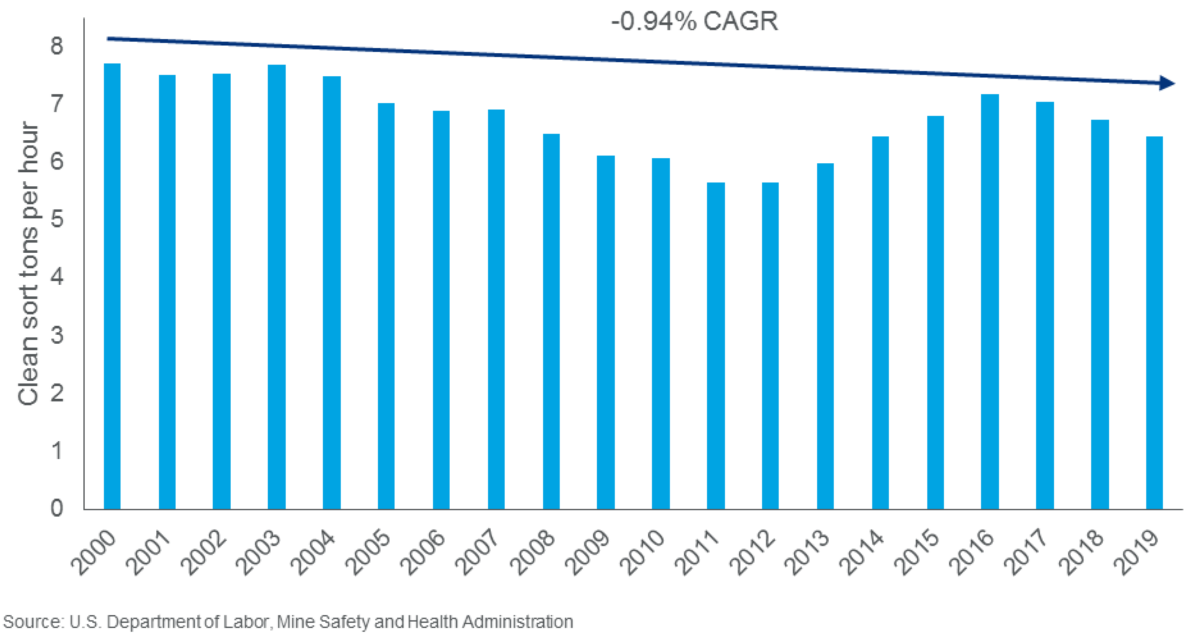
<u>Future Cost Adjustments</u>

Changes in mine productivity are a key factor impacting the evolution of costs over time. In general, mine productivity is expected to continue to decline – in large part due to worsening geology and more difficult

[66] Posted by the Energy Information Administration (EIA) in its Coal Production Report.

to mine reserves. Productivity has declined at a -0.94% compound annual growth rate (CAGR) from 2000-2019 as shown in Figure 7-2.

Figure 7-2 Coal Mine Productivity (2000-2019)



Source: U.S. Department of Labor, Mine Safety and Health Administration

Figure 7-3 Average Annual Cost Growth Assumptions by Region (2021-2050)

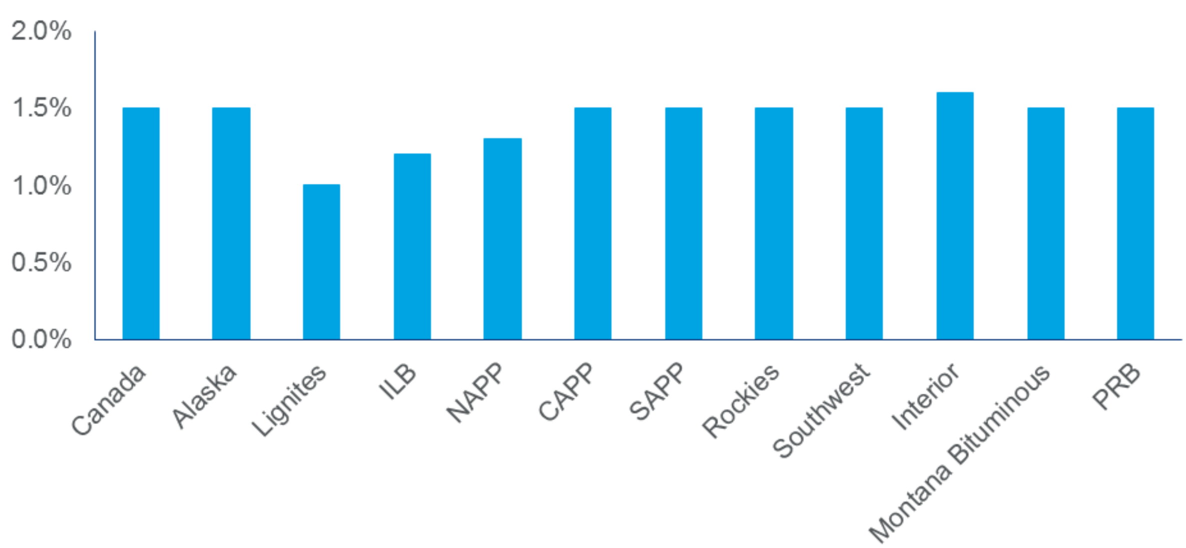


Figure 7-3 shows the compounded average annual growth rate (CAGR) of mining costs by basin over the forecast period. It should be noted that cost increases would ultimately be linked to market demand (as demand grows, the faster the rate of depletion of lower cost reserves). Costs in some supply basins are expected to increase more quickly than others due to issues such as mining conditions, productivity, infrastructure limitations, etc. Region-specific information can be found in section 7.2.9.

Supply Growth Limitations

To the maximum extent possible, the IPM model is set up to determine the optimal volume of coal supply which can be profitably supplied. For two of the lower-cost basins (Powder River and Illinois basins), maximum production capacities are included as constraints (production ceilings) to reflect more accurately the upper bound of what could be produced in a given year. Those limits, represented in millions of tons per year, are shown in Figure 7-4. While not binding in EPA's reference case, these ceilings are necessary to guard against modeling excess annual production capacity in certain basins under sensitivity scenarios. For instance, in the PRB, several of the "new" mines reflect expansion mines that would not be developed until the initial mine is further depleted. In this case, the production ceiling helps safeguard against a modeling scenario that would simultaneously produce from both of these mines.

Figure 7-4 Maximum Annual Coal Production Capacity per Year (Million Short Tons)

	2023	2025	2028	2030	2035	2040	2045	2050
ILB	200	220	240	240	240	240	240	240
PRB	500	520	560	560	600	600	600	600

7.2.8 Cumulative Supply Curve Development

The description below describes the depicts the cumulative supply curve. Table 7-26 shows the actual coal supply curves.

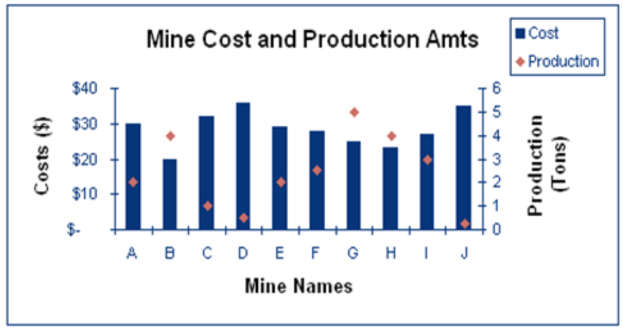
Once costs are estimated for all new or existing mines, they are sorted by cash cost, lowest to highest, and plotted cumulatively by production to form a supply curve. The supply curve then represents all mines – new or existing as well as both underground and surface mines– irrespective of market demand. Mines located toward the bottom of the curve have the lowest cost and are most likely to be developed while the mines at the top of the curve are higher cost and will likely wait to be developed. The process for developing a cumulative supply curve is illustrated in Figure 7-5 and Figure 7-6.

Figure 7-5 Illustration of Preliminary Step in Developing a Cumulative Coal Supply Curve

Key

E = EXISTING MINE
N = NEW MINE
U = UNDERGROUND MINE
S = SURFACE MINE

New or Existing?	Mine	Type	Cost	Production
N	A	S	$ 30	2
E	B	U	$ 20	4
N	C	S	$ 32	1
N	D	S	$ 36	0.5
E	E	S	$ 29	2
N	F	S	$ 28	2.5
E	G	U	$ 25	5
E	H	U	$ 23	4
E	I	U	$ 27	3
N	J	S	$ 35	0.25



In the table and graph above, mine costs and production are sorted alphabetically by mine name. To develop a supply curve from the above table, the values must be sorted by mine costs from lowest to highest. A new column for cumulative production is added, and then a supply curve graph is created, which shows the costs on the 'Y' axis and the cumulative production on the 'X' axis. Notice below that the curve contains all mines – new or existing as well as underground and surface mines. The resulting curve is a continuous supply curve but can be modified to show costs as a stepped supply curve. (Supply curves in stepped format are used in linear programming models like IPM.) See Figure 7-7 for a stepped version of the supply curve example shown in Figure 7-6. Here, each step represents an individual mine, the width of the step reflects the mine's production, and its height shows the cost of production.

Figure 7-6 Illustration of Final Step in Developing a Cumulative Coal Supply Curve

New or Existing?	Mine	Type	Cost	Production	Cum Productio
E	B	U	$ 20	4	4
E	H	U	$ 23	4	8
E	G	U	$ 25	5	13
E	I	U	$ 27	3	16
N	F	S	$ 28	2.5	18.5
E	E	S	$ 29	2	20.5
N	A	S	$ 30	2	22.5
N	C	S	$ 32	1	23.5
N	J	S	$ 35	0.25	23.75
N	D	S	$ 36	0.5	24.25

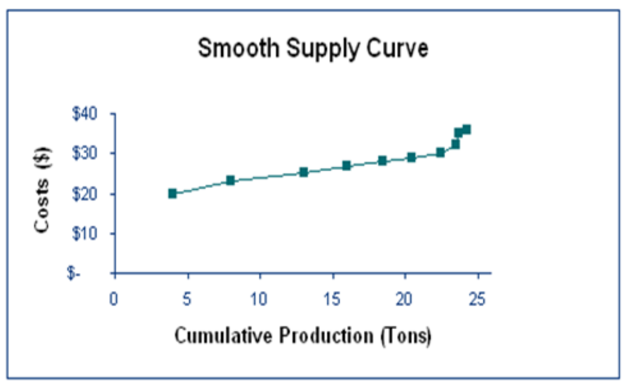
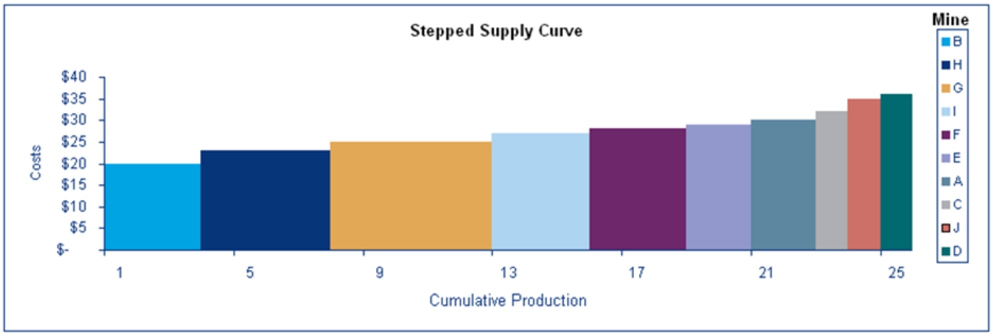


Figure 7-7 Example Coal Supply Curve in Stepped Format



MINE NAME →		B	H	G	I	F	E	A	C	J	D
New or Existing	Production Scalar	4	8	13	16	18.5	20.5	22.5	24	25	25.5
E	1	$ 20	-	-	-	-	-	-	-	-	-
E	2	$ 20	-	-	-	-	-	-	-	-	-
E	3	$ 20	-	-	-	-	-	-	-	-	-
E	4	-	$ 23	-	-	-	-	-	-	-	-
E	5	-	$ 23	-	-	-	-	-	-	-	-
E	6	-	$ 23	-	-	-	-	-	-	-	-
E	7	-	$ 23	-	-	-	-	-	-	-	-
E	8	-	-	$ 25	-	-	-	-	-	-	-
E	9	-	-	$ 25	-	-	-	-	-	-	-
E	10	-	-	$ 25	-	-	-	-	-	-	-
E	11	-	-	$ 25	-	-	-	-	-	-	-
E	12	-	-	$ 25	-	-	-	-	-	-	-
E	13	-	-	-	$ 27	-	-	-	-	-	-
E	14	-	-	-	$ 27	-	-	-	-	-	-
E	15	-	-	-	$ 27	-	-	-	-	-	-
N	16	-	-	-	-	$ 28	-	-	-	-	-
N	17	-	-	-	-	$ 28	-	-	-	-	-
N	18	-	-	-	-	$ 28	-	-	-	-	-
E	19	-	-	-	-	-	$ 29	-	-	-	-
E	20	-	-	-	-	-	$ 29	-	-	-	-
N	21	-	-	-	-	-	-	$ 30	-	-	-
N	22	-	-	-	-	-	-	$ 30	-	-	-
N	23	-	-	-	-	-	-	-	$ 32	-	-
N	24	-	-	-	-	-	-	-	-	$ 35	-
N	25	-	-	-	-	-	-	-	-	-	$ 36

7.2.9 EPA 2023 Reference Case Assumptions and Outlooks for Major Supply Basins

Powder River Basin (PRB)

The PRB is somewhat unique to other U.S. coal basins in that producers are able to adjust production volumes relatively easily. That said, the decisions on production volumes are largely based on the market conditions, namely the price. For instance, in a low-demand environment, producers tend to moderate production volumes to maintain attractive prices and choose to ramp up production when prices are higher. The evolution of costs in the PRB will be strongly correlated to the rate at which producers ramp up production at existing mines, which, as indicated, will depend on market conditions.

Wood Mackenzie anticipates productivity at most existing PRB mining operations to decline at very modest rates over the forecast horizon, with increasing strip ratios at least partly offset by improved usage of labor and capital. As most PRB mines progress downward, the overburden to coal (strip ratios) will increase in the future. The productivity of new mines will be quite low during the early stages of their life span.

Mining at several locations is steadily proceeding westward toward the Joint Line railroad, and, at current and forecasted levels of production, around 2023, several mines are expected to eventually reach the line. This event will result in a costly movement across the railroad, requiring significant capital investment and reduced production as the transition is made. During the move across the Joint Line railroad, strip ratios will spike, and productivity will fall as new box cuts are created.

Illinois Basin (ILB)

Production costs in the Illinois basin have been mostly flat, with a slight downward trend in recent years as higher-cost mines close and newer low-cost longwall mines maximize their economies of scale. Development of these longwalls has been delayed as natural gas prices largely remain below competitive levels. New developments will be delayed until prices and demand recover. In the long term, the shape of the ILB supply curve has the potential to increase production capacity and decrease costs. However, this is not due to lowering costs at existing mines. Rather, it is caused by new mines coming online that have lower operating costs than existing mines.

The ILB has vast reserves and potential for large-scale, low-cost mine development. However, a shrinking customer base will pose a risk to the basin's growth potential as demand could shrink in the long term.

Central Appalachia (CAPP)

Geologic conditions in the CAPP region are challenging, with thin seams and few underground reserves amenable to more efficient longwall mining techniques. Costs of production in CAPP rose substantially in the early 2010s as the region struggled with mining thinner seams depleting reserves. Mining accidents led to increased inspections, and mine permitting has become increasingly difficult.

Producers cut back production significantly in the years prior to 2017 as coal prices plummeted. Many companies went bankrupt and closed a large proportion of mines. As a result, average costs fell substantially as high-cost, low-productivity mines were closed. In an effort to retain margins, producers implemented a variety of tactics at continuing operations to try to keep production costs from continuing to increase, including shifting more production to lower cost operations and selling lesser quality raw coal to save on coal preparation/washing costs. In the long term, costs will remain mostly flat as cost optimization efforts continue within the highly competitive basin.

Northern Appalachia (NAPP)

Similar to CAPP, mining costs in NAPP have remained mostly flat since the closure of high-cost capacity drove costs downwards. Future mine costs in Northern Appalachia will depend largely on the development of new reserve areas. However, few thermal projects have been identified – meaning located at an existing mine or a named project. The remainder are reserves that are available for development in the region but no engineering or permitting work has begun.

7.3 Coal Transportation

Table 7-25 presents the coal transportation matrix.

Within the United States, steam coal for use in coal-fired power plants is shipped via a variety of transportation modes, including rail, barge, truck, conveyor belt, and lake/ocean vessel. A given coal-fired power plant typically has access to only a few of these transportation options and, in some cases, has access to only a single option. The number of transportation options that a plant has when soliciting coal deliveries influences transportation rate levels that plant owners are able to negotiate with transportation providers.

Within the Eastern United States, rail service is provided predominately by two major rail carriers in the region, Norfolk Southern (NS) and CSX Transportation (CSX). Within the Western United States, rail service is provided predominately by two major rail carriers, Burlington Northern Santa Fe (BNSF) and Union Pacific (UP). Plants in the Midwestern United States may have access to rail service from BNSF, CSX, NS, UP, the Canadian National (CN), Canadian Pacific (CP), or short-line railroads. Barge, truck, and vessel service is provided by multiple firms, and conveyor service is only applicable to coal-fired plants located next to mining operations (e.g., mine-mouth plants).

Between 2016 (when the coal transportation rate assumptions for EPA Platform v6 November 2018 Reference Case were finalized), and 2020, coal production in the United States declined by approximately 192 million tons/year, or 26% (from 728 million tons in 2016 to an estimated 536 million tons in 2020.)[67] Approximately 48 gigawatts of coal-fired generating capacity (or about 18% of the total coal-fired generating capacity in the United States) were retired in the period between the end of 2016 and the end of September 2020.[68]

Transportation rate levels for most coal movements declined significantly in real terms between 2016 and 2020, as sustained low prices for natural gas and major expansions in renewable generation during this period reduced the coal volumes used for electric generation further below the already low levels experienced in 2016. However, since natural gas prices were very low throughout the 2016-2020 period (averaging $2.65/MMBtu in nominal dollars between January 2016 and November 2020 at Henry Hub).[69] the decline in coal transportation rates between 2016 and 2020 was not sufficient to make coal-fired generation price-competitive with natural gas-fired generation in most areas of the U.S. Instead, the 2020 coal transportation rates shown in this analysis represent strategic decisions by the railroads and other providers of coal transportation to preserve as much contribution margin as possible on the remaining coal traffic (while accepting volume declines viewed as largely unavoidable) rather than competing aggressively for incremental coal volumes. Rail rates for short-distance coal movements to captive plants either stayed the same or increased in real terms between 2016-2020, as the railroads sought to partially offset nationwide declines in coal volumes at the small subset of plants where they have the most market power.

In this market environment, in which the railroads and other providers of coal transportation are generally seeking to extract the maximum margins from coal traffic which is expected to steadily decline in volume over the long term, any future arrangements tying coal transportation rates to natural gas pricing would likely have to be very limited and site-specific (as was already the case in 2016.)

During 2021-2050, rates for most modes of coal transportation are expected to be flat to decline in real dollars from the 2020 levels, reflecting relatively low levels of expected coal demand throughout the forecast period used in EPA 2023 Reference Case.

The transportation methodology and rates presented below reflect expected long-run equilibrium transportation rates as of August 2020, when the coal transportation rate assumptions for EPA 2023 Reference Case were finalized. The forecasted changes in transportation rates during the 2021-2050 forecast period reflect expected changes in long-term equilibrium transportation rate levels, including the long-term market dynamics that will drive these pricing levels.

All the transportation rates discussed in this document are expected 2020 rates and are shown in 2019 real dollars.

7.3.1 Coal Transportation Matrix Overview

Description

The general structure of the coal transportation matrix in EPA 2023 Reference Case is similar to the structure used in EPA Platform v6 November 2018 Reference Case. Each coal-fired power plant included

---

[67] The coal production data cited here is U.S. Energy Information Administration (EIA) data. 2016-2019 data is from the quarterly coal report released October 2020, is available at https://www.eia.gov/coal/production/quarterly/. 2020 data is estimated based on a 24.1% decline from 2019 coal production levels for 2020 year-to-date through 12/12/2020, as shown in EIA's Weekly Coal Production data (available at https://www.eia.gov/coal/production/weekly/).

[68] Data from EIA Electric Power Monthly, February 2017, and November 2020 releases, available at https://www.eia.gov/electricity/monthly/.

[69] EIA data available at: https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm

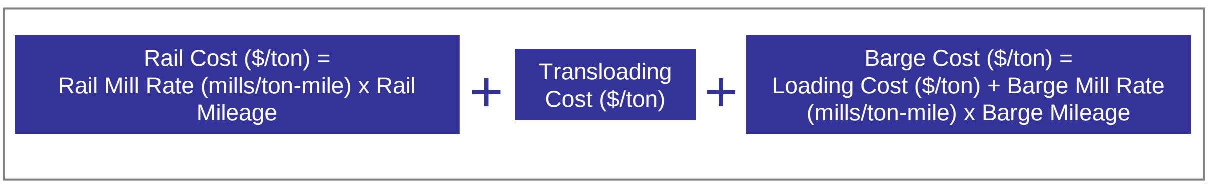
in the EPA 2023 Reference Case is individually represented in the coal transportation matrix. This allows the coal transportation routings, coal transportation distances, and coal transportation rates associated with each individual coal-fired generating plant to be estimated on a plant-specific basis. The coal transportation matrix shows the total rate to transport coal from selected coal supply regions to each individual coal-fired generating plant.

The coal supply regions associated with each coal-fired generating plant in EPA 2023 Reference Case are largely unchanged from the previous version of EPA Platform v6. The coal supply regions associated with each coal-fired power plant are the coal supply regions that were supplying each plant as of the first half of 2020, have supplied each plant in previous years, or are considered economically and operationally feasible sources of additional coal supply during the forecast period in EPA 2023 Reference Case. A more detailed discussion of the coal supply regions can be found in previous sections.

<u>Methodology</u>

Each coal supply region and coal-fired power plant is connected via a transportation link, which can include multiple transportation modes. For each transportation link, cost estimates, in terms of $/ton, were calculated utilizing mode-based transportation cost factors, analysis of the competitive nature of the moves, and overall distance that the coal type must move over each applicable mode. An example of the calculation methodology for movements including multiple transportation modes is shown in Figure 7-8.

Figure 7-8 Calculation of Multi-Mode Transportation Costs (Example)



Calculation of Coal Transportation Distances

<u>Definition of applicable supply/demand regions</u>

Coal-fired power plants are linked to coal supply regions based on historical coal deliveries, as well as based on the potential for new coal supplies to serve each coal-fired generating plant going forward. A generating plant will usually have transportation links with more than one supply region, depending on the various coal types that can be physically delivered and burned at that particular plant. On average, each coal-fired generating plant represented in IPM is linked with about eight coal supply regions. Some plants may have more than the average number of transportation links, and some may have fewer, depending on the location of each plant, the transportation modes available to deliver coal to each plant, the boiler design and emissions control technologies associated with each plant, and other factors that affect the types of coal that can be burned at each plant.

For mine-mouth plants (plants for which the current coal supply is delivered from a single nearby mine, generally by conveyor belt or using truck transportation) that are 200 MW or larger, Hellerworx has estimated the cost of constructing facilities that would allow rail delivery of alternative coal supplies, and the transportation rates associated with the delivery of alternative coal supplies. This includes the construction of rail spurs (between one and nine miles in length depending on the proximity of each plant to existing railroad lines) to connect each plant with existing railroad lines.

Transportation Links for Existing Coal-Fired Plants

Transportation routings from particular coal supply regions to particular coal-fired power plants were developed based on third-party software[70] and other industry knowledge available to Hellerworx. Origins for each coal supply region were based on significant mines or other significant delivery points within the supply region, and the destination points were plant-specific for each coal-fired generating plant represented in IPM. For routes utilizing multiple modes (e.g., rail-to-barge, truck-to-rail, etc.), distances were developed separately for each transportation mode.

Transportation Links for New Coal-Fired Plants

Representative coal transportation costs for new coal-fired power plants not yet under construction (i.e., coal transportation costs for a new coal-fired power plant modeled by IPM) were estimated by selecting an existing coal-fired power plant within each IPM Region whose coal supply alternatives and coal transportation costs, were considered representative of the coal supply alternatives and coal transportation costs that would likely be faced by new coal-fired power plants within that same IPM Region. In cases where there are no existing coal plants within a particular IPM Region, the coal supply alternatives and coal transportation costs applicable to that IPM Region were estimated using a methodology similar to that used for the existing coal plants.[71] Using this consistent methodology across all of the IPM regions helps ensure that coal transportation costs for new coal plants are properly integrated with and assessed fairly vis-à-vis existing coal-fired assets within the IPM modeling structure.

7.3.2 Overview of Rail Rates

Competition within the railroad industry is limited. Two major railroads in the Western U.S. (BNSF and UP) and two major railroads in the Eastern U.S. (CSX and NS) currently originate most of the U.S. coal traffic that moves by rail.

As noted earlier in this section, rail rates for most coal movements declined significantly during 2016-2020, and coal demand for electric generation declined significantly as well. Continued strong competition from natural gas-fired generation and renewables over the duration of the forecast period used in the EPA 2023 Reference Case is expected to limit future coal demand and lead to further real declines in rail rates over the long term.

The differential between rail rates at captive plants and rates at competitively served plants widened slightly during 2016-2020 due to flat or increasing rates at the relatively small subset of coal-fired generating plants where the railroads still have significant market power (short-distance movements to captive plants).

Since August 2016, the Surface Transportation Board (“STB”) has been engaged in a process (STB Ex Part 665, Sub. No. 2, Expanding Access to Rate Relief) designed to make it easier for small shippers to obtain rail rate relief from the STB. On September 11, 2019, the Board issued a Notice of Proposed Rulemaking (NPRM), proposing to adopt Final Offer Rate Review as a rate-setting mechanism. This would be far cheaper and faster than the SAC approach. While designed for small rate cases, it is obvious that the STB is searching for a means of making rate relief more widely available to shippers. Whether this will be adopted, and if adopted withstand legal challenge is unknown, but the STB will likely continue to seek ways to make its regulatory authority feasible for shippers to use. It is also unclear if shippers would spend much to engage in a risky process to try and reduce rail rates to a coal-fired power plant with limited future prospects.

[70] Rail routing and mileage calculations utilize ALK Technologies PC*Miler software.

[71] Since the Canadian government has phased out coal-fired generation in Ontario, and in late 2016 announced plans to phase out coal-fired generation in Alberta by 2030, coal-fired generation was not modeled in the Canadian provinces where it is not currently used.

However, it is unlikely that any new regulatory mechanisms will have a widespread impact on coal rates. Under the legislation that currently governs rail rate relief (the Staggers Act, passed in 1980), the STB is statutorily prohibited from mandating rates that are less than 180% of long-run variable costs (LRVC). Very few rail rates for coal are set above this level (with the possible exception of some short-distance movements to captive plants, which are a small segment of the total coal traffic.) Competition from natural gas-fired generation has caused many high-cost coal plants to be shut down. Any future regulations relating to greenhouse gas emissions would also add to coal's costs relative to all other fuel sources. In summary, the market trends described throughout this analysis are likely to have much greater impacts on rail rates for coal transportation than any future changes in the regulatory scheme.

All the rail rates discussed below include railcar costs and fuel surcharges at expected 2020 fuel price levels. When the rail rate assumptions used in EPA 2023 Reference Case were finalized in August 2020, the latest Form EIA-923 data that was available for the analysis of historical delivered coal prices and rail rates was data through May 2020. Therefore, almost all the data that was relied upon to estimate the trends in historical rail rates between 2016 and early 2020 reflects rail contracts that would have been negotiated before the beginning of the COVID-19 lockdowns in the United States (i.e., before mid-March 2020.) The forward-looking portion of the rail rate analysis (2021-2050) also focused on the expected long-term trends within the coal and rail industries over the entirety of this 30-year period rather than on short-term disruptions related to COVID-19. Thus, neither the 2020 rail rate estimates nor the forecast of expected long-term trends in rail rates should be biased by any short-term disruptions related to COVID-19.

Overview of Rail Competition Definitions

Within the transportation matrix, rail rates are classified as being either captive or competitive (see Table 7-12) depending on the ability of a given coal demand region to solicit supplies from multiple suppliers. Competitive rail rates are further subdivided into high- and low-cost competitive subcategories. Competition levels are affected both by the ability to take delivery of coal supplies from multiple rail carriers, and the use of multiple rail carriers to deliver coal from a single source (e.g., BNSF/UP transfer to NS/CSX for PRB coal moving east), or the option to take delivery of coal via alternative transportation modes (e.g., barge, truck, or vessel).

Table 7-12 Rail Competition Definitions

Competition Type	Definition
Captive	Demand source can only access coal supplies through a single provider; demand source has limited power when negotiating rates with railroads.
High-Cost Competitive	Demand source has some, albeit still limited, negotiating power with rail providers; definition typically applies to demand sources that have the option of taking delivery from either of the two major railroads in the region.
Low-Cost Competitive	Demand source has a strong position when negotiating with railroads; typically, these demand sources also have the option of taking coal supplies via modes other than rail (e.g., barge, truck, or lake/ocean vessel).

Rail Rates

As previously discussed, rail rates are subdivided into three competitive categories: captive, high-cost competitive, and low-cost competitive. Moves are further subdivided based on the distance the coal supply must move over rail lines: <200 miles, 200-299 miles, 300-399 miles, 400-649 miles, and 650+ miles. Within the Western U.S., mileages are only subdivided into two categories (<300 miles and 300+ miles), given the longer distances that these coal supplies typically move.

Initial rate level assumptions were determined based on an analysis of recent rate movements, current rate levels in relation to maximum limits prescribed by the STB, expected coal demand, diesel prices, recent capital expenditures by railroads, and projected productivity improvements. In general, shorter moves result in higher applicable rail rates due to the lesser distance over which fixed costs can be spread. As previously discussed, rail rates reflect anticipated 2020 costs in 2019 real dollars.

Rates Applicable to Eastern Moves

Rail movements within the Eastern U.S. are handled predominately by the region's two major carriers, NS and CSX. Some short movements are handled by a variety of short-line railroads. Most plants in the Eastern U.S. are served solely by a single railroad (i.e., they are captive plants). The practical effect of this is that CSX and NS do not compete aggressively at the limited number of plants that have access to both major railroads, and the rates for high-cost competitive plants tend to be similar to the rates for captive plants. Table 7-13 presents the 2020 eastern rail rates.

Table 7-13 Assumed Eastern Rail Rates for 2020 (2019 mills/ton-mile)

Mileage Block	Captive	High-Cost Competitive	Low-Cost Competitive
< 200	122	122	104
200-299	71	71	60
300-399	57	57	48
400-649	53	53	45
650+	33	33	28

Prior to the EPA Platform v6 November 2018 Reference Case update in 2016, CSX introduced a new structure for some of its rail contracts that includes both fixed and variable components. This was an attempt to help coal-fired generating plants located on the CSX system compete more effectively with natural gas-fired generation by offering the generators the opportunity to include only the variable cost component in their dispatching costs.

However, many larger generators (whose systems included both CSX-served plants, and plants served by NS or other transportation providers) felt that this contracting structure might tend to favor CSX-served plants at the expense of other plants on their own systems, and/or unnecessarily complicate dispatching. Therefore, use of the contracting structure that includes fixed and variable rail rate components was discontinued in EPA 2023 Reference Case. This change will have a very limited effect on the IPM modeling for coal-fired generating plants since this contracting structure was experimental and was only used at a limited number of plants in EPA Platform v6 November 2018 Reference Case.

Rates Applicable to Midwestern Moves

Plants in the Midwestern U.S. may be served by BNSF, CN, CP, CSX, NS, UP or short-line railroads. However, the rail network in the Midwestern U.S. is very complex, and most plants are served by only one of these railroads. The Midwestern U.S. also includes a higher proportion of barge-served and truck-served plants than is the case in the Eastern or Western U.S. Table 7-14 depicts 2020 rail rates in the Midwest.

Table 7-14 Assumed Midwestern Rail Rates for 2020 (2019 mills/ton-mile)

Mileage Block	Captive	High-Cost Competitive	Low-Cost Competitive
< 200	122	122	104
200-299	80	80	68
300-399	57	57	48
400-649	57	57	48
650+	33	33	28

Rates Applicable to Western Moves

Rail moves within the Western U.S. are handled predominately by BNSF and UP. Rates for Western coal shipments from the PRB are forecast separately from rates for Western coal shipments from regions other than the PRB. This reflects the fact that in many cases coal shipments from the PRB are subject to competition between BNSF and UP, while rail movements of Western coal from regions other than the PRB consist primarily of Colorado and Utah coal shipments that originate on UP, and New Mexico coal shipments that originate on BNSF. PRB coal shipments also typically involve longer trains moving over longer average distances than coal shipments from the other Western U.S. coal supply regions, which means these shipments typically have lower costs per ton-mile than non-PRB coal shipments. In the west, there are enough plants that have access to both BNSF and UP or a neutral carrier that the western railroads are concerned with losing coal volume to the competing railroad and therefore offer more of a rate discount to plants that can access both railroads (e.g., high-cost competitive).

Prior to the EPA Platform v6 November 2018 Reference Case update in 2016, BNSF offered temporary spot rail rate discounts to a few selected generating plants using PRB coal to improve the utilization of these plants during periods of unusually lower natural gas prices. However, since Hellerworx believes that these discounts were only offered experimentally and temporarily to a few captive generating plants using PRB coal in the Gulf Coast region, they were not modeled in EPA Platform v6 November 2018 Reference Case. The sustained low prices for natural gas during 2016-2020 appear to have made both BNSF and UP even more reluctant to tie their rail rates to natural gas prices as of 2020 than they were in 2016. Therefore, the rail rate discounts related to natural gas pricing were also not modeled in EPA 2023 Reference Case.

Over the forecast period, coal volumes are likely to continue to decline significantly from the 2020 levels in most forecast scenarios. Therefore, other commodities, such as intermodal traffic and oil which have greater growth potential than coal, are likely to become even more important strategically to the railroads in the future than they are in 2020, and the railroads are expected to be generally unwilling to offer large discounts from their base rates to compete for incremental coal volumes throughout the forecast period.

Non-PRB Coal Moves

The assumed non-PRB western rail rates for 2020 are shown in Table 7-15.

Table 7-15 Assumed Non-PRB Western Rail Rates for 2020 (2019 mills/ton-mile)

Mileage Block	Captive	High-Cost Competitive	Low-Cost Competitive
< 300	69	32	32
300+	40	28	28

The assumed PRB western rail rates for 2020 are available in Table 7-16.

PRB Moves Confined to BNSF/UP Rail Lines

Table 7-16 Assumed PRB Western Rail Rates for 2020 (2019 mills/ton-mile)

Mileage Block	Captive	High-Cost Competitive	Low-Cost Competitive
< 300	46	19	19
300+	21	15	15

PRB Moves Transferring to Eastern Railroads

For PRB coal moving west-to-east, the coal transportation matrix assumes that the applicable low-cost competitive assumption is applied to the BNSF/UP portion of the rail mileage, and an assumption of either \$2.30 per ton or 28 mills per ton-mile (whichever is higher) is applied to the portion of the movement that occurs on railroads other than BNSF and UP. (The $2.30 per ton assumption is a minimum rate for short-distance movements of PRB coal on Eastern railroads.)

7.3.3 Truck Rates

Truck rates include loading and transport components, and all trucking flows are considered competitive because highway access is open to any trucking firm. The truck rates shown in Table 7-17 are expected 2020 rate levels, in 2019 dollars. The lower truck rates in EPA 2023 Reference Case (as compared to EPA Platform v6 November 2018), reflect the fact that the actual change in diesel fuel prices between 2016 and 2020 was significantly lower than was forecast in 2016.

Table 7-17 Assumed Truck Rates for 2020

Market	Loading Cost (2019 $/ton)	Transport (2019 mills/ton-mile)
All Markets	1.00	100

7.3.4 Barge and Lake Vessel Rates

As with truck rates, barge rates include loading and transport components, and all flows are considered competitive because river access is open to all barge firms. The transportation matrix subdivides barge moves into three categories, which are based on the direction of the movement (upstream vs. downstream) and the size of barges that can be utilized on a given river. As with the other types of transportation rates forecast in this analysis, the barge rate levels shown in Table 7-18 are expected 2020 rate levels, stated in 2019 dollars.

Table 7-18 Assumed Barge Rates for 2020

Type of Barge Movement	Loading Cost (2019 $/ton)	Transport (2019 mills/ton-mile)
Upper Mississippi River, and Downstream on the Ohio River System	3.80	12.2
Upstream on the Ohio River System	3.50	11.8
Lower Mississippi River	2.75	10.3

Notes:

1. The Upper Mississippi River is the portion of the Mississippi River north of St. Louis.
2. The Ohio River System includes the Ohio, Big Sandy, Kanawha, Allegheny, and Monongahela Rivers.
3. The Lower Mississippi River is the portion of the Mississippi River south of St. Louis.

Rates for transportation of coal by lake vessel on the Great Lakes were forecast on a plant-specific basis, considering the lake vessel distances applicable to each movement, the expected backhaul economics applicable to each movement (if any), and the expected changes in labor costs and fuel and steel prices over the long-term.

7.3.5 Transportation Rates for Imported Coal

Transportation rates for imported coal reflect expectations regarding the long-term equilibrium level for ocean vessel rates, considering expected long-run equilibrium levels for labor, fuel, and equipment costs.

In EPA 2023 Reference Case, it is assumed that imported coal is likely to be used only at plants that can receive this coal by direct water delivery (i.e., via ocean vessel or barge delivery to the plant). The assumption is based on an assessment of recent transportation market dynamics, which suggests that railroads are unlikely to quote rail rates that will allow imported coal to be cost-competitive at rail-served plants. Moreover, import rates are higher for the Alabama and Florida plants than for New England plants because many of the Alabama and Florida plants are barge-served (which requires the coal to be transloaded from ocean vessel to barge at an ocean terminal, and then moved by barge to the plant), whereas most of the New England plants can take imported coal directly by vessel. The assumed costs are summarized in Table 7-25.

7.3.6 Other Transportation Costs

In addition to the transportation rates already discussed, the transportation matrix assumes various other rates that are applied on a case-by-case basis, depending on the logistical nature of a move. These charges apply when coal must be moved between different transportation modes (e.g., rail-to-barge or truck-to-barge) – see Table 7-19.

Table 7-19 Assumed Other Transportation Rates for 2020

Type of Transportation	Rate (2019 $/ton)
Rail-to-Barge Transfer	2.00
Rail-to-Vessel Transfer	2.50
Truck-to-Barge Transfer	2.00
Rail Switching Charge for Short line	2.50
Conveyor	1.00

7.3.7 Long-Term Escalation of Transportation Rates

Overview of Market Drivers

According to data published by the Association of American Railroads (AAR), labor costs accounted for about 33% of the rail industry's operating costs in 2018, and fuel accounted for an additional 16%. The remaining 51% of the rail industry's costs relate primarily to locomotive and railcar ownership and maintenance, and track construction and maintenance.

The performance of various cost indices for the railroad industry over the past four years (1Q2016-1Q2020) is summarized in Figure 7-9. Since the lockdowns related to COVID-19 in the U.S. began on March 16, 2020, the historical performance of the rail cost indices was assessed based largely on "pre-COVID" data. This analysis period was selected in order to focus the analysis on the expected longer-term performance of the rail cost indices during the majority of the 2021-2050 forecast period, and avoid excessive bias toward the near-term economic disruptions related to COVID-19.

As shown in Figure 7-9, the RCAF[72] Unadjusted for Productivity (RCAF-U), which tracks operating expenses for the rail industry, increased at an annualized rate of 1.8% per year in nominal terms during 1Q2016-1Q2020. Since overall inflation (as measured by the GDP Chained Price Index increased by an average of 1.9%/year during the same period, the railroad industry's operating costs decreased by an average of 0.1%/year in real terms during 1Q2016-1Q2020.

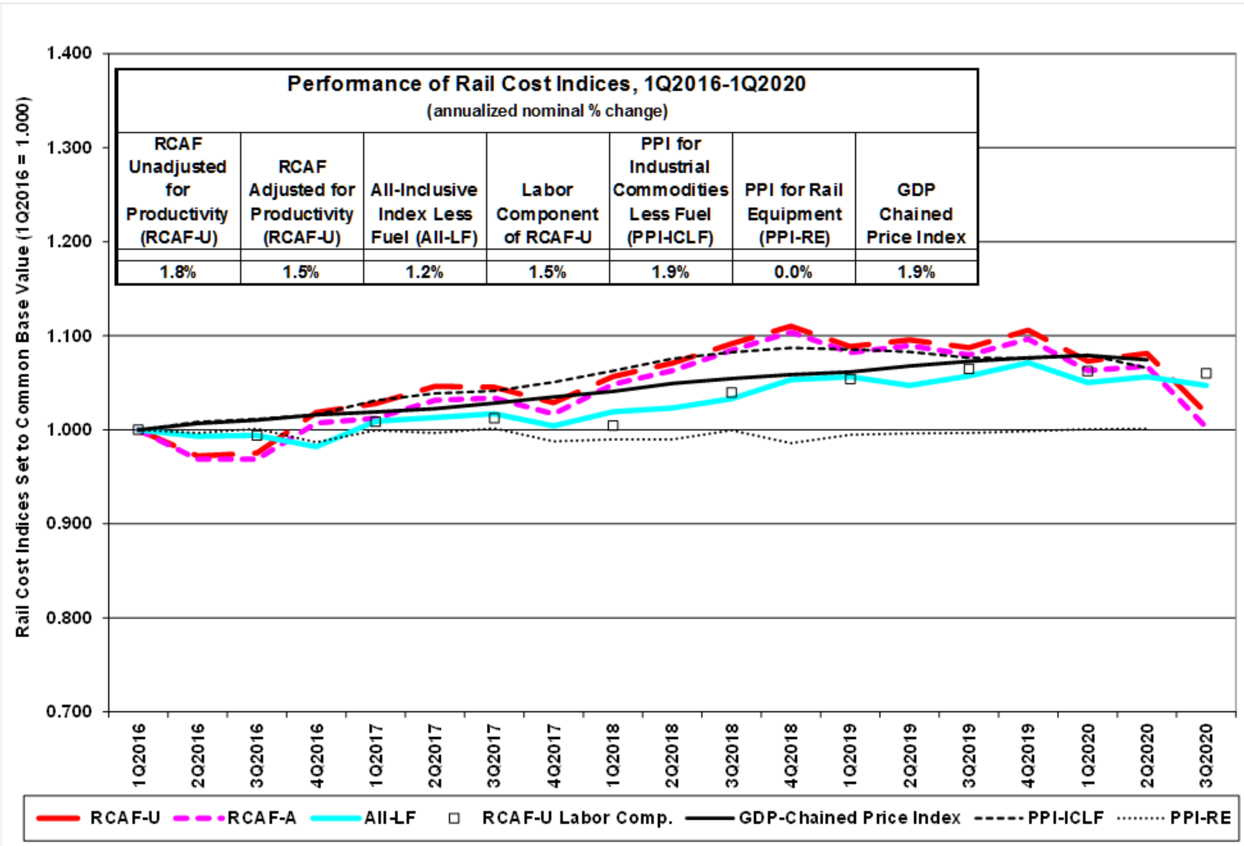
As shown by the All-Inclusive Index Less Fuel (AII-LF), the railroad industry's overall input costs excluding fuel (e.g., labor and equipment costs) decreased by an average of 0.7%/year in real terms during 1Q2016-1Q2020. The railroad industry's labor costs decreased by an average of 0.4%/year in in real terms during the same period.

[72] The Rail Cost Adjustment Factor (RCAF) refers to several indices created for regulatory purposes by the STB, calculated by the AAR, and submitted to the STB for approval. The indices are intended to serve as measures of the rate of inflation in rail inputs. The meaning of various RCAF acronyms that appear in this section can be found in the insert in Figure 7-9.

Since the railroads' labor force is largely unionized, Hellerworx considers the real decline in labor costs during 1Q2016-1Q2020 to be an unusual event, and expects that, on average over the forecast period used in EPA 2023 Reference Case, the rail industry's labor costs are likely to be flat in real terms.

However, since the volume of coal used for electric generation (and thus the volume of coal transported by the rail industry) is expected to continue to decline significantly during the forecast period in most forecast scenarios, there will likely be a long-term surplus of the rail equipment used for coal transportation. Thus, the rail industry's equipment costs are expected to continue to decline in real terms, by an average of 0.5% per year during the forecast period used in EPA 2023 Reference Case.

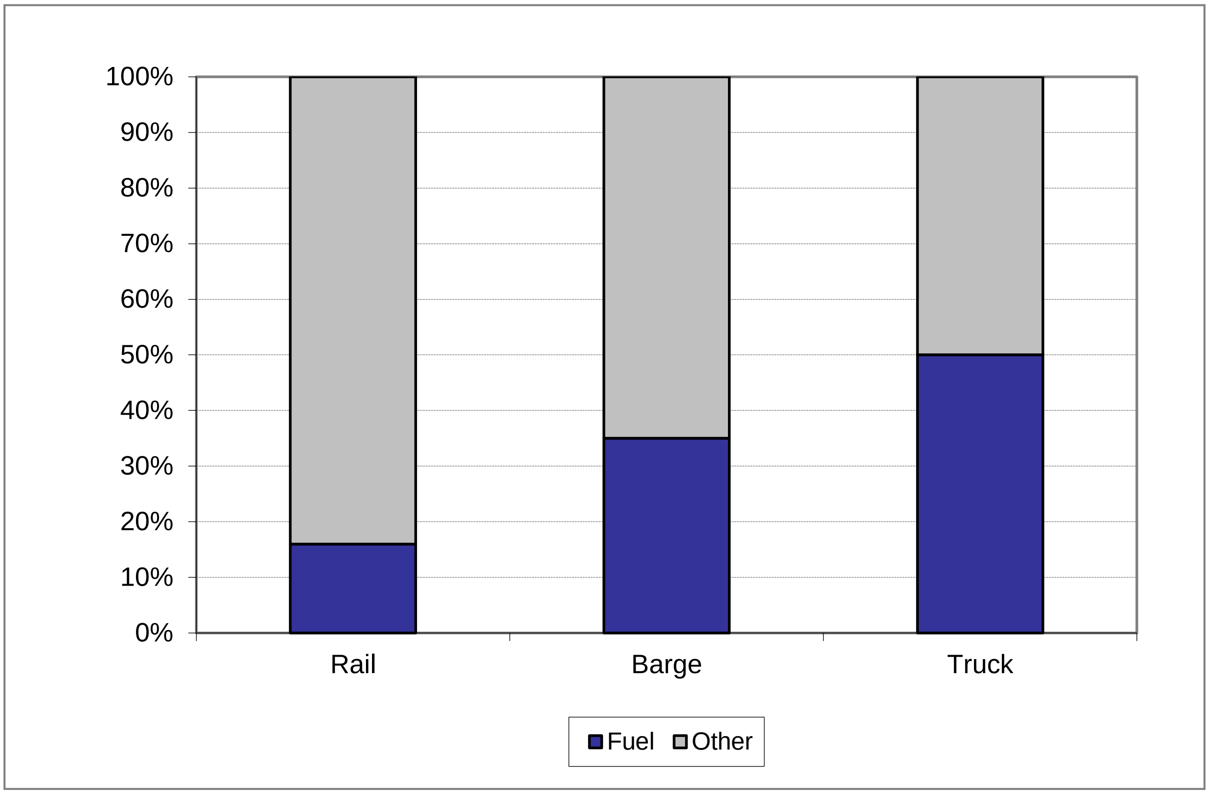
Figure 7-9 Rail Cost Indices Performance (1Q2016-1Q2020)



The other major transportation modes used to ship coal (barge and truck) have cost drivers broadly similar to those for rail transportation (labor costs, fuel costs, and equipment costs). However, a significant difference in cost drivers between the transportation modes relates to the relative weighting of fuel costs for the different transportation modes. Estimates as shown in Figure 7-10 show that, at 2018[73] fuel prices, fuel costs accounted for about 16% of long-run marginal costs for the rail industry, 35% of long-run marginal costs for barges, and 50% of long-run marginal costs for trucks

[73] 2018 was used as the reference point for fuel prices in this analysis because, at the time the coal transportation rate assumptions used in EPA Platform v6 Summer Reference 2021 were finalized in August 2020, the latest analysis of railroad operating expenses available from the AAR contained 2018 data.

Figure 7-10 Long-Run Marginal Cost Breakdown by Transportation Mode



7.3.8 Market Drivers Moving Forward

Diesel Fuel Prices

ICF's forecast of long-term equilibrium prices for diesel fuel used in the transportation sector (see Table 7-20) shows expected prices ranging from about $2.39/gallon in 2020 to about $2.88/gallon in 2050 (2019 real dollars). This represents an average annual real increase in diesel fuel prices of about 0.6%/year during 2020-2050. The coal transportation rate forecast for EPA 2023 Reference Case assumes that this average rate of increase in diesel fuel prices will apply over EPA's entire forecast period.

This is a significantly lower rate of increase in diesel fuel prices than the average real increase of 2.0%/year that was assumed in EPA Platform v6 November 2018 Reference Case, based on the latest forecast that was available from the U.S. Energy Information Administration as of mid-2016 (Annual Energy Outlook 2016, Reference Case forecast for the price of diesel fuel used in the transportation sector.)

Table 7-20 EIA AEO Diesel Fuel Forecast, 2020-2050

Year	Rate (2019 $/gallon)
2020	2.39
2025	2.50
2030	2.79
2035	2.98
2040	2.95
2045	2.94
2050	2.88
Annualized % Change, 2021-2050	0.6%

Source: EIA

Labor Costs

As noted, labor costs for the rail industry are expected to increase at approximately the same rate as overall inflation (flat in real terms), on average, over the forecast period. Labor costs in the barge and truck industries are also expected to increase at approximately the same rate as overall inflation, on average, over the forecast period used in EPA 2023 Reference Case.

Productivity Gains

The most recent data which was available from the AAR at the time the coal transportation rate assumptions used in EPA 2023 Reference Case were finalized in August 2020 (covering 2014-2018), showing that rail industry productivity increased at an annualized rate of approximately 1.0% per year during this period. Since coal-fired generation is expected to continue to face strong competition from natural gas-fired generation and renewables during the forecast period used in EPA 2023 Reference Case (which will significantly limit coal demand), approximately half of the railroad industry's expected productivity gains (0.5% per year) are forecast to be passed through to coal shippers.

The potential for significant productivity gains in the trucking industry is relatively limited since truckload sizes, operating speeds, and truck driver hours are all regulated by law. Although it is possible that increasing the use of electric vehicles may reduce trucking costs to some degree at some point during the forecast period used in EPA 2023 Reference Case, both the timing and the magnitude of this change are very difficult to quantify. Therefore, the potential impact of increasing use of electric vehicles has not been included in the modeling of coal trucking rates for EPA 2023 Reference Case.

Although increased lock outages and the associated congestion on the inland waterway system as the river infrastructure ages may reduce the rate of future productivity gains in the barge industry, limited productivity gains are expected to occur. Since the barge industry is highly competitive, these productivity gains are expected to be largely passed through to shippers.

Long-Term Escalation of Coal Transportation Rates

Based on the foregoing discussion, rail rates are expected to decline at an average rate of 0.7% per year in real terms during the 2021-2050 forecast period used in EPA 2023 Reference Case. Over the same period, barge and lake vessel rates are expected to decrease at an average rate of 0.3% per year, which includes some pass-through of productivity gains in those highly competitive industries. Truck rates are expected to increase at an average rate of 0.3%/year during 2021-2050, largely due to increases in fuel costs. Rates for conveyor transportation and transloading services are expected to be flat in real terms, on average, over the forecast period used in EPA 2023 Reference Case.

The basis for these forecasts is summarized in Table 7-21.

Table 7-21 Summary of Expected Escalation for Coal Transportation Rates, 2020-2050

Mode	Component	Component Weighting	Real Escalation Before Productivity Adjustment (%/year)	Productivity Gains Passed Through to Shippers (%/year)	Real Escalation After Productivity Adjustment (%/year)
Rail	Fuel Labor Equipment	16% 33% 51%	0.60% 0.0% -0.5%		
	Total	100%	-0.2%	0.5%	-0.7%
Barge & Vessel	Fuel Labor & Equip.	35% 65%	0.6% 0.0%		
	Total	100%	0.2%	0.5%	-0.3%
Truck	Fuel Labor & Equip.	50% 50%	0.6% 0.0%		
	Total	100%	0.3%	0.0%	0.3%
Conveyor	Total		0.0%	0.0%	0.0%
Transloading Terminals	Total		0.0%	0.0%	0.0%

7.3.9 Other Considerations

Estimated Construction Costs for Railcar Unloaders and Rail Spurs at Mine-Mouth Plants

To allow mine-mouth generating plants (i.e., coal-fired generating plants that take all of their current coal supply from a single nearby mine) to access additional types of coal, the costs of constructing facilities that would allow rail delivery of coal were estimated for almost all of the mine-mouth generating plants with total capacity of 200 MW or more.

The facilities needed for rail delivery of coal to generating plants of this relatively large size were assumed to be: a) a rotary dump railcar unloader capable of handling unit train coal shipments, which is estimated to cost about $25 million installed (in 2019$). b) at least three miles of loop track, which would allow for one trainload of coal to be unloaded, and a second trainload of coal to simultaneously be parked on the plant site preparatory to unloading, and c) at least one mile of additional rail spur track to connect the trackage on the plant site with the nearest railroad main line. Since construction costs for rail trackage capable of handling coal trains are estimated at about $3 million per mile (in 2019$), the minimum investment required to construct the facilities needed for rail delivery of coal was estimated at $37 million. In some cases, the length of the rail spur required to reach the nearest main line (which was estimated on a plant-specific basis) is considerably longer than one mile. In cases where a rail spur longer than one mile was required to reach the main line, the cost of the additional trackage was estimated using the same construction cost of $3 million per mile (2019$) referenced earlier.

The total cost of the facilities required for rail delivery of coal was converted to an annualized basis based on the assumption that, for capital recovery estimation purposes, each plant's average coal burn during the forecast period used in EPA 2023 Reference Case should be discounted to 50% of the 2019 historical level[74], and a capital recovery factor of 10.58%.

[74] This is intended to represent aa plausible estimate of the average coal burn that might occur at coal-fired generating plants that remain operational for a significant portion of the 2021-2050 forecast period used in EPA 2023 Reference Case, across a range of different forecasting scenarios.

The cost of transporting additional types of coal to each mine-mouth generating plant was then calculated using the same methodology described earlier in this section and added to the annualized cost for the rail delivery facilities to arrive at an estimated all-in cost for delivering additional types of coal to the mine-mouth plants.

7.4 Coal Exports, Imports, and Non-Electric Sectors Demand

The coal supply curves used in EPA 2023 Reference Case represent the total steam coal supply in the United States. While the U.S. power sector is the largest consumer of thermal coal – roughly 95% of U.S. thermal coal consumption in 2019 was used in electricity generation – non-electricity demand must also be taken into consideration in IPM modeling to determine the market-clearing price.[75] Furthermore, some coal mined within the U.S. is exported out of the domestic market, and some foreign coal is imported for use in electricity generation. These changes in the coal supply must be detailed in the modeling of the coal supply available to coal power plants. The projections for imports, exports, and non-electric sector coal demand are based on EIA's AEO 2023.

In EPA 2023 Reference Case, coal exports and coal-serving residential, commercial, and industrial demand are designed to correspond as closely as possible to the projections in AEO 2023 both in terms of the coal supply regions and coal grades that meet this demand. The projections exclude exports to Canada, as the Canadian market is endogenously modeled within IPM. First, the subset of coal supply regions and coal grades in EPA 2023 Reference Case are identified that are contained in or overlap geographically with those in EIA Coal Market Module (CMM) supply regions and coal grades that are projected as serving exports and non-electric sector demand in AEO 2023. Next, coal for exports and non-electricity demand are constrained by the CMM supply region and coal grade to meet the levels projected in AEO 2023. These levels are shown in Table 7-22, Table 7-23, and Table 7-24.

Table 7-22 Coal Exports in the EPA 2023 Reference Case (Million Short Tons)

Name	2028	2030	2035	2040	2045	2050	2055
East Interior - Bituminous High Sulfur	16.13	12.37	10.04	25.04	26.91	26.36	26.36
East Interior - Bituminous Medium Sulfur	1.15	1.22	1.45	0.00	0.00	0.00	0.00
Northern Appalachia - Bituminous High Sulfur	0.50	0.53	0.59	0.53	0.35	0.22	0.22
Rocky Mountain - Bituminous Low Sulfur	6.64	6.64	6.64	6.64	6.64	5.52	5.52
Western Montana - Bituminous Low Sulfur	0.00	0.00	0.03	7.64	9.76	7.89	7.89
Western Montana - Subbituminous Low Sulfur	23.14	29.82	30.33	0.00	0.00	4.47	4.47
WY Northern PRB - Subbituminous Low Sulfur	10.10	0.00	0.00	17.01	12.30	13.06	13.06

IPM then endogenously determines which IPM coal supply region(s) and coal grade(s) will be selected to meet the required export or non-electric sector coal demand as part of the cost-minimization coal market equilibrium. Since there are more coal supply regions and coal grades in EPA 2023 Reference Case than in AEO 2023, the specific regions and coal grades that serve export and non-electric sector demand are not pre-specified but modeled.

Table 7-23 Residential, Commercial, and Industrial Demand in the EPA 2023 Reference Case (Million Short Tons)

Name	2028	2030	2035	2040	2045	2050	2055
Arizona/New Mexico - Subbituminous Medium Sulfur	0.02	0.02	0.02	0.02	0.02	0.01	0.01
Central Appalachia - Bituminous Low Sulfur	0.88	0.85	0.61	0.54	0.48	0.34	0.34
Central Appalachia - Bituminous Medium Sulfur	3.01	2.87	2.70	2.39	2.18	2.19	2.19
Dakota Lignite - Lignite Medium Sulfur	3.61	3.52	3.27	3.02	2.83	2.84	2.84
East Interior - Bituminous High Sulfur	0.10	0.10	0.11	0.10	0.10	0.10	0.10
East Interior - Bituminous Medium Sulfur	3.54	3.47	3.24	2.97	2.37	2.37	1.80
Northern Appalachia - Bituminous High Sulfur	0.30	0.29	0.27	0.25	0.24	0.25	0.25

[75] https://www.eia.gov/coal/annual/pdf/acr.pdf

Name	2028	2030	2035	2040	2045	2050	2055
Northern Appalachia - Bituminous Medium Sulfur	0.48	0.47	0.42	0.37	0.33	0.32	0.32
Rocky Mountain - Bituminous Low Sulfur	1.96	1.86	1.71	1.51	1.32	1.21	1.21
Southern Appalachia - Bituminous Low Sulfur	0.07	0.07	0.06	0.05	0.05	0.05	0.05
Southern Appalachia - Bituminous Medium Sulfur	0.02	0.03	0.04	0.00	0.00	0.00	0.00
West Interior - Bituminous High Sulfur	0.13	0.13	0.11	0.10	0.09	0.14	0.14
Western Montana - Bituminous Low Sulfur	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western Montana - Subbituminous Low Sulfur	1.21	1.19	1.11	1.02	0.96	0.97	0.97
WY North/South PRB - Subbituminous Low Sulfur	4.01	3.87	3.48	3.13	2.90	3.04	3.04

Imported coal[76] is only available to 19 coal facilities, which are eligible to receive imported coal. These facilities, which may receive imported coal, along with the cost of transporting this coal to the demand regions, are in Table 7-25. The total U.S. imports of steam coal are limited to AEO 2023 projections as shown in Table 7-24.

Table 7-24 Coal Import Limits in the EPA 2023 Reference Case (Million Short Tons)

	2028	2030	2035	2040	2045	2050	2055
Annual Coal Imports Cap	0.74	0.70	0.52	0.49	0.50	0.69	0.69

[76] Imported coal is assumed to have a SO_2 emission factor of 1.1 lbs/MMBtu, a mercury emission factor of 7.74 lbs/TBtu, and a HCl emission factor of 0.018 lbs/MMBtu.

Attachment 7-1 Mining Cost Estimation Methodology and Assumptions

Labor Costs

Productivity and labor cost rates are utilized to estimate the total labor cost associated with the mining operation. The estimate excludes labor involved in any coal processing/preparation plant.

Labor productivity is used to calculate mine labor and salaries by applying an average cost per employee hour to the labor productivity figure reported by MSHA or estimated based on comparable mines.

Labor cost rates are estimated based on employment data reported to MSHA. MSHA data provides employment numbers, employee hours worked, and tons of coal produced. These data are combined with labor rate estimates from various sources such as union contracts, census data and other sources such as state employment websites to determine a cost per ton for mine labor. Hourly labor costs vary between United Mine Workers of America (UMWA) and non-union mines, including benefits and payroll taxes. Employees assigned to preparation plants, surface activities, and offices are excluded from this category and are accounted for under coal washing costs and mine overhead.

Surface Mining

The prime (raw coal) strip ratio and overburden volume are estimated on a year-by-year basis. Estimates are entered of the amount of overburden [77] moved each year, split by method to allow for different unit mining costs. The unit rate cost for each method excludes any drill and blast costs, and labor costs, as these are accounted for separately. Drill and blast costs are estimated as an average cost per volume of prime overburden. If applicable, dragline re-handle is estimated separately, and a summation gives the total overburden moved.

- The different overburden removal methods are:
- Dragline - the estimated volume of prime overburden moved
- Dragline re-handle - the estimated volume of any re-handled overburden
- Truck and shovel - including excavators.
- Other - examples would be dozer push, front-end loader, or cast blasting. If overburden is moved by cast blasting, the unit rate is taken to be zero as the cost is already included in the drill and blast estimate.
- Surface mining costs also include the cost of coal mining estimated on a raw-ton basis.

Underground Mining

Raw coal production is split by type into either continuous miner or longwall. Cost estimates can be input either on a unit rate or a fixed dollar amount, as the cost structure of underground mining generally has a large, fixed component from year to year. Costs are divided into:

- Longwall
- Continuous miner
- Underground services

Underground services costs cover categories such as ventilation, conveyor transport, gas drainage, and secondary roof support etc.

[77] Overburden refers to the surface soil and rock that must be removed to uncover the coal.

Mine Site Other

This covers any mine site costs that are outside the direct production process. Examples are ongoing rehabilitation/reclamation, security, and community development costs.

Raw Haul

Costs for transporting raw coal from the mining location to the raw coal stockpile at the coal preparation plant or rail load out. A distance and a unit rate allow for an increasing cost over time if required.

List of tables that are uploaded directly to the web:

Table 7-25 Coal Transportation Matrix in EPA 2023 Reference Case

Table 7-26 Coal Supply Curves in EPA 2023 Reference Case

8. Natural Gas

This chapter discusses the representation of and assumptions for natural gas. The chapter starts with a brief synopsis of ICF's Gas Market Model (GMM), the primary tool used for generating the natural gas supply curves. This is followed by a discussion of the approach taken to translate GMM results to IPM inputs for the EPA's 2023 Reference Case. Lastly, brief descriptions of modeling methodologies and data used in GMM are presented.

Natural gas supply curves and seasonal basis differentials are key inputs to IPM and are developed using GMM. GMM and IPM are iterated in tandem to develop a forecast of Henry Hub gas price and total power sector gas demand that informs the derivation of the supply curves. The approach is described as follows:

- IPM takes the natural gas supply curves, which are developed based on GMM outputs and specified as a function of Henry Hub prices.
- For each year, delivered price adders and four sets of seasonal natural gas transportation differentials (summer, winter, fall, and spring) are added to the supply curves to generate the final delivered curves by IPM region.
- IPM projects the power sector's demand for natural gas. The projected demand is then matched with the supply curve to find the market-clearing price.
- IPM's linear programming formulation takes into consideration the gas supply curves, as well as competing fuels such as coal, and detailed power plant modeling in determining electric market equilibrium conditions.

Like IPM, GMM is a large-scale linear programming model that incorporates a detailed representation of gas supply and demand characteristics and an integrating pipeline transportation model to develop forecasts of gas supply, demand, prices, and flows. GMM is a full supply/demand equilibrium model of the North American gas market. The model solves for monthly natural gas prices throughout North America, given different supply/demand conditions, the assumptions for which are specified by each scenario.

On the supply side, prices from GMM are determined by production and storage price curves that reflect prices as a function of production and storage utilization. Prices are also influenced by "pipeline discount" curves, which reflect the change in basis or the marginal value of gas transmission as a function of load factor. On the demand side, prices are represented by a curve that captures the fuel-switching behavior of end-users at different price levels. The model balances supply and demand at all nodes in the model at the market clearing prices. Figure 8-1 shows the supply side of the calculation in GMM, and Figure 8-2 shows the interaction of IPM and GMM.

Figure 8-1 GMM Gas Quantity and Price Response

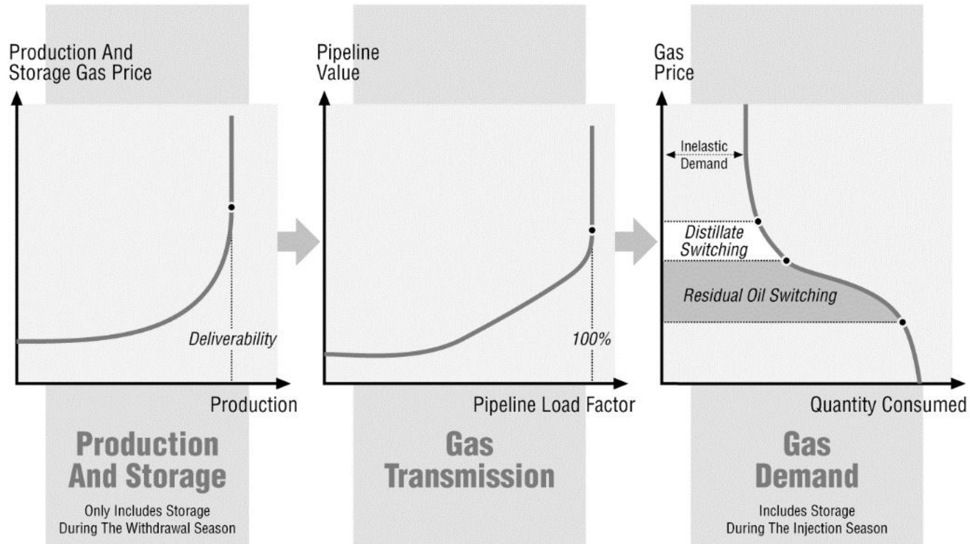
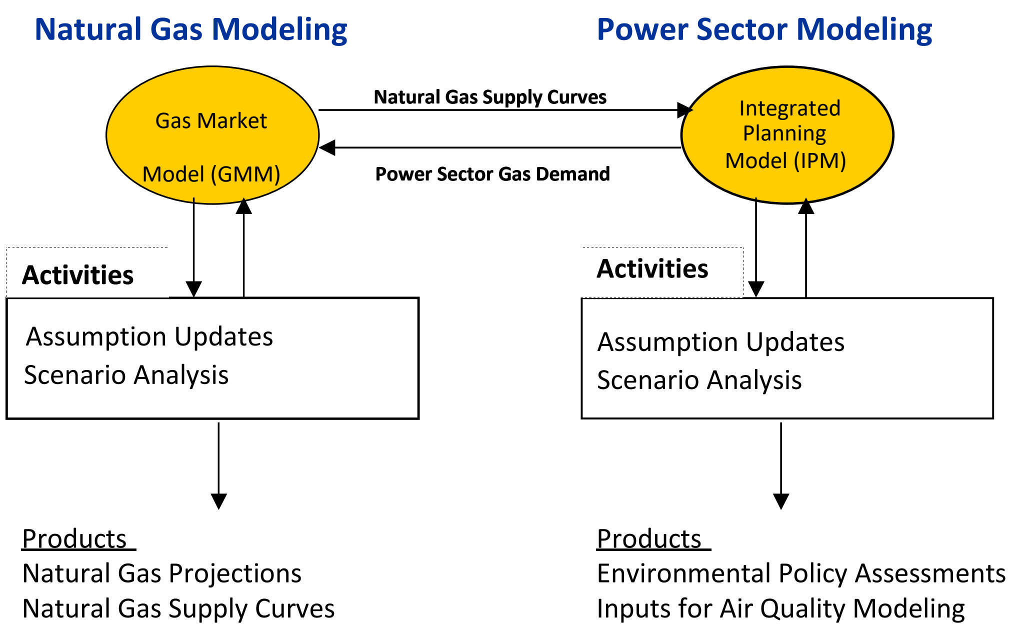


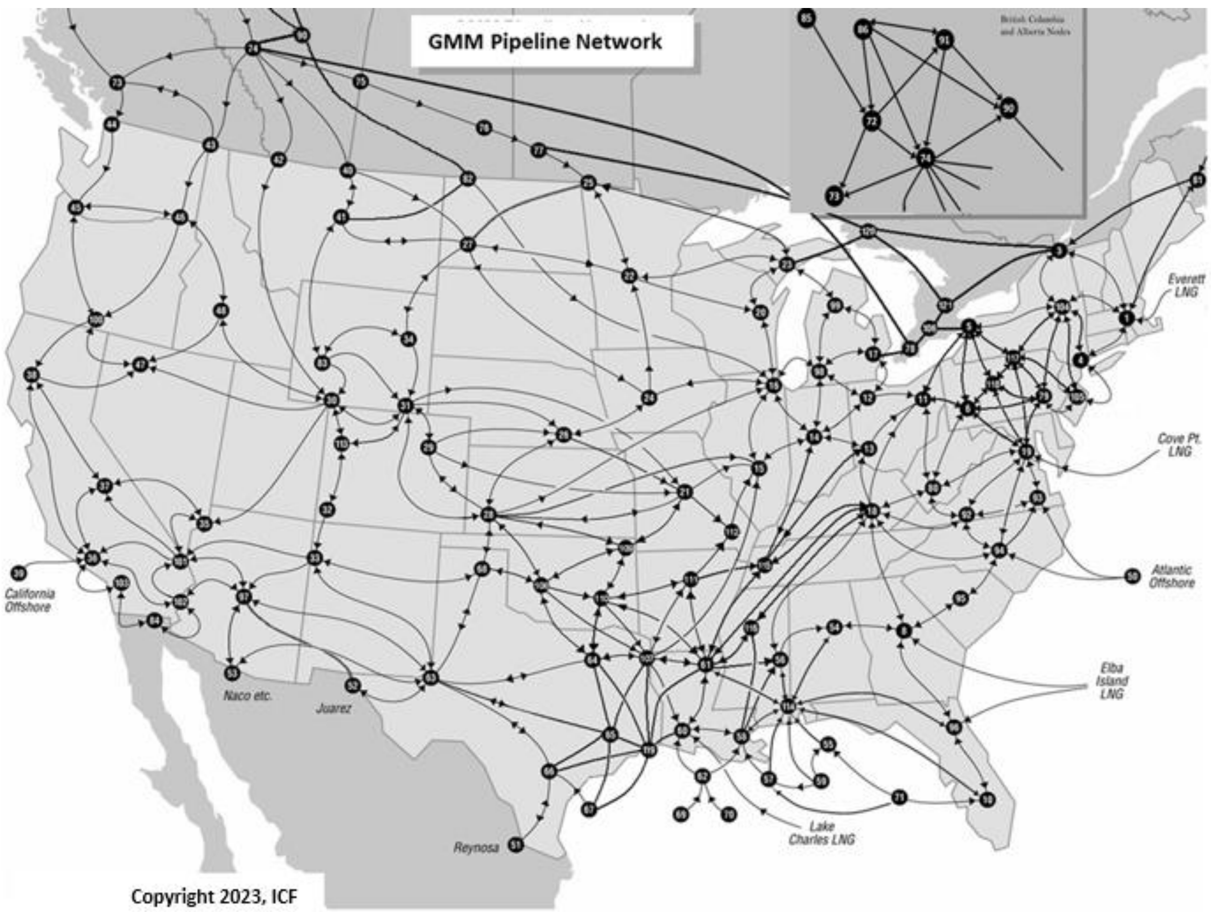
Figure 8-2 IPM/GMM Interaction



8.1 GMM

GMM is designed to perform comprehensive assessments of the entire North American gas flow pattern. It is a large-scale, dynamic linear program that models economic decision-making to minimize the overall cost of meeting natural gas demand. GMM is reliable and efficient in analyzing the broad range of natural gas market issues. Figure 8-3 presents the geographic coverage of GMM.

Figure 8-3 Geographic Coverage of GMM



Important features of GMM are described below.

Natural Gas Market Prices in GMM are determined by the marginal (or incremental) value of natural gas at 121 regional market centers. The regional market centers are also referred to as nodes. Prices are "at the margin", not "average." Marginal prices do not translate directly into pipeline or utility revenues. Prices represent "market center" prices as opposed to delivered prices. Gas prices are determined by the balance of supply and demand in a regional marketplace. Supply is determined considering the availability of natural gas deliverability at the wellhead, the transportation capacity, and the cost to deliver gas to market centers.

Natural gas prices are determined from spot gas price curves that yield price as a function of deliverability utilization: Curves reflect the price for gas delivered into the transmission system (including gathering cost). During the withdrawal season, gas storage withdrawal price curves are added to the production price curves. Pipeline value curves are then added to yield a total supply curve for a node. The intersection of the supply curve and the demand curve (including net storage injections) yields the marginal price at a node. Price is set by the demand curve when all available supply is utilized.

Demand is modeled for residential, commercial, industrial, and power sectors for each of the 121 nodes. GMM solves for gas demand across different sectors, given economic growth, weather, and the level of price competition between gas and oil. Econometric equations define demand by sector. The industrial and power sectors incorporate fuel competition, dispatch decisions, new power plant builds, economic growth, and weather. GMM solves the power generation dispatch on a regional basis to determine the amount of gas used in power generation, which is allocated along with end-use gas demand to model nodes. GMM iterates with IPM to better capture the electric sector demand for natural gas.

Transportation is modeled by over 530 transportation links between the nodes, balancing seasonal, sectoral, and regional demand and prices, including pipeline tariffs and capacity allocation. Node structure was developed to reflect points of change or influence on the pipeline system. These points include major demand and supply centers, pipeline hubs and market centers, and points of divergence in pipeline corridors.

Pipeline capacity expansions address the physical constraints of transporting gas from supply regions to demand regions. They, therefore, contribute to determining the supply curves and seasonal basis. For the near–-term, pipeline capacity expansions are input to GMM based on identifiable, near-term development plans and ICF's market assessment. For the longer term, new "generic" pipeline capacity is added in GMM when the market value of the added capacity exceeds its cost. Generic pipeline capacity in the model can be added starting in 2025 and is deployed in response to expected growth in natural gas markets.

ICF includes projects that satisfy certain criteria in its analysis. The criteria are listed below.

- First Criteria: The project is already under construction; OR…
- Second Criteria: The project has the necessary approvals to proceed from FERC and other relevant regulatory proceedings; OR…
- Third Criteria: The project has been filed with FERC and has the necessary firm shipper commitments; OR…
- Fourth Criteria: The project has been filed with FERC and does not have the necessary shipper commitments but does appear to have sufficient market support; OR…
- Fifth Criteria: The project has NOT yet been filed with FERC but appears to have sufficient market support.

For the fourth and fifth criteria, ICF typically considers supply growth directly upstream of the project, market growth for markets that are relevant to the project's delivery point/s, and basis differentials that exceed the per unit cost of pipeline expansion as indicators of market support. If the indicators are all positive, ICF will add the project as a "generic" project and size it based on the level of market support. In the case in which there are multiple generic projects for a single GMM link, the generic projects will be sized in aggregate based on the total level of market support for the expansion of the link. Generic projects are classified as such until one of the first three criteria is satisfied.
For certain markets, like New York, New Jersey, and New England, ICF looks closely at regulatory support for the project, which could override the criteria above in determining the pipeline additions in GMM. For example, if a project like the Northeast Supply Enhancement Project (NESE) has been denied water permits even though it has broad market support, ICF does not include it in its base case.

Pipeline cost assumptions used in GMM have been derived by considering data from Oil and Gas Journal (OGJ) surveys of pipeline projects. Using regression analysis of the OGJ data across years, we estimated an average U.S. pipeline cost of $243,000 per inch-mile for 2022 (in 2022 dollars) for large gas transmission pipelines. The pipeline cost for future years is kept flat in real terms post 2019. Regional cost multipliers have also been derived from OGJ data, as the pipeline costs vary by region. Cost multipliers can be different across regions; for example, costs are relatively high in the Northeast, where projects have been very difficult and time-consuming to construct.

Supply is modeled by using node-level natural gas deliverability or supply capability, including import and export levels, while accounting for gas storage injections and withdrawals at different gas prices. Total supply in the United States comes from three sources: production from natural gas fields located in the lower 48 states, Canadian imports, Alaska, and LNG imports/exports. Natural gas production activity is represented in 82 of the 121 model nodes where historical production has occurred or where future production appears likely.

Natural Gas Storage activity is represented for 24 United States and two Canadian storage regions, with activity allocated to individual nodes based on historical field-level storage capacity. Regional differences in the physical and market characteristics of storage are captured in the storage injection and withdrawal relationships separately estimated for each region.

Net monthly withdrawals are calculated from a “storage supply curve” that reflects the level of withdrawals relative to gas prices. The curve has been fit to actual historical data. Net monthly injections are calculated from econometrically fit relationships that consider working gas levels, gas prices, and weather (i.e., cooling degree days). The level of gas storage withdrawals and injections are calculated within the supply and demand balance algorithm based on working gas levels, gas prices, and extraction/injection rates and costs.

Storage levels have an impact on GMM’s seasonal basis differentials, which are an important component in constructing the gas supply curves and/or basis differentials that are then input into IPM. The arbitrage value of storage is driven by the seasonal difference in the supply-area gas prices plus the seasonal difference in pipeline transportation value. Storage expansions (or increased utilization of existing storage) decreases seasonal basis differentials in the region surrounding the storage facilities.

8.2 Translating GMM Results to IPM Natural Gas Supply Curves

A typical GMM run that underlies the natural gas supply curves generates the following outputs:

- Natural gas prices
- Natural gas production by region
- Natural gas consumption by region and sector

The regional breakout in the demand/supply data is by census region and the mapping to the state and GMM nodes is provided in Figure 8-4 and Figure 8-5.

Figure 8-4 Demand Region Definition

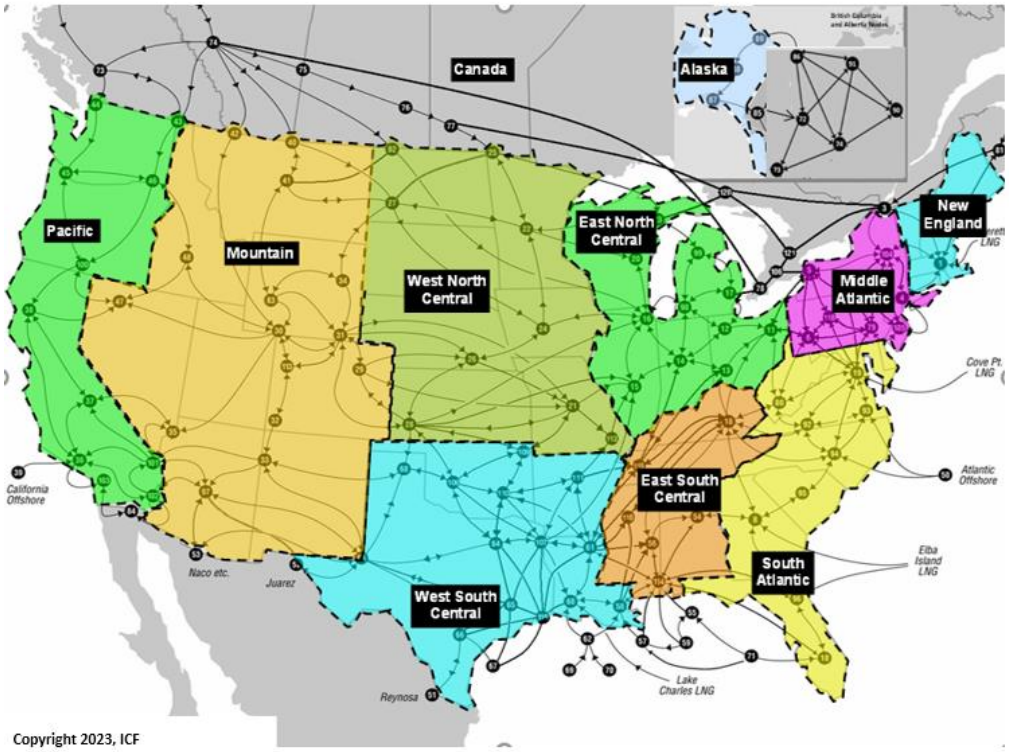
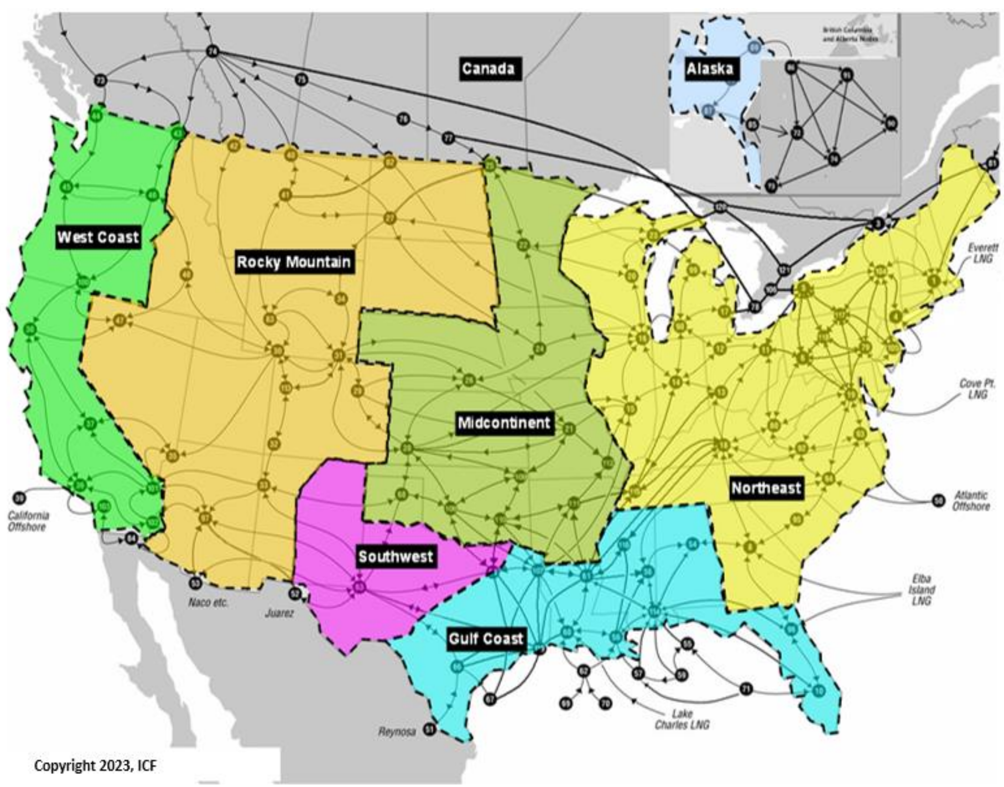


Figure 8-5 Supply Region Definition



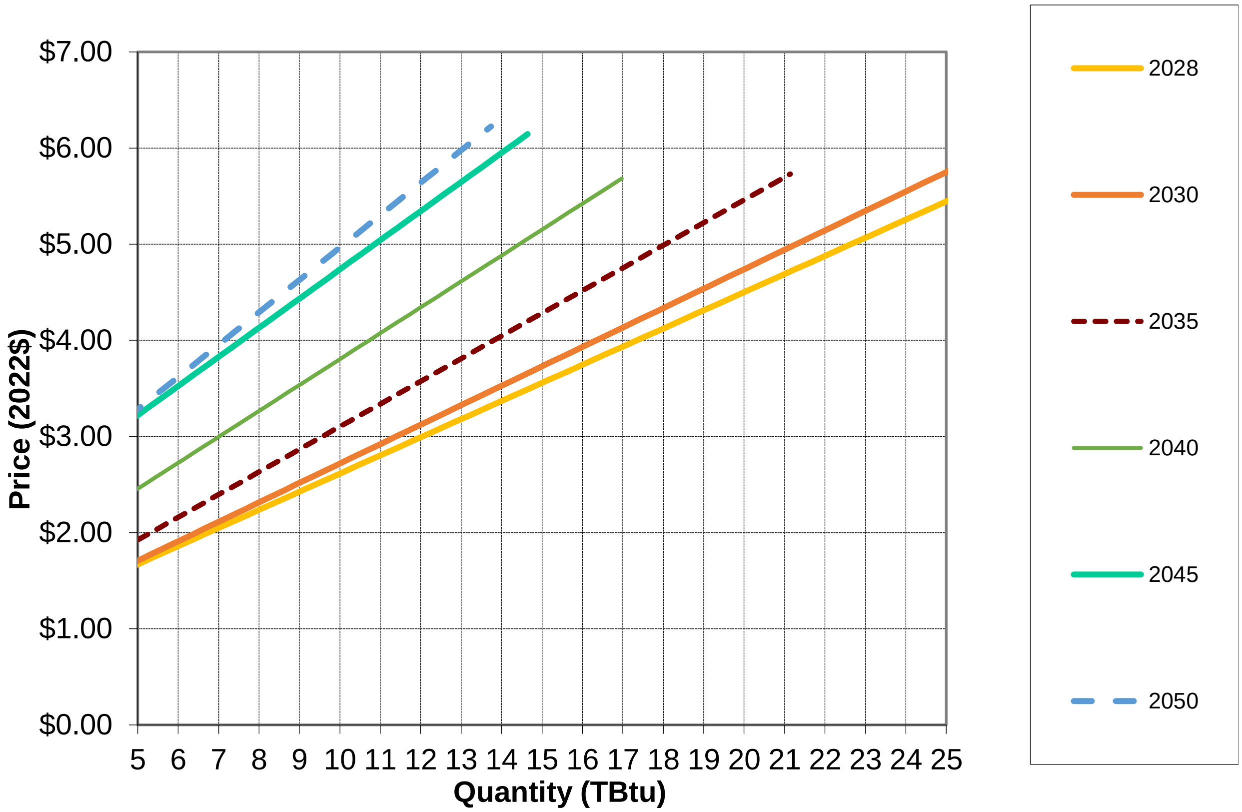
8.2.1 Supply Curves for EPA 2023 Reference Case

Henry Hub is a pipeline interchange hub in Louisiana Gulf Coast near Erath, LA, where eight interstate and three intrastate pipelines interconnect. Liquidity at this point is very high and it serves as the primary point of exchange for the New York Mercantile Exchange (NYMEX) active natural gas futures markets. Henry Hub prices are considered a proxy for U.S. natural gas prices. Natural gas from the Gulf moves through the Henry Hub onto long-haul interstate pipelines serving demand centers. Due to the importance and significance of Henry Hub, GMM-generated supply curves are specified at Henry Hub prices.

For IPM modeling, GMM generates a price forecast over a time horizon and a set of time-dependent price/supply curves based on that price path for each year in the forecast. For each year, the mid-point price of the supply curve is set equal to the solved Henry Hub price from GMM, and the mid-point volume is set equal to the solved gas consumption for the power sector from GMM. Each supply curve's elasticity is set equal to the effective price elasticity for gas supply in that year. In this manner, even while GMM has itself projected particular levels of gas supply and consumption (and corresponding market-clearing prices) over time, the information included in those projections is input into IPM in the form of gas supply curves that enable IPM to solve for levels of power sector gas consumption and resulting gas prices that respect a least-cost power production future. The power generation gas used by the model region from IPM run outputs is used as inputs in GMM to generate a new set of supply curves and basis, which are used by IPM as inputs for the next iteration. This iteration process is repeated until the power generation gas uses from IPM and GMM converge.

Figure 8-6 and Table 8-8 show the final resulting supply curves developed for the years 2028, 2030, 2035, 2040, 2045, and 2050. Over time, gas supply becomes more price elastic because producers have more time to respond to market changes. In the longer term, resource depletion tends to offset elasticity, making the curves slightly less elastic than they were between 2028 and 2030.

Figure 8-6 Supply Curves for 2028, 2030, 2035, 2040, 2045, and 2050



The static national supply curves used for EPA 2023 Reference Case are robust for typical scenario analysis, although EPA re-evaluates price dynamics in scenarios to ensure that IPM and GMM are iterated in cases where the regional natural gas demand in the power sector is expected to be significantly different from the reference case.

8.2.2 Basis

The basis is the difference in gas price in a given market from the widely used Henry Hub reference price. Basis reflects the price in a given market based on demand, available supply, and the cost of transporting gas to that location. A negative basis value represents that the gas price in that area is lower than the Henry Hub price. The basis between two nodes in GMM is the difference in prices between the two nodes. The GMM utilizes its network of 121 nodes that comprises 530 gas pipeline corridors to assess the basis between two desired nodes. The pipeline corridors between nodes are represented by pipeline links and can be characterized by their maximum capacity. Each of the links has an associated discount curve (derived from the GMM natural gas transportation module), which represents the marginal value of gas transmission on that pipeline segment as a function of the pipeline's load factor. The basis value is calculated by using the supply/demand balance in two nodes, along with the resulting prices in each node and the cost of transporting gas between the two nodes as determined by the discount curve on that link. The discount curve is a function of the pipeline tariffs and the load factor. The discount curves are continuously calibrated to accurately reflect historical basis values. Their parameters can be adjusted to account for regulatory changes that can affect pipeline values.

The GMM solves for basis monthly. Basis pressure (i.e., spiking basis) will generally occur when average monthly load factors rise to above 80%. Since many U.S. markets are winter peaking, the higher basis typically occurs in the winter months when gas use and pipeline utilization are highest. The IPM relies on a seasonal basis that reflects averages of the monthly basis values solved for in the GMM for three seasons. IPM uses the gas supply curves and regional price relationships (differentials) on a seasonal basis over time as inputs based on the GMM-projected future of gas supply/demand. While EPA 2023 Reference Case has the flexibility to re-determine the relationship of power sector gas demand to supply and to accordingly find different gas price futures, EPA 2023 Reference Case will maintain the future (basis differential) price relationship between Henry Hub and each regional location in a national supply picture as originally determined by these GMM projections. Table 8-7 provides the full set of seasonal basis differentials at the IPM region level.

8.2.3 Delivered Price Adders

As stated in Section 8.1, GMM prices are market center prices and not delivered prices. An adder is applied to the seasonal basis from GMM to estimate delivered prices at a power plant. The delivered price adder is calculated for each state by comparing the GMM historical prices with historical delivered gas prices to electric power plants based on EIA-176 data. The delivered price adders implemented in EPA 2023 Reference Case are shown in Table 8-1.

Table 8-1 Delivered Price Adders

State	Adder (2022$/MMBtu)	State	Adder (2022$/MMBtu)
Alabama	0.01	Nebraska	0.55
Arizona	0.03	Nevada	0.15
Arkansas	0.14	New Hampshire	-
California	0.22	New Jersey	0.21
Colorado	0.19	New Mexico	0.03
Connecticut	0.06	New York	0.20
Delaware	0.02	North Carolina	0.31
Florida	0.02	North Dakota	0.04
Georgia	0.00	Ohio	0.04
Idaho	0.07	Oklahoma	0.02
Illinois	0.15	Oregon	0.01
Indiana	0.13	Pennsylvania	0.04
Iowa	0.14	Rhode Island	0.00
Kansas	0.15	South Carolina	0.15
Kentucky	0.17	South Dakota	0.01
Louisiana	0.05	Tennessee	0.03
Maine	0.03	Texas	0.23
Maryland	0.16	Utah	0.11
Massachusetts	0.03	Virginia	0.08
Michigan	0.16	Washington	0.10
Minnesota	0.41	West Virginia	0.14
Mississippi	0.03	Wisconsin	0.17
Missouri	0.12	Wyoming	0.10
Montana	0.44	Canada	0.15

8.3 GMM Assumptions

This section describes the key GMM assumptions and data used for the EPA 2023 Reference Case.

8.3.1 GMM Resources Data and Reservoir Description

This section describes the approach used in GMM and documents the changes to the resource data and reservoir characterization work conducted for the EPA 2023 Reference Case.

U.S. Resources and Reserves

This section describes the U.S. resource data sources and methodology used in GMM for EPA 2023 Reference Case.

Current U.S. and Canadian gas production comes from over 470 trillion cubic feet (Tcf) of proven gas reserves. ICF assumes that the U.S. and Canada natural gas resource base totals roughly 4,000 Tcf of unproved plus discovered but undeveloped gas resources. This can supply the U.S. and Canada gas markets for over 100 years (at current consumption levels). Shale gas accounts for over 50 percent of the remaining recoverable gas resources. No significant restrictions on well permitting and fracturing are assumed beyond restrictions that are currently in place.

Data sources: Conventional resource base assessment is based on data from the U.S. Geological Survey (USGS), Minerals Management Service (MMS), and Canadian Gas Potential Committee (CGPC) using ICF's Hydrocarbon Supply Model (HSM).

In the area of unconventional gas, ICF has worked for many years with the Gas Research Institute (GRI)/Gas Technology Institute (GTI) to develop a database of tight gas, coalbed methane, and Devonian Shale reservoirs in the U.S. and Canada. Along with USGS assessments of continuous plays, the database was used to help develop the HSM's "cells," which represent resources in a specific geographic area, characterizing the unconventional resource in each basin, historical unconventional reserves estimates, and typical decline curves. ICF has built up a database on gas compositions in the United States and has merged that data with production data to allow the analysis of net versus raw gas production.

Resources are divided into three general categories: new fields/new pools, field appreciation, and unconventional gas. The methodology for resource characterization and economic evaluation differs for each.

New Fields

Conventional new discoveries are characterized by size class. For the United States, the number of fields within a size class is broken down into oil fields, high permeability gas fields, and low permeability gas fields based on the expected occurrence of each type of field within the region and interval being modeled. The fields are characterized further as having a hydrocarbon make-up containing a certain percent each of crude oil, dry natural gas, and natural gas liquids. In Canada, fields are oil, sweet non-associated gas, or sour non-associated gas.

The methodology uses a modified "Arps-Roberts" equation to estimate the rate at which new fields are discovered. The fundamental theory behind the find-rate methodology is that the probability of finding a field is proportional to the field's size as measured by its areal extent, which is highly correlated to the field's level of reserves. For this reason, larger fields tend to be found earlier in the discovery process than smaller fields. The new equation developed by ICF accurately tracks discovery rates for mid- to small-size fields. Since these are the only fields left to be discovered in many mature areas, the more accurate find-rate representation is an important component in analyzing the economics of exploration activity in these areas.

An economic evaluation is made in the model each year for potential new field exploration programs using a standard discounted after-tax discounted cash flow (DCF) analysis. This DCF analysis takes into account how many fields of each type are expected to be found and the economics of developing each. The economic decision to develop a field is made using "sunk cost" economics, where the discovery cost is ignored, and only time-forward development costs and production revenues are considered. However, the model's decision to begin an exploration program includes all exploration and development costs.

Field Appreciation

Field appreciation refers to potential resources that can be proved from already discovered fields. These inventories are referred to as appreciation, growth-to-known, or “probables.” The inventories of probables are increased due to expected future appreciation due to many factors that include higher recovery percentages of the gas in-place resulting from infill drilling and application of improved technology and experience gained in the course of developing and operating the field.

Unconventional Gas

The ICF assessment method for shale gas is a “bottom-up” approach that first generates estimates of unrisked and risked gas-in-place (GIP) from maps of depth, thickness, organic content, and thermal maturity. Then, ICF uses a different model to estimate well recoveries and production profiles. Unrisked GIP is the amount of original gas-in-place determined to be present based upon geological factors—without risk reductions. “Risked GIP” includes a factor to reduce the total gas volume based on proximity to existing production and geologic factors such as net thickness (e.g., remote areas, thinner areas, and areas of high thermal maturity have higher risk). ICF calibrates expected well recoveries with specific geological settings to actual well recoveries by using a rigorous method of analysis of historical well data.

To estimate the contributions of changing technologies ICF employs the “learning curve” concept used in several industries. The “learning curve” describes the aggregate influence of learning and new technologies as having a certain percent effect on a key productivity measure (for example cost per unit of output or feet drilled per rig per day) for each doubling of cumulative output volume or other measure of industry/technology maturity. The learning curve shows that advances are rapid (measured as percent improvement per period of time) in the early stages when industries or technologies are immature and that those advances decline through time as the industry or technology matures. We find the learning curve effect is roughly 20 percent per doubling of cumulative wells.

Major Unconventional Natural Gas Categories

Definition of Unconventional Gas: Quantities of natural gas that occur in continuous, widespread accumulations in low quality reservoir rocks (including low permeability or tight gas, coalbed methane, and shale gas), that are produced through wellbores but require advanced technologies or procedures for economic production.

Tight Gas is defined as natural gas from gas-bearing sandstones or carbonates with an *in-situ* permeability (flow rate capability) to gas of less than 0.1 millidarcy. Many tight gas sands have *in situ* permeability as low as 0.001 millidarcy. Wells are typically vertical or directional and require artificial stimulation.

Coalbed Methane is defined as natural gas produced from coal seams. The coal acts as both the source and reservoir for the methane. Wells are typically vertical but can be horizontal. Some coals are wet and require water removal to produce the gas, while others are dry.

Shale Gas is defined as natural gas from shale formations. The shale acts as both the source and reservoir for the methane. Older shale gas wells were vertical while more recent wells are primarily horizontal with artificial stimulation. Only shale formations with certain characteristics will produce gas.

Shale Oil with Associated Gas is defined as associated gas from oil shale in horizontal drilling plays such as the Bakken in the Williston Basin. The gas is produced through boreholes along with the oil.

Upstream Cost and Technology Factors

In ICF's methodology, supply technology advancements effects are represented in three categories:

- Improved exploratory success rates
- Cost reductions of platform, drilling, and other components
- Improved recovery per well

These factors are included in the model by region and type of gas and represent several dozen actual model parameters. ICF's database contains base year costs for wells, platforms, operations and maintenance, and other relevant cost items.

8.3.2 Oil Prices

Natural gas prices and LNG export levels are forecasted by taking oil prices into account. ICF uses the Refiner Acquisition Cost of Crude Oil (RACC) price as an oil price input to GMM. The RACC price is a term commonly used in discussing crude oil. It is the cost of crude oil to the refiner, including transportation and fees. ICF's crude oil price forecast uses futures prices for 2022 and a blend of futures and our fundamental forecast for 2022-2025. ICF expects an equilibrium marginal production cost of ~$64/bbl (in 2022$) by 2035 and stays flat beyond 2035 in real terms. The residual oil price averages between 70 and 100 percent of the RACC price on a dollar per Btu basis. This is the price used to determine switching in the industrial sector. Table 8-2 shows the RACC price assumption for EPA 2023 Reference Case.

Table 8-2 Refiners' Acquisition Cost of Crude (RACC)

Year	Annual Average Price in 2022$/bbl
2028	60.9
2030	61.8
2035	64.2
2040	64.2
2045	64.2
2050	64.2

8.3.3 Gas Production

Current United States and Canada gas production is from over 470 trillion cubic feet (Tcf) of proven gas reserves. ICF assumes that the United States and Canada's natural gas resource base totals roughly 4,000 Tcf of unproved plus discovered but undeveloped gas resources. This can supply the U.S. and Canadian gas markets for over 100 years (at current consumption levels). Shale gas accounts for over 50 percent of the remaining recoverable gas resources. No significant restrictions on well permitting and fracturing are assumed beyond restrictions that are currently in place.

To estimate the contributions of changing technologies ICF employs the "learning curve" concept used in several industries. The "learning curve" describes the aggregate influence of learning and new technologies as having a certain percent effect on a key productivity measure (for example, cost per unit of output or feet drilled per rig per day) for each doubling of cumulative output volume or other measures of industry/technology maturity. The learning curve shows that advances are rapid (measured as percent improvement per period of time) in the early stages when industries or technologies are immature and that those advances decline through time as the industry or technology matures. The learning curve effect is roughly 20 percent per doubling of cumulative wells.

In ICF's methodology, supply technology advancements effects are represented in three categories:

- Improved exploratory success rates
- Cost reductions of platform, drilling, and other components
- Improved recovery per well

These factors are included in the model by region and type of gas and represent several dozen actual model parameters. ICF's database contains base year cost for wells, platforms, operations and maintenance, and other relevant cost items. Table 8-3 shows the ICF's United States and Canada dry gas production by source and run year for EPA 2023 Reference Case.

Table 8-3 United States and Canada Projected Dry Gas Production by Source (Bcfd)

Year	Conventional Onshore	Coalbed Methane	Tight	Offshore	Shale	Total
2028	13.0	2.5	7.3	2.2	108.0	133.0
2030	12.0	2.3	6.8	2.0	110.0	133.1
2035	11.1	2.0	6.4	2.3	115.6	137.3
2040	9.9	1.6	5.7	1.7	111.2	130.0
2045	9.4	1.3	4.9	1.7	110.1	127.4
2050	9.3	1.1	4.9	1.9	112.9	130.1

8.3.4 Demand Assumptions

Gas demand is calculated by sets of algorithms and equations for each sector and region. Recent data from DOE/EIA and Statistics Canada have been considered in the calibration of the model. ICF performs market reconnaissance and data analysis each month to support the GMM calibration. GMM models natural gas demand in four end-use sectors: residential, commercial, industrial, and power generation.

Residential/Commercial gas demand calculated from regional equations fit econometrically to weather, economic growth, and price elasticity.

Industrial gas demand is based on a detailed breakout of industrial activity by census region and includes ten industry sectors, focusing on gas-intensive industries.

Power generation demand in the GMM is modeled for 13 dispatch regions, as shown in Figure 8-7 for the contiguous United States. All the power sector inputs in GMM are changed to be consistent with IPM results over time. Most importantly, the total gas use regionally is benchmarked against IPM's gas use.

Pipeline fuel consumption is a function of the fuel rate, and the volume of gas moved on each pipeline corridor. Pipeline gas use is estimated as a percent of natural gas throughput for each link in the pipeline network.

Lease & Plant gas use is forecasted based on historical percentages of the dry gas produced at each node. Regional factors determine the share of lease & plant gas use for each supply region.

There are four key drivers for natural gas demand in GMM. They are:

i) **Macroeconomic parameters:** From Q2 2023 forward, ICF assumes U.S. GDP grows at 2.1% per year, and Canada GDP grows at 2.0% per year.[78]

[78] The U.S. Congressional Budget Office assumes an average annual GDP growth rate of 1.9% between 2022 and 2032 in their July 2022 Long Term Budget Outlook, while the 2022 U.S. Energy Information Administration Annual Energy Outlook used an average annual GDP growth rate of 2.2% between 2023 and 2050.

ii) **Electric Demand Growth:** The electric demand growth rate is assumed to be 0.75% per year, consistent with the EPA 2023 Reference Case.

iii) **Demographics:** Projected demographic trends are consistent with trends over the past 20 years. U.S. population growth averages about 1% per year throughout our projection.

iv) **Weather:** Future weather is assumed consistent with regional and monthly average heating and cooling degree days (HDD/CDD) over the past 20 years (2002 through 2021).

Figure 8-7 GMM Power Generation Gas Demand Regions

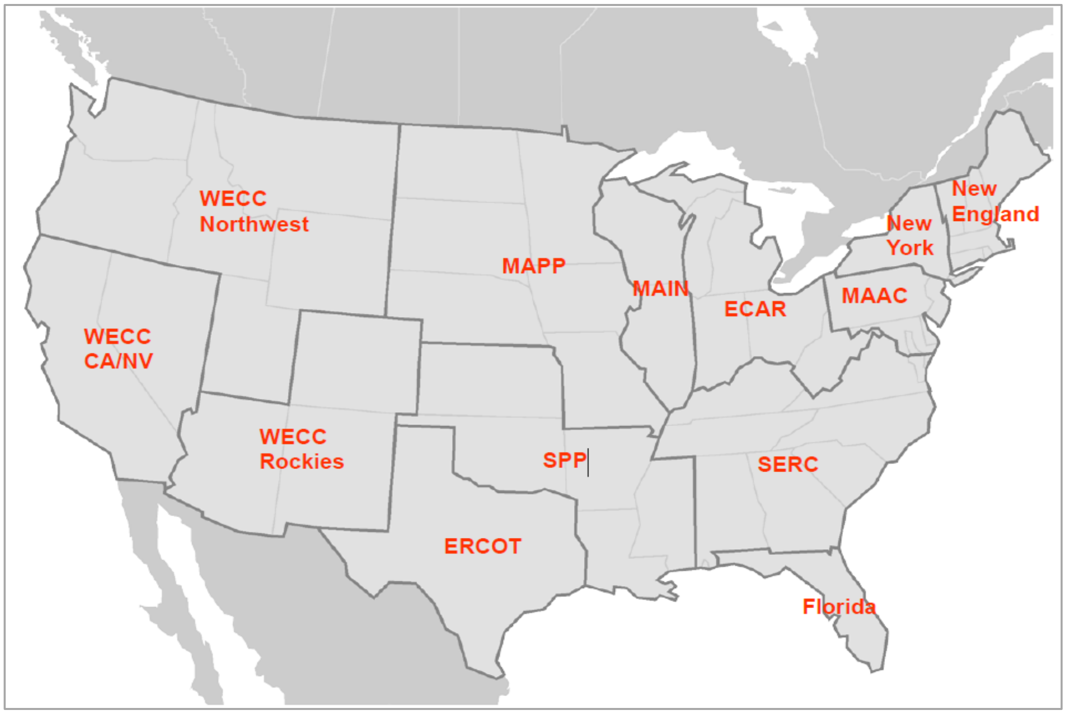


Table 8-4 shows the ICF's United States and Canada natural gas demand by sector and run year for EPA 2023 Reference Case.

Table 8-4 GMM United States and Canada Gas Demand Projection (Bcfd)

Year	Residential	Commercial	Industrial	Other	Non-Power	Power
2028	16.2	10.9	29.9	10.4	57.1	34.4
2030	16.2	10.9	30.2	10.5	57.3	33.8
2035	16.1	10.7	31.3	10.9	58.1	27.4
2040	16.2	10.8	31.9	10.4	58.9	20.0
2045	16.4	11.1	32.1	10.2	59.6	16.4
2050	16.6	11.3	31.1	10.4	59.0	19.4

Note: "Other" includes pipeline fuel and lease & plant.

8.3.5 LNG Exports and Pipeline Exports to Mexico

<u>Existing and Potential Liquefied Natural Gas (LNG) Terminals</u>

ICF aligned its LNG export based demand to EIA's Annual Energy Outlook (AEO) 2023 LNG assumptions. AEO 2023 assumes 13.3 Bcfd of net exports, including feedgas in 2023 which increases to 17.6 Bcfd by 2028. Between 2028 to 2050, an additional 11.9 Bcfd of export based demand is expected to come online. In the long term, the LNG facilities are expected to be 90% utilized.

Table 8-5 Net LNG Export Volumes as per AEO 2023 (Bcfd)

Year	Net LNG Exports (Annual Average)
2028	17.6
2030	20.2
2035	28.0
2040	29.3
2045	29.4
2050	29.4

Pipeline Exports to Mexico

Mexico's demand for natural gas will continue to increase between 2020 and 2030 due to Mexico's expansion of its domestic pipeline infrastructure, increased power generation gas demand, and lower domestic production. Since 2015, Mexico's imports of U.S. gas have undergone a 124% increase, reaching 6.4 Bcfd in 2022. ICF projects that exports will reach 8.2 Bcfd by 2030. ICF assumes the first phase of the Costa Azul LNG export facility will be built in Mexico, further increasing pipeline exports to Mexico from the United States.

Table 8-6 U.S. Pipeline Exports to Mexico (Bcfd)

Year	California	West Texas/ New Mexico	Arizona	South Texas
2028	0.5	2.0	0.6	5.1
2030	0.5	2.1	0.6	5.0
2035	0.5	2.4	0.7	4.4
2040	0.5	2.4	0.7	4.4
2045	0.5	2.4	0.7	4.4
2050	0.5	2.4	0.7	4.3

List of tables that are uploaded directly to the web:

Table 8-7 Natural Gas Basis for EPA 2023 Reference Case

Table 8-8 Natural Gas Supply Curves for EPA 2023 Reference Case

9. Other Fuels and Fuel Emission Factor Assumptions

Besides coal (Chapter 7) and natural gas (Chapter 8), EPA 2023 Reference Case also includes assumptions for residual fuel oil, distillate fuel oil, biomass, nuclear, and waste fuels. This chapter describes the assumptions pertaining to the characteristics, market structures, and prices of these other fuels. As reported in previous chapters, natural gas is represented by an exogenous supply curve along with a basis differential approach informed by a resource fundamentals model. Coal is represented by a robust set of supply curves and a detailed representation of the associated coal transport network. Together, they are designed to capture the intricacies of the resource base and market for these fuels, which accounted for about 62% of U.S. electric generation in 2019.[79] As with coal, the price and quantity of biomass combusted are determined by balancing supply and demand using a set of geographically differentiated supply curves. In contrast, fuel oil, nuclear, waste fuel, and hydrogen prices are exogenously determined and input to IPM during model set-up as constant price points that apply to all levels of supply. The following sections treats each of these remaining fuels and concludes with a discussion of the emission factors for all the fuels represented in the EPA 2023 Reference Case.

9.1 Fuel Oil

Two petroleum-derived fuels are included in EPA 2023 Reference Case. Distillate fuel oil is distilled from crude oil, and residual fuel oil is a residue of the distillation process. The fuel oil prices are based on the AEO 2023 reference case projection and a long-term crude oil projection of 64 $/barrel and are shown in Table 9-1. They are regionally differentiated according to the National Energy Modeling System (NEMS) regions used in the AEO 2023. These prices are mapped to their corresponding IPM regions for use in the EPA 2023 Reference Case.

Table 9-1 Fuel Oil Prices by NEMS Region in the EPA 2023 Reference Case

Residual Fuel Oil Prices (2022$/MMBtu)							
AEO NEMS Region	2028	2030	2035	2040	2045	2050	2055
TRE	13.37	13.49	13.82	13.64	12.65	12.72	12.72
FRCC	13.37	13.49	13.82	13.64	12.65	12.72	12.72
MISW	13.37	13.49	13.82	13.64	12.65	12.72	12.72
MISC	9.59	9.76	10.20	10.21	10.21	10.12	10.12
MISE	13.37	13.49	13.82	13.64	12.65	12.72	12.72
MISS	13.37	13.49	13.82	13.64	12.65	12.72	12.72
ISNE	13.37	13.49	13.82	13.64	12.65	12.72	12.72
NYCW	9.85	13.49	13.82	10.48	10.55	10.47	10.47
NYUP	10.58	10.75	11.20	11.21	11.29	11.21	11.21
PJME	10.58	10.75	11.20	11.21	11.29	11.21	11.21
PJMW	10.12	10.29	10.74	10.74	10.82	10.74	10.74
PJMC	13.37	13.49	13.82	13.64	12.65	12.72	12.72
PJMD	13.37	13.49	13.82	13.64	12.65	12.72	12.72
SRCA	13.37	13.49	13.82	13.64	12.65	12.72	12.72
SRSE	13.37	13.49	13.82	13.64	12.65	12.72	12.72
SRCE	13.37	13.49	13.82	13.64	12.65	12.72	12.72
SPPS	13.37	13.49	13.82	13.64	12.65	12.72	12.72
SPPC	13.37	13.49	13.82	13.64	12.65	12.72	12.72
SPPN	13.37	13.49	13.82	13.64	12.65	12.72	12.72
SRSG	13.37	13.49	13.82	13.64	12.65	12.72	12.72
CANO	13.37	13.49	13.82	13.64	12.65	12.72	12.72
CASO	13.37	13.49	13.82	13.64	12.65	12.72	12.72
NWPP	13.37	13.49	13.82	13.64	12.65	12.72	12.72

[79] EIA. Detailed EIA-923 monthly and annual survey data back to 1990. Available at https://www.eia.gov/electricity/data.php#generation

Residual Fuel Oil Prices (2022$/MMBtu)							
RMRG	9.85	10.00	10.36	10.44	10.58	10.49	10.49
BASN	13.37	13.49	13.82	13.64	12.65	12.72	12.72

Distillate Fuel Oil Prices (2022$/MMBtu)							
AEO NEMS Region	2028	2030	2035	2040	2045	2050	2055
TRE	16.77	16.90	17.37	17.30	17.31	17.10	17.10
FRCC	19.71	19.78	20.22	20.14	20.21	20.02	20.02
MISW	15.07	15.14	15.57	15.49	15.56	15.37	15.37
MISC	15.16	15.21	15.66	15.60	15.68	15.53	15.53
MISE	15.02	15.09	15.51	15.43	15.51	15.31	15.31
MISS	16.77	16.90	17.37	17.30	17.31	17.10	17.10
ISNE	17.32	17.40	17.84	17.75	17.83	17.63	17.63
NYCW	21.65	21.73	22.16	22.08	22.16	21.96	21.96
NYUP	18.68	18.99	19.24	19.10	19.06	21.96	21.96
PJME	21.36	21.36	21.80	21.67	21.74	21.43	21.43
PJMW	17.76	18.51	19.53	19.36	19.44	19.25	19.25
PJMC	18.68	18.99	19.24	19.10	19.06	19.02	19.02
PJMD	19.71	19.78	20.22	19.10	19.06	19.02	19.02
SRCA	19.71	19.78	20.22	20.14	20.21	20.02	20.02
SRSE	16.95	16.77	17.21	17.13	17.47	17.31	17.31
SRCE	16.70	16.77	17.21	17.13	17.15	16.94	16.94
SPPS	16.77	16.90	17.37	17.30	17.31	17.10	17.10
SPPC	15.08	15.15	15.58	15.49	15.57	15.37	15.37
SPPN	15.08	15.15	15.58	15.49	15.57	15.37	15.37
SRSG	20.57	20.72	20.96	20.93	21.02	20.86	20.86
CANO	19.45	19.54	20.01	19.95	20.05	19.86	19.86
CASO	19.45	19.54	20.01	19.95	20.05	19.86	19.86
NWPP	19.57	19.56	20.02	19.97	20.09	19.90	19.90
RMRG	20.63	20.73	21.19	21.14	21.22	21.02	21.02
BASN	20.63	20.73	21.19	21.14	21.22	21.02	21.02

9.2 Biomass Fuel

Biomass is offered as a fuel for existing dedicated biomass power plants and potential (new) biomass direct-fired boilers. In addition to its use as the prime mover fuel for these plants, it is also offered for co-firing to coal-fired power plants that have co-fired biomass in the recent past. Section 5.3 provides further details of these selected plants.

EPA 2023 Reference Case uses biomass supply curves based on those in the Department of Energy's 2016 Billion-Ton Report (DOE Report). Biomass supply curves at the IPM region and state level are generated by aggregating county-level supply curves from the DOE Report. Power plants demand biomass from the supply curve corresponding to the IPM region and state in which they are located. No inter-region trading of biomass is allowed. Each biomass supply curve depicts the price-quantity relationship for biomass and varies over time. There is a separate curve for each model run year. The supply component of the curve represents the aggregate supply in each region of agricultural residues, forestry residues, energy crops, waste, and trees. The price component of the curve includes transportation costs of $15 per dry ton. The supply curves represent the IPM region, and state-specific delivered biomass fuel cost at the plant gate. A storage cost of $20 per dry ton is added to each step of the agricultural residue supply curves to reflect the limited agricultural growing season.[80] The biomass

[80] http://www.extension.iastate.edu/agdm/crops/pdf/a1-22.pdf, http://www.rand.org/content/dam/rand/pubs/technical_reports/2011/RAND_TR876.pdf

supply curves are summarized in Table 9-4. The biomass prices are derived endogenously based on the aggregate power sector demand for biomass in each IPM region and state. The results are unique market-clearing prices for each IPM region and state. All plants using biomass from that IPM region and state face the same market-clearing price.

9.3 Nuclear Fuel

The AEO 2023 price for nuclear fuel is used as the nuclear fuel price assumption in EPA 2023 Reference Case. The 2028, 2030, 2035, 2040, 2045, and 2050 prices are 0.71 2022 $/MMBtu, respectively.

9.4 Waste Fuels

The waste fuels include waste coal, petroleum coke, fossil waste, non-fossil waste, tires, and municipal solid waste (MSW). Table 9-2 describes the characteristics of these fuels, the extent to which they are represented in NEEDS, and the assumptions pertaining to their use and pricing. Furthermore, the fuels are provided to only existing and planned-committed generating units. Potential (new) generating units that the model builds are not given the option to burn these fuels. In the IPM model output, tires, MSW, and non-fossil waste are included under existing non-fossil other plant type, while waste coal and petroleum coke are included under coal plant type.

Table 9-2 Waste Fuels in the EPA 2023 Reference Case

Modeled Fuel in NEEDS	Number of Units in NEEDS	Total Capacity in NEEDS	Description	Supply and Cost	
				Modeled By	Assumed Price
Waste Coal	18	1,364 MW	"Waste coal is a usable material that is a byproduct of previous coal processing operations. It is usually composed of mixed coal, soil, and rock (mine waste). Most waste coal is burned as-is in unconventional fluidized-bed combustors. Waste coal may be partially cleaned by removing some extraneous noncombustible constituents. Waste coal includes fine coal, coal obtained from a refuse bank or slurry dam, anthracite culm, bituminous gob, and lignite waste." https://www.eia.gov/tools/glossary/index.php?id=W	Supply Curve Based on AEO 2023	AEO 2023
Petroleum Coke	11	1,114 MW	A residual product, high in carbon content and low in hydrogen, from the cracking process used in crude oil refining.	Price Point	$56.44/Ton
Fossil Waste	54	1,071 MW	Waste products of petroleum or natural gas including blast furnace and coke oven gas. They do not include petroleum coke or waste coal which are specified separately among the modeled fuels.	Price Point	0
Non-Fossil Waste	201	2,136 MW	Non-fossil waste products that do not qualify as biomass. These include waste products of liquid and gaseous renewable fuels (e.g., red, and black liquor from pulping processes and digester gases from wastewater treatment). They do not include urban wood waste which is included in biomass.	Price Point	0
Tires	1	26 MW	Discarded vehicle tires.	Price Point	0
Municipal Solid Waste	147	1,913 MW	Residential solid waste and some nonhazardous commercial, institutional, and industrial wastes. https://www.eia.gov/tools/glossary/index.php?id=M	Price Point	0

9.5 Hydrogen Fuel

The price of hydrogen is assumed to be 9.64 $/MMBtu.

9.6 Fuel Emission Factors

Table 9-3 brings together all the fuel emission factor assumptions implemented in EPA 2023 Reference Case. For sulfur dioxide, chlorine, and mercury in coal, where emission factors vary widely based on the rank, grade, and supply source of the coal, cross references are given to tables that provide more detailed treatment of the topic. Nitrogen oxides (NO_x) are not included in Table 9-3 because NO_x emissions are a factor of the combustion process and are not primarily fuel based.

Table 9-3 Fuel Emission Factor Assumptions in the EPA 2023 Reference Case

Fuel Type		Carbon Dioxide (lbs/MMBtu)	Sulfur Dioxide (lbs/MMBtu)	Mercury (lbs/TBtu)	HCl (lbs/MMBtu)
Coal					
	Bituminous	202.8 - 212.9	0.67 - 7.78	2.80 - 34.71	0.015 - 0.214
	Subbituminous	209.2 - 215.7	0.52 - 2.15	2.03 - 8.65	0.007 - 0.014
	Lignite	212.6 - 219.3	1.51 - 5.67	7.53 - 30.23	0.011 - 0.036
Natural Gas		117.08	0	0.00014	0
Fuel Oil					
	Distillate	161.39	0	0.48	0
	Residual	173.91	1.04	0.48	0
Biomass		195	0.08	0.57	0
Waste Fuels					
	Waste Coal	204.7	7.78	53.9	0.0921
	Petroleum Coke	225.1	7.70	2.66	0.0213
	Fossil Waste	321.0	0.08	0	0
	Non-Fossil Waste	0	0	0	0
	Tires	189.5	1.65	3.58	0.06
	Municipal Solid Waste	91.9	0.35	71.85	0

Note:

Table 7-4 has coal emission factor on a coal supply region level.

List of tables that are uploaded directly to the web:

Table 9-4 Biomass Supply Curves for EPA 2023 Reference Case

10. Financial Assumptions

10.1 Introduction and Summary

This chapter presents the financial assumptions used in the EPA 2023 Reference Case. EPA 2023 Reference models a diverse set of generation and emission control technologies, each of which requires financing and incorporates updates to reflect The Tax Cuts and Jobs Act of 2017.[81] The capital charge rate converts the capital cost for each investment into a stream of levelized annual payments that ensures recovery of all costs associated with capital investment, including recovery of and return on invested capital and income taxes. The discount rate is used to convert all dollars to present values, and IPM minimizes the present value of annual system costs. The discount rate is set equal to the weighted average costs of capital. The primary purpose of this chapter is to describe the methodological approach to quantifying the discount and capital charge rates in the EPA Platform 2023 Reference Case.

10.2 Introduction to Risk

The cost of capital is the level of return investors expect to receive for alternative investments of comparable risk. Investors will only provide capital if the return on the investment is equal to or greater than the return available to them for alternative investments of comparable risk. Accordingly, the long-run average return required to secure investment resources is proportional to risk. There are several dimensions to risk that are relevant to power sector operations, including:

- **Market Structure –**The risk of an investment in the power sector is heavily dependent on whether the wholesale power market is regulated or deregulated. The risks are higher in a deregulated market compared to a traditionally regulated utility market. Slightly more than half of U.S. generation capacity is deregulated (operated by Independent Power Producers (IPPs), or 'merchants').[82] IPPs often sell power into spot markets supplemented by near-term hedges. In contrast, regulated plants sell primarily to franchised customers at regulated rates, an arrangement that significantly mitigates uncertainty and, therefore, risk.[83]

- **Technology** - The selection of new technology investment options is partially driven by the risk profile of these technology investments. For instance, in a deregulated merchant market, an investment in a peaking combustion turbine is likely to be much riskier than an investment in a combined cycle unit. This is because a combustion turbine operates as a peaking unit and can generate revenues only in times of high demand or via capacity payments, while a combined cycle unit is able to generate revenues over a much larger number of hours in a year from the energy markets as well as via capacity payments. An investor in a combined cycle unit, therefore, would require a lower return due to a more diversified stream of revenue and receive a lower risk premium than an investor in a combustion turbine, all else equal.

- **Leverage** - There are financial risks related to the extent of leverage. Reliance on debt over equity in financing a project increases the risk of insolvency. This dynamic applies to all industries, power included.[84]

- **Financing Structure** – Lastly, there are also financing structure risks (e.g., corporate vs. project financing), also referred to as non-recourse financing. There are no clear risk implications from

[81] The Tax Cuts and Jobs Act of 2017, Pub.L. 115-97.

[82] According to EIA Form 860 2019, the current capacity mix is 58% utility and 42% merchant by MW.

[83] There is a potential third category of risk, where IPPs enter into long-term (e.g., ten years or longer), known-price contracts with credit worthy counterparties (e.g., traditionally regulated utilities). With a guaranteed, longer-term price, the risk profile of this segment of the IPP fleet is similar enough to be treated as regulated plants.

[84] We use the terms debt and leverage interchangeably.

the structure alone, but rather, this element interacts with other dimensions of risks, making considerations of leverage, technology, and market structure more important.

- **Systemic** – Systemic risk is when financial performance correlates with overall market and macro-economic conditions such that investment returns are poor when market and economic conditions are poor, and vice versa. For example, if investors are less likely to earn recovery of and on investments during recessions, then these risks are systemic and increase required expected rates of return. This emphasis on correlated market risk is based on the Capital Asset Pricing Model (CAPM), which is used to produce key financial assumptions for EPA 2023 Reference Case. Other risks are handled in the cash flows and are treated as non-correlated with the market.

10.2.1 Deregulation - Market Structure Risks

As noted, the power sector in North America can be divided into the traditional regulated sector (also known as the cost of service or utility sector) and the deregulated merchant sector (also known as competitive, merchant, deregulated,[85] or IPP sector).

Traditional Regulated

The traditional regulated market structure is typical of the vertically integrated utilities whose investments are approved through a regulatory process, and the investment is provided a regulated rate of return, provided the utility's investments are deemed prudent. In this form of market structure, returns include the return on the original investment plus a return on invested capital that is administratively determined. Returns are affected by market conditions due to regulatory lag and other imperfections in the process, but overall regulated investments are less exposed to the market than deregulated investments, all else equal.

Deregulated Merchant

In a deregulated merchant market structure, investments bear a greater degree of market risk, as the price at which they can sell electricity is dependent on what the short-term commodity and financial hedge markets will bear. Return on investment in this form of market structure is not only dependent on the state of the economy, but also on commodity prices, capital investment cycles, and remaining price-related regulation (e.g., FERC price caps on capacity prices). The capital investment cycle can create a boom-and-bust cycle, which imparts risk or uncertainty in the sector that can be highly correlated with overall macroeconomic trends. The operating cash flows from investments in this sector are more volatile as compared to the traditional regulated sector and, hence, carry more business or market risk.[86]

Overall, there is ample supporting evidence for the theoretical claim that deregulated investments are more risky than utility investments. For example:

- All three large publicly traded IPPs[87] are rated as sub-investment grade,[88] while all utilities are investment grade.

[85] Wholesale generators cannot be economically unregulated; they can be Exempt Wholesale Generator ("EWG") subject to FERC jurisdiction. The moniker of deregulated is used to convey greater market risk relative to regulated utility plants.

[86] In this documentation, the terms merchant financing, deregulated, IPP, non-utility and merchant refer to this type of market structure.

[87] Dynegy Inc. Calpine Corp. and NRG Energy Inc are the three IPP's whose ratings were B2, Ba3 and Ba3 in 2016.

[88] Below minimum investment grade.

- All major IPPs have gone bankrupt over the last 20 years.[89]
- Estimates of beta, a measure of risk using CAPM, leverage, debt costs, and weighted average cost of capital, consistently produce higher risk for deregulated power plants.

10.3 Federal Income Tax Law Changes

EPA 2023 Reference Case incorporates updates to reflect The Tax Cuts and Jobs Act of 2017. The four most significant changes in the federal corporate income tax code are:

- **Rate**—The corporate tax rate is lowered 14 percentage points from 35% to 21%. The 21% rate is in place starting in 2018 and remains in place indefinitely. The lower tax rate decreases capital charges in all periods and sectors, all else held equal. When state income taxes are included, the average rate decreases 13.1 percentage points, from 39.2% to 26.1%. This applies to both sectors, utility and IPP.
- **Depreciation** – The new tax law expands near-term bonus depreciation (also referred to as expensing) for the IPP sector only until 2027; the utility sector is unaffected.
- **Interest Expense** – The new law lowers tax deductibility of interest expense for the IPP sector, which continues indefinitely; the utility sector is unaffected.
- **Net Operating Losses** – The new law limits the use of Net Operating Losses (NOL) to offset taxable income. This applies to all sectors, utility, and IPP.

Other important features of the new tax law include:

- **Annual Variation of Provisions** - The legislation specifies permanent changes (tax rate and NOL usage limit) applying to both sectors, utility, and IPP. The legislation also applies temporary changes that vary year-by-year through 2027 (depreciation and tax deductibility of interest) (See Table 10-1), applying to the IPP sector only. This creates different capital charge rates for each year through 2027. We calculate these parameters for IPM run years 2023, 2025, and 2028 and thereafter. This set covers a wide range of financing conditions even though we do not estimate every year.

[89] Dynegy, Calpine, and NRG were bankrupt – i.e., the three large public IPPs were bankrupt. Also, Mirant (major IPP), Boston Generating (IPP), EFH (utility with large IPP component), and FES (utility with large IPP component) have been or are bankrupt.

Table 10-1 Summary Tax Changes

Parameter	Previous	2023[90]	2025	2028 and Later
Marginal Tax Rate - Federal	35	21	21	21
Maximum NOL (Net Operating Loss) Carry Forward Usage	No limit. All losses in excess of income are carried forward and usable immediately.	Carry Forward cannot exceed 80% of Taxable Income	Carry Forward cannot exceed 80% of Taxable Income	Carry Forward cannot exceed 80% of Taxable Income
Tax Deductibility of Interest Expense	100%[91]	30% of EBIT; Utilities MACRS	30% of EBIT; Utilities MACRS	30% of EBIT; Utilities MACRS
Bonus Depreciation[92]	0[93]	IPP 80%[94]; Utilities 0%	IPP 40%[95]; Utilities 0%	0

- **Utilities Versus IPPs** – As noted, the legislation treats utilities and IPPs differently. The new tax code exempts utilities from changes in tax deductibility of interest and accelerated depreciation. The financing assumptions used in IPM modeling are a blend (weighted average) of the utility and IPP average. The weighting is 60% utility and 40% IPP, and hence, the greatest weight is on the least affected sector. This partly mitigates the impacts of the changes.

- **Capital Charge Rates**—We calculate the capital charge rates for utilities and IPPs and then take the weighted average of the resulting capital charge rates. The legislation, combined with the IPM model's ability to vary capital charge rates by run year, allows us to calculate the blended average for specific run years.

- **Discount Rates**—The discount rate equals the weighted average after-tax cost of capital (WACC) and is affected by the change in the corporate income tax rate only. The discount rate is invariant over time, sectors, and technologies. Therefore, the calculation methodology for the discount rate used in IPM is unchanged.

10.4 Calculation of the Financial Discount Rate

10.4.1 Introduction to Discount Rate Calculations

A discount rate is used to translate future cash flows into current dollars by considering factors such as expected inflation and the ability to earn interest, which make one dollar tomorrow worth less than one dollar today. The discount rate allows intertemporal trade-offs and represents the risk-adjusted time value of money.[96]

---

[90] IPM run years in the near term are 2023, 2025, and 2028.

[91] No limit except losses in excess of income can be carried forward. The losses were limited to first few years.

[92] Referred to as expensing. If depreciation exceeds income in first year, it can be carried forward to succeeding years up to 80% of EBITDA.

[93] Bonus depreciation was available but only in the period before IPM runs, and only for new equipment.

[94] For thermal power plants coming online in 2023, the 100% would apply only to costs incurred through end of 2022. We are hence assuming practically all capital costs are incurred prior to 2023.

[95] Remaining basis depreciated at MACRS schedule.

[96] The discount rate is the inverse of compound interest or return rate; the existence of interest, especially compound interest creates an opportunity cost for not having dollars immediately available. Thus, future dollars need to be discounted to be comparable to immediately available dollars.

The discount rate adopted for modeling investment behavior should reflect the time preference of money or the rate at which investors are willing to sacrifice present consumption for future consumption. The return on private investment represents the opportunity cost of money and is commonly used as an appropriate approximation of a discount rate.[97]

The real discount rate for all expenditures (capital, fuel, variable operations and maintenance, and fixed operations and maintenance costs) in the EPA 2023 Reference Case is 3.76%.[98]

10.4.2 Summary of Results

The tables below summarize the key financial assumptions for the EPA 2023 Reference Case. Throughout the chapter, these values and the attendant methodological approaches are described.

Table 10-2 Financial Assumptions for Utility and Merchant Cases

EPA 2023 Reference Case - Utility WACC using daily beta for 2016-2020	
Parameters	**Value**
Risk-free rate	2.73 %[99]
Market premium	7.15 %[100]
Equity size premium	−0.01 %[101]
Levered beta[102]	0.72
Debt/total value[103]	0.58
Cost of debt	3.50 %[104]
Debt beta	0.00
Unlevered beta[105]	0.36
Target debt/total value[106]	0.50
Relevered beta	0.62

[97] For a perspective on the legal basis for utilities having the right to have the opportunity to earn such returns under certain conditions such as prudent operations, see *Bluefield Water Works and Improvement Co. v Public Service Comm'n 262 US 679, 692 (1923).* See also *Federal Power Comm'n versus Hope Natural Gas Co., 320 US 591, 603 (1944).*

[98] This rate is based on the weighted average after tax cost of capital (WACC), which reflects two weightings. First, it reflects an assumption that 60% of the investments are made by a regulated utility and 40% are made by a merchant investor (also referred to as a hybrid). Second, it assumes a mix of plant types - 55% renewable and 45% gas thermal. This weighting reflects the profile of builds over 2015-2019 of renewable and natural gas-fired units. The financial data used to estimate this rate is primarily from 2016–2020. The EPA 2023 Reference Case uses 2022 (2022$) as its real dollar baseline and assumes 1.76% general inflation. Hence, the nominal discount rate is 5.59%.

[99] Represents 10-year historical average (2011- June 2020) on a 20-year treasury bond. See discussion of risk-free rate and market premium. The 5-year average (2016–June 2020) on a 20-year T bond is 2.45%. The 5-year (2016–June 2020) and 10-year (2011–June 2020) averages for the 30-year bond are 2.66% and 2.99% respectively.

[100] Represents the long horizon expected equity risk premium based on differences between S&P 500 total returns and long-term government bond income returns from 1926–2020 (Duff and Phelps 2020).

[101] Size Premiums according to size groupings taken from Duff & Phelps 2020 Valuation. Equity Size Premium is based on weighted average of each company's Equity Size Premium, weighted by each company's Market capitalization level.

[102] Levered betas were calculated using 5 years (2016–June 2020) and in a sensitivity case discussed separately later 10 years (2011–June 2020) of historical stock price data. Daily returns were used in the current analysis. In the previous case, weekly returns for 5 years (2016-2020) were used.

[103] Debt/total value ratio is the simple average of net debt to equity ratio for the past 5 years.

[104] Cost of debt is based on 5-year (2016–June 2020) weighted average of debt yields for 18 utilities. The weights assigned are equity share of each utility.

[105] Calculated using Hamada equation.

[106] Target debt/total value for utility case is based on historical 5 years of average D/E for utilities

EPA 2023 Reference Case - Utility WACC using daily beta for 2016-2020	
Cost of equity (with size premium) [107]	7.17 %
WACC	4.88 %
EPA 2023 Reference Case - Merchant WACC using 55% Target Debt	
Parameters	**Value**
Risk-free rate	2.73 %
Market premium	7.15 %
Equity size premium	0.89 %[108]
Levered beta[109]	1.04
Debt/total value[110]	0.64
Cost of debt[111]	6.27 %
Debt beta[112]	0.00
Unlevered beta[113]	0.45
Target debt/ total value[114]	0.55
Relevered beta	0.86
Cost of equity (with size premium) [115]	9.74%
WACC	6.65%

Table 10-3 Weighted Average Cost of Capital in the EPA 2023 Reference Case

Utility Share	Utility WACC	Merchant Share	Merchant WACC	Weighted Average Nominal WACC	Inflation	Weighted Average Real WACC
60%	4.88%	40%	6.65%	5.59%	1.76%	3.76%

10.5 Discount Rate Components

The discount rate is a function of the following parameters:

- Capital structure (share of equity and debt)
- Post-tax cost of debt
- Post-tax cost of equity

[107] Cost of Equity represents the simple average cost of equity derived from Risk-Free Rate, Market Premium, Relevered Beta, and Target D/E value.

[108] Size Premiums according to size groupings taken from Duff & Phelps 2020 Valuation Handbook. Equity Size Premium is based on weighted average of each company's Equity Size Premium, weighted by each company's equity capitalization level.

[109] Levered betas were calculated using five years (2016-June 2020) of historical stock price data. Weekly returns were used in the analysis.

[110] Debt/total value for merchant case is calculated as simple average of the 5-year total debt to total value for each IPP.

[111] Cost of debt is based on historical 5-year weighted average of yields to maturity on outstanding debt.

[112] Debt Beta was previously used as Dynegy was in the process of bankruptcy.

[113] Calculated using Hamada equation. In merchant case, it was modified slightly to include the riskiness of debt.

[114] The capitalization structure (debt to equity (D/E)) for merchant financings is assumed to be 55/45.

[115] Cost of Equity (ROE) represents the simple average cost of equity. In the Merchant ROE, the decrease reflects primarily the lower beta.

The WACC is used as the discount rate and is calculated as follows:[116]

WACC = [Share of Equity * Cost of Equity]
+ [Share of Preferred Stock * Cost of Preferred Stock]
+ [Share of Debt *After Tax Cost of Debt]

The methodology relies on debt and equity (common stock) because preferred stock is generally a small share of capital structures, especially in the IPP sector. Its intermediate status between debt and equity in terms of access to cash flow also tends not to change the weighted average.[117] Typically, net cash flows are used to fund senior debt before subordinated debt, and all debt before equity. Therefore, the risk of equity is higher than debt, and the rates of return reflect this relationship. Notwithstanding, consistent with our use of utility debt that has recourse to the corporation rather than individual assets, we use IPP debt that has recourse to the corporation rather than individual assets because the data are more robust.

10.6 Market Structure: Utility-Merchant Financing Ratio

With two distinct market structures, EPA 2023 Reference Case establishes appropriate weights for regulated and deregulated financial assumptions to produce a single, hybrid set of utility capital charge rates for new units. The EPA 2023 Reference Case uses a weighting of 60:40, regulated to deregulated, based on recent capacity addition shares by market type (see Table 10-4).[118]

Table 10-4 Share of Annual Thermal Capacity Additions by Market

Entity	2015	2016	2017	2018	2019	Total
Regulated	61%	81%	51%	52%	63%	61%
Merchant	39%	19%	49%	48%	37%	39%

10.7 Capital Structure: Debt-Equity Share

10.7.1 Introduction and Shares for Utilities and IPPs

The second step in calculating the discount rate is determining the capital structure, specifically the debt to equity (D/E) or debt to value (D/V) ratio for utility and merchant investments. This is calculated by determining the company's total market value and the market value of its debt and equity. The company's market value is the sum of its debt and equity. We also determined the capital structure for the various technology types.

The target capitalization structure for utilities was assumed to be 50:50, based on the capitalization over the 2016 to 2020 period. The capitalization structure for merchant financings is assumed to be 55/45, reflecting the greater risk inherent to this market.[119]

[116] Sometimes abbreviated as ATWACC. The pretax WACC is higher due to the inclusion of income taxes. Income taxes are included in the capital charges. All references are to the after-tax WACC unless indicated.

[117] Debt generally has first call on cash flows and equity has a residual access.

[118] In contrast to new units, existing coal units can be classified as belonging to a merchant or regulated market structure. Hence, for retrofit investments, the EPA 2023 Reference Case assumption is that coal plants owned by a utility get purely utility financing parameters coal plants owned by merchant companies get purely merchant financing parameters.

[119] The U.S. wide average authorized rate of return on equity, authorized return on rate base, and authorized equity ratio during the 5 years (2012–2016) for 146 utility companies was 9.93%, 7.64%, and 50.22% respectively. According to S&P Global Market Intelligence, the authorized ROE approved for the first half of 2020 was 9.55%. Similarly, S&P Global Market Intelligence give an average authorized ROE of 9.64% in 2019, 9.59% in 2018, 9.63%

10.7.2 Utility and Merchant

The empirical evidence suggests that utility rates of return are based on an average return to the entire rate base for utility financing. Thus, EPA 2023 Reference Case assumes that the required returns for regulated utilities are independent of technology. In contrast, merchant debt capacity is based on market risk and varies by technology.

10.7.3 Merchant by Technology

Assigning merchant technology risk is difficult because there is a lack of publicly traded securities that provide an empirical basis for differentiating between the risks and, hence, financing parameters for different activities.[120] Nevertheless, we assigned merchant technology market risk as follows:

- **Combined Cycles** – The capitalization structure for merchant financing of combined cycles is assumed to be 55/45.

- **Peaking Units** – A peaking unit such as a combustion turbine is estimated to have a capital structure of 40/60. Peaking units have a less diverse and, therefore, more risky revenue stream.

- **Coal Units** – A new coal unit is estimated to have a capital structure of 40/60, reflecting higher risk than a combined cycle unit. This is reflected in a lack of proposed new builds, decreases in coal dispatch, financial assessments by other entities such as EIA and NREL indicating greater risk, and greater levels of environmental regulatory risk.

- **Nuclear Units** — A new nuclear unit is estimated to have a capital structure of 40/60. There is a high risk associated with a new IPP nuclear unit. This is supported by: (1) the financial challenges facing existing nuclear units, (2) the very limited recent new nuclear construction, (3) statements by financial institutions, and (4) the lack of ownership of nuclear power plants by pure-play IPP companies. Of the three pure-play companies, only one has partial ownership of a single nuclear power plant. With this one exception, only utilities and affiliates of utilities own nuclear units.

- **Renewable Units** — A new merchant renewable unit is estimated to have a capital structure of 65/35. This is the highest debt share among the major classes of generation options and, therefore, the lowest cost of capital. This is in part because renewables have access to a third source of financing in tax equity. Tax equity receives the tax benefits such as ITC, PTC, and losses available to defray income tax over time by making a payment upfront. These benefits are not transferable to other companies. There is a risk that the tax credits may become less valuable over time (e.g., the company providing the tax equity does not have sufficient taxable income), or the project may not perform and have inadequate operations to generate expected PTC volumes. This risk is less than typical equity since the tax credits and the tax credit value are not subject to as much variation as regular equity. These projects are also easier to hedge because they have zero variable costs, and hence, the annual volume of output is less uncertain, all else equal, and often receive support via power purchase agreements and renewable energy credits. Limits of relying on even greater debt include the scheduled lowering of the PTC and ITC over time and the potential for performance problems.

Table 10-5 Capital Structure Assumptions in the EPA 2023 Reference Case

Technology	Utility	Merchant
Combustion Turbine	50/50	40/60

for 2017, and 9.60% in 2016. In contrast, they state the average earned ROE to be 9.75% for the 12 months ended during the second quarter of 2020, 10.21% in 2019, 10.34% in 2018, 10.00% in 2017.

[120] There were only three major IPP companies with traded equity. This is insufficient to conduct statistical analysis.

Technology	Utility	Merchant
Combined Cycle	50/50	55/45
Coal & Nuclear	50/50	40/60
Renewables	50/50	65/35
Retrofits	50/50	40/60

10.8 Cost of Debt

The third step in calculating the discount rate is to assess the cost of debt.[121] The utility and merchant cost of debt is assumed the same across all technologies.

Table 10-6 Nominal Debt Rates in the EPA 2023 Reference Case

Technology	Utility	Merchant
Combustion Turbine	3.50%	6.27%
Combined Cycle	3.50%	6.27%
Coal & Nuclear	3.50%	6.27%
Renewables	3.50%	6.27%
Retrofits	3.50%	6.27%

10.8.1 Merchant Cost of Debt

The cost of debt for the merchant sector was estimated to be 6.27%. It is calculated by taking a 5-year (2016-2020) weighted average of debt yields from existing company debt with eight or more years to maturity. The weights assigned to each company's debt yields were based on that company's market capitalization. During the most recent 5 years (2016-2020), none of the existing long-term debt exceeded twelve years to maturity; hence, above average yields are based on debt with maturity between eight and twelve years.

[121] Measured as yield to maturity.

10.8.2 Utility Cost of Debt

The cost of debt for the utility sector was estimated to be 3.5%. It is calculated based on the 5-year (2016-2020) average of a set of 18 investment-grade utilities weighted by enterprise value (see Table 10-7).

Table 10-7 Utilities Used to Calculate Cost of Debt

Name
Ameren Corp
American Electric Power Co Inc
Cleco Corporate Holdings LLC
CMS Energy Corp
Empire District Electric Co/The
MGE Energy Inc
Vectren Corp
Evergy Kansas Central Inc
WEC Energy Group Inc
CH Energy Group Inc
Consolidated Edison Inc
Eversource Energy
Southern Co/The
Avista Corp
IDACORP Inc
Pinnacle West Capital Corp
PNM Resources Inc
Xcel Energy Inc

10.9 Return on Equity (ROE)

10.9.1 Introduction and Beta

The final step in calculating the discount rate is the calculation of the required rate of return on equity (ROE). The ROE is calculated using the formula:

ROE = risk free rate + beta x equity risk premium + size premium

The formula is the key finding of the CAPM and reflects that a premium on return is required as investment risk increases, and that premium is proportional to the systemic risk of the investment.[122] Systemic risk is measured by the impact of market returns on the investment's returns and is measured by beta.[123]

[122] The financial literature on CAPM originally did not emphasize the size premium (also referred to as the liquidity premium). It emerged from later findings that the estimated required return was too low for small stocks (i.e., with low equity value).

[123] Beta is the covariance of market and the stock's returns divided by the variance of the market's return.

There are several additional aspects of estimating beta:

- **Time Period** – The most common practice is to use five years of historical returns to estimate beta.

- **Returns** – Daily returns are commonly used to estimate beta except for illiquidly traded stocks when weekly returns are used to avoid underestimating beta. The utility estimates presented use daily data and the IPP estimates used weekly estimates.

- **Unlevered Betas**—It is useful to estimate unlevered betas that eliminate the effects of leverage. This facilitates comparison across investments with different leverage levels and allows recalculation to account for future changes in leverage levels. This recalculation involves a technique known as the Hamada[124] equation.

- **Debt Betas** - When a company is facing financial distress, the debt can become the new equity as part of a corporate reorganization under the federal bankruptcy code. Hence, during the bankruptcy period, the debt trades like equity. There is a technique to adjust the beta by calculating a debt beta. This technique is employed because in past analyses (e.g., 2012–2016), IPP companies were bankrupt.

10.9.2 Risk-Free Rate and Equity Risk Premium

The risk-free rate of return and equity risk premium are market parameters and are not company-specific. They also determine the average market-wide level of returns on equity. Therefore, the average return of the market equals the sum of the risk-free rate of return and equity risk premium.

The EPA estimate uses long-term averages for both the risk-free rate and the market risk premium. This avoids using or giving large weight to the currently depressed risk-free interest rates.

In the current analysis, the EPA used the 10-year Risk-Free rate of 2.73%, based on the 10-year (2011–2020) average of U.S. Treasury 20-year bond rates. Additionally, the Duff and Phelps Long-Term (1926–2020) Market Premium of 7.15% was adopted in this analysis. Thus, the total of the risk-free rate and the market premium is 9.88%. As noted, this sum equals the expected return of the market (i.e., the beta is one).

10.9.3 Beta

Utility betas average 0.72 during the 2016 to 2020 period on a levered basis (see Table 10-8). This estimate is based on daily returns.

Table 10-8 Estimated Annual Levered Beta for S15ELUT Utility Index Based on Daily Returns[125]

Year	Levered Beta
2016–2020	0.72

[124] In corporate finance, Hamada's equation is used to separate the financial risk of a levered firm from its business risk.

[125] S15ELUT Index comprises of 20 utilities. They are: American Electric Power Co Inc, ALLETE Inc, Duke Energy Corp, Eversource Energy, Entergy Corp, Evergy Inc, Edison International, Exelon Corp, FirstEnergy Corp, Hawaiian Electric Industries Inc, IDACORP Inc, Alliant Energy Corp, NextEra Energy Inc, OGE Energy Corp, Pinnacle West Capital Corp, PNM Resources Inc, PPL Corp, Southern Co/The, and Xcel Energy Inc. We have excluded NRG as it is an IPP Company.

IPP levered betas average 1.04 based on weekly returns from 2016–June 2020. After decreasing leverage for IPPs from 64% to 55%, the relevered beta was 0.86. The unlevered betas (i.e., betas without debt impacts) of utilities is 0.33, and of IPPs is 0.45.[126]

10.9.4 Equity Size Premium

It is observed that the long-run returns of smaller, less liquidly traded companies have higher returns than predicted using the market risk premium. Therefore, an equity size of a liquidity premium is added. Based on the 2020 Duff and Phelps Valuation Handbook, there was a significant equity size premium for IPPs of 0.89% and a minimal premium for utilities at -0.01%.

10.9.5 Nominal ROEs

<u>Utility</u>

The utility ROE is 7.17% in nominal terms. The utility ROE is the single most influential parameter in the estimate of the discount rate because of the 60% weight given to utilities compared to IPPs, and the decrease in interest rates due to the tax shield on debt (debt interest payments are tax deductible).

The estimated utility ROE in EPA 2023 Reference Case is lower than what state and federal commissions have awarded the shareholder-owned electric utilities recently.[127] In some cases, commissions use a different approach or assumptions.[128] Regardless of methodology, the trend over time is to lower returns, and this is a long-term analysis focused on the cost of capital for future investments that can occur 25 years or more in the future. Thus, it could be that returns are trending toward this level and that sufficient capital can be attracted in the future at these lower rates. Another possible explanation is that while the utilities are allowed to earn higher returns, actual earnings will be, over time, lower than allowed, and closer to the required utility ROE estimated here.

<u>IPP</u>

The nominal ROE for IPPs is 9.74%. The IPP required ROE is sensitive to the amount of debt, and the analysis assumes future delevering. Specifically, the IPP ROE assumes 55% debt rather than 64% debt, which is the 2016-2020 average.

---

[126] Unlevered betas are lower than levered betas. Levered beta is directly measured from the company's stock returns with no adjustment made for the debt financing undertaken by the company. The leveraged beta of the market equals one.

[127] Based on Bloomberg data, the average authorized ROEs for nine Utility Companies (Southern Company, American Electric Power Co, WEC Energy, CMS Energy, Cleco Corp, Allete Inc., Black Hills Corp, and NextEra Energy) was 9.86% in 2019. This was less than the average earned ROE according to S&P Global Intelligence of 10.21% in 2019, and slightly higher than their average authorized ROE of 9.64%.

[128] Some regulatory commissions use what is known as the dividend growth model. This model assumes that the current market price of a company's stock is equal to the discounted value of all expected future cash flows. In this approach, the time period is assumed to be infinite, and the discount rate is a function of the share price, earnings per share and estimated future growth in dividends. The challenge with using this approach is estimating future growth in earnings. Commissions rely on stock analyst forecasts of future growth rates for dividends. In other cases, commissions may allow for other parameters such as flotation costs (costs of issuing stock). We did not use this approach because it is less commonly used. There also appears to be a tendency of allowed rates of return as a group to be too low during periods with high financial costs and too high during periods of low financing costs. This may be to ensure comparability with similar utility companies. There is also a literature that indicates that as betas deviate from 1, the CAPM returns are too low and too high. We did not address these issues directly in part because the results were comparable to other results, with the exception of being lower than allowed returns.

10.9.6 WACC/Discount Rate

The WACCs are 4.88% in nominal terms for utilities and 6.65% in nominal terms for IPPs (see Table 10-3). Using a 60:40 utility/merchant weighting, the weighted average WACC under utility financing and merchant financing is a 5.59% WACC. The real hybrid WACC is 3.76%.

10.10 Calculation of Capital Charge Rate

10.10.1 Introduction to Capital Charge Rate Calculations

The capital charge rate is used to convert the capital cost into a stream of levelized annual payments that ensures the capital recovery of an investment. The number of payments is equal to the book life of the unit or the years of its book life included in the planning horizon (whichever is shorter). Table 10-9 to Table 10-11 presents the capital charge rates by technology type used in EPA 2023 Reference Case. As discussed in section 10.3, the changes to the Tax Code have caused capital charge rates to vary by run year. Therefore, the tables below show the rates for the individual run years through 2030. Capital charge rates are a function of the underlying discount rate, book and debt life, taxes and insurance costs, and depreciation schedule.

Table 10-9 Real Capital Charge Rate – Blended (%)[129] in the EPA 2023 Reference Case

New Investment Technology Capital Hybrid (60/40 Utility/Merchant)	2023	2025	2028 and Beyond
Environmental Retrofits - Utility Owned	10.58%	10.58%	10.58%
Environmental Retrofits - Merchant Owned	12.66%	12.70%	12.99%
Advanced Combined Cycle	8.29%	8.30%	8.39%
Advanced Combustion Turbine	8.64%	8.63%	8.69%
Ultra-Supercritical Pulverized Coal	7.92%	7.93%	8.01%
Nuclear without Production Tax Credit	7.90%	7.89%	7.94%
Biomass	7.66%	7.65%	7.65%
Wind, Solar and Geothermal	8.15%	8.15%	8.15%
Wind, Landfill Gas, Solar, and Geothermal without Property Tax and Insurance	7.00%	6.99%	6.99%
Landfill Gas	8.14%	8.14%	8.18%
Hydro	7.66%	7.67%	7.75%
Energy Storage	10.94%	10.93%	10.94%
Energy Storage without Property Tax and Insurance	9.79%	9.78%	9.80%

Table 10-10 Real Capital Charge Rate – IPP (%)

New Investment Technology Capital (IPP)	2023	2025	2028 and Beyond
Environmental Retrofits - Merchant Owned	12.66%	12.70%	12.99%
Advanced Combined Cycle	9.43%	9.46%	9.70%
Advanced Combustion Turbine	10.08%	10.05%	10.19%
Ultra-Supercritical Pulverized Coal	9.42%	9.43%	9.64%
Nuclear without Production Tax Credit	9.41%	9.38%	9.49%
Biomass	8.73%	8.72%	8.71%
Wind, Solar and Geothermal	9.14%	9.12%	9.12%

[129] Capital charge rates were adjusted for expected inflation and represent real rates. The expected inflation rate used to convert future nominal to constant real dollars is 1.76%. The future inflation rate of 1.76% is based on an assessment of implied inflation from an analysis of yields on 10-year U.S. Treasury securities and U.S. Treasury Inflation Protected Securities (TIPS) over a period of 5 years (2016-2020).

New Investment Technology Capital (IPP)	2023	2025	2028 and Beyond
Wind, Landfill Gas, Solar, and Geothermal without Property Tax and Insurance	7.99%	7.97%	7.97%
Landfill Gas	9.15%	9.15%	9.28%
Hydro	10.61%	10.67%	11.01%
Energy Storage	11.77%	11.74%	11.77%
Energy Storage without Property Tax and Insurance	10.62%	10.58%	10.63%

Table 10-11 Real Capital Charge Rate – Utility (%)

New Investment Technology Capital Utility	2023	2025	2028 and Beyond
Environmental Retrofits - Utility Owned	10.58%	10.58%	10.58%
Advanced Combined Cycle	7.52%	7.52%	7.52%
Advanced Combustion Turbine	7.69%	7.69%	7.69%
Ultra-Supercritical Pulverized Coal	6.93%	6.93%	6.93%
Nuclear without Production Tax Credit	6.90%	6.90%	6.90%
Biomass	6.94%	6.94%	6.94%
Wind, Landfill Gas, Solar, and Geothermal	7.50%	7.50%	7.50%
Wind, Landfill Gas, Solar, and Geothermal without Property Tax and Insurance	6.35%	6.35%	6.35%
Landfill Gas	7.46%	7.46%	7.46%
Hydro	7.01%	7.01%	7.01%
Energy Storage	10.38%	10.38%	10.38%
Energy Storage without Property Tax and Insurance	9.24%	9.24%	9.24%

10.10.2 Capital Charge Rate Components

The capital charge rate is a function of the following parameters:

- Capital structure (debt/equity shares of an investment)
- Pre-tax debt rate
- Debt life
- Post-tax return on equity
- Other costs, such as property taxes and insurance
- State and federal corporate income taxes
- Depreciation schedule
- Book life

Table 10-12 presents a summary of various assumed book lives, debt lives, and the years over which the investment is fully depreciated. The EPA 2023 Reference Case assumes a book life of 15 years for retrofits. This assumption is made to account for recent trends in financing retrofit investments.

Table 10-12 Book Life, Debt Life, and Depreciation Schedules in the EPA 2023 Reference Case

Technology	Book Life (Years)	Debt Life (Years)	U.S. MACRS Depreciation Schedule (Years)
Combined Cycle	30	20	20
Combustion Turbine	30	15	15
Coal Steam and IGCC	40	20	20
Nuclear	40	20	15

Technology	Book Life (Years)	Debt Life (Years)	U.S. MACRS Depreciation Schedule (Years)
Solar, Geothermal, and Wind	30	20	5
Landfill Gas	30	20	15
Biomass	40	20	7
Hydro	40	20	20
Batteries	15	15	7
Environmental Retrofits	15	15	15

Depreciation Schedule

For the utility sector, the U.S. MACRS depreciation schedules were obtained from IRS Publication 946 which lists the schedules based on asset classes.[130, 131] The document specifies a 5-year depreciation schedule for wind energy projects and 20 years for electric utility steam production plants. These exclude combustion turbines and nuclear power plants, which each have a separate listing of 15 years. As a result of the tax code changes, the merchant sector is allowed to depreciate assets on an accelerated schedule through 2027. Accelerated depreciation is allowed starting in 2018 with 100% depreciation and phases out at 20% annually between 2023 and 2027.

Taxation and Insurance Costs

The maximum U.S. corporate income tax rate is 21%.[132] State taxes vary, but the weighted average state corporate marginal income tax rate is 6.45%. This yields a net effective corporate income tax rate of 26.1%.

U.S. state property taxes are approximately 0.9%, based on the national average. This is based on extensive primary and secondary research conducted by the EPA using property tax rates obtained from various state agencies.

Insurance costs are approximately 0.3% on a national average basis.

[130] MACRS refers to the Modified Accelerated Cost Recovery System, issued after the release of the Tax Reform Act of 1986.

[131] IRS Publication 946, "How to Depreciate Property," Table B-2, Class Lives and Recovery Periods.

[132] Internal Revenue Service, Publication 542.