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

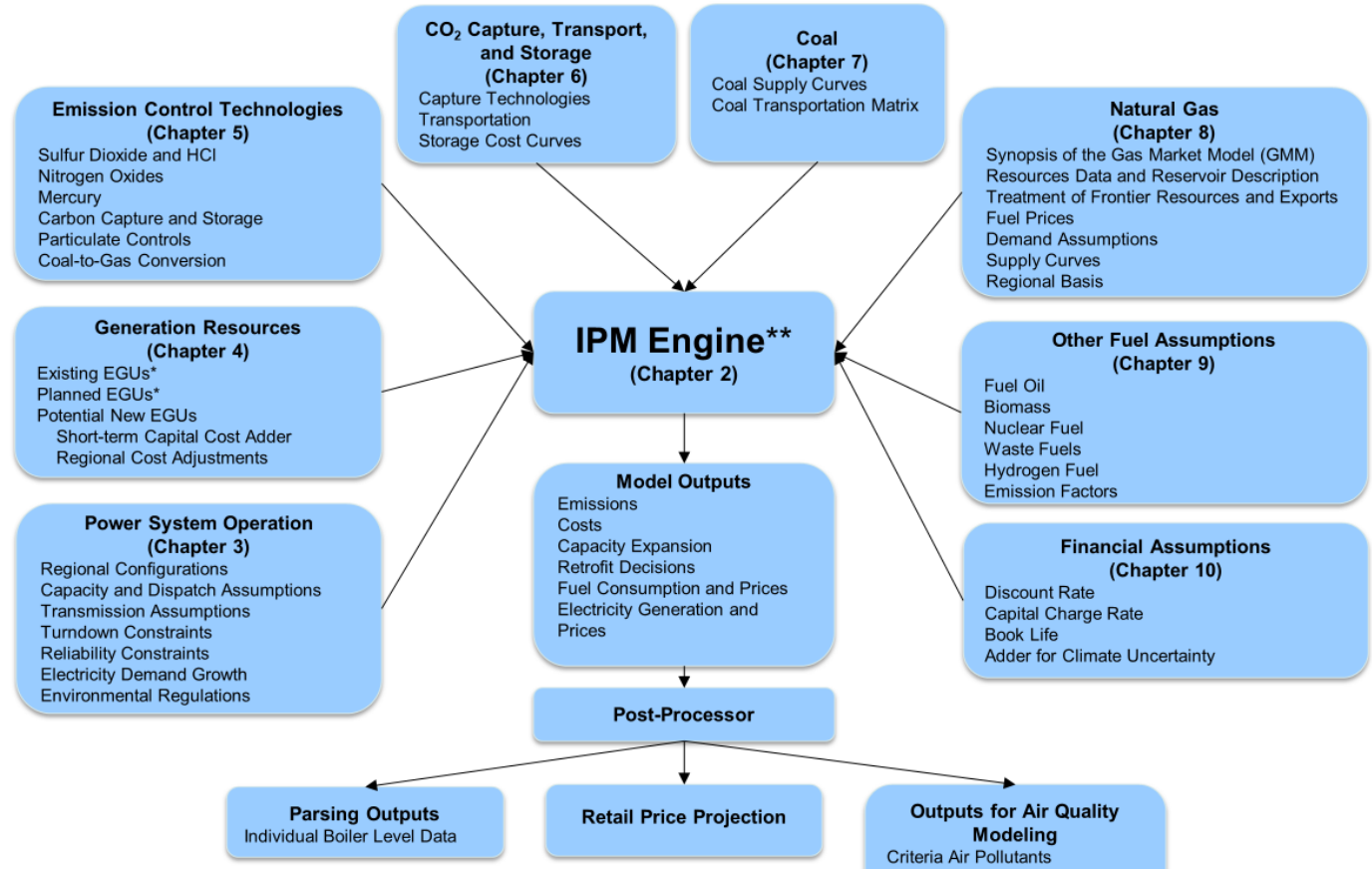
Sulfur Dioxide (SO_2)
Limestone Forced Oxidation (LSFO)
Lime Spray Dryer (LSD)
Nitrogen Oxides (NO_x)
Combustion controls
Selective catalytic reduction (SCR)
Selective non-catalytic reduction (SNCR)
Mercury (Hg)
Combinations of SO_2, NO_x, and particulate control technologies
Activated Carbon Injection
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.