Illuminating Energy Transition Pathways with Accessible Information and Flexible Capabilities

International Energy Workshop

Joe DeCarolis, EIA Administrator

June 14, 2023 | Golden, CO

Talk Outline

EIA overview and priorities

Expanding transparency and energy modeling capabilities

- Annual Energy Outlook 2023
- Plans for the National Energy Modeling System (NEMS)
- Next generation modeling effort

EIA Overview

What does EIA do?

The U.S. Energy Information Administration (EIA) is the statistical and analytical agency within the U.S. Department of Energy.

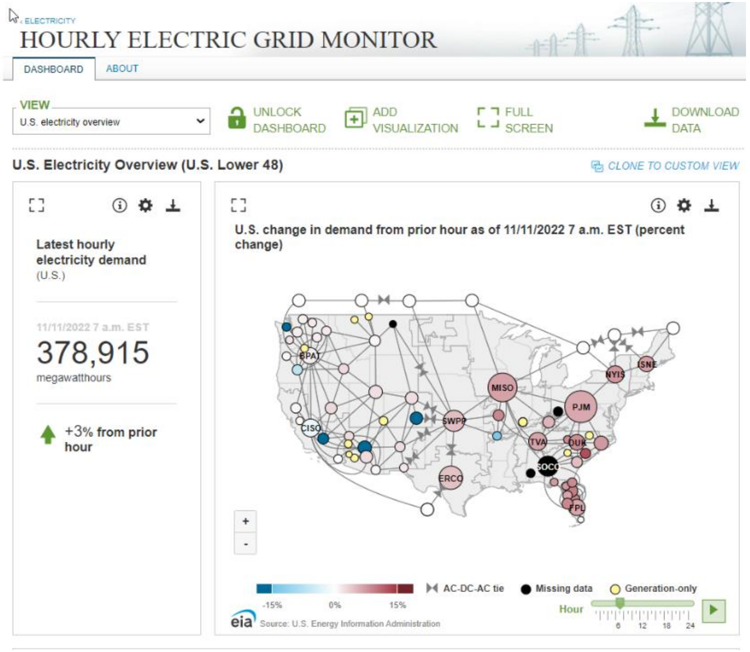
EIA collects, analyzes, and disseminates independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment… by law, its data, analyses, and forecasts are independent of approval by any other officer or employee of the U.S. government.

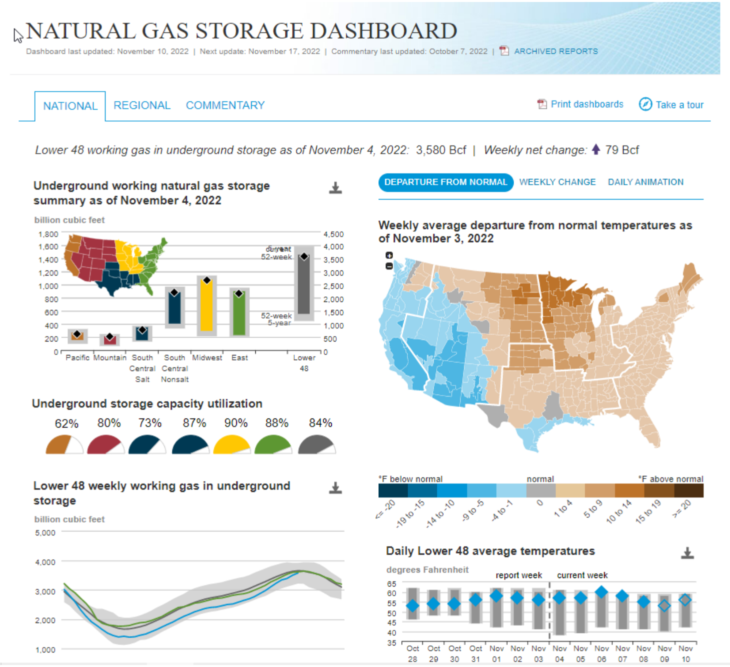
Our strategic priorities address the challenges of a rapid energy transition

- **Strive to make EIA's information more transparent and accessible**
- **Expand energy modeling capabilities to examine a wider range of scenarios**
- Provide new insight into energy trends and their community-level impacts
- Modernize EIA's IT enterprise
- Facilitate a high level of internal communication and employee engagement

Modernize IT and make data more transparent and accessible

Build dashboards on top of new data system to visualize, manipulate, and download data





Expanding Transparency and Energy Modeling Capabilities

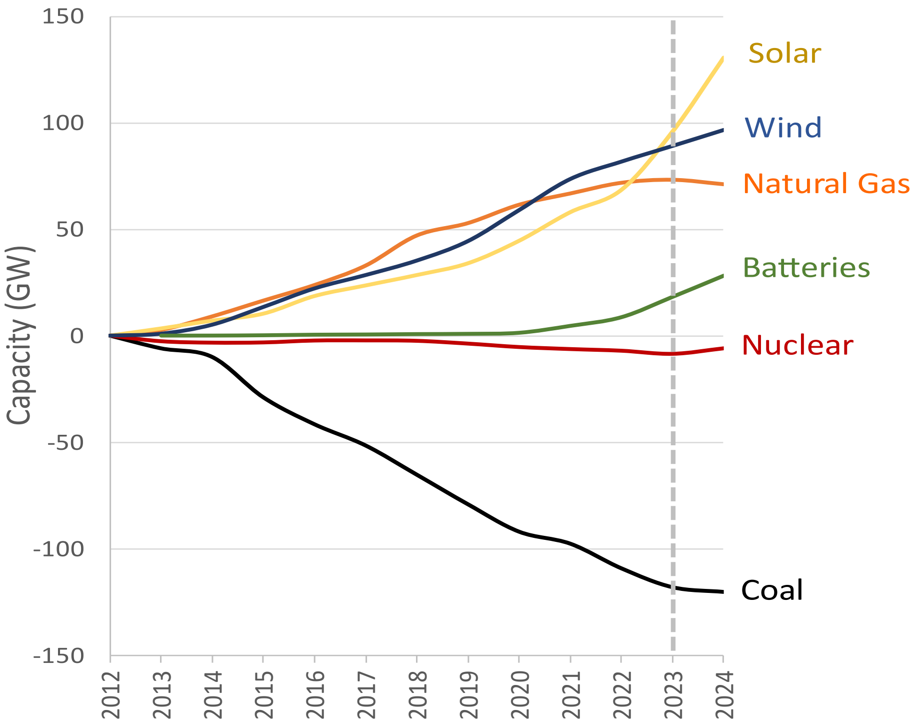
Motivation

Rapidly changing technology mix in a complex and evolving policy landscape

Recent U.S. policy actions:

- Infrastructure Investment and Jobs Act (IIJA)
- Inflation Reduction Act (IRA)

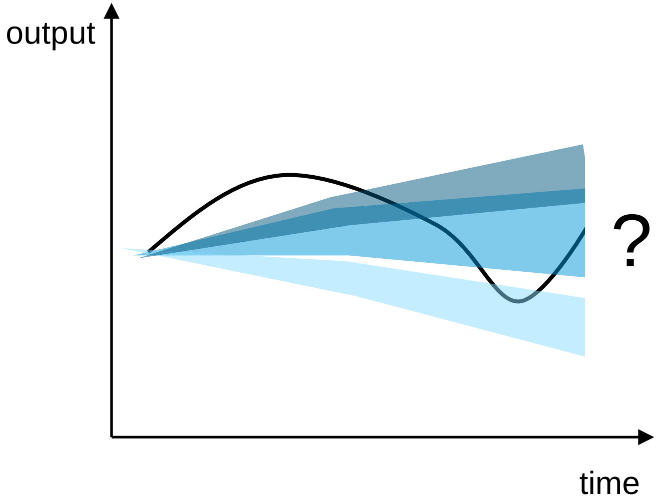
Change in Cumulative Net Summer Capacity **since 2012**



Need to quantify uncertainty

The global energy system is in a period of rapid transition, which heightens uncertainty.

- Climate change impacts
- Infrastructure and supply chains
- International trade and security
- Technology innovation
- Novel technologies
- Policy
- Impacts on *people*
- Surprises!



Uncertainty can no longer be a side bar. Key insights must be conditioned on a consideration of uncertainty.

Need to collaborate using open source code and data

Models with open source code and data enable others to:

- Verify published results
- Introspect model assumptions, governing dynamics, and implementation
- Adapt and run the model for one's own analysis needs
- Redistribute modified code for the benefit of others under clear legal guidelines
- Collaborate to uncover bugs, improve computational performance, or add features

How can we work across institutions to conduct collaborative model development?

Enabling tools are already available:

- An active and growing open source ecosystem: https://wiki.openmod-initiative.org/wiki/Open_Models
- Distributed revision control systems (e.g., Git)
- Collaboration platforms (e.g., Slack, Zoom)

Annual Energy Outlook 2023

What's new in the 2023 *Annual Energy Outlook*?

- A focus on the narrative
- Technical notes
- Emphasis on the range of results
- New combination cases

March 2023

1

The electricity mix in the United States shifts from fossil fuels to renewables

In this section, we cover the displacement of fossil fuels by renewables in the electric power sector and explore the effects on natural gas consumption.

Renewables displace fossil fuels in the electric power sector due to declining renewable technology costs and subsidies for renewable power

Economic growth paired with increasing electrification of the end-use sectors results in stable growth in U.S. electric power demand through 2050 in all cases. Declining capital costs for solar panels, wind turbines, and battery storage, as well as government subsidies such as those included in the IRA, result in renewables becoming increasingly cost-effective compared to the alternatives when building out new power capacity.

> Power demand is increasingly met by renewables throughout the projection period.

Power demand is increasingly met by renewables throughout the projection period (Figure 2). The share of natural gas, coal, and nuclear generation declines. Nuclear power is outcompeted by renewable power even in the Low Zero-Carbon Technology Cost (ZTC) case, which assumes more aggressive cost declines for nuclear and renewables than the Reference case. Most natural gas-fired generation comes from combined-cycled power plants as opposed to natural gas turbines. Uncertainty in natural gas prices across cases leads to various projections for the operation of combined-cycle units in the short term, but in the long term natural gas demand from the power sector stabilizes across all cases.

U.S. Energy Information Administration | AEO2023 Narrative 3

The AEO2023 includes cases that vary technical and economic assumptions, including combination cases that extend the bounds of uncertainty

All cases reflect current laws and regulations as of November 2022, including the Inflation Reduction Act.

Reference	1.9% annual GDP growth; Brent = $101 per barrel (b) in 2050
Economic Growth	Low: 1.4% annual GDP growth High: 2.3%
Oil Price	Low: Brent = $51/b in 2050 High: Brent = $190/b in 2050
Oil and Gas Supply	Low: 50% lower oil and gas resource recovery and 50% higher drilling costs relative to the Reference case High: 50% higher oil and gas resource recovery and 50% lower drilling costs relative to the Reference case
Zero-Carbon Technology Cost (electric power sector)	Low: About 40% reduction in cost by 2050 High: No reduction in costs
Combination	Combinations of Economic Growth and Zero-Carbon Technology Cost cases

AEO2023 Highlights

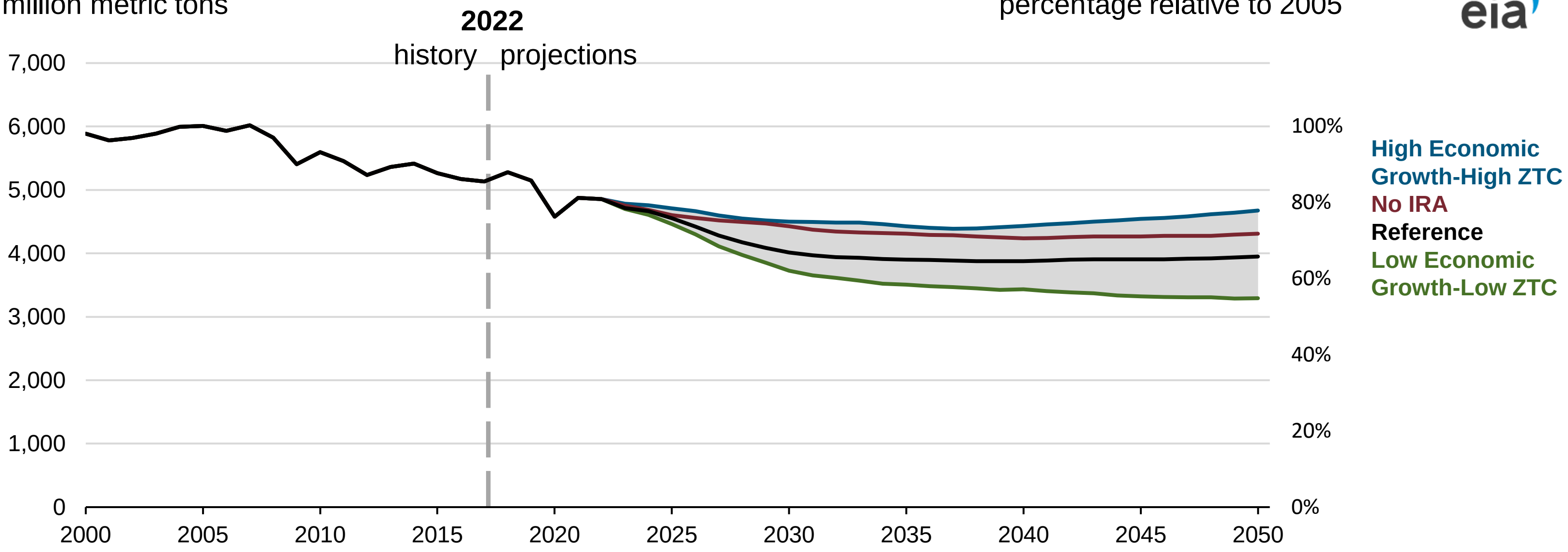
- Energy-related CO_2 emissions fall across all AEO2023 cases because of increased electrification, higher equipment efficiencies, and more zero-carbon electricity generation.
- Renewable generating capacity grows in all regions of the United States in all AEO2023 cases, supported by growth in installed battery capacity.
- Technological advancements and electrification drive projected decreases in demand-side energy intensity.
- The United States remains a net exporter of petroleum products and of natural gas through 2050 in all AEO2023 cases.

* Appendix includes detailed accounting of IRA provisions, and for each provision, whether we were able to model it or not. In the latter case, we provide an explanation.

By 2030, energy-related CO_2 emissions fall 25% to 38% below 2005 levels

Total energy-related carbon dioxide emissions

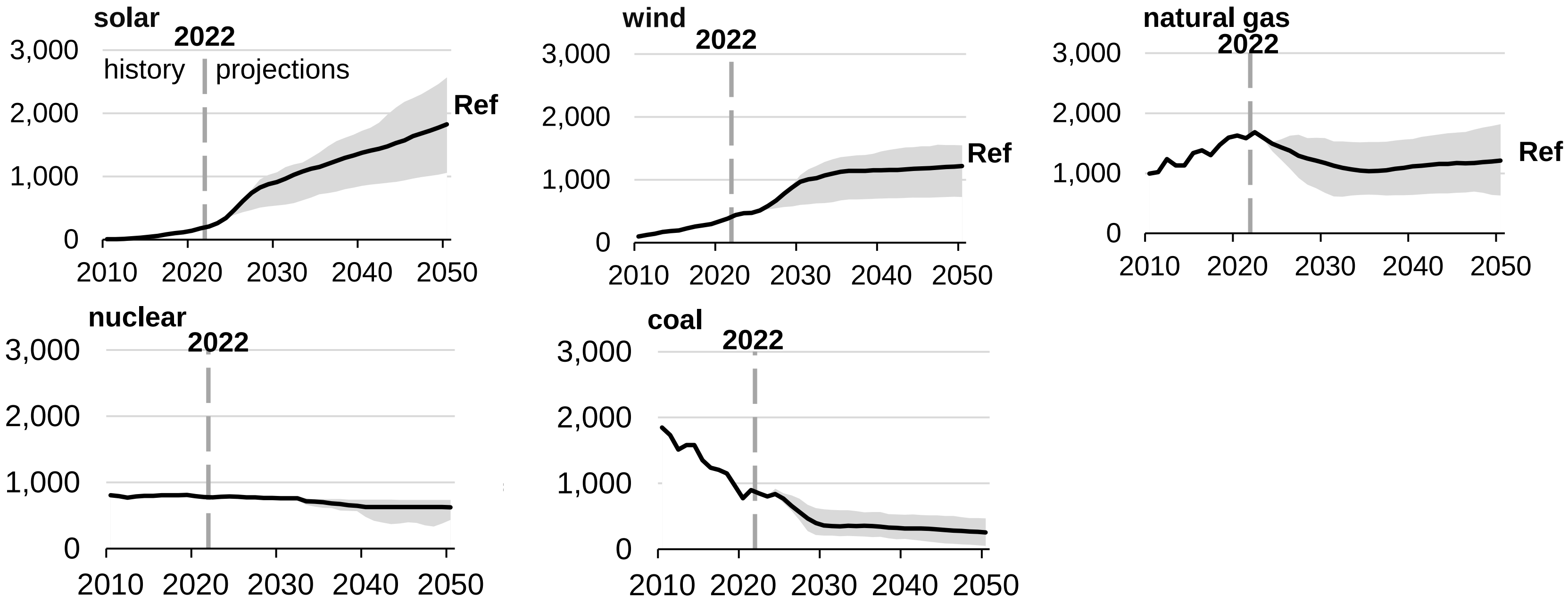
million metric tons



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases.
ZTC=Zero-Carbon Technology Cost; IRA=Inflation Reduction Act.

Electricity demand is increasingly met by renewables

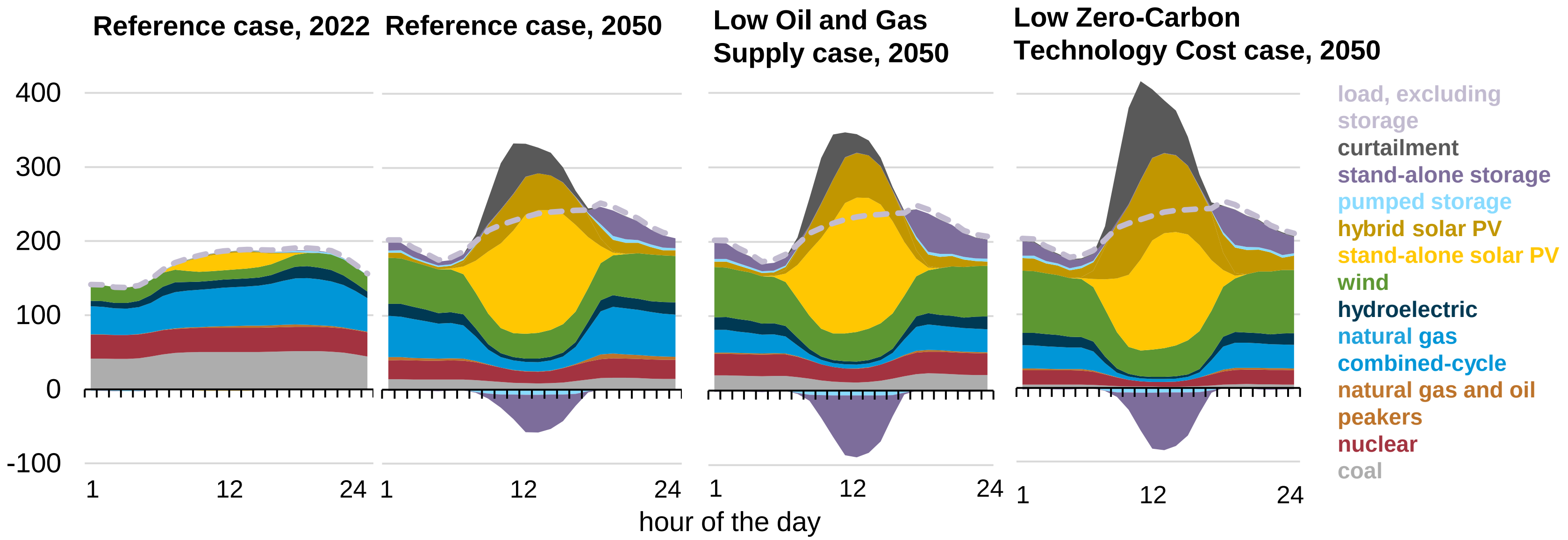
U.S. electricity generation by select technologies for all cases
billion kilowatthours



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. Ref=Reference case

More variable renewables lead to more curtailment and usage of battery storage

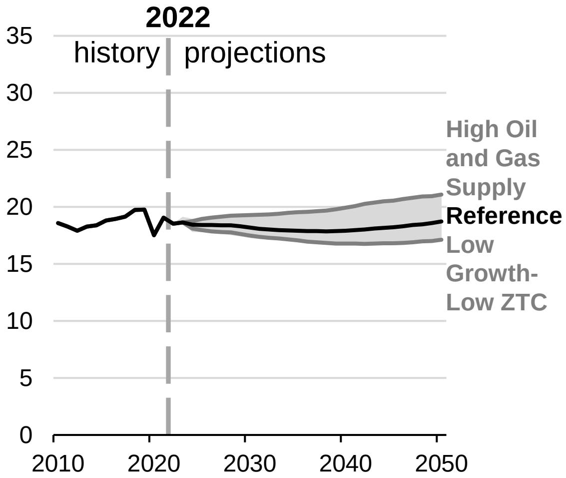
Hourly U.S. electricity generation and load by fuel for selected cases and representative years
billion kilowatthours



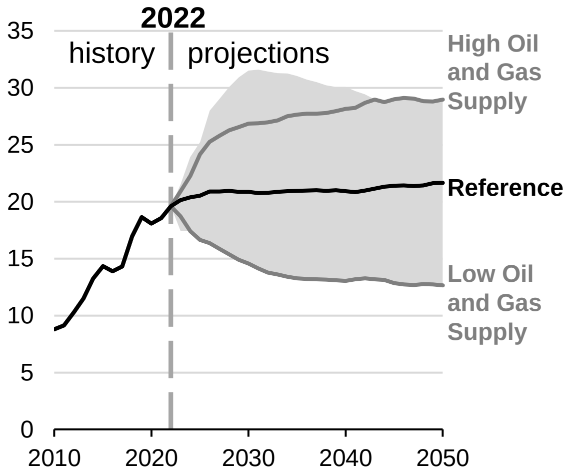
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Negative generation represents charging of energy storage technologies such as pumped hydro and battery storage. Hourly dispatch estimates are illustrative and are developed to determine curtailment and storage operations; final dispatch estimates are developed separately and may differ from total utilization as this figure shows. Standalone solar photovoltaic (PV) includes both utility-scale and end-use PV electricity generation.

In all cases, we project that the United States will remain a net exporter of petroleum products through 2050

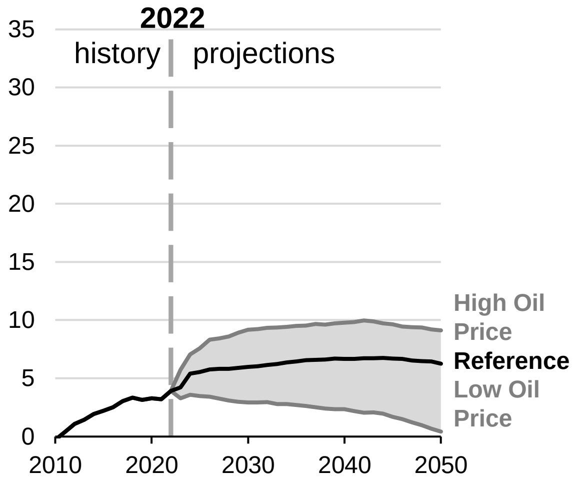
Petroleum and other liquids consumption
million barrels per day



Petroleum and other liquids production
million barrels per day



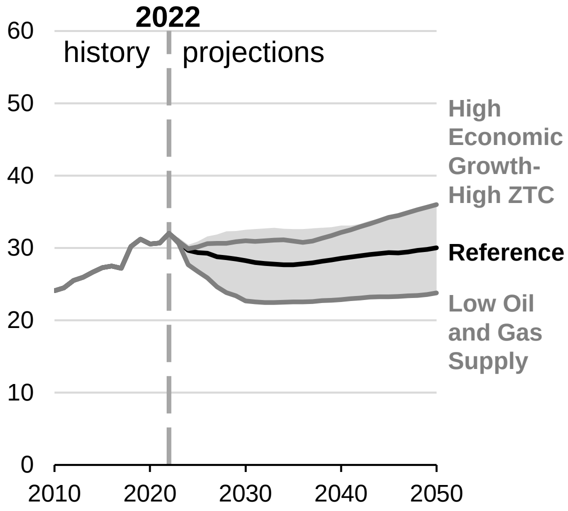
Petroleum products net exports
million barrels per day



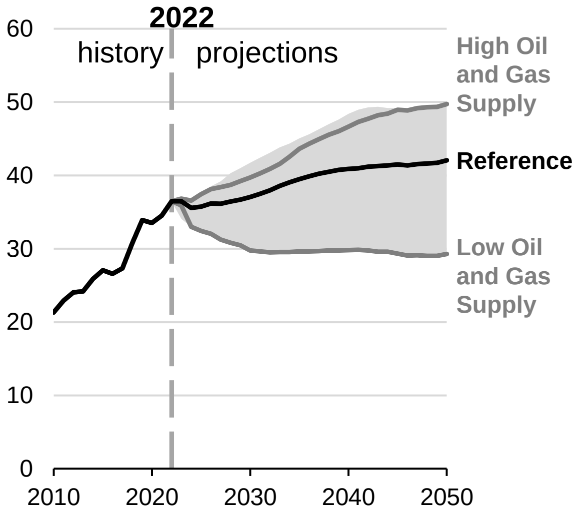
Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Biofuels are not included in *petroleum and other liquids* production or consumption. Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost

Liquefied natural gas exports drive production; domestic consumption remains stable

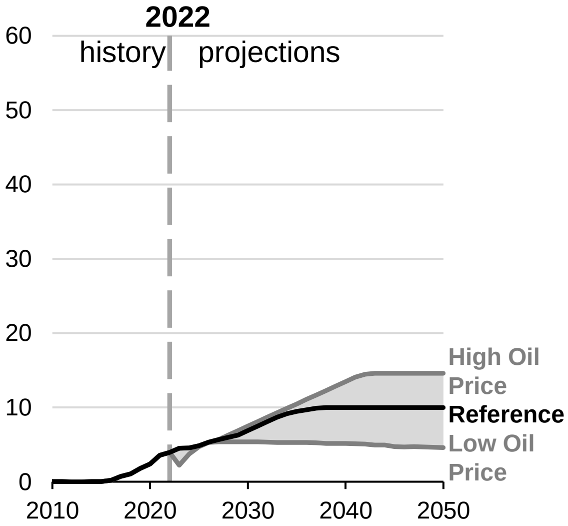
Natural gas consumption
trillion cubic feet



Dry natural gas production
trillion cubic feet



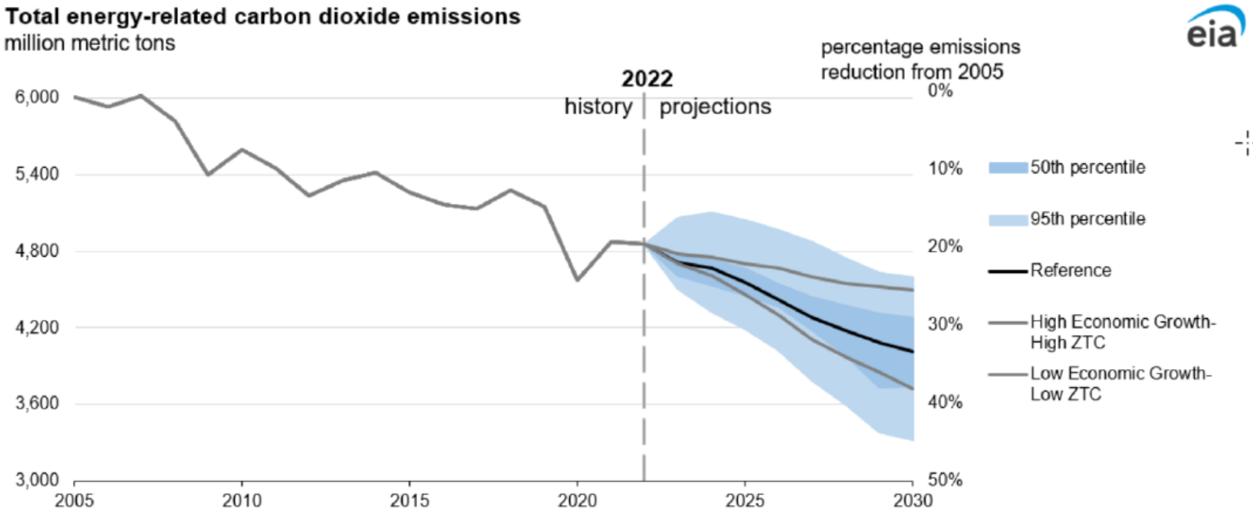
Liquefied natural gas exports
trillion cubic feet



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost

Emissions cone of uncertainty

- Utilized approach by Kaack et al. (2017)* to develop uncertainty cones
- Quantify the difference between our past Reference case values and observed values
- Non-parametric, median-centered method applied to total energy-related CO_2 emissions
- Past differences account for new policy beyond “current laws and regulations”



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: Cone of uncertainty associated with total energy-related CO_2 emissions using empirical projection intervals. Historical values and AEO2023 Reference case are displayed as solid black line. The projection error density forecast by blue shaded areas. The different shades correspond to the 50th and 95th percentiles. AEO2023 envelope side cases are in solid grey lines. ZTC=Zero-Carbon Technology Cost.

There's a 50% chance that actual energy-related CO_2 emissions will fall in the dark blue cone and a 95% chance emissions fall within the lighter blue cone.

* Kaack, L.H., Apt, J., Morgan, M.G. and McSharry, P (2017). Empirical prediction intervals improve energy forecasting. *Proceedings of the National Academy of Sciences*, *114*(33): 8752-8757.

Beyond AEO 2023

Make NEMS open source

- Working to make code repositories open source under a well-established license
- Leaning towards Apache 2.0 because it is permissive and clarifies both copyright and patent rights for developers and downstream users.
- Plan to release main components of NEMS via GitHub by the end of this year.
- Governance plan to process public feedback in a fair and consistent way.

Infrastructure Investment and Jobs Act:

(14) striving to migrate toward a single, consistent, and open-source modeling platform, and increasing open access to model systems, data, and outcomes, for—

Continue intensive effort to model low carbon pathways

- NEMS currently has a restricted representation of low carbon pathways
- Need to update NEMS to provide rigorous, independent views of the U.S. energy system esp. given a quickly evolving policy environment
- Focusing effort to include:
  - Key hydrogen production and utilization pathways
  - Industrial carbon capture and negative emissions technologies
  - Seasonal storage in the electric sector
  - Improved representation of behind-the-meter and high efficiency building technologies

Need to think beyond NEMS

(14) striving to migrate toward a single, consistent, and open-source modeling platform, and increasing open access to model systems, data, and outcomes, for—

- We have been using NEMS to produce the AEO since 1994
- Born witness to significant changes in the real energy system, energy modeling methods, and software development practices
- Code base has become unwieldy and hard to maintain
- Broad recognition that we need to develop a new modeling framework

Goal: Develop a next generation modeling framework

Desired characteristics:

- **Open:** source code and input data available under open source licenses
- **Nimble:** update or change quickly
- **Flexible:** handle diverse modeling needs, adjust model complexity to suit the question
- **Fast:** solves quickly
- **Cloud-capable:** Needs to operate on the cloud
- **Modular:** separate code and data; system representation
- **Broad:** critical minerals, novel technologies, industrial policy, new market designs
- **Endogenous:** ability to capture simultaneous changes across the system
- **Granular:** resource availability, system operation, community impacts
- **Robust:** rigorous consideration of uncertainty, including probabilistic outcomes

Addressing uncertainty in a next generation model

How do we illuminate and inform transition pathways embedded in a continuous decision space?

Depends on the specific question.

Parametric uncertainty: uncertainty in the model input parameters

- Scenario analysis, parametric sensitivity analysis, Monte Carlo simulation, Method of Morris, stochastic optimization, robust optimization

Structural uncertainty: imperfect and incomplete nature of the model equations describing the system

- Alternative model formulations, modeling-to-generate alternatives

National Research Council (1992)*:

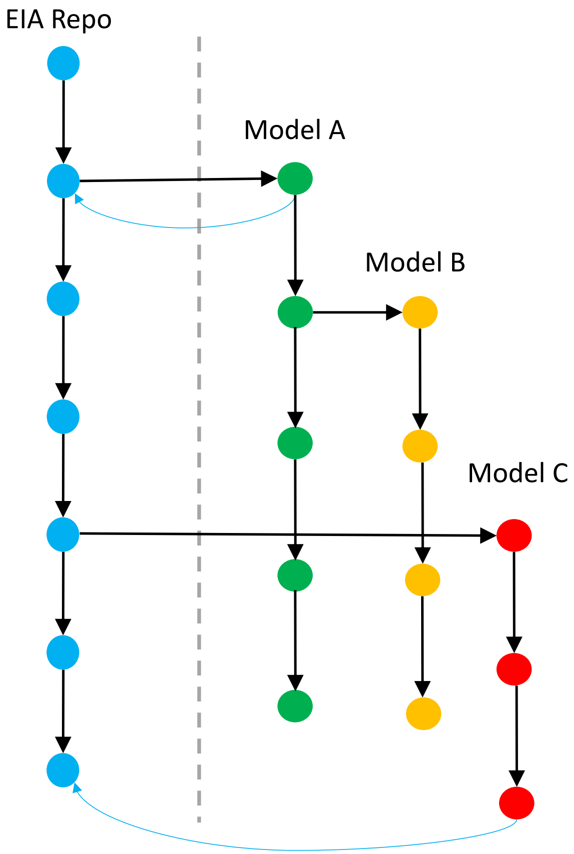
"Uncertainty is inherent in the nature of models and cannot be eliminated. Nor should it be ignored."

"NEMS should be designed to represent and analyze the effects of uncertainty explicitly."

** National Research Council 1992. The National Energy Modeling System. Washington, DC: The National Academies Press. https://doi.org/10.17226/1997.*

Approach to development

- A strength of EIA is our ability to convene modelers
- We want this to be a **community effort**
  - We plan to seek input and feedback throughout
  - Want to help with development? Great!
  - Stay tuned for opportunities to engage with us
- Leverage well-established open source modeling ecosystem
- Requires governance; imperative to maintain control and independence
- Thinking in terms of three broad categories of development:
  - Input data
  - Source code; implementation of governing model dynamics
  - Routines to handle input / output data



Effort led by EIA's Chief Modeler Sauleh Siddiqui (Sauleh.Siddiqui@eia.gov)

Parting Thoughts

- Rapid changes across the energy system require us to continually adapt our modeling approaches
- Ongoing EIA efforts:
  - Retooled AEO2023 to focus on ranges and explanation rather than singular projections
  - Make NEMS open source and build in new low carbon pathways
  - Develop a next generation, open source, community-based energy modeling framework
- We need to work together as a community
- Need to leverage and build on the existing open source ecosystem
- Get in touch if you want to be involved in discussions on the next generation model framework! (Sauleh.Siddiqui@eia.gov)