Independent Statistics and Analysis
U.S. Energy Information Administration

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MEMORANDUM FOR: Angelina LaRose
Assistant Administrator for Energy Analysis

FROM: Jim Diefenderfer
Director, Office of Long-Term Energy Modeling

Subject: Summary of Introduction to Hydrogen Market Module (HMM) Working Group Meeting held on June 12, 2024

This memorandum summarizes the presentation given during the *Annual Energy Outlook* (AEO) 2025 Introduction to HMM Working Group meeting and the resulting discussions that took place.

The presentation slides are available in a separate document on our website. All slides, charts, and discussions for AEO2025 were preliminary and, therefore, should not be quoted or cited. We will release final AEO2025 materials in early 2025.

Key takeaways and status of HMM implementation in NEMS:

- The representation of hydrogen markets allows insight into key questions about the impacts of policy and model assumptions.
- We are running tests with other National Energy Modeling System (NEMS) modules to verify interactions and input-output exchange.
- We announced the availability of the Requirements Document to stakeholders that defines our expectations for AEO2025.

Katie Dyl reviewed the scope, hydrogen market representation, and relationship to other modules in NEMS. Stephen York reviewed HMM modeling methodology, including:

- Data sources
- A module overview
- The 45V tax credits implementation
- Transportation and storage representation

HMM Overview

HMM is one of three new modules being introduced into NEMS with the release of AEO2025. We scoped out the model in terms of the hydrogen market emergence, policy and legislation impacts, and the role hydrogen can play in deep decarbonization scenarios in the future.

Katie spelled out exactly which production, consumption, and transmission technologies we will include in the HMM and which we will not include in the AEO2025 release. She also specified that HMM is not modeling DOE-funded Hydrogen Hubs. We represent three hydrogen production pathways:

- Electrolysis using grid electricity
- Steam methane reforming (SMR)
- SMR with carbon capture and sequestration (CCS)

Katie compared how hydrogen will be handled in AEO2025 with how it was handled in previous editions. In AEO2023 and prior years, hydrogen was implicitly produced in SMRs and consumed in other modules; we did not directly account for hydrogen volumes. Moving forward with AEO2025, all hydrogen produced by SMRs and the way that hydrogen is delivered to end users in other modules are explicitly represented in HMM. She introduced the concept of hydrogen production via electrolysis in the HMM based on decisions made each hour across four seasons and aligned geographically with EIA's Electricity Market Module (EMM).

HMM performs many functions, including interacting with other modules that consume hydrogen and affect hydrogen production technology decisions:

- EMM
- Liquid Fuels Market Module (LFMM)
- Industrial Demand Module (IDM)
- Transportation Demand Module (TDM)
- Carbon Capture, Allocation, Transportation, and Sequestration (CCATS) Module

We modified these other NEMS modules to integrate with HMM. Katie shared how the quantity and price of natural gas, electricity, carbon dioxide (CO_2), and hydrogen are exchanged among NEMS modules.

HMM Modeling Methodology

Stephen explained that HMM is a linear program that minimizes total costs to meet hydrogen demand, subject to constraints. HMM yields the quantity of hydrogen produced by technology, region, and season, and it transports the hydrogen by pipeline between regions and to or from storage caverns. The model considers the following constraints:

- Supply, demand, and storage mass balances at market clearing hubs
- Pipeline capacities and regional production capacities
- Volumes of renewable electricity available at an hourly and regional resolutions that are eligible for tax credits

Stephen described how HMM uses the concept of market-clearing hubs and supply, demand, and storage nodes in its linear program design.

We designed HMM to allow us to assess the mid- to long-term impacts of current policies, laws, and regulations governing hydrogen markets. Specifically, we can analyze the impacts of the Inflation

Reduction Act (IRA), for example, Section 45V hydrogen production tax credits and Section 45Q tax credits for capturing CO_2. HMM assumes that electrolyzers claim the 45V credit, and SMRs with CCS will claim the 45Q credit. We make simplifying assumptions to implement Section 45V, addressing the incrementality, deliverability, and time-matching criteria to align with clean electricity purchases through Energy Attribute Certificates (EACs).

HMM is programmed in AIMMS with a Python preprocessor to prepare input data. The module has three planning periods that provide foresight to aid hydrogen production capacity expansion decisions.

Stephen described the simplified representation of hydrogen pipelines that allow economic transmission of pure (not blended) hydrogen between U.S. census divisions with assumed distances and costs. HMM allows long-duration, seasonal storage of hydrogen in underground salt caverns, and the construction of new storage facilities if economical.

Discussion

Initial questions from attendees addressed CO_2, specifically, how CO_2 prices are calculated and if the destination for sequestered CO_2 is determined in HMM (e.g., whether it is used for enhanced oil recovery in oil wells or sequestered in underground caverns). The lead modeler from CCATS explained that those decisions are made in the CCATS module, not HMM. CCATS decides the amount of CO_2 sequestered in saline caverns or injected for enhanced oil recovery, and it returns CO_2 prices to HMM and other modules in NEMS.

One attendee questioned what we meant by grid electricity, specifically, if we included grid-connected, low-carbon renewables. Our slides addressing Section 45V answered his question. Another attendee questioned if we were modeling hydrogen production from off-grid renewables. We explained that we include grid-connected renewable electricity; however, we do not currently model off-grid renewable electricity in HMM.

Another attendee asked what we are putting off for AEO2026, for example, Hydrogen Hub investments or natural gas blending. We explained that EMM plans to implement on-site hydrogen-natural gas blending, but that representation is outside of HMM. We will not model regional transmission of blended hydrogen in HMM. We anticipate that in future years hydrogen blending will be represented in that way (e.g. by end use modules at the point of consumption), and we currently do not plan to model hydrogen blending within transmission pipelines. We are considering off-grid renewables in subsequent AEOs, but we need considerable coordination with EMM and the Renewable Fuels Module (RFM) to share renewable resource parameters (for example, costs related to building and operating wind and solar generators, capacity factors, and technology learning). Current information on DOE's Hydrogen Hub grants remains too open-ended. We will watch as projects evolve and as production and pipeline capacity are built out to establish a basis for incorporating some of the specific projects associated with Hydrogen Hubs, such as production facilities or new consumers, in future modules.

Two attendees who participated in the National Petroleum Council *Harnessing Hydrogen* report commissioned by DOE asked if we would consider autothermal reformers (ATRs) with CCS in addition to SMRs with and without CCS. They provided a link (harnessinghydrogen.npc.org) and pointed us to

Chapter 2 and Appendix D where ATR assumptions are summarized. We responded that we have read the reports, which state that ATRs might be preferable in the future, particularly with CCS because CO_2 is easier to capture with ATRs than SMRs. But, with no facilities built to date and assuming capital and operating costs are similar to SMRs with CCS, we would find ourselves facing knife's-edge decisions regarding which reformers to build. The model would have no good way to decide between technologies and may oscillate in its solution as to which to build. Furthermore, ATR is still an emerging technology whose required input assumptions into HMM are difficult to determine. We can consider ATRs with CCS in the future as more data become available. A senior IDM modeler confirmed that although one ATR facility might be under construction on the Gulf Coast, he does not believe any are operational in the United States.

An attendee asked if HMM includes the hydrogen pipeline networks on the Gulf Coast. We responded that the module does not explicitly include the existing network of hydrogen pipelines because HMM only represents inter-regional transportation of hydrogen between census divisions. However, we are looking into implicitly representing the hydrogen pipelines on the Gulf Coast via lower end-use price markups because the existing intra-regional pipeline infrastructure would lower the price to deliver hydrogen to an end user. Thus, in the future, we hope to reflect to implications of the existing Gulf Coast hydrogen infrastructure on prices without an explicit representation in HMM.

An attendee asked if we are using hourly grid-mix carbon content to capture carbon intensity. We responded that although we initially considered that approach, after reading the preliminary Section 45V guidance and inspecting the 45V-GREET, we believe that changing the credit received at an hourly basis by the hourly carbon intensity on the region's grid would not be allowed. Our investigation of the Section 45V-GREET model revealed that the only pathway for calculating carbon intensity of an electricity grid was annually. We added that we believe the Energy Attribute Certificates (EACs) will define and ensure that carbon intensity requirements are met (in other words, carbon intensity will not be defined by the hourly grid mix).

An attendee asked us to describe the scope of the representative hours in HMM and if these are the same as those used by REStore in EMM. Our lead EMM Modeler responded that REStore uses 864 representative hours (24 hours × 12 months × 3 day-types), but it will aggregate the hourly representation and pass information to HMM at 24 hours × 4 seasons time slices.

Two attendees asked about electrolyzers and Section 45V credits, specifically, how EAC purchases (beyond the cost of electricity) and retirements are formulated in our new model. We responded that HMM does not explicitly retire SMR or any other hydrogen production capacity. We are designing HMM to use clean generation capacity additions from the past three years and match hourly clean generation patterns to constrain how much electricity electrolyzers consume to produce hydrogen that qualifies for the Section 45V credit. For EAC acquisition costs, HMM does not model the cost of purchasing EACs. With no current hourly EAC market for Section 45V, the cost of acquiring the EACs are unclear, so we are still investigating how EACs work, and the representation is likely to change.

Attendees

Guests (Webex)	Affiliation
Neal Elliott	American Council for an Energy-Efficient Economy
Elena Giyenko	Canadian Energy Centre
Nicholas Chase	Congressional Budget Office
Dan Esposito	Energy Innovation
Brittany Westlake	Electric Power Research Institute
Bryan Chapman	ExxonMobil/National Petroleum Council (NPC)
Mike Kerby	ExxonMobil/NPC
Steve Kellogg	ExxonMobil/NPC
Alex Fridlyand	GTI Energy
Ansh Nasta	GTI Energy
Derek Wissmiller	GTI Energy
Matthew Ives	GTI Energy
Ram Dharmarajan	GTI Energy
Rosa Dominguez-Faus	GTI Energy
Shadi Salahshoor	GTI Energy
Sergey Paltsev	Massachusetts Institute of Technology/NPC
Eric Lewis	National Energy Technology Laboratory
Caitlin Murphy	National Renewable Energy Laboratory (NREL)
Charalampos Avraam	NREL
Chris Nichols	NREL
Reid Holben	NREL
Amogh Prabhu	OnLocation Inc
Frances Wood	OnLocation Inc
Hao Deng	OnLocation Inc
Michael Schaal	OnLocation Inc
Pete Whitman	OnLocation Inc
Samaneh Babaee	OnLocation Inc
Ben King	Rhodium Group
Hannah Kolus	Rhodium Group
Joshua Junge	Sargent & Lundy LLC
Lasse Wagene	SouthWest Capital
Ashna Aggarwal	U.S. Department of Energy (DOE)
Brandon McMurtry	DOE
Eric Goode	DOE
Eva Rodezno	DOE
Jai-woh Kim	DOE
Jennifer Li	DOE
John Wimer	DOE
Jordan Kislear	DOE
Katie Spreitzer	DOE

Levi Kilcher	DOE
Marc Melaina	DOE
Reginald Mitchell	DOE
Tomy Granzier-Nakajima	DOE
Emily Beagle	University of Texas at Austin
Laura Rivera	University of Texas at Austin
Tyler Huckaby	Wood Mackenzie

EIA participants (Webex)

Monica Abboud
Tuncay Alparslan
Jeffrey Bennett
Erin Boedecker
Richard Bowers
Singfoong Cheah
Peter Colletti
Anna Cororaton
Jim Diefenderfer
Michael Dwyer
Kathryn Dyl (presenter)
Mindi Farber-DeAnda
Jonathan Inbal
Mala Kline
Angelina LaRose
Vikram Linga
Laura Martin
Chris Namovicz
Brittany Phalon
Bill Sanchez
Elizabeth Sendich
Sauleh Siddiqui
Nicholas Skarzynski
Matthew Skelton
William Sommer
Daniel Stadt
John Staub
Claire Su
Manussawee Sukunta
Edward Thomas
Stephanie Tsao
Gregory Vance
Neil Wagner
Mary Webber
Josh Whitlinger
Stephen York (presenter)
Jordan Young