Introduction to Hydrogen Market Module

AEO2025 Working Group

Internal and external stakeholders

Katie Dyl and Stephen York

June 12, 2024 | Virtual

Key takeaways and status of Hydrogen Market Module (HMM) implementation in NEMS

- The representation of hydrogen markets allows insight into key questions about the impacts of policy and model assumptions.

- We running tests with other National Energy Modeling System (NEMS) modules to verify interactions and input/output exchange.

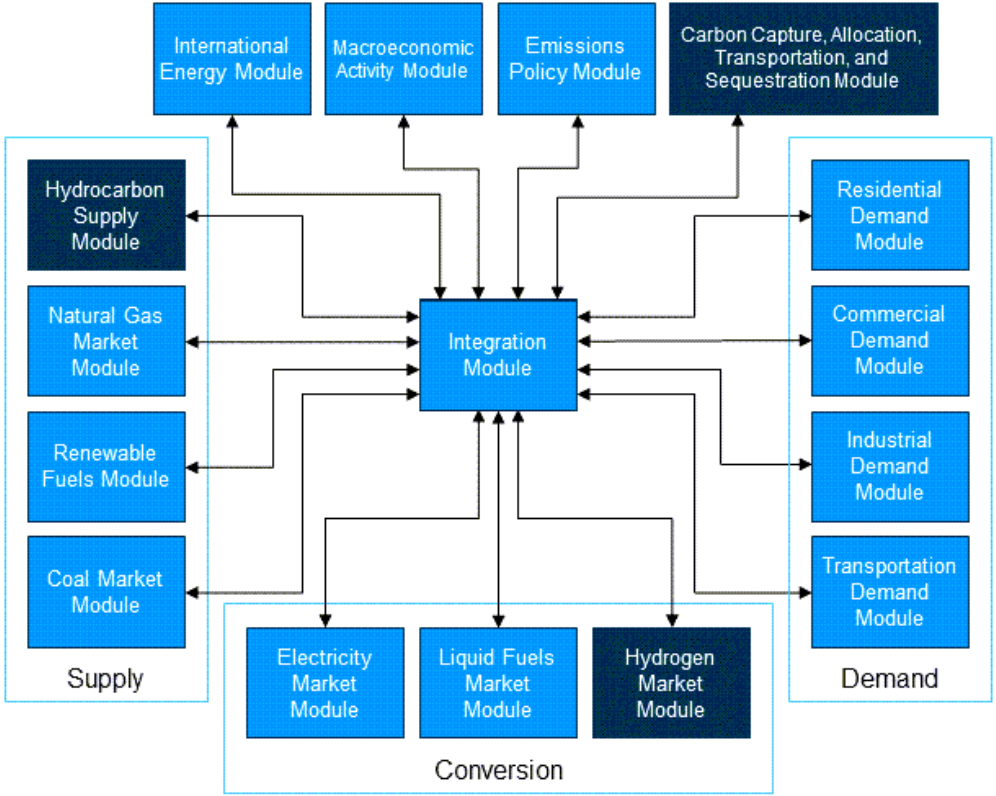
- We presented a Requirements Document to stakeholders that defines our expectations for AEO2025.

Outline

- HMM Overview
  - Scope
  - Hydrogen market representation
  - Relationship to other modules in NEMS
- HMM Modeling Methodology
  - Data sources
  - Model overview
  - Transportation and storage

HMM Overview

AEO2025 will mark the introduction of three new modules in NEMS, one of which is a new Hydrogen Market Module (HMM)



Scope of new Hydrogen Market Module (HMM)

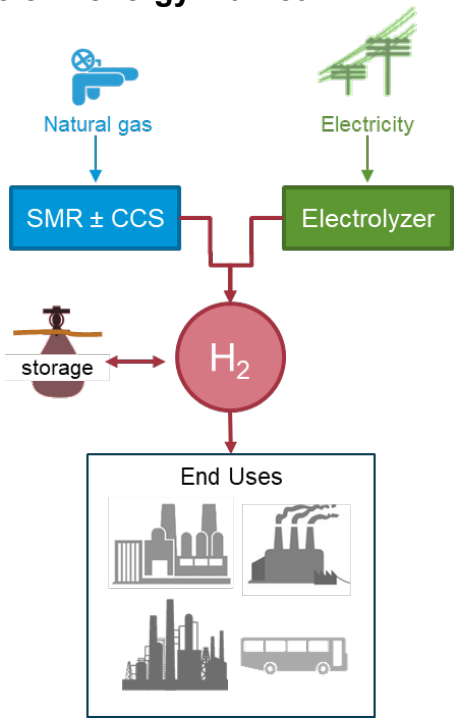
- In defining modeling scope, we first identified the key questions related to the role of hydrogen in the future.
  - How will hydrogen markets emerge and evolve over time?
  - What is the impact of policy and legislation on emerging markets and developing technologies?
  - What role will hydrogen play in deep decarbonization scenariosachieving net[add hyphen]zero emissions in the future?

- Given these questions, we identified the sectors, technologies, and policies we expect to drive hydrogen markets, particularly as they emerge over the next ~20 years.

Hydrogen Market Module (HMM) will represent key production technologies and end uses of H_2

- Three hydrogen production pathways represented:
  - Electrolysis
  - Steam methane reforming (SMR)
  - SMR with carbon capture and sequestration (CCS)
- Production technology options allow HMM to analyze the mid- to long-term impacts of current policies, laws, and regulations governing hydrogen markets, specifically the Inflation Reduction Act.
  - Section 45V hydrogen production tax credits from the IRA
  - Section 45Q tax credits for capturing CO_2
- Hydrogen consumption in the industrial, electric power, refining, and transportation sectors.

Simplified diagram of hydrogen's role in energy market



Key H_2 production, consumption, and transmission technologies that will and will not be included in HMM

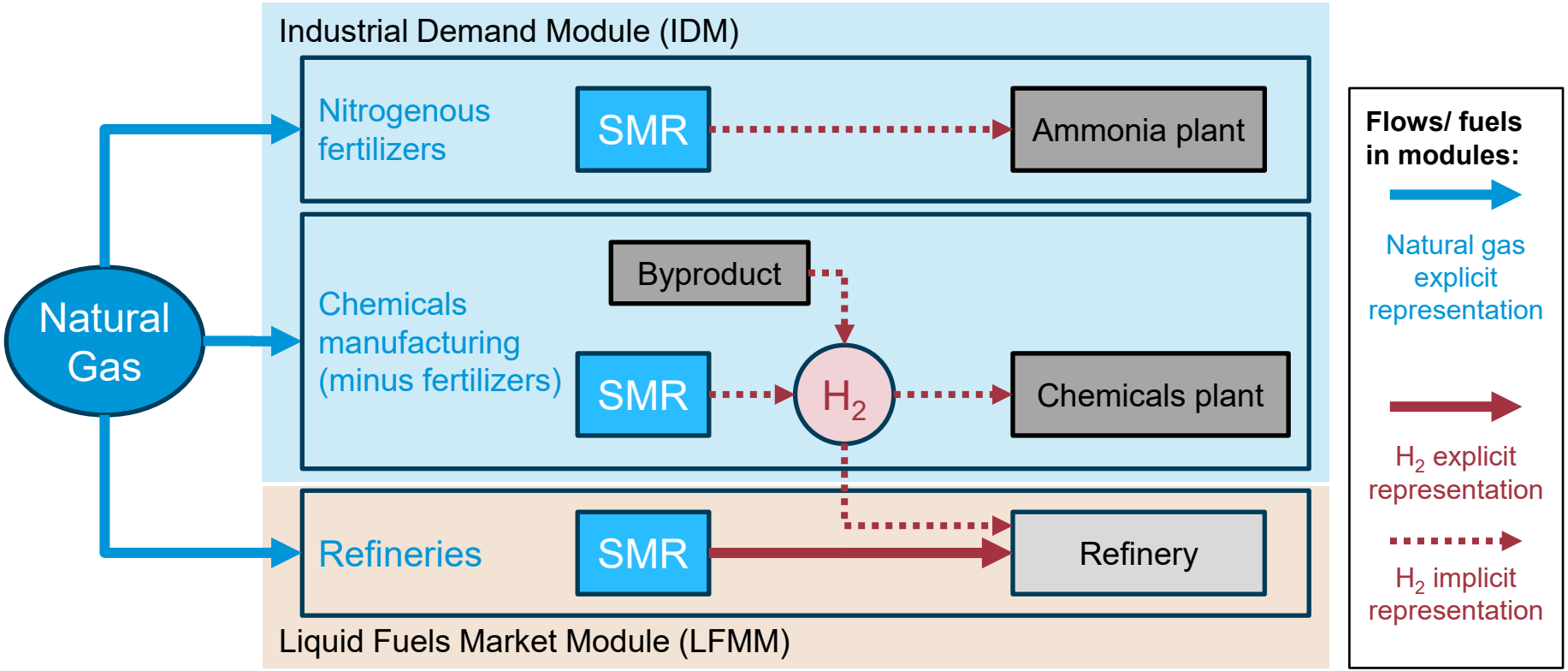
Included – AEO2025

Not Included – AEO2025

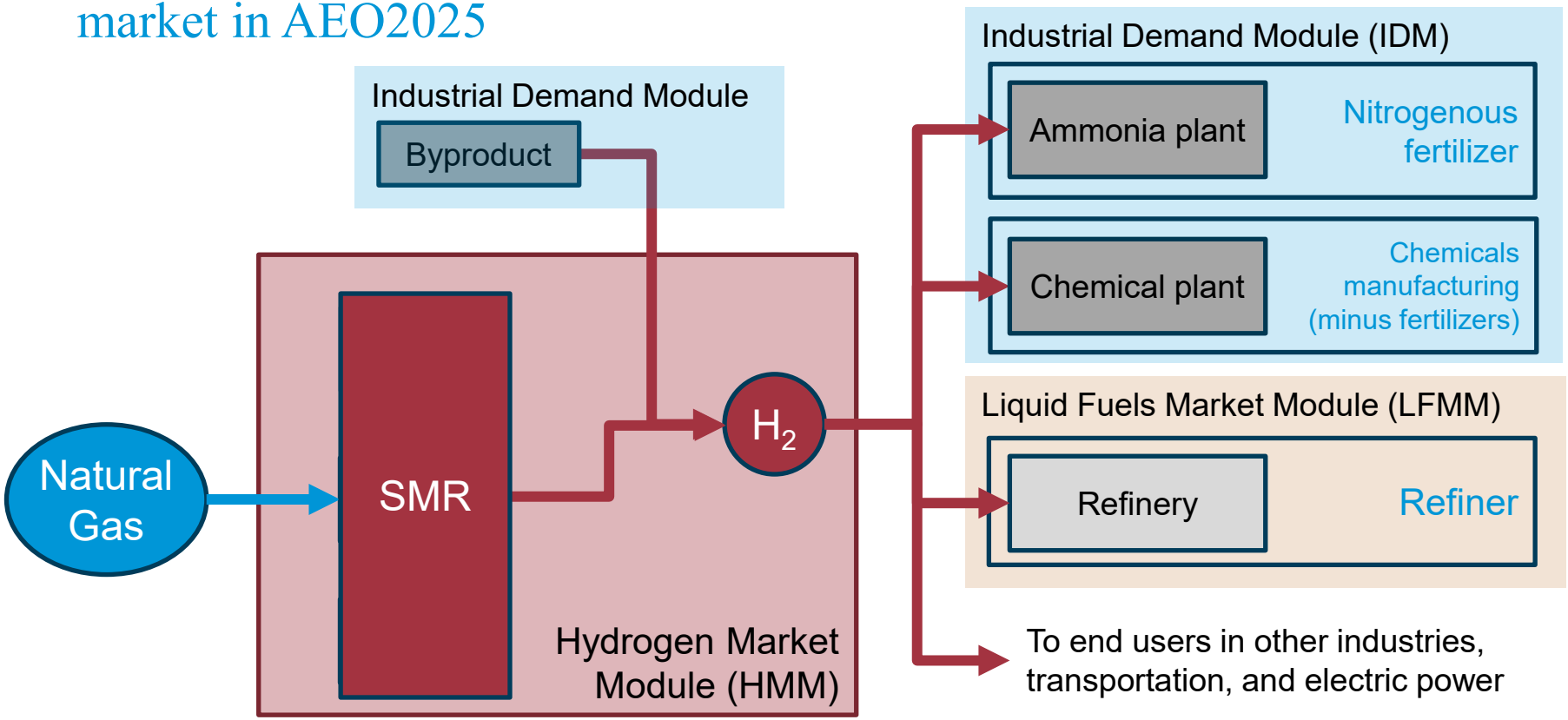
	In HMM	Not in HMM
Production	SMR ± CCS	Biomass and coal gasification ± CCS
	Grid-fueled electrolysis	Off-grid, on-site electrolysis
		Other (for example, pyrolysis, nuclear-fueled)
Consumption	Chemicals	Natural gas blending
	Refineries	Biofuel production
	Electric power	Efuels
	Heavy-duty vehicles	Exports (including via ammonia)
Transport, storage	Pipelines	Conversion to ammonia, methanol for transport
	Seasonal storage	

- DOE Hydrogen Hubs funding is not represented in HMM for AEO2025

AEO2023 and prior years largely treated H_2 as an implicit fuel and feedstock in industrial and liquid fuels modules

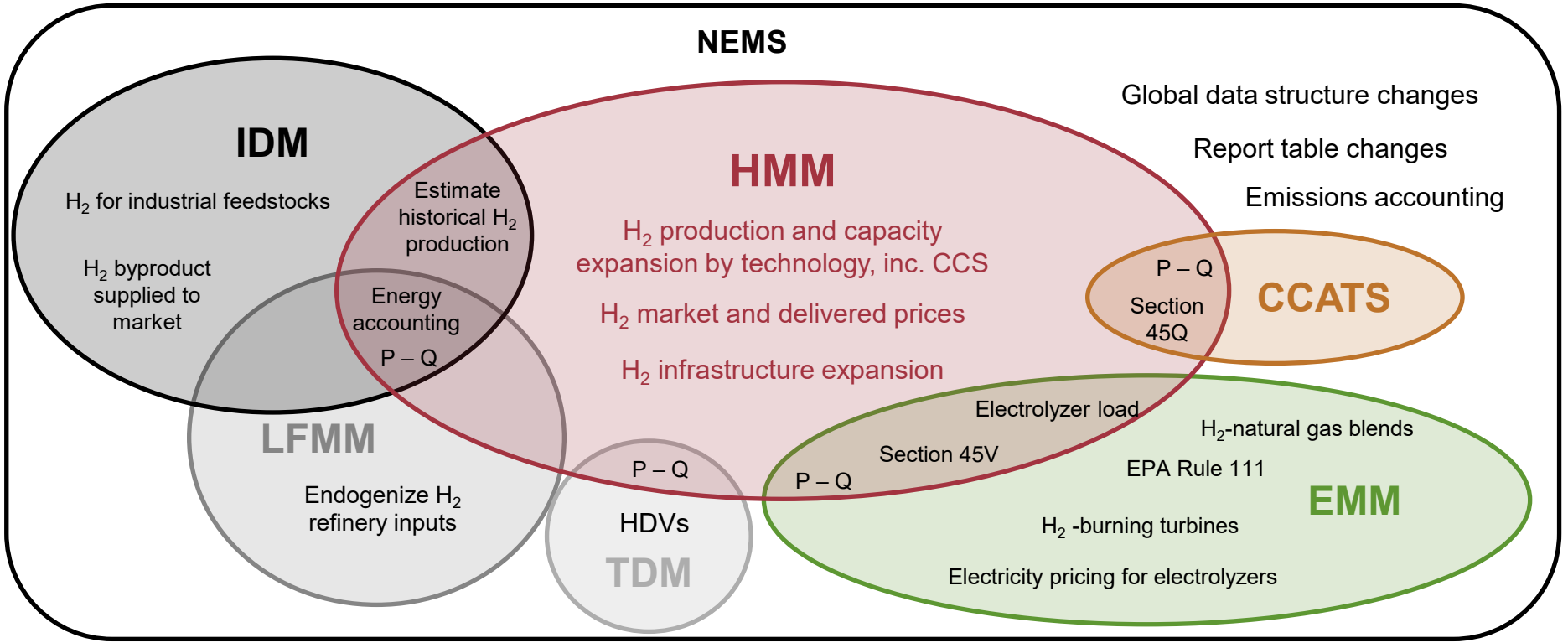


New relationships and more explicit representation for existing H_2 market in AEO2025



Note: H_2 supplied via electrolysis is not in this because it is not reflected in AEO2023 NEMS or industrial data.

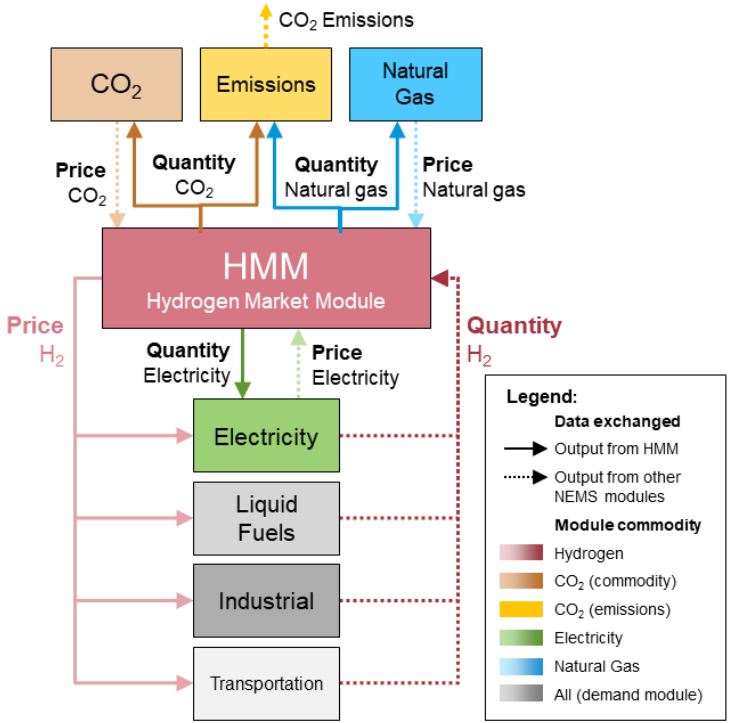
Integrating HMM into NEMS required modifications to H_2 modeling in multiple modules and coordination across NEMS modules



HMM performs many NEMS functions, including interacting with other modules that consume H_2 and affect H_2 production technology decisions

- Receive CO_2, natural gas, and electricity prices as inputs for hydrogen production
- Send end-use hydrogen prices to the electricity, liquid fuels, industrial, and transportation sectors
- Balance quantity of hydrogen demand from end-use sectors with hydrogen produced
- Send quantity of CO_2 captured during hydrogen production to CO_2 market

HMM's role within NEMS



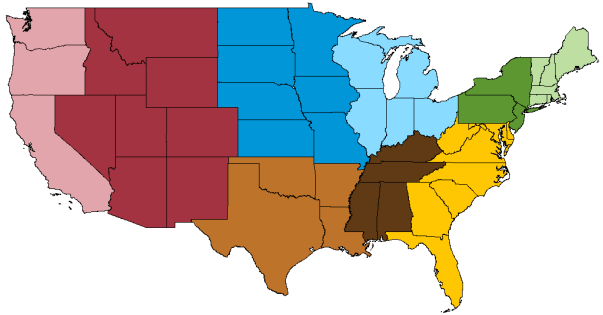
With blended regionality and detailed temporal resolution, HMM will project hydrogen production at a granular level

- Electrolysis production decisions represented at the Electricity Market Module (EMM) region level
- SMR production and regional hydrogen market balances represented at census-division level
- Four seasons modeled, with electrolysis production decisions made at hourly resolution

Seasonal and hourly representation in HMM

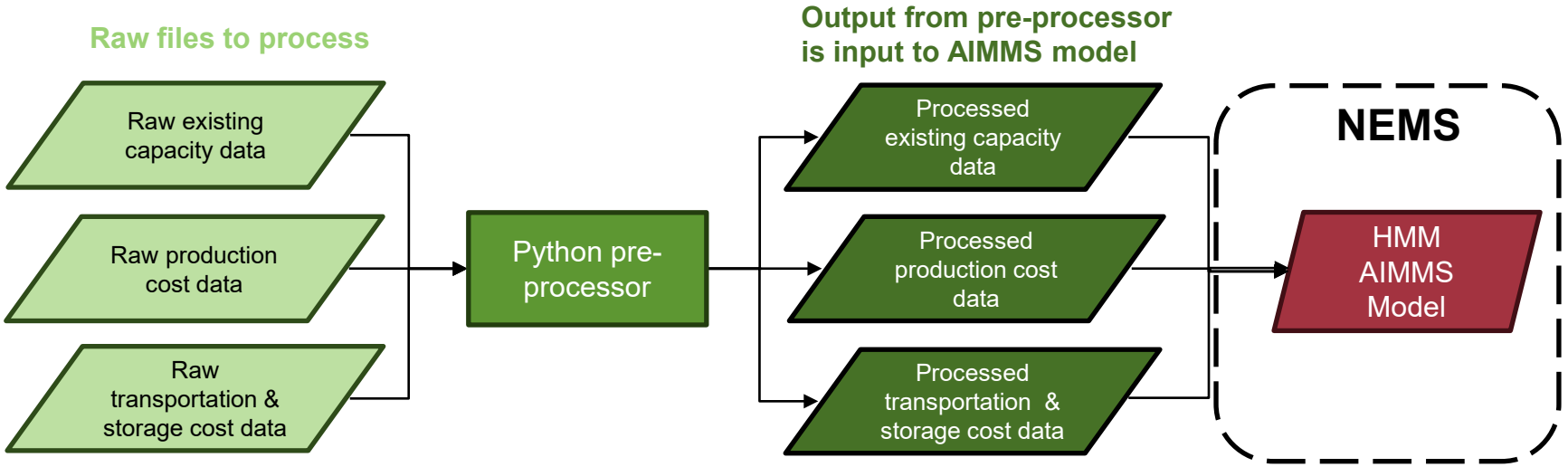
Electricity Market Module regions

U.S. Census Divisions



HMM Modeling Methodology

HMM is programmed in AIMMS and uses a Python pre-processor to prepare input data outside of NEMS



HMM is a linear program that minimizes costs

- Objective function: Minimize total cost to meet hydrogen demand, subject to capacity and mass balance constraints

- Primary decision variables include:
  - Quantity of hydrogen produced by technology type, region, and season
  - Seasonal hydrogen storage withdrawals and injections
  - Transportation of hydrogen between U.S. census divisions

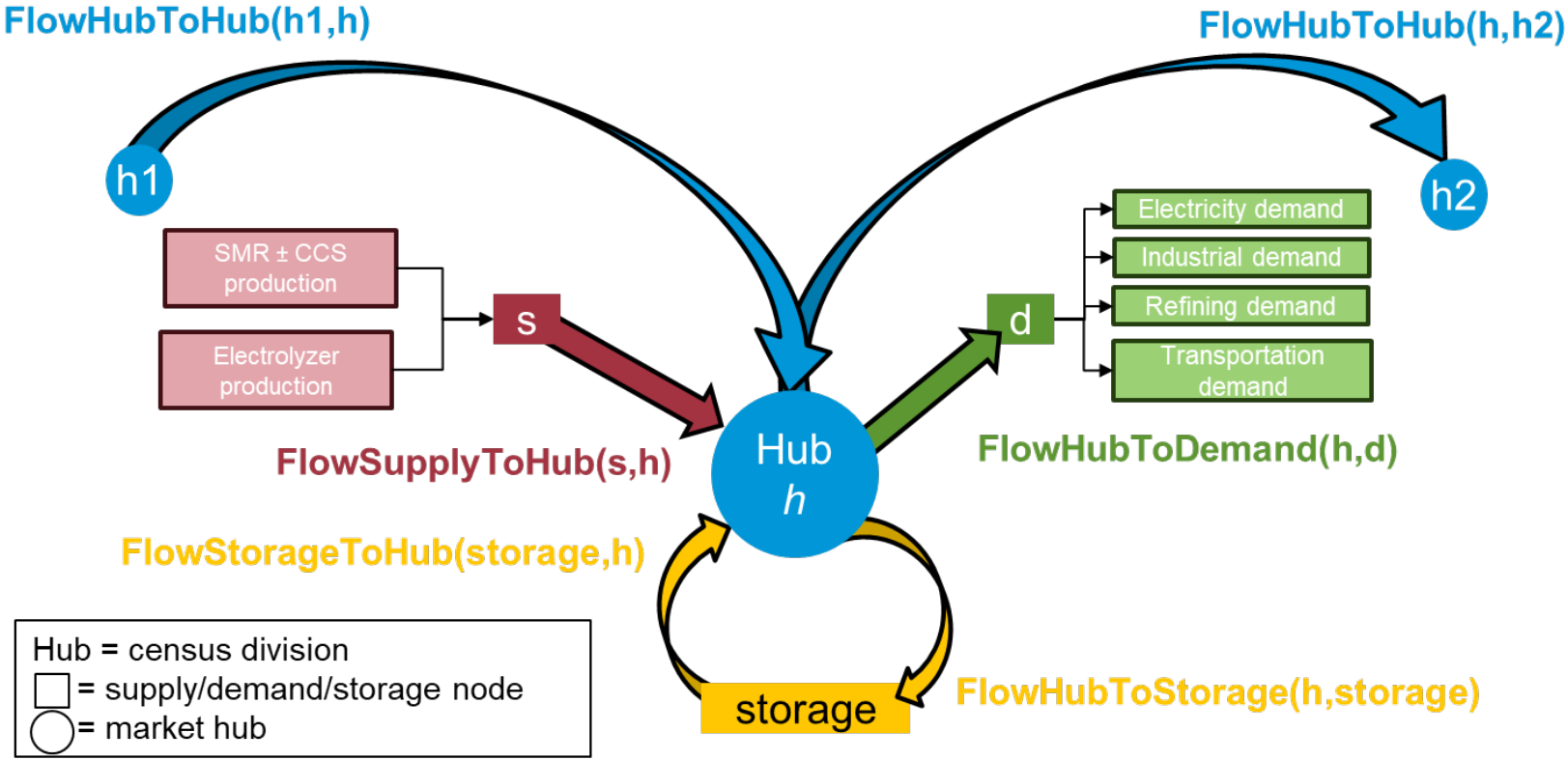
- Primary constraints include:
  - Mass balance for supply and demand nodes and market-clearing hubs
  - Inter-regional pipeline flows, storage injections and withdrawals, and regional production limited to projected capacity
  - Quantity of eligible renewable electricity that can be consumed to qualify for the 45V tax credit

- The shadow price is extracted from a constraint on the market-clearing hub balance that represents the market's marginal price of one additional unit of hydrogen.

We used a variety of data sources to estimate production costs and existing hydrogen production capacities

- National Renewable Energy Laboratory's (NREL) H2A Production Model (2020–2022)
  - Capital costs
  - Operating costs
- Argonne National Lab's (ANL) GREET 2018
  - Carbon capture efficiency
  - Fuel consumption
- SMR capacity from EIA's Petroleum Supply Annual (refineries) and estimated from the 2018 Manufacturing Energy Consumption Survey (MECS)

HMM uses the concept of market-clearing hubs and nodes in its linear program



Section 45V tax credit legislated in the Inflation Reduction Act

- HMM represents the 45V tax credits from the Inflation Reduction Act.
  - We assume that electrolyzers will claim the 45V credit, and SMR CCS facilities will claim the 45Q tax credit.
  - Construction for hydrogen facility must begin by 2033 and can receive the credit for 10 years.
- Hydrogen producers can purchase clean electricity via Energy Attribute Certificates (EACs), subject to certain criteria:
  - Incremental to existing generation
  - Deliverable to the hydrogen facility
  - Time-matched to when the hydrogen facility is using electricity to produce hydrogen
- Tiered credit rates are based on lifecycle well-to-gate GHG emissions determined by GREET.

Lifecycle GHG emissions ($kg\ CO_2e\ /\ kg\ H_2$)	Credit amount ($/kg H_2)
2.5 – 4	$0.60
1.5 – 2.5	$0.75
0.45 – 1.5	$1.00
0 – 0.45	$3.00

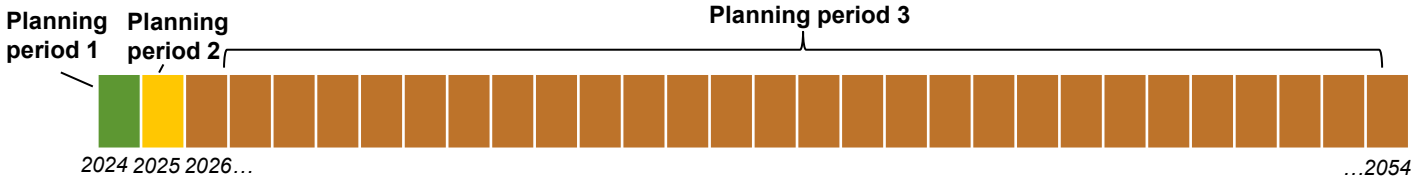
HMM makes simplifying assumptions to implement Section 45V

- HMM models grid-connected electrolysis.
- Section 45V eligibility assumes electrolyzers receive EACs by contracting power purchases from a grid-connected, third-party renewable generation facility.
- We assume that all hydrogen producers receiving EACs qualify for maximum $3/kilogram credit.

Summary of 45V implementation in HMM

	Incrementality	Deliverability	Time-matching
Requirement	Clean power generators must begin commercial operations within 3 years of H_2 facility start-up	EAC must be sourced in the same region as H_2 producer	EACs must match H_2 production on an hourly basis beginning in 2028, with time allowed for hourly tracking and EAC markets to become established
Implementation	Obtain hourly renewable generation data from EMM by year the capacity entered into service, which constrains volume of qualified H_2 produced in a given hour	Assume H_2 facility and renewable generator are located in same EMM region	EACs meet the hourly matching requirements because electrolyzers pay EMM's hourly electricity prices to produce H_2 in that hour

Modeling decision variables for three distinct planning periods provides foresight to model to aid capacity expansion decisions

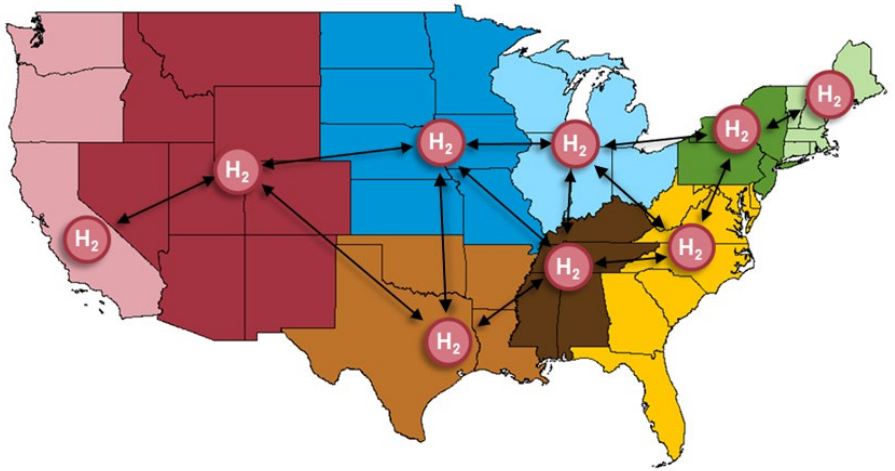


Objective function minimizes sum of total costs to meet hydrogen demand, taking into account all three planning periods using discounted cashflows.

	Planning Period 1 *Time t*	Planning Period 2 *Time t+1*	Planning Period 3 *Time t+2 to t+28*
Capacity Expansion	Not allowed	Allowed	Allowed
Purpose	Determines current model year output. Hydrogen prices are derived from extracting the shadow price of the demand balance constraint.	Capacity expansions built in this period will be available as existing capacity for the current year planning period for the next model year.	Provide cost and price foresight to aid capacity expansion decisions. Capacity expansions are allowed but are not carried over into future model years.

Simplified representation of hydrogen pipeline network allows inter-regional hydrogen transmission

- The model represents inter-regional transmission as hydrogen (not blended with natural gas) moving between census divisions via pipeline, if economic to do so.
- We use an assumed distance for each possible inter-regional transmission arc.
- We use the assumed distances to calculate pipeline capital costs, operations and maintenance costs, and the electricity required to move a unit of hydrogen across the arc.



Modeling seasonal storage allows hydrogen to be produced in one season but consumed in a different season

- HMM's storage representation is limited to long-duration, seasonal storage.
  - Storage levels do not persist between model years; all storage injected in one model year must be withdrawn during that model year.
  - Storage injections and withdrawals are modeled at the census division level.

- The model has the option to build salt cavern-based storage facilities for long-duration hydrogen storage if HMM deems it economic to build.
  - Model can invest in capital cost to construct storage facility
  - HMM also considers costs for electricity consumed to compress hydrogen during storage injections

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 and output exchange.
- We presented a Requirements Document to stakeholders that defines our expectations for AEO2025.

For more information

Hydrogen modeling team:

Katie Dyl | Kathryn.Dyl@eia.gov

Stephen York | Stephen.York@eia.gov

Neil Wagner | Neil.Wagner@eia.gov

Annual Energy Outlook | www.eia.gov/aeo

Annual Energy Outlook 2025 Resources | https://www.eia.gov/outlooks/aeo/resources/

Model Development | https://www.eia.gov/outlooks/documentation/workshops/

Working Groups | https://www.eia.gov/outlooks/aeo/workinggroup/

HMM Requirements Document can be found here:
https://www.eia.gov/outlooks/documentation/workshops/pdf/2024_HMM_requirements.pdf