International Energy Outlook 2023 Fact Sheet: World Hydrocarbon Activity Model

We introduced the new World Hydrocarbon Activity Model (WHAM) in *International Energy Outlook 2023 (*IEO2023). WHAM is made up of two parts: an optimization model coded in AIMMS and an integration wrapper written in Python that connects the model to the greater World Energy Projection System (WEPS). WHAM provides the following projections by region:

- Production of upstream natural gas, natural gas plant liquids (NGPLs), and crude oil by type
- Energy used in upstream production and natural gas transmission
- Refinery activity, which includes natural gas consumption and converting crude oil into refined products
- Petroleum product and natural gas end-use prices by WEPS region and sector
- Spot prices for crude oil and natural gas in select markets

WHAM also provides global projections for total refinery gain and exogenous estimates of biofuels production, coal-to-liquids and gas-to-liquids production, and other liquids production such as methanol.

WHAM is a linear program that minimizes the cost of supplying every WEPS region with the natural gas and liquid fuels demanded by the other WEPS modules. Structurally, WHAM has three types of regions—supply, refining, and demand—that are based on geography and economic activity. Each country is assigned to a supply region, a refining region, and a demand region.

Supply regions produce the various crude oil types, natural gas, and NGPLs. Each supply region has an established cost-of-supply curve for each commodity that dictates the maximum amount of each commodity that a specific region could produce for a set market price. Natural gas prices are tied to the historical relationship between a region's natural gas prices and the Brent crude oil price. The amount of NGPLs produced is a ratio of the total natural gas produced within a region based on historical production numbers.

Refining regions consume crude oil and convert it into refined petroleum products such as motor gasoline, distillate fuel oil, and jet fuel. Refining regions also consume natural gas and electricity as inputs to the conversion process. The refining capacity of refining regions is an aggregation of the refining capacities of their member countries. Capacity utilization is allocated across a variety of refinery operation types to efficiently produce the products required to meet demand for each region.

Demand regions consume refined petroleum products and natural gas to satisfy the demand from other WEPS modules that represent sectors such as transportation and electric power generation. Each region receives an associated sector-level commodity price corresponding to the regional consumption.

WHAM's logistic network ties the economic activity of each region type together. This logistic network covers the transportation cost of shipments via pipeline, ship, and a generic *domestic* term covering all other within-region transportation modes. This network enables the efficient trade of petroleum products and natural gas between regions to minimize the total cost of satisfying the liquid fuels and natural gas demand of each region.