Independent Statistics & Analysis
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World Energy Projection System (WEPS): World Hydrocarbon Activity Module (WHAM)

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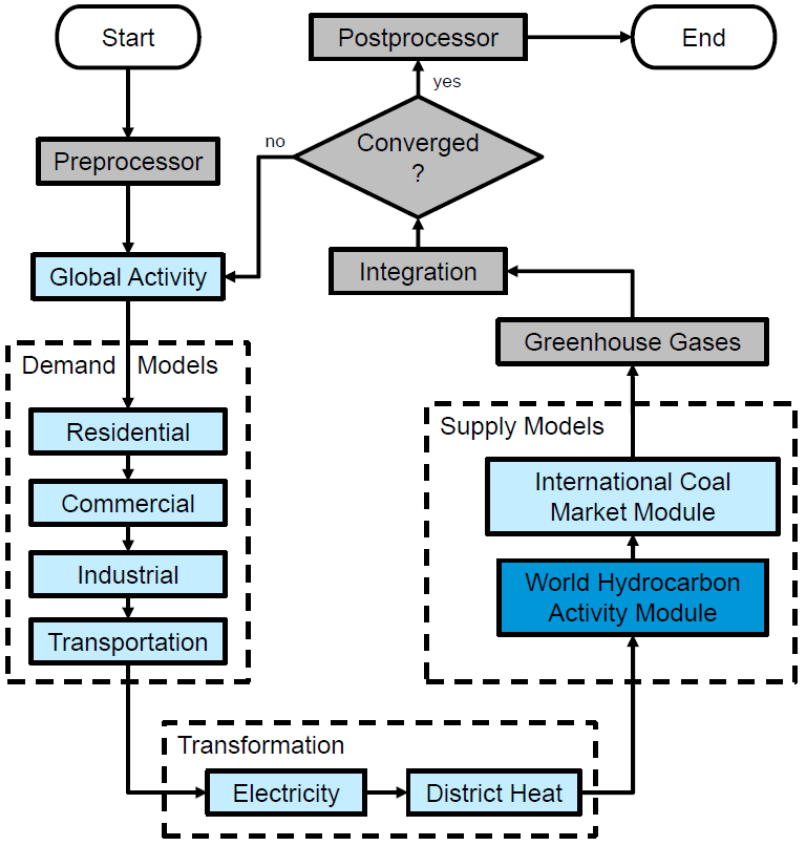
Introduction

The World Energy Projection System's (WEPS) World Hydrocarbon Activity Module (WHAM) projects global production, prices, and trade of petroleum liquids and natural gas globally for the *International Energy Outlook* (IEO). In addition, WHAM estimates capacity expansion and fuel consumption in the liquid fuels, natural gas, and liquefied natural gas production industry. WHAM is also used to analyze a variety of issues and policies related to petroleum liquids and natural gas to foster a better understanding of the global hydrocarbon gas and liquids industry.

Figure 1 shows the role that WHAM plays in the operation of the WEPS.

Figure 1. Schematic of WEPS



Source: U.S. Energy Information Administration, Office of Energy Analysis

Structurally, WHAM models two broad categories of production activities. In the first, upstream supply equations handle regional production decisions for crude oil and natural gas. In the second, refining equations handle regional conversion of crude oil by type into a variety of refined petroleum products. A logistics network handles the trade between upstream supply and refining activity, along with satisfying regional demand for final petroleum products and natural gas. The logistic network currently represents trade through interregional pipeline and waterborne trade. Intraregional trade costs are captured by a

catch-all *domestic* method. This method may include trade costs from barge, rail, truck, or smaller pipeline networks.

The essential outputs of this model are international natural gas and petroleum product prices, crude oil and natural gas supply, and consumption of fuel at refineries and liquefied natural gas facilities. However, WHAM also represents the marketing and distribution of the fractionated natural gas liquids from natural gas processing plants; the production of distillate and naphtha blending streams from natural gas (gas-to-liquids, GTL), coal (coal-to-liquids, CTL), and biomass (biomass-to-liquids, BTL); and the processing and marketing of renewable fuel feedstocks (corn, biomass, seed oils, fats, and greases) into alcohol and biomass-based diesel and naphtha liquid blends.

Inputs to WHAM:

- Consumption of individual petroleum liquid commodities by end-use sector and WEPS region
- Consumption of natural gas by end-use sector and WEPS region
- Initial projection of Brent crude oil price
- International natural gas and crude oil cost-of-supply curves for six crude oil types
- Yield coefficients (the quantity of petroleum products yielded per barrel of mixed crude slate) for crude oil distillation and other processing units
- Existing and planned process unit capacities
- Capacities and tariffs for pipeline and waterborne transportation for crude oil, natural gas, and petroleum products

From these inputs, WHAM provides:

- Projections for production of crude oil, natural gas, and petroleum products
- End-use prices for petroleum products and natural gas
- Net trade of petroleum liquids and natural gas
- Estimates of refinery gain
- Natural gas consumption by regasification, liquefaction, pipeline, and production activities
- Refinery fuel consumption, including electricity, natural gas, still gas, and catalyst coke

WHAM represents the liquid fuels production and marketing sector in projections published in the IEO. WHAM can project how changes in the following factors affect refinery operations and the marginal costs of refined products:

- Demand for petroleum products
- Crude oil prices and domestic production levels
- Refinery processing unit capacities

The following is a list of inputs that we believe have a high degree of influence on WHAM results. We provide it to help users understand the critical factors affecting WHAM.

- World oil price

- Product demand
- Crude oil production cost curves
- Cost of transportation between regions
- Refinery yields

Model Rationale

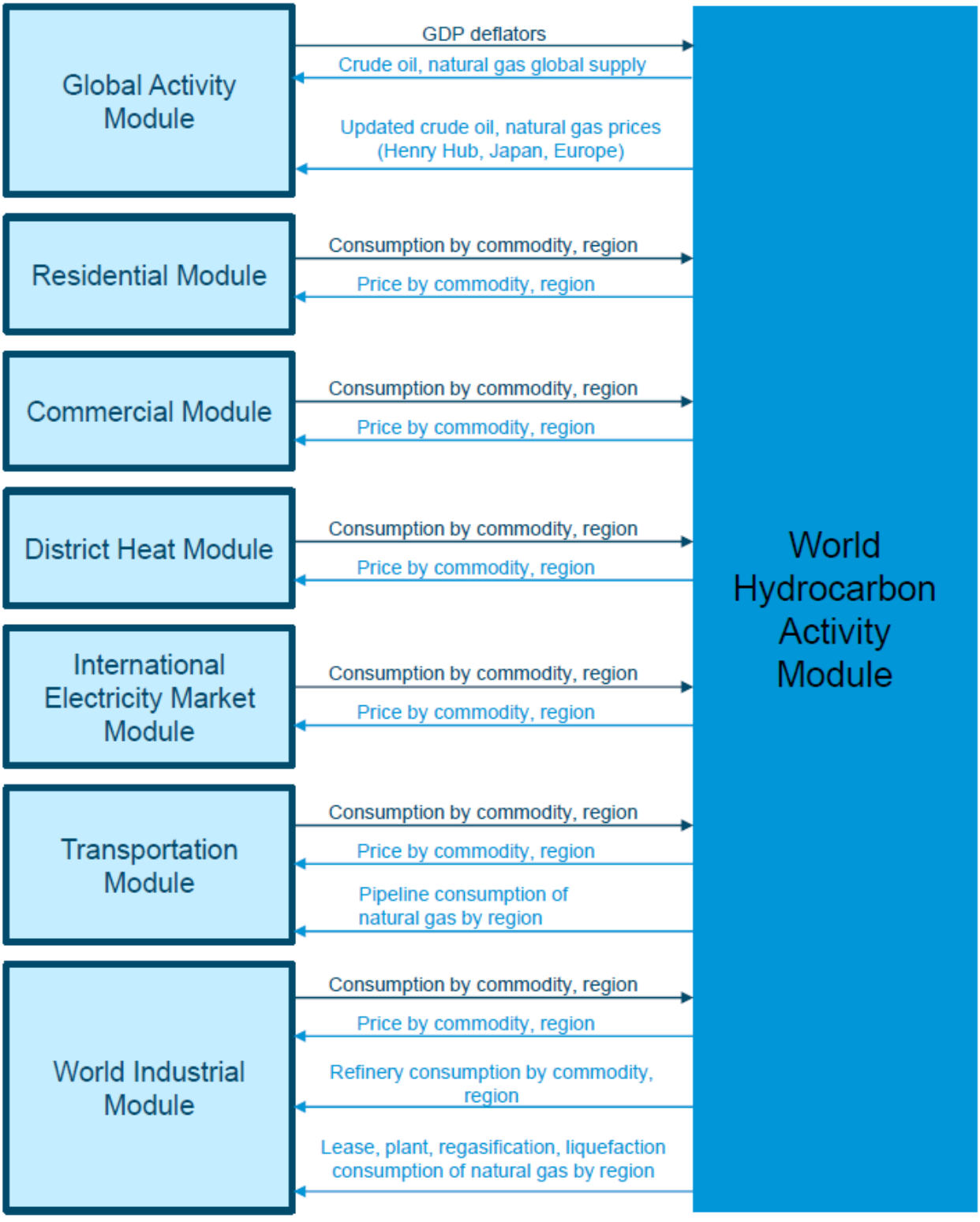
Theoretical approach

WEPS generates the IEO's projections of energy consumption, prices, and production. WEPS is a modular system, consisting of a number of separate energy modules joined through a common database. The overall system uses an iterative solution technique that works toward converging quantities and prices in an equilibrium solution.

Relationship to other modules

WHAM receives inputs from the macroeconomic, consumption, and transformation modules of WEPS and provides supply and price information in return (Figure 2).

Figure 2. Interactions between the World Hydrocarbon Activity Module and the World Energy Projection System, by module



Source: U.S. Energy Information Administration, Office of Energy Analysis

WHAM uses a cost-minimization integer program to represent international crude oil and natural gas production, as well as liquid fuels refining, consumption, distribution, and marketing operations. The module includes 21 international production regions, 15 international refining regions, and 19 international demand regions, all based on the regional framework used by WEPS. A transportation network model represents transport of domestic crude oils and natural gas from the production regions to the refining and demand regions and transport of petroleum products from the refining regions to the demand regions. Changes in one refining region can affect operations in other refining regions because each demand region can be supplied by more than one refining region (if the transportation connections exist).

An optimal solution minimizes net total cost while simultaneously meeting regional demand and constraints. The module estimates the cost of recovering crude oil and natural gas resources, the cost of refinery operations, and the cost of logistic activities for both raw materials and finished products. The liquid fuels production activities are constrained by material balance requirements on feedstocks and intermediate streams, processing and transportation capacities, demand, and policy requirements.

Fundamental assumptions

WHAM assumes that the crude oil and liquid fuels production and marketing industry is competitive and that regional natural gas prices are linked to crude oil prices. The market will move toward lower-cost refiners who have access to lower-cost crude oil (or non-petroleum feedstocks) and markets. The selection of feedstocks, process utilization, renewable fuel blends, and logistics will adjust to minimize the overall cost of supplying the market with petroleum products. If petroleum product demand is unusually high in one region, the price will increase, driving down demand and providing economic incentives for bringing supplies in from other lower-cost regions (or imports), thus restoring the supply and demand balance. Because WHAM runs annually, it cannot be used to analyze sub-annual petroleum and natural gas market issues related to supply, demand, or prices.

Model Code Structure

During each WEPS iterative solution (each iteration for all model years), product demand quantities and other data provided by the other WEPS demand modules are used to update WHAM's matrix. Once the mathematical model provides an updated solution, crude oil and petroleum product prices and other material balance information are extracted, followed by the post-processing needed to convert results into the output required by other modules and reports. For example, additional costs (such as taxes and distribution costs) are added to the product prices to define domestic petroleum product prices for each end-use sector in each WHAM demand region. System variables are updated and reports are produced.

WHAM is composed of three programs that help execute the module and its mechanical interaction with WEPS:

- An offline data preprocessor (written in Python)
- The integration wrapper called by WEPS (written in Python)
- The optimization model (written in AIMMS)

The data preprocessor handles static input data that does not change during a WEPS iterative run. Data such as historical capacities, prices, and production are prepared independently at least once a year. These input data are uploaded into the WEPS repository for WHAM AIMMS code to access each cycle.

The python integration wrapper is called by WEPS every cycle after the macroeconomic, consumption, and electricity modules run. The integration wrapper collects, converts, and sends data back and forth between the greater WEPS system and the WHAM optimization model. It also writes reports, collects debugging information, and runs tests to ensure mass balance is maintained.

The AIMMS model takes the static inputs from the preprocessor and the dynamic WEPS inputs from the integration wrapper and solves for every projection year.