Independent Statistics & Analysis
U.S. Energy Information Administration

World Hydrocarbon Activity Model (WHAM) Requirements

December 2021

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Contents

Revision History

Name	Date	Reason for changes	Version
Project Team	Dec. 27, 2021	Brand New	0

Abbreviations

AIMMS	Advanced Integrated Multidimensional Modeling Software
AEO	*Annual Energy Outlook*
b	barrel
CTL	coal-to-liquids
EIA	U.S. Energy Information Administration
GTL	gas-to-liquids
GLAM	Global Activity Module
GHySMo	Global Hydrocarbon Supply Model
GRTMPS	Generalized Refining Transportation Marketing Planning System
IEMM	International Electricity Market Model
IEA	International Energy Agency
IEO	*International Energy Outlook*
IES	International Energy Statistics (EIA)
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LTEM	Long-Term Energy Modeling (Office)
Mb	thousand barrels
MMBtu	million British thermal units
MMb/d	million barrels per day
NGPL	natural gas plant liquids
OECD	Organization of Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
STEO	*Short-Term Energy Outlook*
Mcf	thousand cubic feet
Tcf	trillion cubic feet
ULSD	ultra-low sulfur diesel
WHAM	World Hydrocarbon Activity Model
WEPS	World Energy Projection System
WIM	World Industrial Model
WOP	world oil price
WTI	West Texas Intermediate

Introduction

EIA requires a model that represents global natural gas and petroleum liquids markets to support its international modeling efforts. The tool developed to meet this objective for *International Energy Outlook 2019* (IEO2019) was the Global Hydrocarbon Supply Module (GHySMo). GHySMo consisted of three modules interacting through an Integration module:

- Upstream module, run outside of WEPS iteration
- Conversion module, a linear program representing international refining
- Logistics module, a linear program representing transportation and trade of hydrocarbons

After extensive evaluation, we determined that the existing GHySMo design did not meet the design objective because the two linear programs did not converge on a solution and could not adequately represent the intended markets. As a result, for IEO2021, we built a workaround solution called the Oil & Gas Tool that balanced hydrocarbon production with consumption estimates from other modules, based on previous analysis. The Oil & Gas Tool cannot model economic behavior and therefore is unable to capture complex international trade interactions.

The Office of Long-Term Energy Modeling (LTEM) proposes the design and development of a replacement for GHySMo, the World Hydrocarbon Activity Module (WHAM). WHAM will represent core global natural gas and liquid fuels markets by optimizing a single linear program for refining and global movements of hydrocarbon commodities, eliminating the need for convergence between multiple linear programs. This solution will include volumes, prices, and flows to be passed into WEPS (World Energy Projection System), the modeling system that creates projections for the IEO.

Purpose

This document highlights the requirements for WHAM prior to development and will facilitate project planning by aligning theoretical and practical model development with the core objective of the GHySMo overhaul plan. Clearly stated requirements will further reduce the likelihood of a failed overhaul due to a loosely defined scope.

This document is intended for EIA management, the LTEM team developing WHAM, and future users of WHAM.

Scope

What's in scope?

WHAM will:

- Provide a single global supply of crude oil and natural gas (in other words, upstream production), at a minimum
- Balance supply and demand of petroleum and other liquids and natural gas
- Represent global refining to deliver end-use product prices by sector to WEPS
- Represent global transportation between suppliers, refineries, and demand markets consistent with existing infrastructure (see Requirement 2.6 for expanding infrastructure)
- Use historical data where appropriate
- Benchmark to our *Annual Energy Outlook* (AEO) and *Short-Term Energy Outlook* (STEO) where appropriate
- Ensure consistency with our International Energy Statistics (IES) and the International Energy Agency (IEA) historical data processing and data reconciliation process
- Provide documentation to facilitate future use of model
- Be a generalized model that can be easily improved and developed in the future

What's out of scope for now but considered in development?

As global natural gas and liquids markets continue to evolve, WHAM should include a framework that facilitates future development necessary for meeting the primary objective of WHAM. The following list includes items that are not in scope currently but will be considered while we develop WHAM and may be handled by exogenous inputs. We will design WHAM to accommodate the following future model improvements:

- Addition of fuel types (for example, biofuels, hydrogen, and ammonia) that substitute for fossil fuels
- Ability to calculate and report out revenue by region and region type
- Regional realignments and aggregations of country-level data when possible within the code
- Quantification of infrastructure investments required in terms of cost, capacity, and materials
- Addition of climate-related policy including CO_2 accounting, carbon taxes, and carbon trade
- More detailed representation of natural gas and liquids trade by U.S. subregions
- Provide crude oil, other petroleum liquids, and natural gas production volumes by upstream supply region (in other words, the G tables in the IEO)

What's out of scope?

The following elements remain out of scope for development of WHAM, so the model will not:

- Run the GHySMo Upstream module or rely on the GHySMo Upstream module outputs as basis for WHAM
- Include co-production of crude oil and natural gas
- Account for changes to infrastructure (that is, refinery, pipeline, fleet, and liquefied natural gas [LNG] regasification) in a dynamic manner
- Represent multiple LNG pricing mechanisms
- Increase interconnectivity with the Macroeconomic and Transportation modules within WEPS

Team members and audience

The team associated with WHAM includes the Petroleum and Natural Gas Modeling Team staff, who will design, develop, and test WHAM, as well as management involved in the approval process (Table 1).

In addition to the team in Table 1, the WEPS modelers and teams identified in Table 2 were consulted as we identified requirements and drafted this document.

The team will follow the project timeline, which will be updated monthly to reflect current expectations and progress to-date. The modeling team will communicate daily via Microsoft Teams and hold weekly meetings every Thursday with our Team Leader. In addition, we have scheduled monthly status update meetings to keep leadership apprised of the most recent progress to ensure objectives are aligned each step of the way. Any material changes to the requirements laid out below will be presented to management for approval.

Table 1. WHAM project team, roles, and responsibilities

Name	Title	Project Role	Responsibilities
Angelina LaRose	Assistant Administrator for Energy Analysis	Executive Sponsor	Evaluate and approve project activities after each Task (1–3)
John Staub	Senior Advisor, Quality and Innovation Council	Executive Advisor	Provide feedback and identify cross-agency opportunities; assist Executive Sponsor as-needed in review of materials
Jim Diefenderfer	Director, Office of Long-Term Modeling	Project Sponsor	Approve project budget and staff efforts; advocate for project and resources
Mindi Farber-DeAnda	Team Leader, PNGM	Team Leader	Approve project budget and staff efforts; advocate for project and resources
Peter Colletti	Operations Research Analyst	Project Manager/Lead, Modeler	Project manager, key role in developing component design report (CDR) and model documentation, and serve as SME for refinery operations and petroleum markets
Kathryn Dyl	Operations Research Analyst	Advisor, Project Management support, Modeler	Key role in developing requirements and CDR; provide feedback and advice during design and development; serve as SME for natural gas markets and AIMMS
Neil Wagner	Industry Economist	Modeler	Primary lead for model design and development
Andrew Smiddy	Industry Economist	Modeler	Primary lead for data design and processing

Table 2. Teams consulted during requirements development

Team	Date	Attended	Summary
Macroeconomic	September 28, 2021	Elizabeth Sendich, William Swanson	Macro Notes
Integration	October 1, 2021	Michael Cole, Ari Kahan, Christopher Marquardt	Integration Notes
Industrial	October 4, 2021	Peter Gross, Matt Skelton, Nicholas Skarzynski	Industrial Notes
Transportation	October 4, 2021	Caroline Campbell, Michael Dwyer, John Maples	Transportation Notes
Buildings	October 5, 2021	Erin Boedecker, Courtney Sourmehi	Buildings Notes
Electricity	October 5, 2021	Kenneth Dubin, Augustine Kwon, Manussawee Sukunta	Electricity Notes

Document organization

The second section of this document provides an overview of WHAM, its relationship to WEPS and other EIA data and products, and the assumptions and constraints underlying the development of WHAM requirements.

The next three sections detail model requirements, which have been numbered to align with Appendix A:

1. Integration Requirements
2. Functional Requirements
3. Other System Requirements

We have also included two Appendices covering the following topics:

A. WHAM Hierarchy of Requirements
B. WEPS Restart File Variables in WHAM

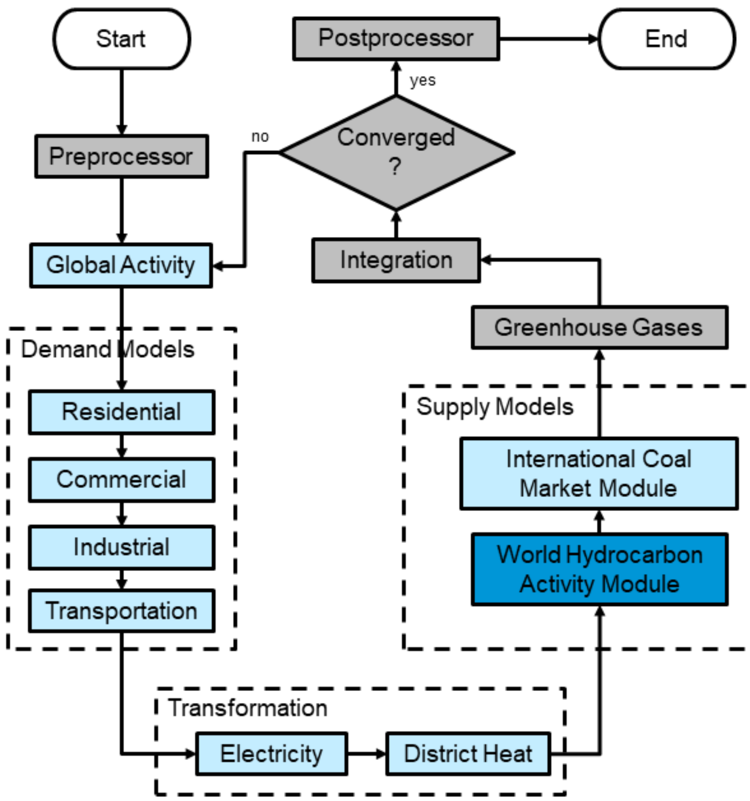
Overview of World Hydrocarbon Activity Model (WHAM)

This section provides an overview of WHAM, its context within the WEPS modeling system, and the role we expect it to play in our international modeling efforts. We also outline the assumptions and constraints that might affect the requirements.

Model perspective

WHAM projects the global price and quantity of liquid and gas hydrocarbons within WEPS. It will be one of 11 individual models that makes up WEPS (Figure 1).

Figure 1. Schematic of WEPS



Relation to other WEPS modules

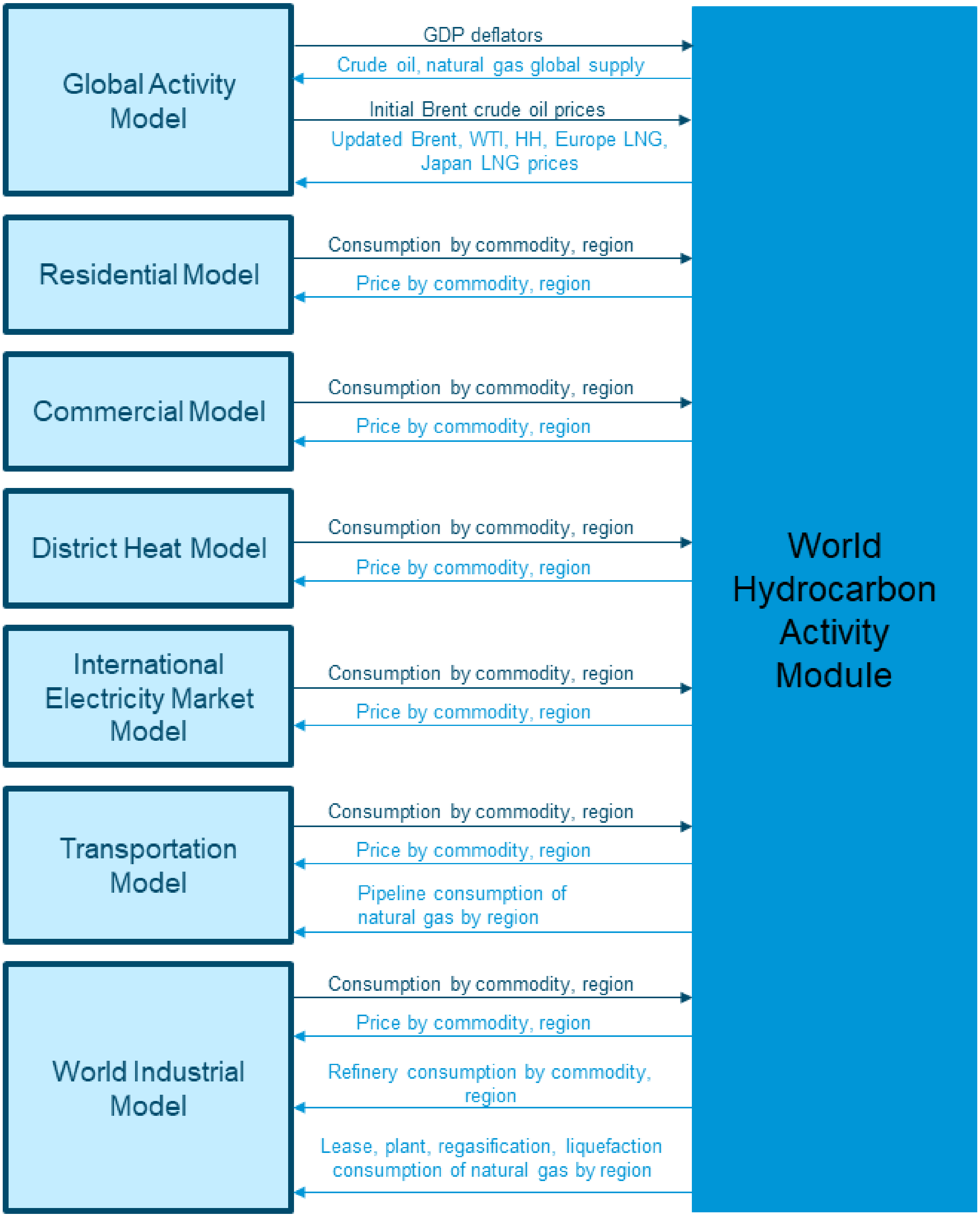
WHAM receives data from and provides data to other WEPS modules (Figure 2).

WHAM receives annual projections through 2050 of the following:

- 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 Brent crude oil price projection (in other words, the World Oil Price [WOP] path)

WHAM provides delivered hydrocarbon commodity prices back to the demand and transformation models. It also provides additional consumption volumes related to hydrocarbon production, refining, and transportation: lease and plant fuel, pipeline fuel use, liquefaction and regasification volumes, and refinery consumption.

Figure 2. Interactions between WHAM and WEPS by module



Software interfaces

WEPS runs inside a Python virtual environment managed by the EIA Integration Team. The virtual environment enables close control of which Python packages are used by WEPS, including exact versions of various packages.

As of November 20, 2020, WEPS runs in Python 3.7 (64 bit). Commonly used python libraries are also loaded onto the system.

The restart file (*restart.hdf5*) is formatted as a binary *hdf5* file. WHAM must read input variables from and write output variables to the WEPS *hdf5* restart file.

Model functions

WHAM must serve and perform the following functions as part of an integrated WEPS cycle:

- Provide supply projections for liquid fuels (that is, crude oil, condensate, and other liquids) and natural gas for publication in the IEO
- Represent the transformation of crude oil and other liquids in the refining process into petroleum products such that the quantity supplied equals the quantity demanded, as projected by WEPS
- Project consumption of energy during the production, transformation, and distribution of hydrocarbons
- Project spot prices as-needed for other WEPS modules and construct end-use prices
- Project end-use commodity prices by sector, commodity, and WEPS demand region as expected by other WEPS modules
- Represent trade of hydrocarbons using commodity flows between supply regions, refining regions, and demand regions
- Benchmark projections to both the latest AEO and STEO

The Functional Requirements in Section 2 describe and explain how WHAM must carry out these model functions. In addition, a complete list of all WEPS global variables that must be filled by WHAM are listed in Appendix B.

User characteristics

Modeler

An LTEM modeler will run WHAM for every IEO production cycle for the Reference case and all additional side cases. The modeler must prepare inputs to the model, run WHAM in a non-integrated environment, run WHAM within an integrated environment, analyze model results, and be able to debug the model.

A modeler will generally have a technical background in either economics or operations research along with some subject matter expertise in petroleum liquids and natural gas. WHAM should be straightforward for the modeler to update, maintain, and operate.

Analyst

An LTEM analyst may be called to evaluate results produced by WHAM or provide insight into the constraints used by the model. This user will not run the model during IEO production cycles, only provide feedback in the form of subject matter expertise.

Analysts will generally have less of a technical background in modeling and may have a stronger background in the subject matter of petroleum liquids and natural gas.

Design and implementation constraints

Software and programming language

We specify that the AIMMS platform should be used for developing optimization models. This guidance adds some additional constraints to the system, including the formatting and file types for input and output files.

We have also invested significant staff development and resources into Python. Therefore, any supporting code or code related to the main linear program should use Python.

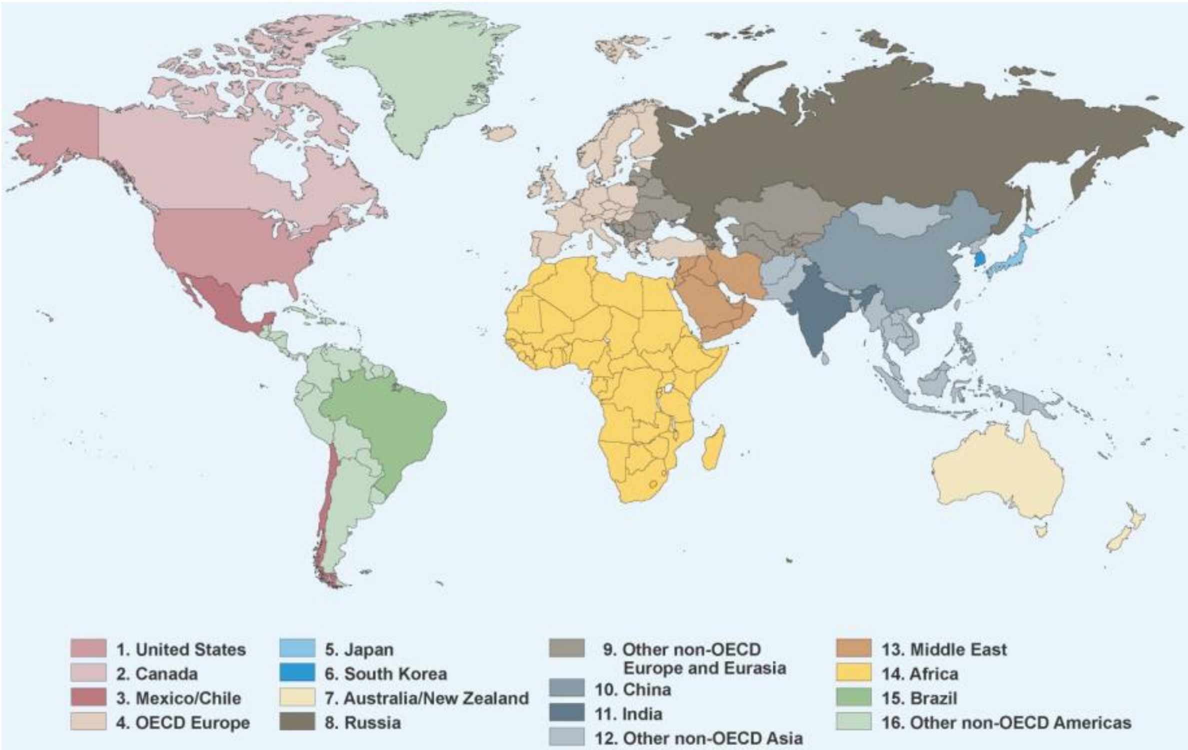
Associated pre- and post-processing of data can be done either within AIMMS or via Python.

WEPS System

The regional representation of WEPS limits the representation of WHAM because all the data received from WEPS—and all data provided back to other modules—must adhere to these geographic aggregations.

Figure 3 defines the WEPS regions, corresponding to consumption received from WEPS.

Figure 3. WEPS regions*



* Colombia is included in region 3, Mexico/Chile

International data gaps

The availability and access to specific international data sets is another constraint in developing WHAM. The Data Availability section includes a fuller discussion on this topic.

Assumptions and dependencies

Oil prices

We will continue to provide the Brent world oil price projections as an exogenous input into our domestic and international models for both the Reference case and the high and low oil price side cases. This model will not replace or evaluate the World Oil Price (WOP) projections provided; however, it may be asked to adjust the WOP, given changes in total global consumption of petroleum products.

WHAM will use Brent oil price projections, in conjunction with historical price differentials between regions and crude oil quality, to extrapolate the world oil prices for all crude oil types and production regions.

Data availability

Although access to international data series may constrain the design and development of this model, the specified requirements in this document assume that we continue to have access to existing international data sources. These sources include:

- Refinitiv
- Clipper
- Bloomberg terminal
- International Gas Union
- Global Infrastructure Tracker (pipelines)
- Oil & Gas Journal (refineries)
- GlobalPetrolPrices.com (end-use delivered prices of gasoline and diesel to the transportation sector)[1]

Loss of access to these data providers—or the products provided to EIA staff—may affect both the schedule and requirements of the proposed model.

External models

We assume two external models, or data related to external models, are available and operational for our use during WHAM development.

GRTMPS

The Generalized Refining Transportation Marketing Planning System (GRTMPS) refinery model is a critical tool used to generate data for the model. GRTMPS provides refinery yield data for a number of different refinery profiles, including different crude oil slates and refinery types. These data provide the basis for modeling refinery operations in WHAM.

Upstream GHySMo Resource Data

Upstream GHySMo was designed to provide the Logistics and Conversion modules with quantities of natural gas, crude oil by grade, and condensate by year and region based on the Brent oil price path provided to it. In its current state, Upstream GHySMo does not provide quantities that are reflective of the behavior the producing countries historically and currently show. Therefore, we will not use Upstream GHySMo to provide prices and quantities to WHAM. The Resource Handler portion of Upstream GHySMo includes a comprehensive dataset of country-level resource costs. This dataset, in conjunction with other tools, may be leveraged to generate prices for WHAM. Research and development of our approach toward a sufficient representation of upstream supply will be outlined in the Component Design Report.

Staff resources

Modelers and advisory staff specified in the Project Team (Table 1) will be available to the project throughout the duration of model design, development, and testing. For team members Neil Wagner and Andrew Smiddy, the design and development of WHAM will be their primary task and at least 50% of their time will be dedicated to this project. For team members Peter Colletti and Kathryn Dyl, the

[1] Currently requested as part of FY 2022 budget

project management and documentation development will be their primary tasks and that 25%–50% of their time will be dedicated to this project.

WHAM Requirements

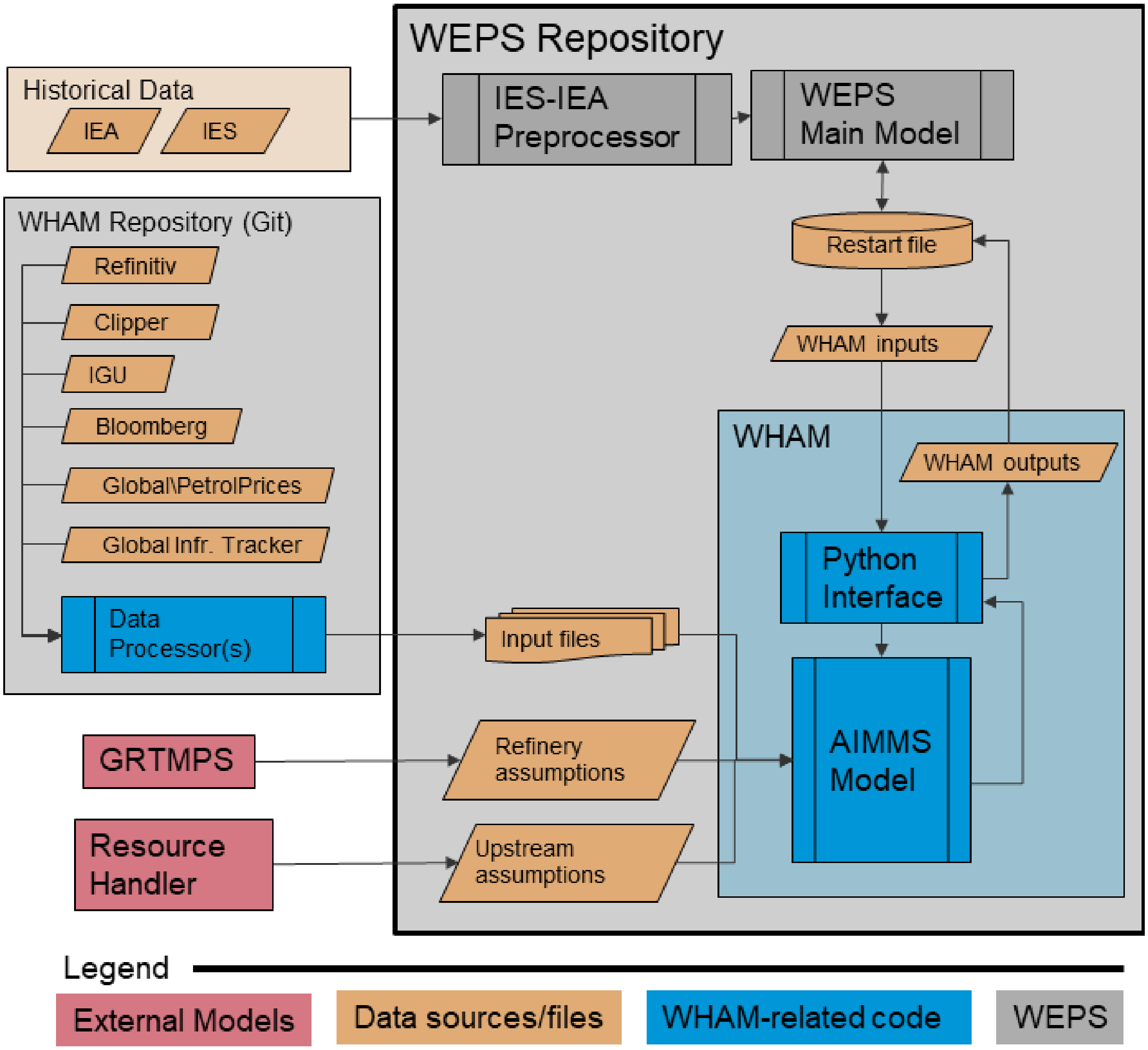
1. Integration Requirements

The requirements classified as Integration Requirements relate to any other software, interfaces, or systems related to WHAM, as detailed in Figure 4. WHAM system contextWHAM will interact with three main systems:

- WEPS, via restart file
    a. All files needed for a WEPS model run, including source code and input files, will be part of the WEPS Repository
- WHAM Repository, where preprocessors, input data, and other offline files will be stored
- GRTMPS, offline software to generate refinery yield and operation assumptions

All requirements are identified by an ID number.

Figure 4. WHAM system context



1.1. WEPS

Table 3. Requirements for integrating WHAM with WEPS

ID	Requirements	Description
1.1.1	WHAM-WEPS interface	Construct Python interface to allow interaction between WHAM and WEPS
1.1.2	WEPS runtime parameters	Use case-specific runtime parameters as specified by WEPS
1.1.3	Restart file interface	Interface with the WEPS restart file, including input and output variables and output data
1.1.4	Debug .csv files	Produce an output .csv file for debugging
1.1.5	Input file formatting	Conduct all data preprocessing prior to WEPS run
1.1.6	IES data	IES historical data will be received directly from WEPS
1.1.7	IEA data	WEPS integration team will handle IEA data processing to ensure consistency with data reconciliation process, IES data
1.1.8	STEO data	Use STEO data file from STEO_Importer tool in WEPS integration
1.1.9	AEO data	Use AEO overwrite tool in WEPS for any AEO data; track AEO original projections separately from model input/output
1.1.10	No database use	Database will not be used for storing data in WEPS repository. Input files will be .csv, .txt, or similar

1.2. WHAM Repository

Per Integration Team guidance, all files associated with external (that is, non-IES, non-IEA, non-STEO, non-AEO) historical input data or assumptions will be stored as part of a separate WHAM Repository in the Git system. This includes any preprocessing code or routines required for data preparation prior to running WHAM. The only files transferred from the WHAM repository to the WEPS repository will be files that are ready for WEPS runtime.

Table 4. WHAM repository requirements

ID	Requirements	Description
1.2.1	Pre-processed input data (non-IES, non-IEA, non-STEO, non-AEO)	Ensure all exogenous data, historical data that is not part of IES or IEA is saved in WHAM repository
1.2.2	Data processing files	Make sure all code and data processing tools are included and stored in WHAM repository separate from WEPS
1.2.3	Transfer to WEPS Repository	Ensure any files read directly into WHAM are part of WEPS repository as well

1.3. GRTMPS

WHAM Integration code will provide WHAM with yield parameters calculated by GRTMPS outside of WEPS runtime

2. Functional Requirements

The functional requirements include the operations, outputs, and methods which will be required in the design and development of WHAM. Detailed descriptions of how these functions will be met will be included in the future Component Design Report.

2.1. Supply

WHAM must project global supply and year at a level sufficient for publication in the IEO. Table 5 provides detailed descriptions of each element that WHAM will project.

Table 5. Supply projections

ID	Requirements	Description
2.1.1	Crude oil and condensate production	Includes different crude type (for example, light vs. heavy, sweet vs. sour)
2.1.2	Dry natural gas production	Dry production equal to total consumption; excludes NGPL or other impurities
2.1.3	Other liquid fuels production	
2.1.3.1	NGPL supply	Consistent with natural gas production; refers only to NGPL from natural gas processing
2.1.3.2	Biofuel supply	Exogenous assumption; includes ethanol, biodiesel, and renewable diesel
2.1.3.3	Refinery gain	Consistent with volume balance between feeds and products
2.1.3.4	Coal-to-liquids supply	Exogenous assumption
2.1.3.5	Gas-to-liquids supply	Exogenous assumption
2.1.3.6	Other liquid fuels	Exogenous assumption; includes hydrogen, coal tar, gilsonite

2.2. Refining

WHAM must represent the refinery industry to adequately translate crude oil production volumes into the petroleum product consumption volumes projected (Table 6).

Table 6. Refining requirements

ID	Requirements	Description
2.2.1	Petroleum liquids production	Petroleum liquids supply equals WEPS demand
2.2.2	Mass and energy balance	Accounts for byproducts, utility consumption, and refinery gain
2.2.3	Refinery gate prices	Consistent with historical price relationships
2.2.4	Account for differences in refinery operations, equipment, and crude oil feeds	Differences in refinery equipment and crude oil feed selection
2.2.5	Refinery consumption	Consumption of refinery utility streams

2.3. Other consumption

The energy consumption in specific subsectors of the industrial sector (oil and natural gas production activities, refining, LNG liquefaction and regasification) and the transportation sector (pipeline fuel use) are a function of hydrocarbon supply, refinery activity, and global trade and transportation logistics.

Therefore, WHAM must represent, calculate, and account for these consumption volumes within WEPS (Table 7. Other consumptionTable 7).

Table 7. Other consumption

ID	Requirements	Description
2.3.1	Lease and plant fuel	Consistent with hydrocarbon production
2.3.2	Pipeline fuel	Consistent with natural gas trade and transmission
2.3.3	Liquefaction fuel	Consistent with LNG exports
2.3.4	Regasification fuel	Consistent with LNG imports
2.3.5	Fuel consumed in gas-to-liquids (GTL) operations	Consistent with GTL operations

2.4. Market spot prices

Market (for example, spot, marginal, or wholesale) prices have two key purposes in WEPS. First, specific crude oil and natural gas spot prices are a required input into the Global Activity Model (GLAM), which projects macroeconomic drivers. Second, market prices are the basis for any further calculation of end-use delivered prices (see Requirement 2.5). The specific spot prices that WHAM will output are included in Table 8.

Table 8. Market spot prices

ID	Requirements	Description
2.4.1	**Crude oil spot prices**	
2.4.1.1	Regional supply prices by supply type	Determined prior to WEPS run; use Brent crude oil price to extrapolate to other regions, crude oil qualities
2.4.1.2	Brent crude oil price	Exogenous assumption
2.4.1.3	West Texas Intermediate crude oil price	Exogenous assumption from AEO
2.4.1.4	Crude oil prices to refiners by refinery region, supply type	Includes supply prices plus transportation markup
2.4.2	**Natural gas spot prices**	
2.4.2.1	Regional spot prices	Natural gas spot prices for all regions based on supply fundamentals and transmission
2.4.2.2	Japan natural gas price	Key input for GLAM
2.4.2.3	Europe natural gas price	Key input for GLAM
2.4.2.4	Henry Hub natural gas price	Exogenous assumption from AEO

2.5. End-use delivered prices

End-use delivered prices are the key output from WHAM used by demand models to inform their projections (Table 9).

Table 9. End-use delivered prices

ID	Requirements	Description
2.5.1	Market or wholesale price by demand region	Includes competitive market price plus transportation markup between supply and demand region
2.5.2	Buildings sectors end use delivered prices	For residential and commercial buildings, wholesale price plus markup
2.5.3	Industrial sector end use delivered prices	For the industrial sector, wholesale price plus markup
2.5.4	Electric power sector end use delivered prices	For power generation and district heat, wholesale price plus markup
2.5.5	Transportation sector end use delivered prices	For transportation sector, wholesale price plus markup

2.6. Logistics and trade

While international trade projections are only published at the net level for natural gas in the IEO, representing trade is a key factor when modeling commodity prices to demand markets.

Table 10. Trading and logistics

ID	Requirements	Description
2.6.1	Node or region types	Differentiate between supply and production regions, refining regions, and demand regions
2.6.2	Capacity expansion	Based on exogenous assumptions
2.6.3	Natural gas trade	
2.6.3.1	Pipeline capacity	Represent actual pipeline capacity
2.6.3.2	Assumptions regarding pipeline and LNG	Exogenous, simplify decisions
2.6.4	Liquid fuels trade	
2.6.4.1	Constraints for select pipelines	Represent pipeline capacity as allowable or required
2.6.4.2	Characterization of marine fleet	Fleet types, constraints required to model markets

2.7. Benchmarking

Our short-term and long-term forecasts, as well as our international and domestic energy market projections, need to be consistent. We have applied the following rules to projections in the IEO:

- STEO forecasts define EIA's short-term (1–2 year) projections, where available
- AEO projections define EIA's projection of U.S. energy markets, including U.S. energy trade

Furthermore, because WHAM needs to balance supply and demand, this benchmarking must be endogenous and not be a requirement satisfied by overwriting volumes (Table 11).

Table 11. Benchmarking requirements

ID	Requirements	Description
2.7.1	Additive and multiplicative factors	Use additive or multiplicative factors to benchmark (in other words, not overwrite) in order to track discrepancy and maintain supply and demand balance
2.7.2	*Annual Energy Outlook*	Use U.S. AEO projections as model inputs, where appropriate. Do not overwrite model results with AEO projections.
2.7.3	*Short-Term Energy Outlook*	
2.7.3.1	Production of total liquids	Provide production that matches STEO *total liquids* by region
2.7.3.2	Production of crude oil	Benchmark to STEO crude oil and other liquids production forecasts by international country or region as allowed, given inconsistent regional representation and commodity definitions
2.7.4	Benchmarking on and off switch	Ability to choose whether or not to benchmark; allow model to solve without matching STEO or AEO

3. Other System Requirements

The requirements below describe additional system requirements of WHAM. These system requirements relate to WHAM's performance as part of the integrated WEPS, the quality of the model and associated code, documentation, and other aspects of quality analysis and quality control throughout the project.

3.1. Performance

3.1.1. Runtime

Guidance from the Integration team is that new models' runtime should be at or below 20 minutes. It is important than any new models integrated into the WEPS system do not result in extending runtime—the time it takes for several WEPS iterations to run and converge. This requirement ensures that a WEPS run can be completed overnight, allowing for daily evaluation of model results by analysts.

3.1.2. Feasibility

WHAM's optimization routine should solve, producing feasible results, across a wide range of inputs and assumptions. It should only produce infeasible results if given erroneous or *zero* results from other modules via the restart file.

3.1.3. Unique and reproducible results

The solution to WHAM's mathematical program should be a unique solution; alternatively, WHAM should have a procedure in place to handle alternative solutions and modify the mathematical program to arrive at a unique, reproducible solution. This requirement ensures that the WEPS system can reach convergence over multiple iterations.

Table 12. Performance

ID	Requirements	Description
3.1.1	Runtime below 20 minutes	Ensures that a WEPS run can be completed overnight
3.1.2	Feasibility	
3.1.3	Unique and reproducible results	

3.2. Software quality attributes

Software best practices will be followed according to those detailed in Table 13.

Table 13. Software quality practices

ID	Requirements	Description
3.2.1	Discrepancy tracking	Rapid identification of potential issues with supply and demand balance
3.2.2	Use set logic	Dimensions will be defined by root sets with subset structure
3.2.3	AIMMS best practices	Includes use of set logic, case files, procedures for defining parameters, and generalized equations
3.2.4	Python best practices	Best practices to be codified and published
3.2.5	Data processing and regional aggregation and disaggregation	Data aggregation to occur internally endogenously
3.2.6	Naming conventions of regions	Regional names will be consistent and follow set conventions; no use of special characters

3.3. Technical reviews

During the design and development of the WHAM model, the team will leverage staff expertise across the Office of Energy Analysis to review progress. The review requirements aim to ensure that the team gets important feedback regarding model design, is adhering to EIA best practices, and is communicating progress and decisions with key internal stakeholders (Table 14).

Table 14. Technical review plan

ID	Requirements	Description
3.3.1	Technical review of mathematical program	Conducted by senior modelers with linear program experience
3.3.2	Model code peer review	Conducted by EIA staff
3.3.3	Integration team meetings	Monthly coordination meeting

3.4. Model documentation

We will produce mathematical model documentation that is consistent with AIMMS implementation. The WHAM model documentation will include:

- A full set of mathematical equations used in the optimization model
- Plain language description of WHAM, including mathematical program, preprocessing, and postprocessing
- Complete list of inputs and outputs
- Visualizations of modeling system, information flow, and curves constructed as part of the objective function (if applicable)

3.5. Debugging tools

The debugging requirements help us debug the model, understand model results, and deconstruct interactions within other modules of WEPS (Table 15).

Table 15. Debugging requirements

ID	Requirements	Description
3.5.1	AIMMS report pages	Visualization of model outputs in the AIMMS environment
3.5.2	Restart file data transfer verification	Record restart file data to .csv format for reference
3.5.3	Error handling	Develop code to prevent WEPS crashes in case of WHAM errors
3.5.4	WHAM-WEPS interface code compartmentalization	WHAM-WEPS Interface code will not overwrite or benchmark any model results or WHAM outputs it receives

Appendix A. WHAM Hierarchy of Requirements

The matrix of requirements will be the basis for requirements tracking and traceability during model design and development.

Table A. WHAM Hierarchy of Requirements

ID	Requirement
1	**Integration**
1.1	WEPS
1.1.1	WHAM-WEPS Interface
1.1.2	WEPS runtime parameters
1.1.3	Restart file interface
1.1.3.1	Input variables
1.1.3.2	Output variables
1.1.3.3	Completion of output data received
1.1.4	Debug .csv files
1.1.5	Input file formatting
1.1.6	IES data
1.1.7	IEA data
1.1.8	STEO data
1.1.9	AEO data
1.1.10	No database use
1.2	WHAM Repository
1.2.1	Data processing files
1.2.2	Transfer to WEPS Repository
1.3	GRTMPS
2	**Functional**
2.1	Supply
2.1.1	Crude oil and condensate production
2.1.2	Dry natural gas production
2.1.3	Other liquid fuels production
2.1.3.1	NGPL supply
2.1.3.2	Biofuel supply
2.1.3.3	Refinery gain
2.1.3.4	Coal-to-liquids supply
2.1.3.5	Gas-to-liquids supply
2.1.3.6	Other liquid fuels
2.2	Refining
2.2.1	Petroleum liquids supply equals WEPS demand
2.2.2	Mass and energy balance
2.2.3	Refinery gate prices
2.2.4	Account for differences in refinery operations, equipment, and crude oil feeds
2.2.5	Refinery consumption

Appendix B. WEPS Restart File Variables in WHAM

The full table, which includes descriptions of variables, sectors, and fuels, is available in the file WEPS_GlobalVariables_Reference_Hydrocarbons.

Table B. WEPS Restart File Variables in WHAM

Restart variable	Units	Dimension	Input or output
wptpprc	$/b	Year	Both
wptprc	$/MMbtu	Year	Both
sec_qhngin	Tbtu	Industry x Region x Year	Input
cnvfacep	MMb/d, Tcf	Region x Year	Input
liqconvforsteo	TBtu per MMb/d	Region x Year	Input
qcddh	TBtu	Region x Year	Input
qcdin	TBtu	Region x Year	Input
qcdpg	TBtu	Region x Year	Input
qcdtr	TBtu	Region x Year	Input
qcdun	TBtu	Region x Year	Input
qdscm	TBtu	Region x Year	Input
qdsdh	TBtu	Region x Year	Input
qdsin	TBtu	Region x Year	Input
qdspg	TBtu	Region x Year	Input
qdsrs	TBtu	Region x Year	Input
qdstr	TBtu	Region x Year	Input
qdsun	TBtu	Region x Year	Input
qettr	TBtu	Region x Year	Input
qetun	TBtu	Region x Year	Input
qjftr	TBtu	Region x Year	Input
qjfun	TBtu	Region x Year	Input
qkscm	TBtu	Region x Year	Input
qksin	TBtu	Region x Year	Input
qksrs	TBtu	Region x Year	Input
qksun	TBtu	Region x Year	Input
qlgcm	TBtu	Region x Year	Input
qlgin	TBtu	Region x Year	Input
qlgrs	TBtu	Region x Year	Input
qlgtr	TBtu	Region x Year	Input
qlgun	TBtu	Region x Year	Input
qmgcm	TBtu	Region x Year	Input
qmgin	TBtu	Region x Year	Input
qmgtr	TBtu	Region x Year	Input
qmgun	TBtu	Region x Year	Input
qngcm	TBtu	Region x Year	Input
qngdh	TBtu	Region x Year	Input

Restart variable	Units	Dimension	Input or output
qngin	TBtu	Region x Year	Input
qngpg	TBtu	Region x Year	Input
qngrs	TBtu	Region x Year	Input
qngtr	TBtu	Region x Year	Input
qngun	TBtu	Region x Year	Input
qobtr	TBtu	Region x Year	Input
qobun	TBtu	Region x Year	Input
qopin	TBtu	Region x Year	Input
qoptr	TBtu	Region x Year	Input
qopun	TBtu	Region x Year	Input
qpcin	TBtu	Region x Year	Input
qpcun	TBtu	Region x Year	Input
qrscm	TBtu	Region x Year	Input
qrsdh	TBtu	Region x Year	Input
qrsin	TBtu	Region x Year	Input
qrspg	TBtu	Region x Year	Input
qrstr	TBtu	Region x Year	Input
qrsun	TBtu	Region x Year	Input
qspin	TBtu	Region x Year	Input
qsptr	TBtu	Region x Year	Input
qspun	TBtu	Region x Year	Input
qsteo	TBtu	Region x Year	Input
suppet	TBtu	Region x Year	Input
conngtcf	Tcf	Year	Input
qclrf_subtype	TBtu	CoalType x Region x Year	Output
netimpngas_2021	Tcf	Region x Year	Output
pcngtr	$/MMBtu	Region x Year	Output
pdscm	$/MMBtu	Region x Year	Output
pdsdh	$/MMBtu	Region x Year	Output
pdsin	$/MMBtu	Region x Year	Output
pdspg	$/MMBtu	Region x Year	Output
pdsrs	$/MMBtu	Region x Year	Output
pdstr	$/MMBtu	Region x Year	Output
pettr	$/MMBtu	Region x Year	Output
pjftr	$/MMBtu	Region x Year	Output
pkscm	$/MMBtu	Region x Year	Output
pksin	$/MMBtu	Region x Year	Output
pksrs	$/MMBtu	Region x Year	Output
plgcm	$/MMBtu	Region x Year	Output
plgin	$/MMBtu	Region x Year	Output
plgrs	$/MMBtu	Region x Year	Output

Restart variable	Units	Dimension	Input or output
plgtr	$/MMBtu	Region x Year	Output
plngtr	$/MMBtu	Region x Year	Output
pmgcm	$/MMBtu	Region x Year	Output
pmgin	$/MMBtu	Region x Year	Output
pmgtr	$/MMBtu	Region x Year	Output
pngcm	$/MMBtu	Region x Year	Output
pngdh	$/MMBtu	Region x Year	Output
pngin	$/MMBtu	Region x Year	Output
pngpg	$/MMBtu	Region x Year	Output
pngrs	$/MMBtu	Region x Year	Output
pobtr	$/MMBtu	Region x Year	Output
popin	$/MMBtu	Region x Year	Output
poptr	$/MMBtu	Region x Year	Output
prscm	$/MMBtu	Region x Year	Output
prsdh	$/MMBtu	Region x Year	Output
prsin	$/MMBtu	Region x Year	Output
prspg	$/MMBtu	Region x Year	Output
prstr	$/MMBtu	Region x Year	Output
qbmrf	TBtu	Region x Year	Output
qctlprod	TBtu	Region x Year	Output
qdsrf	TBtu	Region x Year	Output
qelrf	TBtu	Region x Year	Output
qgtlprod	TBtu	Region x Year	Output
qhtrf	TBtu	Region x Year	Output
qksrf	TBtu	Region x Year	Output
qlgrf	TBtu	Region x Year	Output
qmgrf	TBtu	Region x Year	Output
qnglgin	TBtu	Region x Year	Output
qnglpin	TBtu	Region x Year	Output
qngpptr	TBtu	Region x Year	Output
qngrf	TBtu	Region x Year	Output
qoprf	TBtu	Region x Year	Output
qpcrf	TBtu	Region x Year	Output
qrsrf	TBtu	Region x Year	Output
qsprf	TBtu	Region x Year	Output
qwsrf	TBtu	Region x Year	Output
supngas	TBtu	Region x Year	Output
supngas_tcf	Tcf	Region x Year	Output
totliqkbpd	Mb/d	Region x Year	Output
totnatgastcf	Tcf	Region x Year	Output
svregionalproduction	MMb/d, Tcf	SupplyType x Region x Year	Output

Restart variable	Units	Dimension	Input or output
eurngprc	$/MMBtu	Year	Output
hhngprc	$/MMBtu	Year	Output
jpnngprc	$/MMBtu	Year	Output
svbiofuel	MMb/d	Year	Output
svlpg	MMb/d	Year	Output
svother	MMb/d	Year	Output
svrefinerygain	MMb/d	Year	Output
wptreq	TBtu	Year	Output
wtipprc	$/b	Year	Output
qclrf_subtype	TBtu	CoalType x Region x Year	Unused
svregionalexports	MMb/d, Tcf	Commodity x Region x Year	Unused
svnetgasexports_pipe	Tcf	ContractMode x Region x Year	Unused
svnetgasexports_ship	Tcf	ContractMode x Region x Year	Unused
pngwd	$/MMBtu	Region x Year	Unused
qclrf	TBtu	Region x Year	Unused
sngls	TBtu	Region x Year	Unused
svrefineryproduction	MMb/d	Region x Year	Unused

Notes: Restart variable names for consumption (q*) and price (p*) correspond to the fuel type and end-use sector. Unused variables may or may not be used by WHAM. To be determined.
$/b=dollars per barrel; $/MMBtu=dollars per million British thermal units; TBtu=trillion British thermal units; MMb/d=million barrels per day