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# Introduction to the Global Hydrocarbon Supply Project (GHSP)

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## Background and Motivation

The global markets for hydrocarbons (coal, petroleum, and natural gas, and their related derivative products) are becoming increasingly inter-related. The longstanding position of the United States as a net importer, or limited trading partner, of these products made modeling the United States and a limited representation of international supply sufficient for most policy purposes; however, as this position changes, due in part to the rapid development of low-permeability resources (e.g., tight oil, shale gas), a more robust representation of global hydrocarbon supply and demand is required to reliably project potential outcomes under different scenarios.

On the supply side, the development of continuous resources, including shale and other low permeability geologic formations, has more tightly coupled the production of oil and gas. On the demand side, all three hydrocarbons (i.e., petroleum, natural gas, and coal) compete globally for electricity production, while alternative fuels in the transportation sector are creating options for substitution away from petroleum products. The expansion of global infrastructure is changing the flow of hydrocarbons and their products. Where crude oil once flowed from fields in the Middle East to refineries in North America, the future may see the Middle East refine their own crude and export petroleum products to the Far East. The continued increase in liquefied natural gas shipments has the potential to change both traditional trading partners and prices of natural gas. In the past several years, the United States has seen crude and natural gas pipelines reverse flows, an increasing use of rail to transport petroleum, product pipelines repurposed, and more overseas coal trade. The general international policy trend is toward more open trade and less price subsidization, encouraging new mechanisms for price formation. In this evolving environment, the ability to model the impacts of changing supplies, logistics, transformation (i.e. refining), and demands on energy prices and commodity flows is paramount to making informed decisions.

The U.S. Energy Information Administration (EIA), an independent statistical and analytical agency within the U.S. Department of Energy (DOE), is required by law to produce energy “forecasts under various assumptions” that help inform policy-makers, industry, and the public. EIA’s products are designed to be policy-neutral; its projections generally include existing U.S. Federal and State laws and regulations, but do not anticipate future laws, policies or programs, nor do they include sections of legislation that have been enacted but still require regulatory action or funding mechanisms that have not been indicated. EIA’s Office of Energy Analysis (OEA) develops and maintains various energy models, and it uses these models to inform the Short-Term Energy Outlook (STEO), the Annual Energy Outlook (AEO), the International Energy Outlook (IEO), and other analyses it is asked to undertake periodically. Currently, OEA lacks a robust, dynamic, interconnected representation of global hydrocarbon markets, and the Office of Petroleum, Natural Gas, and Biofuels Analysis (OPNGBA) is seeking to fill this gap by initiating the Global Hydrocarbon Supply Project (GHSP).

## The Global Hydrocarbon Supply Project (GHSP)

The goal of the GHSP is to enhance the capabilities of OEA to address questions relating to the production, transport & storage (i.e., logistics), transformation, and distribution of coal, petroleum, natural gas and their related products under a variety of policy-relevant scenarios. It is desired that the GHSP result in a module or modules suitable for replacing the relevant existing modules within the

World Energy Projection System Plus (WEPS+)<sup>1</sup>, which is the modeling system used to make the projections published in the IEO. However, the GHSP is not a WEPS+ enhancement project; it is desired that this project result in enhancements or improvements to the international representation of the National Energy Modeling System (NEMS)<sup>2</sup>, which is used to make projections of the U.S. energy system for the AEO publication, and to other models and tools used to project global and U.S. hydrocarbon quantities and prices. Testing the capability developed by this project will be carried out within WEPS+, but the capability is distinct from WEPS+.

Organizationally, the Global Hydrocarbon Supply Project is structured along three parallel tracks corresponding to different segments of the supply chain: the production model, the logistics model, and the refining model. The production model captures the dynamics of the production of coal, petroleum, and natural gas from all resources in the world using any available production technology relevant under the economic conditions and in the timeframe of the model. The refining model captures the dynamics of petroleum refining and other transformative processes involving coal and natural gas that result in end-use hydrocarbon products along with production of renewable fuels. Transformative processes may include natural gas processing, coal-to-liquids (CTL), natural-gas-to-liquids (GTL), and other processes that impact global hydrocarbon supply, demand and/or trade. The logistics model will handle the transportation of both unprocessed hydrocarbons and processed hydrocarbon products between geographic nodes. The logistics model fills two distinct segments of the supply chain, immediately upstream and immediately downstream of the transformation (i.e., refining) step. The demands for hydrocarbon products (including electricity) do not fall within the scope of the GHSP, but it is assumed that the relevant demands will be supplied from existing models (e.g., WEPS+ or NEMS modules) or specified exogenously.

It is envisioned that the three models will be compatible with, but largely independent from each other. At a minimum, they will need to respond to downstream queries for quantities of energy products with corresponding prices. The production model will calculate prices endogenously based on such factors as production costs, infrastructure constraints, and policy assumptions (e.g., OPEC quotas). The logistics and refining models will receive pricing signals from models upstream before they can add their own considerations. At the interfaces between the three component models, there will be a common understanding of (at least) timing, geography, and energy products.

The modular structure of the GHSP reflects the modular nature of other modeling systems employed by EIA, such as NEMS and WEPS+. Each model/module may employ different solution techniques, incorporate different data, and use different model structures to suit the unique challenges facing the modelers. This allows for simple and powerful techniques (e.g., linear programming) to be used where appropriate, while permitting other constructs in other parts of the model where that might make more sense. It also allows for targeted input from subject matter experts (SMEs) in specific areas without requiring the SMEs to engage on the entire model outside those areas. This flexibility has been used successfully in the development of large-scale models at EIA over the past two decades.

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<sup>1</sup> <http://www.eia.gov/forecasts/ieo/models.cfm>

<sup>2</sup> <http://www.eia.gov/oiaf/aeo/overview/>

Each model must operate within a framework encompassing four elements: supply chain, products, geography, and time. Each element is defined with respect to both scope and granularity. The supply chain element specifies the processes that are included in each model. While this is largely delineated by the structure of the three models within the GHSP, there remain open questions that must be resolved, such as whether natural gas processing should be included in the production model or as part of the refining model. The product element specifies which hydrocarbon products that will be represented by the models; for example, the specific grades of crude oil. For the GHSP, the product scope should include all hydrocarbons and their products, and it may also include ancillary products (e.g., biofuels) that are considered integral to the end-use product. The geographic scope of the project is global; however, the geographic granularity is less well-defined. In order to be compatible with WEPS+, each GHSP model should be able to operate at the level of the 16 regions used by WEPS+. It may be convenient for the models to operate at a finer granularity than those 16 regions, though, only rolling up to the 16 WEPS+ regions for integration and reporting purposes. For example, WEPS+ defines the countries of Mexico and Chile as a single region, but from a logistics standpoint, it might make more sense to keep these countries separate until a solution has been found. Finally, the time element specifies the future time period of the projection, and the number of projections made within this time period. To maintain compatibility with WEPS+, the time period of projection should be at least to 2040, and the granularity should be at least annual.

The three models of the GHSP must have a common understanding of the four elements of the modeling framework above in order to communicate among themselves; however, internally, each model may choose a different framework. The simplest solution would be to adopt a common internal and external framework that is also the same as that used by WEPS+. However, it is greatly desired that the capability developed by the GHSP be applicable across more than just the WEPS+ model. To that end, each model should strive for maximum granularity and, more importantly, flexibility, so that different frameworks can be imposed with minimal model reconfiguration. For instance, while changing the projection period from 2040 to either 2030 or 2050 is a relatively easy configuration change within most model specifications, it is usually harder to imagine how an annual model can be reconfigured to make monthly projections. Similarly, while choosing a country-level geographic granularity makes redefining regions (e.g., changes to OECD or OPEC membership) fairly straightforward, some countries may require internal regions because of their size and complexity (e.g., U.S., China), while it may be preferable to aggregate other countries (e.g., parts of Africa, Asia) due to unreliability of national-level data. For the purposes of testing, the GHSP models will interface with WEPS+, which is an annual model solving to 2040 with 16 regions for three commodities: coal, natural gas, and oil. While each model in the GHSP should be compatible with that framework, each should also specify how it would handle changes to geographic regions, projection timeframe, energy products, and supply chain.

## Development Process and Schedule

The development of the three models of GHSP will proceed in parallel. Each sub-project will adopt a similar, seven-step development process:

1. Define requirements
2. Solicit multiple external component design reports (CDRs)
3. Synthesize external CDRs into single draft CDR

4. Construct and test prototype model
5. Review prototype with external experts
6. Implement and test model
7. Review results with experts

This process is based on best practices and lessons learned by EIA developing previous models, such as the liquid fuel market module (LFMM) of NEMS. It is designed to maximize the input of experts and stakeholders early in the process, and also to have multiple points for engagement along the way. The schedule has the prototype models informing the AEO2016 (should be ready by early summer 2015), and the full models impacting IEO2017 (summer of 2016).

All three projects are currently at the first step of the development process enumerated above. This step begins with a problem statement or needs assessment and ends with the production of a requirements document that is used in the following step. Some of EIA's needs are discussed above, and the requirements document will address some of the open questions raised above, such as the scope and granularity of the four elements that form the model framework. A major activity of the first step is holding a technical workshop with internal and external experts to discuss potential issues and possible solution techniques to some of the challenges likely to be encountered in developing these models. This workshop is discussed in more detail later in this paper.

The second step ("Solicit multiple external CDRs") is designed to produce independent proposals of solutions to the issues identified in the first step. The CDRs should satisfy the elements in the requirements document, and they should be informed by the discussion of issues from the technical workshop. Multiple CDRs will be commissioned to get independent viewpoints on methods and techniques that could be employed to address the requirements.

The third step ("Synthesize external CDRs into draft CDR") produces a single CDR upon which the prototype model is built. The best ideas from the multiple external CDRs produced in step two are combined into a single document by EIA, making sure that the combined draft CDR is internally consistent and coherent. Going back to the needs assessment and requirements document, a set of test questions or problems will be identified that the prototype model should be able to test. These questions should represent key problem areas or uniquely-challenging policy scenarios for each model to which the prototype model should demonstrate solutions. At the end of the third step, a prototype work plan will be developed that outlines the steps and schedule for implementing the prototype model.

During the fourth step, the prototype model is built. The prototype model does not necessarily need to be a complete representation of all aspects of the problem, but it should include enough functionality to address the test questions posed in step three. The results of the prototype model will be reviewed by experts in the subsequent step, but they may also be used to inform EIA products, such as the AEO and IEO.

During the fifth step, an independent expert review (IER) will be held, in which the CDR, prototype work plan, prototype model and results will all be evaluated. During the IER workshop, issues with the

prototype will be surfaced, and modifications may be made to the draft CDR and/or workplan to address them.

With the experience gained in developing the prototype model, and based on the revised CDR and work plan, the full production model is developed in step six. This model will be tested in the WEPS+ environment, and potentially the NEMS environment as well, to test the capability of the model. The test scenarios identified at the end of step one are run to validate model operation. Finally, the model is fully documented, including a description and explanation of its mathematical and computational formulation, variables used, and data requirements.

The final step in the model development process involves an expert review of the CDR, work plan, production model, and test results. Any suggestions for improvements are recorded and used as one input to future model enhancements and improvements.

### Technical Workshop

As part of the first step in the development of the three components of the GHSP, OPNGBA is sponsoring a series of three one- to two-day technical workshops to discuss issues that need to be addressed by each model. The workshops are to include experts with relevant energy modeling experience from academia, industry, and government; participation is by invitation only, they are not open to the general public; and any comments made are not for individual attribution. It is anticipated that each workshop will have 30 to 40 attendees. The workshops will be held on consecutive days of the same week in consideration of the schedules of some experts who might be invited to more than one workshop.

To facilitate discussion at these workshops, and to solicit some deeper thought on a few topics of particular interest, EIA is commissioning several white papers in advance of the workshops, to be delivered and discussed at the workshops. Topics and authors will be selected by EIA, and it is expected each paper will be 10-15 pages in length. White papers will be available for all workshop participants, and white paper authors will present a summary of their findings at the workshop. These white papers are meant to facilitate discussion at the workshops, but there will also be opportunities to discuss other topics as well.

Topics discussed at the workshops will be noted in written workshop summaries, and particular pitfalls to avoid or potential solutions to challenges will likewise be captured. The workshop summaries will be used by EIA to inform the production of requirements documents for the next step in the development of the three models.

It is envisioned that the workshops will uncover such things as questions to be resolved in the requirements document, challenges to be overcome or open questions to which particular solutions may be proposed in a CDR, and scenarios or test questions that could be used to test the performance of a prototype model. This process will benefit from the candor of workshop participants, and from lessons learned from successes and/or failures in previous attempts to model similar energy systems.

## Questions for Discussion

The following list of questions encompasses some of the issues that could be discussed either in the technical workshops or in the requirements document. It is provided as an aid to the discussion, and to solicit additions where appropriate.

All three models in the GHSP will need to coordinate on handing data between them. The common set of questions that must be addressed by all three include the following:

1. How can the model(s) support the AEO, the IEO, and the STEO? The AEO is a long-term (through 2040) projection, reports on an annual basis through its projection period, includes a detailed representation of the United States, but requires an interaction with the rest of the world; the IEO represents the entire world at a high level of geographic abstraction, and also runs annually through 2040; the STEO forecasts the U.S. energy system one to two years into the future, but it operates monthly and therefore includes seasonality effects.
2. How should this model relate to other EIA efforts to project global commodity prices? Should these models inform those efforts, should they be informed by them, or should the models replace those efforts?
3. Coupled to an appropriate demand model, can GHSM generate crude pricing endogenously?
4. What data must be passed between models, and are there common sources of data that must be available to all three? Can a downstream module ask an upstream module for a price, given a quantity demanded? Can a downstream request a quantity from an upstream module at a given price? Can an upstream module request prices/quantities from a downstream module in response to proposed quantities/prices? How much independence can the three models have from one another? Where are the points of interconnection?
5. How many and what types of energy commodity flows can/must/should be modeled by this model? Should there be different grades of crude oil, and if so, how many and which types? How should lease condensate be handled? How many and which types of refined products should be modeled? How are hydrocarbon gas liquids (HGLs) handled?
6. Which (common) geographic representation should the models use? Does it have to be the same as WEPS+?
7. Which processes should be handled by the production model and which by the refining model? Does the production model produce wet or dry gas (i.e., are gas processing plants modeled by the production model or the refining model)? Where are hydrocarbon gas liquids handled? If the production model produces wet gas, how is the data on the non-methane component of the gas stream passed between models? Should the production model produce GTL/CTL/CBTL, or should the production of liquids from non-petroleum feedstocks be better handled in the refining model?
8. Which processes should be handled by the logistics model and which by the refining model? How is intra-regional logistics handled (e.g., transportation from production sites to export terminals)?



All three models will also need to address the following questions, but they don't necessarily need to agree on a common approach:

1. Which model structures and solution algorithms are most appropriate to the problem(s) addressed by the model?
2. How should the model address uncertainties? Does a probabilistic approach make sense, or is it enough to run sensitivity cases on the input parameters?
3. Which regional structure should the model use internally, given the common external geographic structure and available data? What does the model need to do to support changes to the external geographic structure (e.g., membership changes in OPEC, OECD)?
4. Which temporal structure should the model adopt internally, given the common external projection requirements. Are there any advantages to a seasonal representation if the model only ever runs annually?
5. (How) Should the models handle the prospect of future disruptions? Disruptions can include things such as wars, lost capacity due to accidents and natural disasters, new capacity additions, and future environmental and other regulation. Some of these can be predicted statistically, others can be modeled with a capital investment model, but others require model input assumptions. Should the models incorporate a quantitative value for political risk?
6. How should the future evolution of technologies be handled? At what level of detail should technologies be represented?
7. How should non-competitive (e.g., cartel, national strategic) behavior be modeled? How are prices set or otherwise determined by each model?
8. What are the sources of data that are currently available or could conceivably become available in the future? Does the model have sufficient structure to incorporate currently-available data, and can it easily (i.e., with minimal coding changes) incorporate new data as that becomes available?
9. Are there existing models (e.g., commercial off-the-shelf) that would be sufficient and/or could be modified to satisfy EIA requirements? Could NEMS modules be repurposed to this end?
10. Is a mathematical model required at all?

In addition, there are several model-specific questions that should be addressed. For the production model, these include the following:

- P1. How should cartel behavior be modeled?
- P2. Does this model produce wet natural gas or dry natural gas?
- P3. How is the non-methane component of gas handled?
- P4. How should water production, gas venting, and flaring be considered?
- P5. How should lease condensate be accounted for and modeled?
- P6. How should resources that undergo significant upgrading in the field be handled (e.g., kerogen/oil shale, bitumen/oil sands)?
- P7. How should resource size and cost uncertainties be handled?
- P8. How should changes in capital allocation (within regions, between regions) in response to price changes be handled?

- P9. Should the model represent the development of wells, projects, fields, or aggregate regional production?
- P10. How detailed should the cost data and assumptions be?

The logistics model should address the following questions:

- L1. Can crude oil and natural gas transportation be handled in the same way, or should they be modeled separately?
- L2. Should the transportation of finished products (e.g., refined products, hydrocarbon gas liquids) be treated in the same way as feedstock transport (e.g., crude oil), or should it be modeled differently?
- L3. (How) Should the logistics model handle disruptions?
- L4. How should the logistics model treat storage?
- L5. Are there commercial off-the-shelf (COTS) logistics models that can be adapted for this?

The refining model should address the following questions:

- R1. Should refinery regions be distinct from the overall model geographic structure?
- R2. What level of geographic detail should the refinery model represent? Individual refineries? Single representative refinery in each region?
- R3. To what level of detail should refinery processes be modeled?
- R4. Should xTL processes be modeled differently from petroleum refining?
- R5. How many refined products should be modeled? (Regardless of the products passed between models, are there economic considerations for a refinery that require modeling different product streams?)
- R6. How many crude types should be modeled? How should the refinery model handle changes in the crude slate?
- R7. Should the refining model be able to make capital investments to optimize refining capacity to different crude types?
- R8. Can LFMM be adapted to be used as the global refinery model? What are the implications for data requirements and run-time performance?
- R9. Are there other refinery models that would be better suited for this task?

### Policy Scenarios

The GHSP is meant to enhance the ability of EIA to address policy questions that could become important within the next 10 to 20 years. As a guide to model developers, and as a test of the capability developed by the GHSP, the following (non-exhaustive) list of test questions has been developed. Questions from this list, or others proposed during or after the technical workshop by EIA staff or external experts, will be used as test scenarios for the prototype and production models to examine their ability to deliver the desired capability.

1. What are the expected equilibrium prices and quantities of crude oil, natural gas, and products over time by region?
2. What are the inter-regional flows of crude oil and refined products over time?

3. What demand markets will emerge in response to gas growth in the United States?
4. How do interregional patterns of crude and product flows change in the event of a new refinery or refinery rationalization?
5. How would a disruption in (crude or product) flow affect global supply patterns?
6. How would the refining sector adapt to an increase in light oil from low permeability formations? How would this affect crude and product flows worldwide?
7. How would crude and product flows change if OPEC increased production/exports? What if they decreased exports (e.g., increased domestic consumption)?
8. What would be the impact on global flows and prices if the United States lifted the moratorium on crude oil exports?