Needs Assessment and Model Development Process: the Liquid Fuel Market Module (LFMM) for the National Energy Modeling System

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Energy Information Administration

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Background

The Office of Integrated Analysis and Forecasting (OIAF) in the Energy Information Administration (EIA) of the Department of Energy (DOE) has undertaken a project to develop a new Liquid Fuel Market Module (LFMM). The LFMM will replace and improve upon the current Petroleum Market Module (PMM) of the National Energy Modeling System (NEMS). This paper serves to provide background information for participants in a technical workshop to be convened in the summer of 2009 to solicit comment and discussion on the technical design of the LFMM. As input and a starting point for discussions at the workshop, four outside experts have been asked to provide technical papers in advance.

Among other products, OIAF is responsible for the yearly publication of the *Annual Energy Outlook* (*AEO*), which provides annual projections of U.S. energy production, conversion, consumption, imports, exports, and prices, and the *International Energy Outlook* (*IEO*), which provides annual projections of global energy production, consumption, and electricity generation. The former publication is based upon NEMS, and the latter upon the World Energy Projection System (WEPS+).

In addition, EIA is frequently requested to analyze the potential impacts of possible legislative and regulatory changes. These analyses often rely upon NEMS. Analytic requests generally come from the U.S. Congress, although they occasionally come from other Federal government organizations, both within and outside DOE. Other organizations occasionally use NEMS themselves for policy or sensitivity analysis, and other parts of DOE rely upon NEMS to assess the impacts of their programs on energy markets as part of their budget justification.

NEMS

NEMS is a large, regional, technology-rich energy-economy model of U.S. energy markets, encompassing domestic production of energy sources, imports and exports, prices, and consumption. A comprehensive accounting is included of energy-related carbon dioxide (CO_2) emissions, as well as other emissions from the electricity generation sector, including sulfur dioxide, nitrogen oxides, and mercury.

The model is structured in a modular fashion, including four end-use demand sectors (residential, commercial, industrial, and transportation), two conversion sectors (electricity and refining), four supply sectors (oil and natural gas supply, natural gas transmission and distribution, coal, and renewable fuels), a macroeconomic module, and an international energy module. Regional energy markets are represented throughout NEMS although the regional breakdown varies by module, dependent on the data availability and analytical requirements.

Currently, NEMS solves annually through 2030. In brief, the model reaches an annual energy-economy equilibrium using an iterative solution algorithm known as “Block Gauss-Seidel.” Within each solution year, the algorithm repeatedly visits each module until the prices and quantities supplied and demanded are equal within a convergence tolerance. That is, the demand modules calculate the regional consumption of the energy products given the delivered prices, while the supply and conversion modules meet the requirements for energy at a price that covers the costs of production, imports, transportation, and conversion. The model iterates until supply, demand, and price are balanced within a convergence tolerance.

The projections generally include current Federal and State laws, regulations, and standards with significant impacts on U.S. energy markets. By statute, EIA projections are policy-neutral and do not anticipate future laws, policies, or programs or sections of legislation that have been enacted but require implementing regulations or funding appropriations that are not provided, specified, or historically demonstrated. Accordingly, the baseline projections provide a starting point for policy analysis. A more comprehensive, but slightly dated, summary of NEMS can be found at www.eia.doe.gov/oiaf/aeo/overview/index.html.

PMM and Related Satellite Modules

The PMM projects petroleum product, crude oil, and product import prices and domestic refinery, blending, and product transport operations. The sources of supply include: domestic and imported crude oil; petroleum product imports; unfinished oil imports; other refinery inputs, including alcohols, ethers, and bio-esters; corn; biomass; coal; and natural gas plant liquids, while accounting for refinery processing gain. In addition, the PMM projects capacity expansion and fuel consumption at domestic refineries. U.S. end-use prices are based on the marginal costs of production, plus markups representing the costs of product marketing, importing, transportation, distribution, and dispensing, as well as applicable State and Federal taxes.

The PMM contains a linear programming representation of U.S. refining activities for each of the five Petroleum Administration for Defense Districts (PADDs), linked to a simplified world refining industry representation of U.S. crude and product imports. The U.S. segment of PMM is created by aggregating individual U.S. refineries within a PADD into two types of representative refineries, simple and complex, and linking all five PADDs and world refining regions via crude oil and product transit links. This representation provides the marginal costs of production for a number of conventional and new liquid products. In order to interact with other NEMS modules with different regional representations, certain PMM inputs and outputs are converted from PADD regions to other regional structures and vice versa. The linear programming results are used to determine end-use product prices for fuels for each Census division.

The products represented in PMM include:

- Motor gasoline: conventional unleaded, oxygenated, reformulated, containing up to 10 percent ethanol;
- E85, an ethanol-gasoline blend containing up to 85 percent ethanol;
- Kerosene-type jet fuel;
- Distillate fuels: kerosene, heating oil, low-sulfur-diesel, ultra-low-sulfur-diesel;
- Residual fuels: low sulfur, high sulfur;
- Liquefied petroleum gases: propane, liquefied petroleum gases mixed;
- Petrochemical feedstocks: petrochemical naphtha, petrochemical gas oil, propylene, aromatics;
- Other: lubricating products and waxes, asphalt and road oil, still gas, petroleum coke, special naphthas, aviation gasoline.

PMM explicitly models the liquids requirements of the Energy Independence and Security Act of 2007 (EISA2007) and the Clean Air Act Amendments of 1990 (CAAA90) and includes the production of biofuels for blending in gasoline and diesel. The *Annual Energy Outlook 2009* (*AEO2009*), published in March 2009, represents regulations that limit the sulfur content of all nonroad and locomotive and marine diesel to 15 parts per million by mid-2012. PMM also reflects the new renewable fuels standard (RFS) in EISA2007 that requires the use of 36 billion credits of ethanol gallons equivalent by 2022 if achievable, with corn ethanol credits limited to 15 billion gallons per year. The total renewable fuels requirement which is modeled in the PMM begins with 4.0 billion gallons in 2006, and ends in 2022 at 36.0 billion gallons. Within this requirement is the advanced biofuels requirement that comes into effect in 2009 at 0.6 billion gallons and rises to 21 billion gallons in 2022, which includes both the cellulosic biofuels and biomass-based diesel fuels requirements. The cellulosic biofuels requirement starts in 2010 at 0.1 billion gallons, and reaches 16 billion gallons in 2022. Lastly, the biomass-based diesel requirement begins at 0.5 billion gallons in 2009 and reaches a maximum of at least 1 billion gallons in 2012 with the remaining years to be determined by the Environmental Protection Agency Administrator. All of these requirements are subject to the requirement that the appropriate capacity is built to provide the necessary production. In doing so, the PMM accounts for production of corn, other grains, cellulosic materials, etc., and produces corn and cellulosic ethanol and biodiesel. While these legislative requirements are modeled in the PMM along with the various technologies for producing ethanol and biodiesel, including biomass-to-liquids (BTL), the integration of the satellite technologies is not seamless, and market adoption of the alternative liquids technologies need to be better integrated with the economics and market limitations of all liquid products with which they compete.

The *AEO2009* version of NEMS did not include the American Recovery and Reinvestment Act (ARRA). However, the size and scope of the recent market changes and ARRA's focus on stimulating investments in energy efficiency and renewable energy made a revision to NEMS and the reference case necessary to properly analyze the impacts of new Congressional requests for energy analysis. These changes were completed and published as the updated reference case of *AEO2009* in April 2009.

Fuel ethanol and biodiesel are included in the PMM because they are commonly blended into petroleum products. The module allows ethanol blending into gasoline at 10 percent or less by volume, E10, as well as E85, a blend of up to 85 percent ethanol by volume. Both domestic ethanol and imported ethanol count toward the RFS. Domestic ethanol production is modeled from two feedstocks, corn and cellulosic materials. Imported ethanol may be produced from cane sugar or bagasse, the cellulosic byproduct of sugar milling. The sources of ethanol and biodiesel are modeled to compete on an economic basis and to meet a renewable fuels mandate.

Interfaces with Other Modules

The terms "petroleum market" or "liquid fuels market" can cover a very broad segment of the energy market. The current PMM and the replacement LFMM are intended to model the processing and determine market prices of liquid fuels from a variety of feedstocks, such as crude oil, natural gas, coal, and biomass.

Within NEMS, the economic competition between liquid fuels and other energy products, such as natural gas, coal, and electricity, are represented in the four end-use demand modules and the electricity market module. The end-use and electricity modules consume liquid fuels based on their individual characteristics and service demand in various end-use applications. For example, the transportation module chooses between conventional and unconventional fuels, vehicle technology and size, fuel efficiency, and travel.

Similarly, on the upstream side of the market, exploration, development, and production of crude oil resources and reserves, as well as natural gas, are represented in the oil and natural gas supply module of NEMS. Currently, in order to represent import markets, PMM has been expanded regionally to encompass world supply, demand, and refinery operations in a very simple framework primarily using yield vectors for refineries and supply curves of various types of international crude oil, which are developed from an international analysis.

More details on the linkages between PMM/LFMM and the rest of NEMS are provided later.

Development of the LFMM

Increasingly, policy attention is being paid to liquid fuel markets and the potential to improve the efficiency of liquids consumption, reduce greenhouse gas (GHG) emissions associated with the production and consumption of liquids, and improve U.S. energy security by reducing reliance on imported liquids supplies. Such attention necessitates a robust modeling tool able to analyze a wide array of policy options that might be considered.

World energy markets have evolved and changed significantly in the past 15 years. In the transportation sector, demand for fuels is no longer limited to traditional petroleum-based products such as gasoline, distillate, jet fuel, and residual fuel oil. On the supply side, ethanol has made significant penetration in the transportation fuel market due to recent legislation, often exceeding the legislative mandates due to recent high gasoline prices. Other technologies such as coal-to-liquids (CTL), gas-to-liquids (GTL), and BTL all have the potential to penetrate the market in the next several decades. In addition to changes in demand and supply technologies, there are other potentially complex policy analyses on the horizon, in addition to GHG reductions and renewable fuel standards, such as a low carbon fuel standard (LCFS).

Maintaining and operating the existing PMM has become costly and time-consuming. Much of the difficulty stems from a mismatch between EIA’s analytical needs and the PMM emphasis on liquid flows, an overly complex refinery-level representation, and an overly simple linkage to the international liquids market. Efforts to update and enhance PMM have not been sufficiently successful, leading to the conclusion that a new module should be developed. Without highly constraining PMM, it is very difficult to develop reasonable projections of:

- Market prices and price differentials between different types of crude oil;
- Petroleum product margins;
- Refinery natural gas and still gas consumption;
- Crude oil versus petroleum product imports;
- Refinery expansions, retirements, and new construction.

In addition to NEMS requirements, the WEPS+ system does not adequately represent the international liquid fuels market. Assuring consistency between a domestic and an international liquid fuels outlook with earlier models has proven to be time-consuming and often elusive. A LFMM that also serves WEPS+ would provide consistent, seamless analysis of all forms of liquids production in domestic and international markets.

LFMM will be designed to model the liquid fuels market with explicit and improved technology representation. It should simulate the market transformation behavior that takes as input the demand for liquid energy, such as gasoline or gasoline blends, diesel, biodiesel, jet fuel, ethanol, etc., the cost and performance characteristics of transformation technologies, and the crude oil and product import supply and price relationships. It will provide information such as liquid product prices and margins, processing fuel consumption, conversion losses, refining capacity, including existing, revisions, and additions, liquid fuels imports and exports, and CO_2 emissions.

LFMM should correct the deficiencies of the current PMM, providing greater confidence in the results. It should enhance the capability to analyze complex policies and satisfy the needs for both domestic and international liquid fuels market analysis. LFMM will be fully integrated within NEMS, will be consistent with the WEPS+ liquid fuels market analysis, and will provide all of the explicit outputs needed by other modules of NEMS. The design and structure should also include details necessary to capture the effects of policy changes.

Project Plan and Schedule

The project includes the following participants:

- Review board, comprised of the senior managers of OIAF;
- Core team, who solicited and organized the stakeholder input, prepared this paper, organized the technical workshop, and will review the outcome of the workshop and take the next steps in the development of the LFMM, with membership possibly being rotated as needed in each phase of the project;
- Extended team, which includes any members of OIAF or EIA who may provide input and support to the project;
- Workshop participants; and
- Independent expert reviewers who will ultimately review the LFMM.

The project is currently in Phase I. In this phase, OIAF and the core team have been interacting with our customers, stakeholders, and technical experts to develop and refine the characteristics that the LFMM model must have and the issues and questions it must address. Phase I is expected to be completed by July or August 2009. A technical workshop is tentatively scheduled for July 30, 2009, and a summary report of the technical conclusions and recommendations from the workshop will be issued by the core LFMM team.

In Phase II, OIAF and the core team will develop a requirements analysis for the LFMM model, model development options, develop a Component Design Report (CDR), and complete an independent expert review (IER)[1] of the proposed model design. If the original proposal proves

[1] The IER may be coordinated with the Statistical Methods Group of EIA if the IER contract and processing is determined to be timely.

to be unacceptable, an alternative plan will be developed. The options will be submitted to the review board, and a decision will be made on the modeling approach or approaches to be taken for the domestic and international market analysis. This will be followed by a full mathematical specification of the model. The completion date of this phase is yet to be determined but is tentatively estimated to be March or April 2010.

In Phase III, a model test plan will be developed for verification and validation of the LFMM, the model will be implemented and tested and will be reviewed and modified as necessary based on internal evaluations and results of the IER. The test plan should include a set of test cases, designed to exercise the LFMM across a range of market perturbations, including shifts in internal inputs and assumptions and possible or probable analysis cases. The testing and evaluation should consider impacts on the operation of NEMS and, if applicable, of WEPS+.

The completion date of Phase III is yet to be determined; however, the ultimate goal is to complete the project by July 2011, including integrated testing of the module in NEMS, so that the new LFMM can be used in NEMS for the *Annual Energy Outlook 2012*, which would likely be released in November or December 2011.

First Steps

Request for Stakeholder Input

Early in 2009, the review board and core team sent letters seeking input from stakeholders, including people within EIA and DOE, industry specialists, trade associations, and academia. Attached to the letter was a short paper outlining some initial plans and model requirements. This also included some discussions of initial design features, general uses of the model, and a number of questions designed to encourage feedback from the stakeholders.

The following information was presented in the short paper as EIA's initial view of the requirements and issues that the LFMM model needed to provide or address. However, the stakeholders were encouraged to review these and provide their own conclusions and suggestions. The stakeholders were provided the following list of the primary outputs needed from the LFMM by region:

- Quantities and prices of crude or crude-like products produced, consumed, imported and/or exported;
- Quantities and prices of liquid products, both petroleum-based and non-petroleum-based, produced, consumed, imported and/or exported;
- Refinery capacity additions and enhancements to existing refineries;
- Refinery margins for each major refined product;
- Quantities and prices of key non-petroleum feedstocks, including biofuels, CTL and GTL, and other unconventional crude or crude-like liquids with their cost and performance characteristics, such as oil sands, oil shale, and ultra heavy crude;
- Quantity of fuels consumed in the conversion/production of liquid fuels in the United States and other world regions and their associated emissions.

Additional LFMM requirements presented to the stakeholders included:

- Simulating the international liquid supply/production market using both economic and behavioral factors for investment decisionmaking, consistent with historical behavior where it still applies;
- Seamless integration of the new LFMM with NEMS to derive and energy-economy equilibrium, subject to legislative, environmental, or policy constraints;
- Vintaged refinery and conversion stock by region, with details to be determined by availability of data;
- Capacity planning consistent with the refinery market capacity investment strategy and based on multi-period expectations of the market.

Additional guidance included:

- The module will not simulate the operational decisions of an actual refinery as used by a refinery manager;
- Data on currently operating refineries in the world and the degree to which each can process different crude or crude-like liquids, including operating costs, efficiency, crude types it can process, and potential product slates, are incomplete;
- The way decisions are made may depend on geopolitical interests as well as pure economics, and it may not be possible to represent both decisionmaking processes.

Synthesis of Stakeholder Input

Following the receipt of responses from the stakeholders, the core team summarized the responses and placed them into broad topic categories. Each member was asked to score the responses from 1 (highest priority) to 5 (lowest priority). The scores for each broad category were then averaged.

This information was provided to the OIAF review board. Following clarifying discussions, the board members also provided their priorities and the scores of the review board were similarly derived. The lower the average score, the higher the derived priority.

List of Inputs and Outputs for LFMM

It is important that the new LFMM operate seamlessly within NEMS. Other NEMS modules receive a variety of information from the current PMM and expect similar information from LFMM. Conversely, other modules provided information to PMM, which serves as an indication to a designer of the new module of what information is likely to be available within the NEMS framework.

This list, which is provided later in this paper, is not meant to be an absolute limiting factor on the design of LFMM. However, it should provide a guideline of information expected from the LFMM and available to it. Changes to the inputs and outputs might require changes to other modules of NEMS, and the costs of doing so will necessarily factor into decisions about the LFMM design.

Technical Workshop

The technical workshop is tentatively scheduled for the summer of 2009, but should be held no later than July 2009.[2] This is intended to cover technical design aspects, such as the choice of a suitable modeling platform, data requirements, crude oil and fuel detail, regional detail, model complexity, and model structure, i.e., how the model is organized, and methodology, i.e., how the model is solved. As noted above, there will be a follow-up to that in terms of a summary report on the workshop, which will provide input to a requirements analysis.

As input and a starting point for discussions at the workshop, four outside experts have been asked to provide technical papers in advance. This paper serves as background information for the development of those papers.

Recommendations from Stakeholders

Process

The letter to the stakeholders primarily focused on identifying the type of analysis that the LFMM should be capable of addressing. However, many recommendations about features and methodologies were received, and these were all treated in a similar fashion by the core team. It was not straightforward to assign priorities from the stakeholders themselves, so this was not done. In addition, in some cases there were extreme differences in the stakeholders' opinions on an issue. For example, some stakeholders thought that it was very important to model externalities such as water use while others thought that a simple accounting of water use for new processes, if possible, was sufficient to include. Some stakeholders thought that the use of a single model within NEMS was the ideal while others thought that multiple models, one simple for NEMS and another complex outside of NEMS, would provide enhanced refinery analysis capability needed for the future.

In reviewing and processing the stakeholder input, the core team synthesized and consolidated many of the recommendations when they were similar, so the exact wording of suggestions is not necessarily included here. Also, the team bundled the recommendations into the broader categories discussed below, while recognizing that some recommendations straddle these categories. As noted earlier, priorities were assigned by the core team and then by the OIAF review board, following discussion and clarification.

It is important to note that, in assigning priorities, consideration was not given to the resources or expertise required to carry out the recommendations. In addition, a high priority ranking indicates an interest in investigating the feasibility of including the topic area in the LFMM, but does not guarantee its representation within LFMM.

[2] The workshop was held on September 30, 2009 due to scheduling and contract difficulties.

For completeness, all recommendations are included, although some suggestions, such as those related to efficiency standards, travel, and transportation technologies, are outside the scope of the LFMM, given the current NEMS structure.

The priority assigned to each recommendation by the review board and core team is provided in the following list. The priority scoring ranged from 1 to 5. A low number means a higher priority. A list of these same recommendations, sorted by priority, is provided in Appendix A.

Recommendations

1. Prices and Margins
    - Provide fuel prices and margins, with prices disaggregated by market segment, product, and region and margins by product and region – 1.0
    - Distinguish refinery gate prices, transportation charges, and distribution and dispensing charges by product – 1.8
2. Technology Assessment
    - Analyze cost and benefits of new technology penetration to producers and consumers – 2.2
    - Simulate market penetration of liquid fuel technologies and associated technology costs, including investment and operating and maintenance costs, and any manufacturing cost reductions through learning – 2.6
    - Include a detailed technology representation for each liquid production process, with potentially alternative technology learning rates, and the ability to test the impact of the successful development of new technologies for liquid product production – 2.8
    - Include multiple refinery types by vintage to represent retrofit costs and retirement decisions – 2.8
    - Treat all liquid technologies at the same level of detail, including conventional refineries, BTL, CTL, GTL, in both the technological representation and the emissions accounting – 3.4
3. Petroleum and Fuel Specifications
    - Analyze alternative and new fuel product specifications – 2.2
    - Address differences between different crude types and sources with respect to important product characteristics, e.g., sulfur content, particulates, viscosity, heavy vs. light, etc. – 2.6
    - Include the processing of all major crude oil types, including heavy crude and bitumen by region, both domestic and international – 3.0
    - Analyze the level of intermediate product transfers between different refineries and between or within regions – 3.4
    - Account for the resources and reserves of all crude oil types – 5.0
4. Alternative Fuels
    - Include all non-petroleum sources of liquids, their economics and potential market – 1.2
    - Include competition between feedstock use for biofuels versus power, heat, electricity, or hydrogen production – 2.0

- Include the flexibility to add non-petroleum feedstocks that can be converted to liquids as they are developed or evolve through research and development (R&D) and/or experience – 2.0
- Incorporate and represent multiple biomass supply categories – 2.4

5. Competition and Market Behavior
- Represent market behavior and competition between fuels and technologies in liquids production, transmission, and distribution – 1.4
- Represent realistic market adoption for new technologies, incorporating costs, risks, infrastructure issues, and investor and consumer behavior in liquids production, transmission, distribution – 2.2
- Improve the representation of infrastructure and fuel availability by relating those to economic factors that affect technology adoption and diffusion in transportation – 3.8
- Represent all feasible transportation technologies, especially those that might be required or promoted in a constrained carbon scenario, including possibly those producing or using hydrogen – 4.4
- Evaluate alternative cartel or market dominance behavior on prices, which implies that dominant oil producers must be explicitly represented as specific supply regions – 4.8
- Analyze the impacts of efficiency standards on travel – 5.0

6. International Markets and Trade
- Evaluate the impact of the ethanol tariff – 1.6
- Evaluate the potential for cellulosic ethanol and other biofuels imports and the affects that domestic GHG and renewable fuel policies may have on their cost and availability to U.S. markets – 2.0
- Represent imports by type of crude oil, products, and alternative liquids by region – 2.0
- Analyze international liquids markets to assess crude oil and product flows, product demand, and crude oil and product prices and impacts on U.S. market, by crude type and region – 2.2
- Assess how changes in specific world liquid product demands affect liquid crude and product trade for crude oil, products, and manufactured substitutes with their attributes and the associated prices – 2.4
- Assess alternative assumptions on crude oil availability and refinery expansion worldwide – 2.6
- Represent world markets for natural gas plant liquids and liquefied petroleum gases – 2.8
- Characterize supply/production decisionmaking by country and/or groups – 4.2
- Analyze peak oil scenarios by region – 5.0

7. Capacity Expansion and Investment
- Explicitly account for and simulate new investments and other associated costs for new capacity in either refineries or other non-refinery production of liquids like CTL, GTL, and BTL, using some expectations that simulate market behavior – 2.0

- Represent industry learning for conversion plants and refineries, endogenously, if possible, and how liquids technology cost reductions might occur – 2.4
- Include multiple refinery types for each region, i.e., variations of simple and complex, to represent the processing mix and limits to process different crude types – 2.6
- In making decisions on capacity expansion and investments in existing refineries, i.e. retrofitting refineries, explicitly incorporate all new cost and performance characteristics and the alternative cost and performance options to retrofit existing refineries, using a vintaged stock representation and accounting of all costs – 2.6
- Simulate which capacity will be retired, by region and refinery type, if overall capacity requirements shrink – 3.2

8. Infrastructure
- Account for infrastructure to allow analysis of some potential bottlenecks, including fuel distribution constraints and evolution of fuel dispensing infrastructures – 2.4
- Account for the costs, risks, and bottlenecks of realistic infrastructure expansion in the model – 2.6

9. Externalities
- Analyze the implications of policies to decarbonize transportation fuels on the fuels produced and the specifications of the fuels – 2.4
- Analyze all biomass synfuels with respect to water use, GHGs, soil carbon/nutrients, land use, crop markets or at least provide an accounting of these whenever possible – 3.2
- Account for all energy used and emissions to produce liquids, including mining/drilling and transportation, processing, and delivery to ultimate consumer and accounting for GHGs, sulfur dioxide, nitrogen oxides, and mercury – 3.2
- Account for water and land use for all liquids production and consumption – 3.8

10. Energy Security
- Address any key limits to supply by region – 3.0
- Provide additional measures of energy security, including import dependence by region and security as defined in a paper by David Greene – 3.8
- Include the ability to address supply disruptions by region, e.g., from specific nations in the Organization of Petroleum Exporting Countries or because of accidents that remove capacity to produce specific products required in certain U.S. regions, such as California – 4.8

11. Policy
- Analyze carbon dioxide taxes, cap-and-trade systems, and energy taxes on both a primary and delivered basis – 1.0
- Analyze renewable portfolio standards, renewable fuel standards, and low carbon fuel standards, including competition for biomass, land, and water – 1.4
- Analyze impact of taxes, tax incentives, and other liquids consumption, production or environmental constraints on process technologies utilized for liquids production, new conversion and transformation investments, liquid product prices, and resulting environmental emissions – 1.6
- Analyze impacts of environmental regulations on product specification changes and requirements and costs – 1.8

- Capture the interaction of non-GHG polices with GHG polices and their impacts on refinery choices – 2.2
- Analyze impacts of climate policies on domestic and international liquids markets, including prices by crude and product and region – 2.2
- Assess cost of policies to refineries, including upstream and downstream operations, and the impact on margins, e.g., policies like the RFS – 2.4
- Assess policy impacts on capacity expansion, retirements, and retrofits and on the entire liquids supply chain and the infrastructure – 2.4
- Address restrictions on bunker fuel and heavy oil and blending – 3.0
- Analyze polices that affect fuel demand and refinery fuel mix – 3.0
- Assess cost of fuel use policies to consumers, including impact on food – 3.0

12. Model Structure and General Features

- Consider developing a single more complex model vs. a simpler model combined with a more complex refinery model for detailed analysis – 1.0
- Consider features of perfect foresight for investment decisionmaking or at least some other form of multi-period expectations that more appropriately simulate the decisionmakers in the market – 1.0

LFMM Information Needs and Outputs for NEMS and WEPS+

Interactions between the LFMM and the International Liquids Component of WEPS+

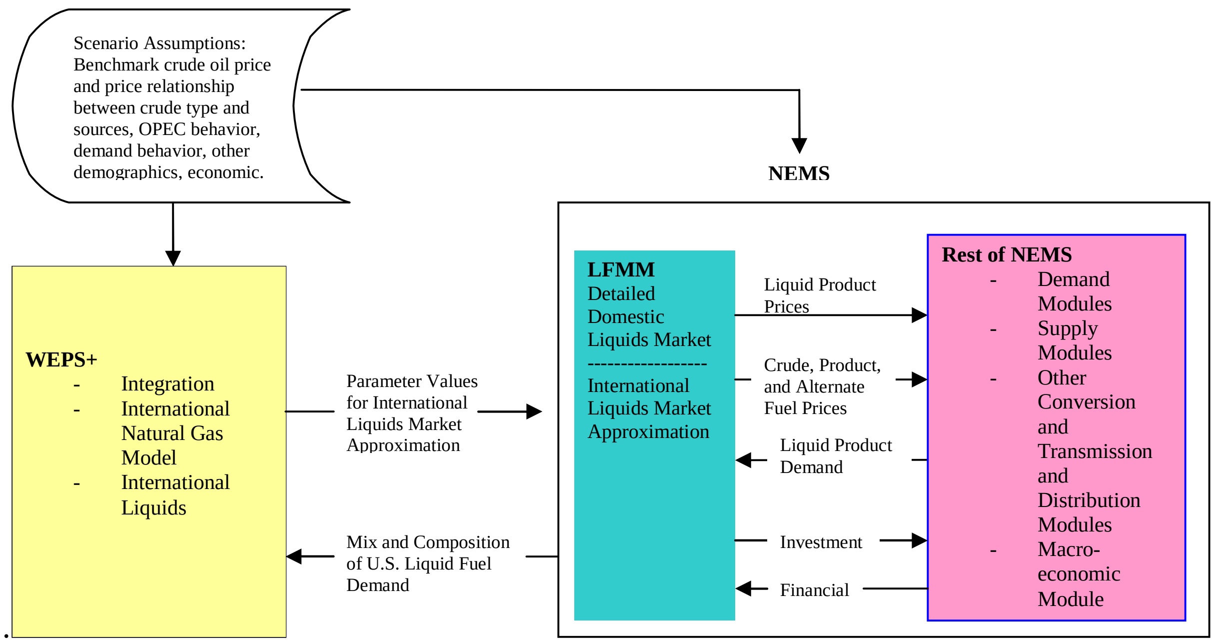
The design of the new LFMM is intended to explicitly provide the information needs of the rest of the NEMS. At the same time, the modeling framework and detail must be sufficiently rich and flexible to address critical energy-related policy issues and questions, as well as emerging market changes, within the context of an integrated energy-economic-environmental model.

The specific questions and issues that the LFMM must be able to address and the information it must be able to reliably provide to the rest of the NEMS are critical components that will shape the LFMM model design and structure. Since the United States is largely a price taker, the quality of the design of the LFMM will also be critically dependent on plausible and consistent information inputs to LFMM about the demand and supply and associated prices of liquid fuels from the international market. The input information requirements of the LFMM include not only the domestic market conditions but also the international market conditions. The quality of the domestic projection critically depends on the quality of the international projection.

Figure 1 illustrates conceptually one possible implementation of the interaction of the world liquids component in WEPS+ and how it interacts with NEMS. Note that this design only highlights the liquids portion of a fully integrated energy market. Conceptually, the international component informs the simplified representation of the world liquids component of the LFMM through parameter estimates and an initial state of the world liquids market. Substantive changes in U.S. liquids demand, supply, and prices can influence the expected international liquids equilibrium, including crude oil and product quantities and prices, quantities of alternative liquids production and prices, and international liquids demand.

While the international liquids fuel model may be a separate module, the international model must provide liquids information needed by the LFMM; that is, the liquid quantities and prices between the two models, if different, must map into each other. Furthermore, to allow for feedback from the U.S. liquids market to the international market, the LFMM liquids quantities and prices must map into the international liquids model. The specific structure of the international liquids model and the approximation of the international liquids component in the LFMM will be determined after further research.

Figure 1. Liquids Market Overview



Interactions between the LFMM and the Rest of NEMS

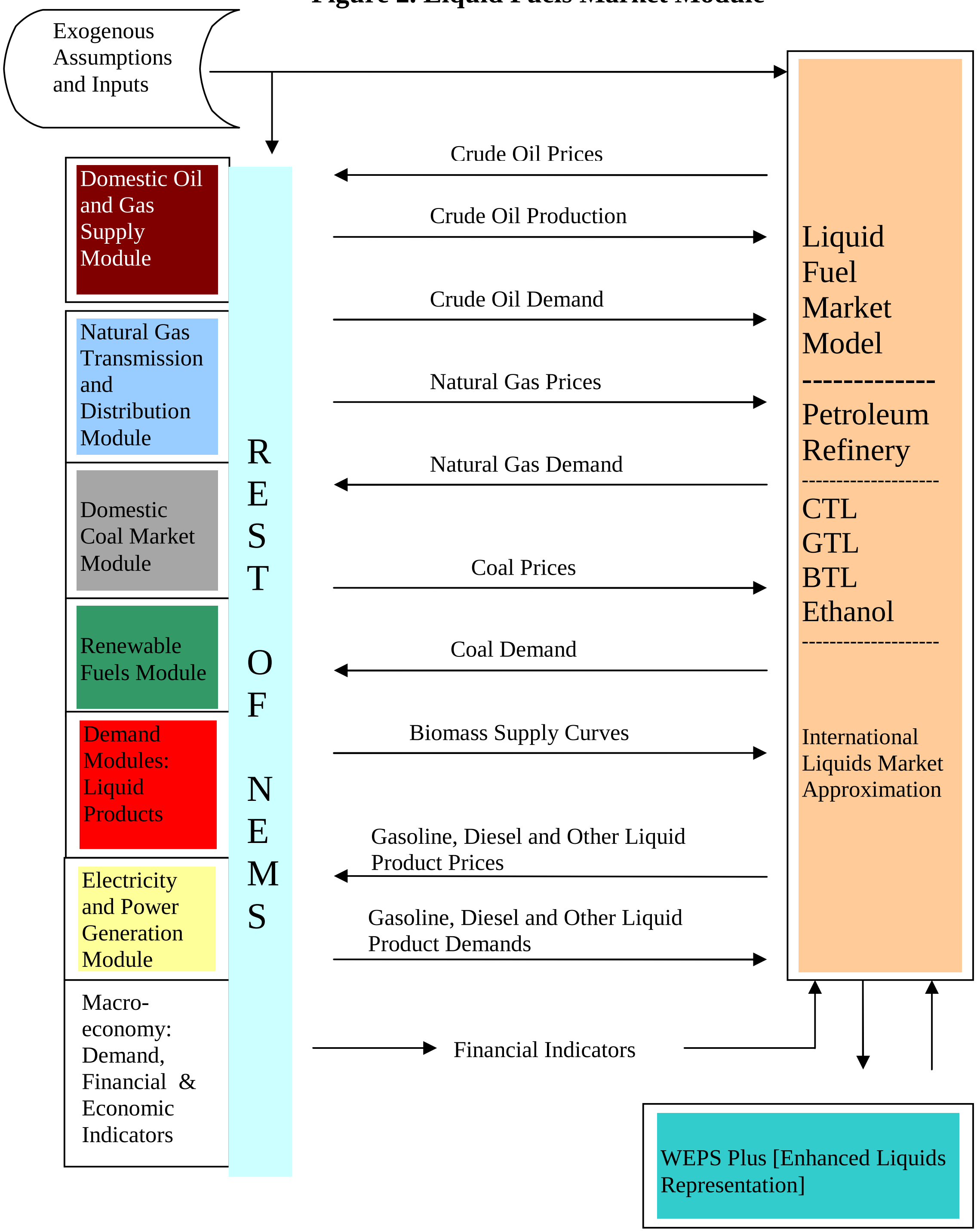
The information exchanges between the LFMM and the rest of NEMS can be conceptually represented as shown in Figure 2. In general, each end-use and conversion sector requires the prices of the liquid products and returns the quantity of each liquid demanded. The LFMM sets the prices for the liquids for the level at which they are demanded. The LFMM will invest in new facilities to refine crude oil or produce alternative liquids based on financial market conditions, expected demand and supply for specific liquids, and fuel use or emissions regulations.

Information Required from the LFMM

A complete listing of the inputs and outputs, regionality, and units required by the NEMS modules is provided in Appendix B. Future NEMS information lists are provided where they are expected to change prospectively. The information required from the LFMM by the rest of NEMS is virtually identical to those listed for the PMM, with the exception of hydrogen for transportation. The list of required LFMM outputs includes domestic and imported regional prices for the following products:

- Motor gasoline: conventional unleaded, oxygenated, reformulated, containing up to 10 percent ethanol;
- E85, an ethanol-gasoline blend containing up to 85 percent ethanol;
- Kerosene-type jet fuel;

Figure 2. Liquid Fuels Market Module



- Distillate fuels: kerosene, heating oil, low-sulfur-diesel, ultra-low-sulfur-diesel;
- Residual fuels: low sulfur, high sulfur;
- Liquefied petroleum gases: propane, liquefied petroleum gases mixed;
- Petrochemical feedstocks: petrochemical naphtha, petrochemical gas oil, propylene, aromatics;
- Other: lubricating products and waxes, asphalt and road oil, still gas, petroleum coke, special naphthas, aviation gasoline;
- Hydrogen availability and delivered price by dispensing stations;
- Transportation fuel CO_2 intensity limits, such as grams of CO_2 per gigajoule, as specified in a LCFS, an expected new analysis requirement.

Hydrogen availability and price is currently not well represented in NEMS although a possible structure is being currently evaluated for eventual use by EIA.

Information Required by the LFMM

The LFMM inputs from the rest of NEMS are essentially indicated by the outputs portion of the modules which are more completely identified in Appendix B. The information needs by the LFMM are largely the same as the PMM and are primarily derived from the regional liquids consumption by product by the rest of NEMS, with the exception of the interaction with the international liquids market through WEPS+. The following summarizes the information needed from domestic and international market models.

- Domestic crude oil production potential by type[3] with associated production cost by domestic producing region;
- Domestic demand for all liquid products by domestic region;
- Foreign crude supply curves available to the United States regions by type;
- Foreign unfinished oil supply curves to the United States regions, by type of unfinished product;
- Functional relationship defining liquid product exports available to the United States regions and by specific liquids product, e.g., motor gasoline by type, distillate by three sulfur content levels, heating oil, jet fuel, liquid petroleum gases, low-sulfur residual fuel oil, high-sulfur residual fuel oil, petrochemical feedstocks, petroleum coke, asphalt and road oil, other petroleum;
- Liquid product import supply curves for conventional motors gasoline, CBOB, RBOB, heating oil, diesel fuel by sulfur type, jet fuel, liquid petroleum gases, low-sulfur residual fuel oil, high-sulfur residual fuel oil, petrochemical feedstocks, other petroleum, methanol, ethanol, cellulosic and sugarcane/advanced, biodiesel, and palm oil from the United States regions;
- Natural gas plant liquids supply curves by region;
- Coal, natural gas, biomass and corn feedstock supply cost curves by region used as input to CTL, GTL, and BTL, cellulosic ethanol, and corn ethanol;
- Oil and greases supply curves by region to produce biodiesel and naphtha, e.g., seed oil, white grease, yellow grease;

[3] Crude oil types are aggregated roughly by gravity from light through very heavy and sulfur content.

- Fuel feedstock prices by region for coal, natural gas, and electricity used for fuel processing.

In addition to these information requirements, the LFMM will also require:

- Cost and performance characteristics of all liquids conversion technologies and dates of initial availability;
- Learning rates as a function of manufacturing experience;
- Capacity retrofit costs by process for refineries and other liquids production facilities and the associated product slate change;
- Infrastructure costs with cost elements for each major infrastructure component for conventional and unconventional liquids, i.e., E85, BTL, biodiesel, and hydrogen;
- Market diffusion potential for newly introduced technologies.

Sample Analysis Topics

The following four topics were developed primarily for two reasons: (1) to provide some specific examples of topics that the authors might consider in writing their white papers, and (2) to help frame the initial discussions at the technical workshop. That is, these topics are not intended to limit discussion at the workshop but may be used to provide a starting point for the discussions that ensue. Those providing comments at the technical workshop should consider how the methodology and structure of the new LFMM would allow for the analysis of these topics.

Incorporating Technology Assessment

Technology detail throughout NEMS is important in order to be able to capture the long-term impacts on energy markets as newer technologies are developed and improved and gradually penetrate the market. Explicit representation of technologies also enables the analysis of efficiency standards and various incentives to encourage the penetration of new technologies.

In addition to EIA's own baseline projections and analytical studies, another important application of NEMS is the use by DOE program offices to estimate the costs and benefits of their R&D investments within a broad national context. Typically, DOE program offices develop their own estimate of what their requested R&D budget will have on reducing the cost and improving the performance of technologies in their program. Then NEMS is used to incorporate these improved technology assumptions and evaluate the impacts, relative to the baseline, on energy prices, emissions, costs, imports, and other metrics.

The LFMM should incorporate technological detail to represent the emerging liquid fuel sources, such as CTL, GTL, and BTL. Also, it must also be able to represent the impact of policies that reduce consumption of petroleum-based fuels, thus changing refining economics, co-products versus by-product, product margins, etc. To do these assessments, the LFMM must have technology detail yet not so much that it slows the solution while not materially adding analytical value. Moreover, the technology representations should be similar enough in detail to avoid any model bias, when evaluating the costs and benefits of new technologies.

The challenge is to strike a balance in the level of technological detail in the LFMM to allow for fuel specification and refinery operations analysis, price and margin analysis, as well as represent the emerging liquid sources in a balanced fashion. Linkage with an external model that is more focused on refinery operations is a possible consideration.

Representing the Domestic and International Markets

NEMS is primarily a domestic energy model; however, the interactions with international energy markets are critical. This is particularly true in the liquid fuels market, which is already a world market and where the United States has already experienced the impact of rapid worldwide demand growth on the price of crude oil and petroleum products.

NEMS is a mid-term model and represents energy markets on an average annual basis. As such, it is not expected to be suitable for analyzing short-term supply disruptions or surges in demand, either domestically or globally. However, it should be able to account for the impacts of long-run global shifts in liquid fuels consumption or shifts in the sources of liquid fuel supplies on refinery profits and margins and liquid product prices.

The impact of shifts in global liquid consumption patterns are likely to impact domestic refinery economics and must be captured by the LFMM. For example, domestic polices that reduce the demand for gasoline will also change refinery operations and profitability in the United States. In Europe, sales of diesel vehicles have been increasing due to their efficiency relative to gasoline vehicles. Increased demand for diesel fuel in Europe, unless matched by investments to change the refinery mix of outputs, would very likely increase gasoline production as a joint product and lead to additional gasoline supplies for the U.S. market. The economics of such investments opportunities should also be represented in the LFMM. The analysis should also capture the impact of changing global competition between all sources of liquids and account for the impacts on investment in liquids production from biofuels, coal, and natural gas.

Shifting patterns of liquid supplies and consumption around the world will also have implications for energy security. To some extent, the issues of import dependence and diversification, both regionally and by fuel source, should be incorporated into the LFMM if reasonably possible, by carefully considering options for representing the regionality of international supply sources within the LFMM .

Representing Alternative Fuels

The choices between alternative-fuel and conventional vehicles and between fuels in flex-fuel vehicles are determined in the transportation demand module of NEMS. The purpose of the new LFMM is to represent the production, distribution, dispensing, and pricing of the various liquid fuels, accounting for the processing and blending of biofuels and other non-petroleum-based liquids.

In order to address emerging liquid fuels markets, LFMM must incorporate the economic competition between the various feedstocks for liquid fuels and blending options and account for a variety of incentives and mandates to encourage the introduction of alternative fuels. LFMM should be to analyze the impacts of expanding alternative fuel markets on finished product prices and on emissions. A question arises as to the extent to which the LFMM should be able to account for the development of an infrastructure to produce and transport the feedstocks and to distribute and dispense the finished products. An additional question is the possible accounting for externalities associated with new liquid product sources, e.g., the use of water and land in expanding the use of biofuels.

Evaluating the Impacts of New Policies

Major interests of the new Congress and President over the next few years include the issues of climate change and energy security. A straightforward cap-and-trade program is seen by some as useful to address climate change, but is not necessarily adequate to improve energy security. Furthermore, some interest groups want renewable generation technologies to play a much greater role in reducing CO_2 emissions than a cap-and-trade system might imply. Others believe that by combining policies, the overall cost to the consumer and possibly to the economy might be minimized. The following should be considered an outline of a potentially complex bill that EIA might be asked to analyze; however, other potential polices can be considered.

Congressional Bill 111.X

- Section I. Reduce CO_2 emissions in the United States to annual targets beginning in 2013, reaching 70 percent of 2000 levels of CO_2 emissions by 2030. Assume that this is a linear reduction with banking. Also assume that there is no grandfathering of emission allowances. The implementation will include a cap-and-trade program for 80 percent of the allowances, and the remaining 20 percent will be allocated to the Federal government to auction and use the revenues to fund R&D and return a portion to consumers.
- Section II. Increase CAFE standards still further than in EISA2007, to 55 miles per gallon for cars and 40 miles per gallon for light trucks by 2030. The Federal government increases the penalty for missing the CAFE standards from about $50 to $1,000 per vehicle for each mile per gallon the manufacturer falls below the standard.
- Section III. Introduce a renewable portfolio standard that starts in 2013 and requires the share of nonhydropower renewables electricity generation to reach 25 percent by 2025 and 30 percent by 2030.
- Section IV. Introduce a LCFS for motor transportation fuels that reaches 30 percent below the reference case by 2030, starting in 2013.

Key questions that need to be addressed in the analysis include but are not limited to:

- The mix of generation capacity over time and the quantity of stranded generation assets;
- The costs of these policies, together and individually, to the power generation and refinery industries and to the consumers;
- The price of electricity;
- The prices and quantities of transportation fuels demanded;
- The impact on domestic and international refinery capacity additions and retirements;
- The mix, quality, and price of crude oil and products imported to the United States by world region;
- The impact on liquid fuel refinery margins and delivered prices;
- CO_2 emissions;

- The cost of each of the separate policies and their joint costs to producers as well as consumers;
- The impact on renewable fuel production due to greatly reduced transportation demand;
- The impacts on technology choices, technology costs for both existing and new technologies, and infrastructure investments and costs;
- The impacts on the economy, as measured by gross domestic product, consumption, investment, imports, exports, employment, and interest rates.

This section provides an example of the level of sophistication on policies, technological and product detail, and international trade questions that the LFMM model should be able to address in its design. However, there are resource and maintenance costs associated with any specific modeling choice and that should be a discussion point in the white papers and discussed at the workshop, i.e., what modeling approach should EIA choose, how much detail, and what is the regional scope of the model, global, domestic only, or some hybrid of the these two.

Next Steps

This paper serves as background information for all participants in the technical workshop to be held in June or July 2009, particularly those experts providing technical papers in advance of that workshop. Following this workshop, the core team will prepare a summary report and a requirements analysis.

Future milestones for the project and tentative dates include:

- Develop two CDR proposals – October 2009
- Review proposals and develop a single CDR – November 2009
- Conduct IER of CDR – January 2010
- Prepare full mathematical specification – March 2010
- Implement and test pilot model – July 2010
- Present model results to IER participants – August 2010
- Implement, test, and document full LFMM – July 2011.

The ultimate goal is the use of the new LFMM in the summer and fall of 2011 for preparation of the *Annual Energy Outlook 2012,* likely to be released in November or December 2011.

Appendix A: Stakeholder Recommendations Sorted by Priority

- Provide fuel prices and margins, with prices disaggregated by market segment, product, and region and margins by product and region – 1.0
- Analyze carbon dioxide taxes, cap-and-trade systems, and energy taxes on both a primary and delivered basis – 1.0
- Consider developing a single more complex model vs. a simpler model combined with a more complex refinery model for detailed analysis – 1.0
- Consider features of perfect foresight for investment decisionmaking or at least some other form of multi-period expectations that more appropriately simulate the decisionmakers in the market – 1.0
- Include all non-petroleum sources of liquids, their economics and potential market – 1.2
- Represent market behavior and competition between fuels and technologies in liquids production, transmission, and distribution – 1.4
- Analyze renewable portfolio standards, renewable fuel standards, and low carbon fuel standards, including competition for biomass, land, and water – 1.4
- Evaluate the impact of the ethanol tariff – 1.6
- Analyze impact of taxes, tax incentives, and other liquids consumption, production or environmental constraints on process technologies utilized for liquids production, new conversion and transformation investments, liquid product prices, and resulting environmental emissions – 1.6
- Distinguish refinery gate prices, transportation charges, and distribution and dispensing charges by product – 1.8
- Analyze impacts of environmental regulations on product specification changes and requirements and costs – 1.8
- Include competition between feedstock use for biofuels versus power, heat, electricity, or hydrogen production – 2.0
- Include the flexibility to add non-petroleum feedstocks that can be converted to liquids as they are developed or evolve through research and development (R&D) and/or experience – 2.0
- Represent imports by type of crude oil, products, and alternative liquids by region – 2.0
- Evaluate the potential for cellulosic ethanol and other biofuels imports and the affects that domestic GHG and renewable fuel policies may have on their cost and availability to U.S. markets – 2.0
- Explicitly account for and simulate new investments and other associated costs for new capacity in either refineries or other non-refinery production of liquids like CTL, GTL, and BTL, using some expectations that simulate market behavior – 2.0
- Analyze cost and benefits of new technology penetration to producers and consumers – 2.2
- Analyze alternative and new fuel product specifications – 2.2
- Represent realistic market adoption for new technologies, incorporating costs, risks, infrastructure issues, and investor and consumer behavior in liquids production, transmission, distribution – 2.2
- Analyze international liquids markets to assess crude oil and product flows, product demand, and crude oil and product prices and impacts on U.S. market, by crude type and region – 2.2
- Analyze impacts of climate policies on domestic and international liquids markets, including prices by crude and product and region – 2.2

- Capture the interaction of non-GHG polices with GHG polices and their impacts on refinery choices – 2.2
- Incorporate and represent multiple biomass supply categories – 2.4
- Assess how changes in specific world liquid product demands affect liquid crude and product trade for crude oil, products, and manufactured substitutes with their attributes and the associated prices – 2.4
- Represent industry learning for conversion plants and refineries, endogenously, if possible, and how liquids technology cost reductions might occur – 2.4
- Account for infrastructure to allow analysis of some potential bottlenecks, including fuel distribution constraints and evolution of fuel dispensing infrastructures – 2.4
- Analyze the implications of policies to decarbonize transportation fuels on the fuels produced and the specifications of the fuels – 2.4
- Assess cost of policies to refineries, including upstream and downstream operations, and the impact on margins, e.g., policies like the RFS – 2.4
- Assess policy impacts on capacity expansion, retirements, and retrofits and on the entire liquids supply chain and the infrastructure – 2.4
- Simulate market penetration of liquid fuel technologies and associated technology costs, including investments, operating and maintenance costs, and any manufacturing cost reductions through learning – 2.6
- Address differences between different crude types and sources with respect to important product characteristics, e.g., sulfur content, particulates, viscosity, heavy vs. light, etc. – 2.6
- Assess alternative assumptions on crude oil availability and refinery expansion worldwide – 2.6
- Include multiple refinery types for each region, i.e., variations of simple and complex, to represent the processing mix and limits to process different crude types – 2.6
- In making decisions on capacity expansion and investments in existing refineries, i.e. retrofitting refineries, explicitly incorporate all new cost and performance characteristics and the alternative cost and performance options to retrofit existing refineries, using a vintaged stock representation and accounting of all costs – 2.6
- Account for the costs, risks, and bottlenecks of realistic infrastructure expansion in the model – 2.6
- Include a detailed technology representation for each liquid production process, with potentially alternative technology learning rates, and the ability to test impact of successful development of new technologies for liquid product production – 2.8
- Include multiple refinery types by vintage to represent retrofit costs and retirement decisions – 2.8
- Represent world markets for natural gas plant liquids and liquefied petroleum gases – 2.8
- Address any key limits to supply by region – 3.0
- Include the processing of all major crude oil types, including heavy crude and bitumen by region, both domestic and international – 3.0
- Address restrictions on bunker fuel and heavy oil and blending – 3.0
- Analyze polices that affect fuel demand and refinery fuel mix – 3.0
- Assess cost of fuel use policies to consumers, including impact on food – 3.0
- Simulate which capacity will be retired, by region and refinery type, if overall capacity requirements shrink – 3.2

- Account for all energy used and emissions to produce liquids, including mining/drilling and transportation, processing, and delivery to ultimate consumer and accounting for GHGs, sulfur dioxide, nitrogen oxides, and mercury – 3.2
- Analyze all biomass synfuels with respect to water use, GHGs, soil carbon/nutrients, land use, crop markets or at least provide an accounting of these whenever possible – 3.2
- Treat all liquid technologies at the same level of detail, including conventional refineries, BTL, CTL, GTL, in both the technological representation and the emissions accounting – 3.4
- Analyze the level of intermediate product transfers between different refineries and between or within regions – 3.4
- Improve the representation of infrastructure and fuel availability by relating those to economic factors that affect technology adoption and diffusion in transportation – 3.8
- Account for water and land use for all liquids production and consumption – 3.8
- Provide additional measures of energy security, including import dependence by region and security as defined in a paper by David Greene – 3.8
- Characterize supply/production decisionmaking by country and/or groups – 4.2
- Represent all feasible transportation technologies, especially those that might be required or promoted in a constrained carbon scenario, including possibly those producing or using hydrogen – 4.4
- Evaluate alternative cartel or market dominance behavior on prices, which implies that dominant oil producers must be explicitly represented as specific supply regions – 4.8
- Include the ability to address supply disruptions by region, e.g., from specific nations in the Organization of Petroleum Exporting Countries or because of accidents that remove capacity to produce specific products required in certain U.S. regions, such as California – 4.8
- Account for the resources and reserves of all crude oil types – 5.0
- Analyze the impacts of efficiency standards on travel – 5.0
- Analyze peak oil scenarios by region – 5.0

Appendix B: Detailed Inputs and Outputs of Non-LFMM Modules of NEMS

	LIQUID NAME	INPUT NEEDED	UNITS	Regional Detail	OUTPUT PROVIDED	UNITS	Regional Detail
Residential/ Commercial	Distillate Fuel Oil	Price	$/MMBtu	CD	End-use Consumption	quads	
	Residual Fuel Oil	Price	$/MMBtu	CD	Sectoral Consumption	quads	CD
	LPG	Price	$/MMBtu	CD	Sectoral Consumption	quads	CD
	Motor Gasoline	Price	$/MMBtu	CD	Sectoral Consumption	quads	CD
	Kerosene	Price	$/MMBtu	CD	Sectoral Consumption	quads	CD
Transportation	Motor Gasoline	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	Diesel	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	E-85	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	LPG	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	Jet Fuel	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	Residual	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	CNG	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	Hydrogen	Price	$/MMBtu	CD	Consumption by Mode	quads	CD
	Lubricants				Consumption by Mode	quads	CD
	E-85	Availability	Percent of Stations	CD	Consumption by Mode	quads	CD

ıdustrial	Motor Gasoline	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Distillate	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Kerosene	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Liquid Petroleum Gases	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Residual Fuel	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Petrochem Feedstocks	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Petroleum Coke	No Price			Sectoral Consumption	tBtu	CD
	Asphalt and Road Oil	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Other Petroleum	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Total Petroleum	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	LPG Feedstock	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Ethanol (corn)	Production Volume	Million Bushel	CD	Sectoral Consumption	tBtu	CD
lectricity	Distillate	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD
	Residual Fuel	Price	$/MMBtu	CD	Sectoral Consumption	tBtu	CD

CD = Census Division
quads = quadrillion Btu
tBtu = trillion Btu
$/MMBtu = dollars per million Btu
price = liquid fuel product price