Concepts, Data Sources, and Techniques

Handbook of Energy Modeling Methods

Short-Term Energy Outlook: Hydrocarbon Gas Liquids Module

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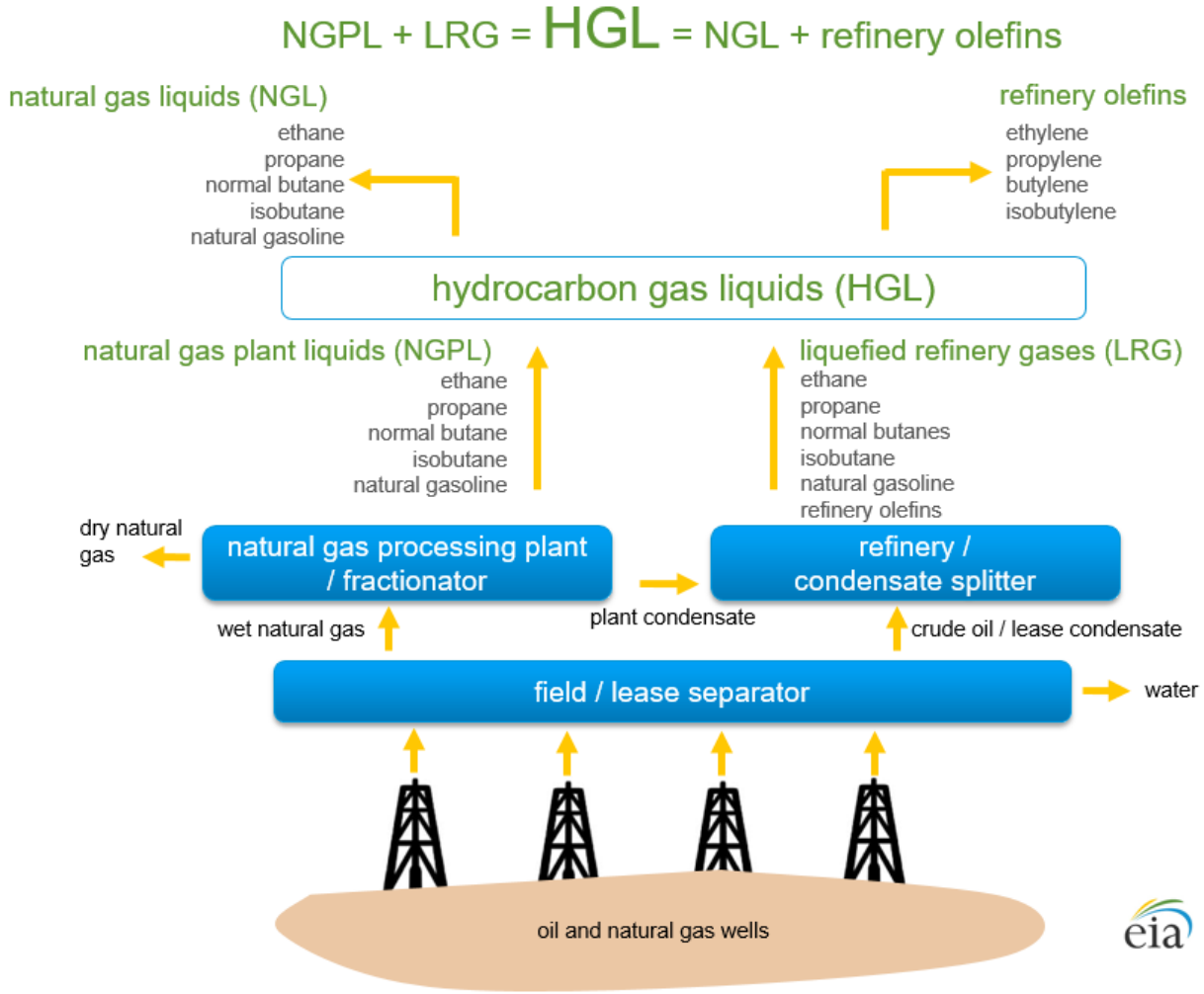
1. Introduction

Hydrocarbon gas liquids (HGLs) are a set of natural gas liquids and refinery olefins produced by natural gas processing plants, fractionation facilities, refineries, and condensate splitters (Figure 1). The *Short-Term Energy Outlook* (STEO) HGL module forecasts the supply and demand balance of total HGLs and HGL subproducts.

Figure 1. HGL taxonomy, simplified



Source: U.S. Energy Information Administration

The HGL module combines natural gas liquids and refinery olefins into five products:

1) Ethane (including a trace of refinery produced ethylene)
2) Propane
3) Propylene (the only refinery olefin that is modeled separately)
4) Butanes (including normal butane and isobutane and their refinery olefins: butylene and isobutylene)
5) Natural gasoline (pentanes plus)

The HGL module only includes an energy balance for olefins that are produced at refineries, mainly propylene as well as iso and normal butylenes. Most olefins are produced at petrochemical plants and are not included in our data or forecasts.

The HGL module is a set of linear regression equations and accounting identities used to forecast the series included in the U.S. HGL balances, which we publish in STEO's Hydrocarbon Gas Liquids and Petroleum Refinery Balances (Table 4b). The HGL module generally forecasts the following supply-side and demand-side activities for each product. Quantities are measured in million barrels per day except for inventory changes and levels, which are measured in million barrels:

- Natural gas plant (field) production
- Renewable fuels and oxygenate plant net production (for natural gasoline only)
- Refinery production
- Refinery inputs
- Consumption (product supplied)
- Inventory builds, inventory draws, and total inventories
- Net imports and exports for HGLs
    - Gross imports only for propane and for propylene
    - Gross exports only for propane

The total U.S. HGL forecast for each of the activities is calculated as the sum of the quantities for all HGL products.

2. Data Sources

The HGL module uses monthly data for the supply, consumption, inventories, and trade of HGLs from our *Petroleum Supply Monthly* (PSM). A complete set of data is available in PSM Table 3, U.S. Daily Average Supply and Disposition of Crude Oil and Petroleum Products.

PSM data are published with a two-month lag. For example, the PSM released at the end of March will contain data through January. STEO uses monthly estimates based on weekly data from our *Weekly Petroleum Status Report* (WPSR) to fill in the two most recent months for propane (including propylene) data series that are available in WPSR. Ethane, butanes, and natural gasoline data are not available in WPSR, and STEO uses model estimates for the most recent two months of historical data.

In addition, the number of households that use propane as their primary space heating fuel in the HGL module comes from the U.S. Census Bureau's annual American Community Survey. Heating degree day history and forecasts are obtained from the National Oceanic and Atmospheric Administration (NOAA).

3. Linear Regression Models

The HGL module contains a set of regression models and accounting identities for HGL supply and consumption as well as the inventory change series. Regression models forecast net imports (the

difference between gross imports and gross exports) for ethane, butanes, and natural gasoline. The models forecast gross imports and gross exports separately for propane and refinery propylene.

The HGL module uses an accounting identity for each product that serves as a balancing item, calculated as the difference between the sum of the supply-side forecasts and the demand-side forecasts. The balancing item varies by product, as follows:

- Ethane—natural gas plant production
- Propane—gross exports
- Refinery propylene—consumption
- Butanes—net imports
- Natural gasoline—net imports

3.1. Common independent variables

Multiple factors drive the supply of HGLs, including the following:

- Relative prices of crude oil and natural gas
- Marketed (raw) natural gas production
- Natural gas pipeline specifications that dictate how much ethane can remain in the natural gas stream
- Infrastructure constraints and additions
- Seasonal factors
- Costs of transporting fuels from production hubs to demand centers

Demand for HGLs results from a wide range of factors, including the manufacturing of petrochemicals, residential heating and cooking, agriculture, and motor fuel blending.

The petrochemical manufacturing sector is the primary consumer of ethane and propane (and its olefin propylene). Consumption of these products typically occurs in petrochemical facilities, such as ethylene crackers and propane dehydrogenation plants (PDH). Propane is also a significant space heating fuel in the residential and commercial sectors. Natural gasoline and normal butanes are primarily consumed by the transportation sector as a denaturant for ethanol (to make fuel ethanol undrinkable) and as a blendstock for gasoline. More information about the HGL market is available on EIA's *Hydrocarbon Gas Liquids Explained* web page. Multiple factors can affect demand for HGL products, including the price of a given HGL product relative to substitute prices, demand conditions such as regional weather, and economic and seasonal factors.

Some of the independent variables, for example, crude oil prices, that affect HGL production and consumption are observable, and data are readily available to include in our models, while other variables are not directly observable or data are not available. EIA uses proxy variables to account for those factors that are not directly known.

Many of the linear regression models for HGL products include similar types of independent variables, as listed below.

For natural gas plant HGL production:

- Monthly Lower 48 states (non-Gulf of Mexico) marketed natural gas production
- Monthly propane production
- Monthly crude oil price (Brent)
- Monthly natural gas price (Henry Hub)
- Monthly dummy variables, to capture seasonal effects

For refinery HGL production:

- Crude oil inputs to U.S. refineries
- Unfinished oils inputs to U.S. refineries
- Refinery gasoline yield
- Refinery gasoline production
- Monthly crude oil price (Brent)
- Monthly propane prices (Mont Belvieu, Texas)
- Monthly dummy variables, to capture seasonal effects

For renewable fuels and oxygenate plant net production (for natural gasoline only):

- Monthly ethanol production

For inventory changes:

- Difference between the current month's inventories for a given HGL product and the average inventory for that month during a previous multiyear period
- Difference between the current month's weather and historical 30-year normal weather
- Monthly dummy variables, to capture seasonal effects
- Change from previous month's ethane consumption (for modeling ethane inventory changes only)
- Refinery production of butanes (for modeling butane inventory changes only)

For consumption:

- Manufacturing index for the petrochemical industry, from the IHS Markit macroeconomic model
- Additions to U.S. ethane cracking capacity at U.S. ethylene crackers, based on capacity expansion projects tracked by EIA analysts
- The number of households, by region, that use propane as a heating fuel
- Monthly dummy variables, to capture seasonal effects
- A trend variable, to reflect structural market changes
- A one-month lagged dependent variable, to capture the effect of the previous month's consumption on the current month's consumption

3.2. Natural gas plant production

The largest share of HGL production comes from natural gas plants—including natural gas processing plants and fractionators. Natural gas processing plants and fractionators separate marketed (raw) natural gas into pipeline-quality natural gas (methane) and natural gas plant liquids (NGPL), including ethane, propane, butanes, and natural gasoline. Natural gas plants do not produce olefins. The production of NGPLs is highly correlated with natural gas production, especially for propane, butanes, and natural gasoline.

3.2.1 Propane

The regression model for propane natural gas plant production uses the following independent variables:

- Lower 48 states (excluding the Gulf of Mexico) marketed natural gas production
- The ratio of Brent crude oil prices to Henry Hub natural gas prices
- Monthly dummy variables

3.2.2 Butanes and natural gasoline

Butanes and natural gasoline production are also correlated with natural gas production but are constrained by the yield of propane production and are modeled as a function of the following:

- Propane production
- The ratio of Brent crude oil prices to Henry Hub natural gas prices (natural gasoline only)
- Monthly dummy variables

3.2.3 Ethane

The module calculates natural gas processing plant production of ethane as an accounting item that balances the forecasts from the following supply-side and demand-side equations: consumption, net imports, stock change, and refinery production.

NG Plant Ethane Production = Ethane Consumption
- Net Ethane Imports
+ Ethane Stock Change
- Refinery Ethane Production

3.3. Renewable fuels and oxygenate plant net production

Natural gasoline is the only HGL product for which net production is measured at renewable fuel and oxygenate plants. When natural gasoline is blended into ethanol as a denaturant, it is measured as negative net production. Natural gasoline blending is modeled as an accounting identity that equals -2% of ethanol production.

3.4. Refinery and blender net production

Refineries produce HGLs from crude oil, and blenders input butanes for producing finished gasoline. Refinery production of HGLs is counted as positive net production, and refinery or blender inputs of HGLs are counted as negative net production. Propane and propylene together accounted for 97% of refinery and blender net production of HGLs in 2020.

3.4.1 Propane (only)

Refineries produced about 14% of the propane produced in the United States in 2020; the remainder came from natural gas plants and fractionators. Refinery production of propane is highly correlated with gasoline production because the two fuels come from a similar distillation range. Propane production is also influenced by the margin between propane prices and crude oil prices. Refinery propane production is modeled as a function of the following variables:

- Refinery gasoline yield
- Refinery inputs of crude oil
- Ratio of the propane spot price at Mont Belvieu, Texas, to the Brent crude oil price
- Monthly dummy variables

3.4.2 Propylene produced at refineries

We estimate that refineries produced about 60% of U.S. propylene in 2020. The remainder was produced at petrochemical plants and is not included in the HGL module because it is not counted in our energy balance. Refinery production of propylene depends on the composition of crude oil and the configuration of refinery process units to maximize profits from the production of gasoline, diesel, jet fuel, and other products. Refineries produce most propylene through fluid catalytic cracking, as a byproduct mixed with other compounds, including propane. Propylene is the primary feedstock for alkylation and polymerization, which in turn produce certain blendstocks for motor gasoline blenders. Refinery propylene production is modeled as a function of the following variables:

- Refinery inputs of unfinished oils
- Refinery gasoline yield
- Refinery inputs of crude oil
- Monthly dummy variables

3.4.3 Butanes

Refinery and blender net production of butanes represents the balance of the production and blending of butanes at refineries and blenders. During the winter months, net production is negative because blenders input more butanes than refineries produce. During the summer months, however, net production is positive because refineries produce more butanes than blenders input. This seasonality is the result of regulatory specifications that allow winter-grade gasoline to have a higher vapor pressure than summer-grade gasoline. Because butanes have a relatively high vapor pressure compared with many other gasoline blending components, they are input into gasoline at a higher percentage during winter months than during summer months. Refinery production of butanes is modeled as a function of refinery gasoline production and monthly (seasonal) dummy variables.

3.4.4 Natural gasoline
Refineries do not produce natural gasoline, so it is not modeled.

3.4.4 Ethane
Refineries contribute about 1% of ethane (including ethylene) production in the United States. Most ethane is produced at natural gas processing plants. Most ethylene is produced at petrochemical plants and is not modeled because it falls outside of the energy balance. Refinery production of ethane is forecast as function of refinery inputs of crude oil and monthly (seasonal) dummy variables.

3.5. Refinery and blender net inputs
The only HGLs that are input into refineries and blenders are butanes and natural gasoline, which are used for gasoline blending. Refinery inputs of butanes and natural gasoline are modeled as a function of the following variables:

- Motor gasoline production
- A lagged dependent variable (natural gasoline only)
- Monthly dummy variables

3.6. Consumption (product supplied)

3.6.1 Propane (only)
Five million (4%) U.S. households report using propane as their primary space heating fuel, and rural areas in the Northeast and Midwest account for most residential and commercial propane consumption. Propane can also be consumed for water heating, cooking, and clothes drying. In the industrial sector, propane is used primarily as a feedstock for petrochemical plants as well as for heating barns and coops, grain drying, and other uses. Propane consumption is modeled as a function of the following variables:

- Heating demand
- Petrochemical demand
- Grain drying demand
- Monthly dummy variables

3.6.2 Propylene produced at refineries
We do not collect data for propylene production or consumption at petrochemical plants, and propylene consumption is grouped with propane product supplied for the STEO forecast.

3.6.3 Butanes
Most butane is blended into gasoline, especially during the cooler months. Demand for isobutane exceeds supply, so normal butane is also converted into isobutane through isomerization. Normal butane can also be used as a feedstock in the petrochemical industry and as fluid for lighters. Isobutane is used to produce alkylates, which increase the octane in gasoline and control the volatility of gasoline. High-purity isobutane can also be used as a refrigerant. We model isobutene and normal butane consumption, aggregated, as a function of the ratio of natural gas prices to crude oil prices and monthly dummy variables.

3.6.4 Natural gasoline

Natural gasoline (also known as pentanes plus) can be blended into the fuels used in internal combustion engines, particularly motor gasoline. In the United States, natural gasoline may be added to fuel ethanol as a denaturant. Some ethanol producers use natural gasoline to make E85. It is also used as a petrochemical feedstock and blending component for heavy crude oil. Natural gasoline consumption is modeled as a function of the following variables:

- Natural gas and crude oil price ratio
- Monthly dummy variables

3.6.5 Ethane

Ethane is mainly consumed by petrochemical facilities to produce ethylene, which is then used by the petrochemical industry to produce a range of intermediate products, most of which are converted into plastics. Ethane consumption in the United States and exports from the United States have increased during the past several years because of ethane's increased supply and lower cost relative to other petrochemical feedstocks such as propane and naphtha. Ethane can also be used as a fuel for power generation, either on its own or blended with natural gas. Ethane consumption is modeled as a function of the following variables:

- Domestic ethane cracker capacity, which is tracked by EIA analysts who consider ethylene cracker feedstock requirements, new projects, shutdowns, and maintenance
- Natural gas and crude oil price ratio
- Monthly dummy variables

3.7. Inventory builds and draws and total inventories

The HGL module includes regression models for monthly inventory changes for each HGL product. Total monthly inventory levels are calculated by adding the change to the previous end-of-month inventory level. The module forecasts PADD-level (Figure 2) inventory changes for propane and propylene but forecasts only total U.S. inventory changes and levels for butanes, natural gasoline, and ethane.

3.7.1 Propane (only)

The HGL module forecasts propane inventory builds and draws at the PADD level. Propane inventories typically build during spring and summer and are drawn down in the fall and winter to meet space heating demand.

The module forecasts propane inventory changes for each of the five PADDs based on the following factors:

- Deviation from normal heating demand (using regional heating degree days weighted by number of household that use propane as a primary space heating fuel)
- The deviation of the previous month's inventory level from a multiyear average
- Monthly dummy variables

Instead of using heating demand, the module forecasts propane inventory changes for PADD 3 (Gulf Coast), based on the change in consumption from the previous month because most of the propane demand in this region is for petrochemical use, which is consistent from month to month, rather than for heating demand.

Figure 2. Petroleum Administration for Defense Districts (PADDs)

Source: U.S. Energy Information Administration

3.7.2 Propylene stored at refineries

EIA models propylene inventories stored at refineries and excludes inventories stored at bulk terminals. The propylene HGL module includes inventory change regression models for PADDs 1, 2, and 3, where almost all refinery propylene inventories are held. The module forecasts propylene inventory builds and draws in the three regions based on the deviation of regional inventory levels from a multiyear average, along with monthly (seasonal) dummy variables.

3.7.3 Butanes

Butane inventories typically build during the summer when butane is blended into gasoline at a lower percentage than during winter because of regulatory restrictions. The module forecasts butane inventory builds and draws based on refinery and blender net output of butanes, along with monthly (seasonal) dummy variables.

3.7.4 Natural gasoline

The module forecasts natural gasoline inventory builds and draws based on the deviation of inventory levels from a multiyear average, along with monthly (seasonal) dummy variables.

3.7.5 Ethane

The module forecasts natural gasoline inventory builds and draws based on the following factors:

- Deviation of heating degree days from the 30-year normal
- The deviation of inventory levels from a multiyear average

- Monthly dummy variables

3.8 Net imports and exports

Net imports and exports are measured as the difference between gross imports and gross exports. For butanes and natural gasoline, the HGL module forecasts net imports as an accounting identity, or balancing item, that is the difference between supply-side and demand-side forecast series. For propane, the module includes a regression model for gross imports and calculates gross exports as the balancing item. It then calculates net imports as the difference between the gross imports and gross exports.

3.8.1 Propane (only)

The module includes a regression model for gross propane imports and considers gross propane exports as the balancing item, calculated as the difference between the supply-side and demand-side forecast series.

Gross propane imports are forecast as a function of the following variables:

- A lagged dependent variable
- Trend variables that start in 2015 and in 2016 that account for new export facilities
- Monthly dummy variables

3.8.2 Propylene produced at refineries

The United States imports a small amount of refinery-produced propylene and does not export propylene produced at U.S. refineries. Therefore, net imports of refinery propylene are the same as gross imports. The HGL module forecasts gross propylene imports based on the following factors:

- A trend variable for each year starting in 2018 to reflect structural changes in the market
- Monthly dummy variables

3.7.5 Ethane

Net imports of ethane is a negative number because the United States does not import ethane. The level of U.S. exports is largely determined by the demand for ethane by petrochemical plants around the world and the relative cost of U.S. ethane plus transportation costs to the cost of competing feedstocks from other sources. The HGL module forecasts net ethane imports based on the following factors:

- World total petroleum consumption, a proxy for world petrochemical plant consumption
- Ethane export capacity, which is calculated by tracking contractual obligations between pipeline and marine terminals and international crackers as well as their maintenance schedules
- Monthly dummy variables